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Coastal and Hydraulics Laboratory

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Engineer Research and Development Center

ERDC Workplan Report - DRAFT

West Bay Sediment Diversion Effects

November 2009

Gary Brown, Chris Callegan, Ronnie Heath, Lisa Hubbard, Charlie Little, Phu Luong, Kieth Martin, Pat McKinney, David Perky, Freddie, Pinkard, Thad Pratt, Jeremy Sharp, Michael Tubman.

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Prepared for:

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Preface

The U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) conducted the West Bay Diversion Study from April 2009 to November 2009, under the direct supervision of William Martin, Director CHL, Bruce A. Ebersole, Chief, Flood and Storm Protection Division, Lisa Hubbard Chief, River Engineering, Pat McKinney, Chief, Field Data Collection and Analysis Branch, Robert McAdory, Chief, Estuarine Engineering Branch. Thad Pratt was the field data collection project manager and Lisa Hubbard the overall project manager. John Bull, William Butler, Chris Callegan, John Kirklin, Pat McKinney, David Perky, and Terry Waller performed the field work. William Butler, Chris Callegan, and David Perky processed and analyzed the data. Michael Tubman wrote the data collection report. Charlie Little was the lead on the geomorphic assessment, assisted by Peggy Hoffman and Deborah Cooper. Freddie Pinkard lead the 1 dimensional modeling effort assisted by Ronnie Heath and Jeremy Sharp. Gary Brown lead the multi-dimensioanl effort assisted by Keith Martin, Phu Luong and Ben Brown.

The authors gratefully acknowledge the contribution of Mr. Rick Broussard of USACE, New Orleans District, Engineering Division, Civil Branch, as author of the historic events timeline report. The comprehensive events chronology prepared by Mr. Broussard was an invaluable resource in developing a thorough understanding of the history of the study area from a river engineering perspective. His contributions were essential to accurate interpretation and evaluation of the results of this study and are greatly appreciated.

At the time of the study, COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Executive Summary – West Bay Sediment Diversion Study

An investigation is underway to examine whether or not the West Bay Diversion is inducing shoaling in the Pilottown Anchorage Area and in the navigation channel of the Mississippi River. Flow diversions are known to have the potential to induce downstream shoaling. The technical note entitled “River Diversions and Shoaling” by Letter et al (2008), which was commissioned by the LCA S&T Office, discusses this potential of diversions to induce shoaling in the river channels from which water is being withdrawn. Diversions can significantly reduce the sediment transporting capacity of the main-stem river and thereby induce shoaling. The actual effect on shoaling is dependent upon a number of factors that include the amount of water and sediment being diverted and the characteristics of the sediment being transported in the river. Diversion of increasing amounts of water generally increases the potential for induced shoaling within the river. The potential for induced shoaling is not necessarily linearly related to the withdrawal of water. For example, water withdrawal might not lead to significant induced shoaling for the types of sediment being transported until a “tipping” point is reached when water withdrawal reaches a threshold level, at which point induced shoaling might become substantial.

The objectives of this study are to understand the sediment transport processes in the Mississippi River in the vicinity of the West Bay Diversion and what, if any, effect the West Bay diversion has on these processes. The study involves several components or tasks, which together are designed to shed light on this issue and facilitate both qualitative and quantitative analyses. These tasks include: a comprehensive flow and sediment field data collection effort, a geomorphic assessment of the entire lower Mississippi River south of Belle Chase; a decadal, regional scale modeling effort for the entire lower Mississippi River down to and including Southwest Pass, using an enhanced version of the existing 1-D HEC-6T regional model; a hydrograph length (6 month), 2-D depth-averaged modeling effort using the AdH hydrodynamic model coupled to the SEDLIB sediment transport library; and a multi-day, high flow modeling effort conducted using the 3-D CH3D-SED sediment transport model.

The combined analyses have yielded a conceptual model of the general patterns of sand transport in the study area. The loss of water through each of the 4 major diversions upstream of head of passes (Grand Pass, Baptiste Collette, West Bay Diversion, and Cubit's Gap), together with the increase in river width that begins upstream of West Bay Diversion, results in a loss of transporting power sufficient to induce the deposition of most of the sandy sediment carried by the river. The magnitude and spatial distribution of this deposition is influenced primarily by 2 factors: the inflowing discharge hydrograph, and the available sediment supply. During moderate flow years, significant amounts of sandy sediment can be stored in the channel upstream of West Bay Diversion, and a relatively small volume of this sediment reaches the study site. During high flow years, this sediment can be mobilized and redistributed to the anchorage area and adjacent navigation channel, resulting in a large volume of deposition. However, if the high flow event occurs during a year with limited upstream in-channel sediment storage (i.e. if a high flow event in the previous year has scoured the channel of available sediment), then the flow can become sediment starved, and some erosion of the face of the point bar in the anchorage area can occur.

The field data collection effort has shown that as much as 45% of the measured water discharge at River Mile 12.1 is captured by Grand Pass, Baptiste Collette, West Bay Diversion, Cubit's Gap, and various other small cuts. These cuts capture sediment loads that are approximately proportional to this water discharge volume. The sediment associated with both suspended sediment and bed sediment sampling consists of clay, silts, and sand up to the medium sand size class. The bed material gradations are variable, but the deposit in the anchorage area has been found to consist primarily of fine sand.

The geomorphic assessment indicates that the anchorage area footprint rests along the face of a point bar. This point bar has been building for many years previous to the establishment of the West Bay Diversion. The growth of the point bar is likely associated with several factors, including the deepening of Grand Pass and Baptiste Collette in the late 1970's, deepening and decreased width of the navigation project that occurred in 1987, and the construction of West Bay Diversion.

The combined modeling analyses (1-D, 2-D and 3-D) indicate that the West Bay Diversion is responsible for 20-40% of the deposition in the combined dredging footprint of the anchorage area and the adjacent navigation channel. This percentage is fairly robust among all modeling efforts, and over many different discharge and sediment loading conditions. These estimates are based on current conditions where approximately 7% of the RM 12.1 flow is diverted through West Bay Diversion. Note that measurements have indicated that the percentage of flow captured by the West Bay Diverison has increased since it opened in 2003. Any future increases will likely influence the impact of the diversion on downstream shoaling.

The percent of sediment deposition associated with each dredge footprint independently (the anchorage area and the adjacent navigation channel) is more uncertain than the combined result. The location of the anchorage area footprint along the face of the point bar means that any adjustment of the cross-section resulting from changing flow and/or sediment flux conditions is reflected strongly in the volume of dredging in the anchorage area. Hence, although the impact of the implementation of West Bay Diversion on the combined anchorage area and adjacent navigation channel footprint is fairly consistent, the partitioning between these footprints can vary dramatically with changing forcing conditions.

Modeling results indicate that the percent of deposition due to West Bay diversion in the anchorage area footprint ranges generally from 15% to 55%, and in the adjacent navigation channel footprint it ranges from 10 to 30 %. These variations are observed on an inter-annual time-scale. The uncertainty associated with this percentage is high, and will require more study to quantify the induced percentage more precisely. A suitable set of flow and sediment conditions, for a pre-defined time frame, will have to be defined to quantify the percentage as a function of these conditions.

1 Introduction

Purpose

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), West Bay Sediment Diversion Project (MR-03), is located on the right descending bank of the Mississippi River in Plaquemines Parish, LA, at River Mile 4.7 above Head of Passes. An ERDC workplan to evaluate the West Bay Sediment Diversion effects on the lower Mississippi River in the vicinity of the diversion and the West Bay receiving area (Appendix A) was proposed and funded. This report is an interim report documenting the 6 month effort outlined in the ERDC workplan. The 6-month ERDC effort is focused on determining if the West Bay Sediment Diversion induces shoaling in the Pilottown Anchorage Area (PAA) and navigation channel, and if so, the percentage of shoaling being caused by the diversion and the percentage being caused by "natural" effects i.e., other passes, dredging, or unknown.

Study area

The West Bay Subdelta Complex is one of the six subdelta complexes of the modern Mississippi River Birdfoot Delta identified by Coleman and Gagliano (1964). This subdelta originated around 1838 during a flood stage as a break in the natural Mississippi River levee just below Venice, LA known as "The Jump" (Andrus 2007). By the mid 1900's the subdelta had entered into the natural deterioration phase of its life cycle (Andrus 2007). During this phase the marsh undergoes erosion and subsidence as inputs of fresh water, nutrients and sediment are decreased.

To address the decline of the West Bay Subdelta Compex CWPPRA submitted the West Bay Sediment Diversion Project (MR-03) to Congress in November 1991 as part of the annual Priority Project List. The project was approved for planning, design, and construction funding sponsored by the Louisiana Department of Natural Resources (LDNR) and the U.S Army Corps of Engineers (USACE). The project was designed to restore and maintain approximately 9,831 acres of fresh to intermediate marsh in the West Bay area by diverting fresh water and sediment from the Mississippi River over the 20-year project life through 2023 (Figure 1.1). The diversion benefits were based on construction of a 50, 000 cfs conveyance channel at the 50 percent duration stage of the Mississippi River, and construction of sediment retention enhancement devices (SREDS) in the receiving area. The project included the excavation of an uncontrolled diversion channel through the west bank of the Mississippi River at River Mile 4.7 (Figure 1.2). Construction was completed in November 2003 to deliver the design discharge of 20,000 cfs at the 50 percent duration stage of the Mississippi River at Venice, making the West Bay Sediment Diversion the largest constructed sediment diversion in Louisiana. The diversion channel was initially constructed using a hydraulic cutterhead dredge with a pipeline transport system (Figure 1.3) as a 25-ft-deep channel 195 ft wide. It was intended for the project to be mechanically enlarged after two to three years so that a flow capacity of 50,000 cfs at the 50 percent duration stage of the Mississippi River at Venice would be reached, if it was determined that the channel would not capture the thalweg of the Mississippi River. The enlargement of the conveyance channel has not occurred and the SREDS have not been constructed. It appears that the initial target discharge of 20,000 cfs was not reached as measured discharge data from 2004 and 2005 showed a discharge for the diversion of 14,000 cfs at the 50 percent duration stage (reported by the New Orleans Districts in the ERDC workplan, Appendix A). However, the diversion did grow over time and according to measured discharge data in 2007 and 2008 the capacity of the diversion had almost doubled to 27,000 cfs at the 50 percent duration stage (reported by the New Orleans District in the ERDC workplan, Appendix A). Andrus (2007) gives a more detailed account of the development of the study area and the design of West Bay Sediment Diversion itself.

Figure 1.1. West Bay Sediment Diversion Project Area location.

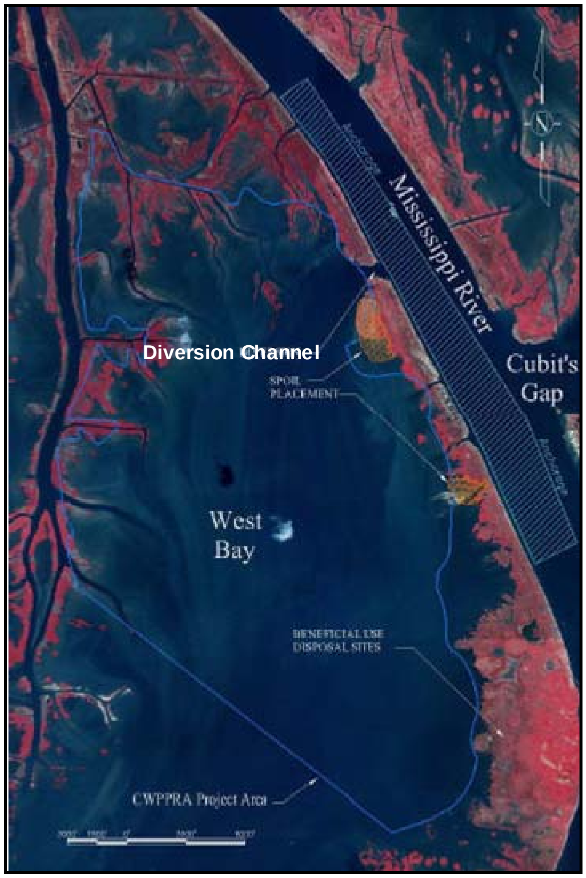


Figure 1.2. Satellite image of Project Area.

Figure 1.3. Diversion channel under construction.

The local and Federal sponsors recognized that a potential consequence of the West Bay Sediment Diversion was shoaling in the main navigation channel of the Mississippi River and the adjacent PAA. The PAA is a U.S. Coast Guard designated safe harbor outside of the Federal maintained navigation channel. It is the first federally authorized deep-draft anchorage but is used by both shallow and deep-draft vessels traveling on the Lower Mississippi River. It is located along the right descending bank from river mile 1.5 to 6.7 (Figure 1.2). After thorough negotiations with the navigation industry, an agreement for maintaining the PAA was developed and executed. As stated in the Cost Sharing Agreement executed between the State of Louisiana and the Corps of Engineers and the budget approved by the Task Force in 2002: "Included as a Project feature is the maintenance of the outermost (eastern) 250-ft-wide strip of the Pilottown Anchorage area and the entire width of the adjoining access area between this strip of the Pilottown Anchorage area and the Mississippi River navigation channel. Advanced maintenance of the Pilottown Anchorage area shall be undertaken to account for the anticipated shoaling induced by the Project. Below the conveyance channel, the anchorage and access areas shall be maintained at the depths existing at the time the Phase One interim conveyance channel is constructed. Above the cut, three 45-ft deep by 1,500-ft long anchorage berths shall be constructed and/or maintained." The project is responsible for this channel maintenance as a direct project cost through the project life, which ends in 2023 unless a new project cost sharing agreement is negotiated and signed by the State of Louisiana and the Corps of Engineers.

Approach

The ERDC prepared a workplan that included four primary tasks. Those tasks included a comprehensive data collection program, a detailed geomorphic assessment, 1D modeling, and multi-dimensional modeling of the West Bay reach. The data collection program included channel geometry, discharge, suspended sediment, bed material data and salinity. The geomorphic assessment included geometric data analysis, gage and discharge data analysis, dredge records analysis, sediment data analysis and events timeline analysis. The 1D sediment routing modeling provides the opportunity of evaluating long term channel changes and delivery of sediments at a regional spatial scale and provides boundary condition input for multi-dimensional modeling. The 1D modeling effort was undertaken using the HEC-6T Sediment in Stream Networks software, a proprietary software owned by MBH Software, Inc. of Clinton, Mississippi and is an enhanced version of Corps' HEC-6 program, Scour and Deposition in Rivers and Reservoirs. The multi-dimensional modeling task will conduct simulations using both the Adaptive Hydraulic Model (AdH – a 2D model) and Curvilinear Hydrodynamics in 3 Dimensions (CH3D) to simulate the effects of the diversion on shoaling in the navigation channel and PPA. AdH was developed at the ERDC while the basic sigma-stretched version of CH3D was developed by Peter Sheng, University of Florida, for ERDC. However, extensive modifications have been made to CH3D since then by Ray Chapman, Billy Johnson, and others of ERDC.

Each of the tasks developed for the West Bay Sediment Diversion workplan (data collection, geomorphic assessment, 1D modeling and multi-D modeling) have their individual strengths and limitations. The overall strategy behind the workplan was to utilize all of the tools at our disposal such that the limitations of any one tool do not inhibit the success of the overall effort. The finial interpretation of any findings will be undertaken using the knowledge gained from the combined aspects of the study. This strategy will also aid in resolving any conflicts that may arise between tasks or sub-tasks.

West Bay issues

Five issues were identified as important in considering the West Bay Diversion sedimentation effects on the lower Mississippi River in the vicinity of West Bay and the receiving area. Issue A is related to the degree of shoaling, issue B is concerned with the longer–time scale, large spatial scale sediment transport-morphology change, issue C considers the amount and characteristics of flow and sediment passing through the diversion, Issue D is focused on the amount of sediment retained and leaving the West Bay receiving area and issue E looks at the ecological benefits. In the following paragraphs the issues will be listed in detail and the ERDC workplan tasks that address them listed. The detailed answers will be given in the relevant chapters pertaining to each task.

Issues A

Is the diversion inducing shoaling in the Pilottown anchorage area and the Mississippi River Navigation Channel? If so by how much? At what rate? If so, how does the induced amount/rate vary with river stage (i.e., transporting power) and sediment load on the rising, peak and falling hydrograph? If so, how does the induced shoaling amount/rate vary along the anchorage area, and with position across the river? How do observations since 2003 relate to a longer term perspective (scale of 20-50 years?).

The increased shoaling observed in the anchorage area could result from any of several causes, such as:

- Sediment deposition induced by the recent flood events on the river.
- Transport of existing sediment depositional loads from further upstream (i.e., “legacy” events from previous floods and/or changes to the configuration of the river.
- Shoaling induced by local changes to the river configuration (i.e., West Bay diversion).

To investigate the relative contributions of each of these potential causes to the observed shoaling in the anchorage area, it is necessary to first interrogate the available data. Where does the shoaling occur? What types of sediment are present? What are the antecedent stage, flow, and sediment loading conditions? What historical conditions and/or changes to the river configuration might have resulted in the development of a slug of sediment in the river? These and other questions can be used to infer likely candidates for the sources of the sediment, which in turn can inform the process of ascertaining the cause of the deposition. The geomorphic assessment and 1D modeling will look at these long term, large spatial scale issues.

Next a multi-dimensional sediment transport model will be used to gain specific insight into the role of the West Bay division itself in causing deposition. The model can be run for various sediment loading conditions, both with and without the division included. These simulations can be used to provide qualitative insight into the expected changes in erosional and/or depositional trends in the anchorage area that result from the West Bay diversion. The model can also be used to yield quantitative insight into the expected sediment deposition in the anchorage areas as a function of observable parameters (i.e. stage, discharge, sediment load).

Issues B

Is there a large space scale, longer-time scale sediment transport-morphology change event taking place in the river that is creating the observed shoaling? If so, what is attributable to the diversion and what to the background larger-scale process? What is the time and space scale of such a background process/event? How do observations since 2003 relate to a longer term perspective (scale of 20-50 years?).

The dominant morphological processes that drive the observed changes in the lower Mississippi River and delta system can operate over very large spatial and temporal scales. There are many factors, both natural and man induced, that can contribute to these processes. The effects of large floods and storms, changing sediment loads and characteristics, channel maintenance activities, dredging practices, diversions (natural and man-made), subsidence and relative sea level rise are just a few such factors, but are not a comprehensive list. In terms of temporal scales that are typically associated with river morphology, the diversion at West Bay has been operating for a very short time period. The question must be asked to what degree the observed shoaling at the Pilottown anchorage is a result of large-scale, long-term river morphology, or a direct result of the impacts of the West Bay diversion. It is therefore important to establish the long-term morphological trends that are occurring in this reach of the river and to evaluate the observed shoaling at the Pilottown anchorage with regard to these trends. These morphological trends are determined by means of a geomorphic assessment.

A geomorphic assessment brings together all the known information about a river reach, and provides an understanding of how the river works and has responded to changes in a historical perspective. Methods and tools typically used in a geomorphic assessment can include analysis of discharge and sediment data, specific gage records, and analysis of channel geometry including form, pattern and profile. Each part of the geomorphic assessment provides additional clarity to the overall understanding of the dominant processes that have shaped and formed the system. Insight derived from this analysis can often be used to predict and assess future conditions. In addition, the geomorphic assessment can provide information of baseline conditions necessary for development, application and interpretation of numerical models.

A geomorphic assessment provides a qualitative evaluation of the factors that impact channel morphology. This type of assessment answers the “why” are changes occurring questions. However, water and sediment routing models provide a quantitative evaluation which answers the “how much” questions. A 1D sediment routing model provides for a long term simulation of sedimentation impacts. These models can simulate both with and without diversion conditions which allows for a comparison of the direct impact of a particular diversion over an extended period of time. However, utilizing a 1D model in a 3-dimensional environment does not allow for the site specific, detailed quantitative analysis available through the use of multi-dimensional analysis. While the geomorphic assessment provides the morphologic changes required as input for 1D modeling, the 1D model output provides the boundary conditions required for the more detailed multi-dimensional modeling effort.

Issues C

How much sediment passes through the diversion? What are the characteristics of the flow and sediment passing through, as a function of river stage and rising/falling limb?

Previous 1-D modeling of the lower Mississippi River has included various diversions. These models require the user to specify the concentration of sediment passing through the diversion. To date, no sediment load measurements have been acquired in the diversions. Therefore, the previous efforts were more sensitivity evaluations with sediment concentrations of sand ranging from 100 percent of those in the Mississippi River to no sediment being diverted through the diversions. This range results in significant differences in the quantities and location of sediment deposition downstream. The current scope of work includes acquiring sediment measurements on the Mississippi River as well as at the diversion/distributary sites. These include West Bay, Cubits Gap, Grand Pass, and Baptiste Colette Bayou. Since sediment loads vary depending on the flow, the scope of work includes measuring the sediment over a wide range of flows. This data collection effort will provide the sediment data required in the modeling effort to allow for a more accurate simulation of long term diversion impacts.

Issues D

How much sediment is retained within West Bay? What are the amounts/characteristics of sediment into West Bay compared those leaving West Bay? How does the velocity and deposition regime within West Bay change spatially (down the long axis and along the fringes)? What is the rate of accumulation within West Bay, and how does it vary spatially? How do observations since 2003 relate to a longer term perspective (scale of 20-50 years?).

This effort requires the modeling of silts and clays through the multidimensional modeling effort outlined in Task 4. This effort will only be conducted upon completion of the initial 6 month work plan effort, if deemed necessary after the field data collection, and only if the project performance in the receiving area still requires additional analysis to determine future benefits. Further development of the modeling capabilities may be required to forecast the subsequent development of the delta, or the development can be modeled in conjunction with other analytic or empirical forecasts of channel bifurcation.

Sediment retention and redistribution within West Bay can be investigated using both available data and model predictions. The available data sets can be used to ascertain information about the governing processes that have impacted the West Bay diversion so far. These include:

- Sediment loads into the Bay
- Sediment deposition within the Bay
- Sediment deposition resulting from the 2008 storm event.
- Sediment sorting within the Bay
- Wind loads and wind wave conditions within the Bay
- Subsidence within the bay, and local values of relative sea level rise (both current and anticipated)

Using these process descriptions, anticipated trends for the West Bay can be developed. These trends can be investigated in a multi-dimensional numerical model, to determine how different forcings and conditions might alter the trends in the future, and to estimate the total sediment retention in the Bay (i.e., loading minus losses to wind wave resuspension and recirculation).

All of these insights can be used together to forecast the life cycle of the West Bay diversion.

The bulk of answers to Issue D will be gained from the 12 month ERDC workplan effort. However, the field data collection task has gained some insight into the amounts/characteristics of sediment entering West Bay and how the deposition regime changes specifically within the receiving area.

Issues E

What is the current assessment of the ecological benefits of the West Bay project? How close is the area to depositing subaerial "land"? Are there benthic areas that are currently shallow that have moved into the photic zone, thus encouraging epiphytic algae production or other signs of primary productivity? Are there areas that, though below the water surface now, can be expected to support emergent vegetation in the near future? How has the dredged material deposited in the area persisted? Is it now vegetated? Have the dredged material areas trapped more sediments and grown or have they eroded? How do these results fit within the anticipated receipt of environmental benefits used to justify the cost of the projects? Are there activities that need to take place to update the project projections?

The initial attempts to address Issue E should be coordinated with the State of Louisiana by utilizing the existing CWPRRA monitoring plan. The planned “re-surveying” of the West Bay receiving area should more forward rapidly. However, some consideration needs to be given to the seasonality of this surveying. Is it possible that sediments are being deposited into the receiving area as suggested by Kolker et al. (date), and then resuspended during storm events and low water events? Additionally a group can be developed to evaluate whether the rate at which ecological benefits are being accrued from the project has changed enough from the original project planning to require a re-calculation of the benefits.

2 Data Collection

Purpose of Data Collection

The work plan calls for field data collection to serve as the primary foundation for increasing the usefulness of any additional modeling efforts. The new data improves definition of boundary conditions for one-dimensional and multi-dimensional models. The data is essential for describing the ratio of diversion sediment to river sediment, which is critical required information for the one-dimensional model. Also, the data are essential in calibrating and verifying the numerical model results.

As specified in the work plan, the deliverables of the field data collection effort are:

- A bathymetric base map of the Mississippi River channel in the vicinity of the diversion entrance channel and through the diversion entrance channel into West Bay to the extent that water depths in the Bay allow.

- Current speeds and directions across transects of the Mississippi River in the vicinity of the diversion, and across the diversion entrance, as well as acoustic backscatter intensity measurements across the same transects.

- Suspended sediment concentrations and suspended sediment types (percent sand and fines) at horizontal and vertical sample locations along the ADCP transect.

- Optical backscatter and salinity measurements along the ADCP transect.

- Bottom-sediment types and grain-size distributions at selected locations in the Mississippi River and West Bay, and samples for additional analyses at the same locations.

Design of the Data Collection Program

Several issues impact how surveys should be conducted in this reach of the lower Mississippi River. The first involves the possibility of a salt-water wedge, which can enter the River at discharges below 300,000 ft^3/s (Soileau et al., 1989). Recent observational studies have shown the wedge is an effective sediment trap for fine particulates in the River channel adjacent to the West Bay diversion channel (Galler and Allison, 2008). However, there are very limited observational data of sediment transport in this reach of the River. The work plan calls for salinity profiling to detect the presence of the wedge, and suspended sediment concentration and water current measurements to provide these data.

A second factor is the limited availability of detailed bathymetry information. To provide this information, the work plan (Appendix A) calls for a multi-beam bathymetric survey in the Mississippi River in the vicinity of the diversion entrance channel, and through the diversion entrance channel into West Bay to the extent that water depths in the Bay allow. During planning for the field work, following the development of the work plan, it was decided that a previously conducted muti-beam survey which extended about 2.25 miles south of the diversion channel, about 0.5 miles north of the channel, and through the diversion channel entrance into West Bay to the extent that water depths in the Bay allowed, provide sufficient data to fulfill the purposes of the work plan.

The data limitation extends to the absence of nearby monitoring stations for anything but river stage. The nearest real-time active monitoring station is at Belle Chasse (RM75.5), but the station record only extends to December 2007. Long-term monitoring data is unavailable below the station at Tarbert Landing (RM306.2), immediately below the Old River control structure. Given what has recently been learned about sediment storage and remobilization processes in the lower river due to a reduction in water surface slope in lower discharges, which extends upriver to the approximate tidal limit (at about Baton Rouge), predicting suspended sediment concentrations in the river at the diversion entrance is imprecise. This set of processes, and the likelihood that suspended sediment concentrations likely differ significantly from those at even Belle Chasse, mean a single integrated survey of suspended sediments and currents (combined with historical monitoring data) is unlikely to answer the objectives. Further, while bed-load measurements have recently been made in the lower river using modern techniques (Nittrouer and Allison, 2008), none of these measurements have been made at monitoring stations like Belle Chasse, making estimation of the bed-load component of sediment transport at West Bay difficult. Several measurements of sediment transport are necessary to answer the objectives. Sediment fluxes do not co-vary linearly with water discharge in the river adjacent to the diversion. Thus the work plan calls for six surveys within a single flood year.

Instrumentation

The bathymetric survey was conducted using an interferometric (phase measuring) swath sonar. The swath system (Geo-Acoustics 250 kHz) measures both bathymetry and seabed acoustic backscatter from a hull mounted transducer, providing co-registered depth soundings and side scan sonar information in water depths ranging from 1.64 to 328 ft. In contrast to fixed-angle algorithms utilized by beam-forming multi-beams, interferometric swath systems determine angle and travel time for every sampling interval (~50ms). Measuring angles from phase shifts at rapid sampling intervals provide a denser number of soundings at the outer ranges resulting in a wide horizontal swath (approximately 8-10 times water depth) in shallow water and resolution of three-dimensional features ranging in size from inches to miles. Coupled with GPS, during the survey, an Applanix POSMV IMU system measured the inertial position of the vessel along with its angular orientation. These measurements are typically acquired at a rate of up to 200 Hz. Each trajectory measurement is described by 7 parameters. They are 3 position coordinates, typically latitude, longitude and elevation relative to some datum, 3 angular coordinates, roll, pitch, heading, and a time stamp. These 7 parameters completely describe the vessel position and orientation at each sample time.

The current and acoustic backscatter surveys were conducted using a vessel mounted broadband Acoustic Doppler Current Profilers (ADCP) manufactured by RD Instruments, Inc. (RDI). The work plan (Appendix A) calls for a 1200 kHz ADCP to be used for the measurements. The first current measurements, made on March 10 and 11, 2009 were made using a 1200 kHz ADCP. However, it was discovered that because of the high degree of turbulence in the area, a 600 kHz system would produce better statistical reliability and a 600 kHz system was used for all subsequent current surveys. During data collection, the ADCP is capable of measuring vessel velocity, water velocity, water temperature, bottom bathymetry, and acoustic backscatter. The measurement of the velocity of the vessel over the bottom allows the current velocity data to be corrected for the movement of the survey vessel. However, if there is sufficient sediment transport down-river at the bottom, the ADCP measurements of the velocity of the survey vessel over the bottom will contain some inaccuracies that will introduce errors in the calculated current velocities. These can be removed by using a GPS to measure the velocity of the survey vessel. The surveys included a GPS system to measure the vessels speed and track (i.e., ship track). The GPS system also provided required heading information to the ADCP system.

All water samples were collected in clean 1L HDPE plastic bottles. At each collection point a five depth profile at approximately 1ft below surface, 25 percent water depth, 50 percent water depth, 75 percent water depth, and 1ft above bottom was collected. A P-6 isokinetic sampler was lowered to each target depth and opened for 30-50 seconds, depending upon flow conditions. Sample bottles were filled to 50-75 percent full to ensure that over filling and flushing of sediment from the bottle did not occur. Water flows below 2.0 ft/s were found to be insufficient to purge the air from within the P-6 sampler and fill the bottle. Therefore, a water pump was used to fill the sample bottles when average flows were below 2.0 ft/s. In these instances a water hose was attached to a 100 lb weight and lowered to each target depth. Sufficient time was allowed to flush the water line before filling a bottle from a specified depth. After collection, samples were stored upright in a cooler and transported back to the lab for analysis.

During the suspended sediment sampling and current survey conducted on May 29 and 30, July 21 and 22 and September 23 and 24, 2009, measurements were made using an optical backscatter device (OBS). The OBS is an optical sensor for measuring turbidity by detecting infra-red light scattered from suspended matter. The OBS-3A manufactured by D&A Instruments also records depth, temperature and salinity along with the backscatter data. During the surveys, the OBS and the P-61 sampler were connected to give concurrent suspended sediment samples and OBS data. On July 3, 2009, CTD casts were made using a YSI 600 XLM sensor.

Bottom sediments were obtained using a push-core type sampler. The sampler consists of a 1.5-in.-diam PVC pipe, 18 in. in length (Figure 2.1). Attached to this is a smaller section of pipe with a valve attached at the upper end. The purpose of the valve is to create a reduced pressure holding the sample in the larger-diameter pipe. The samples were then brought to the surface and classified by visual inspection or transported back to ERDC for more detailed analysis. The push-core sampling method is only good for water depths less than 15 ft in materials that have a high clay/silt content. At the deeper and sandier locations, bottom samples were taken using a drag bucket. The bucket was dragged along the bottom by a rope, and the weight of a chain attached to the open end of the bucket forced it to dig into the bed and fill the bucket with a bottom sample.

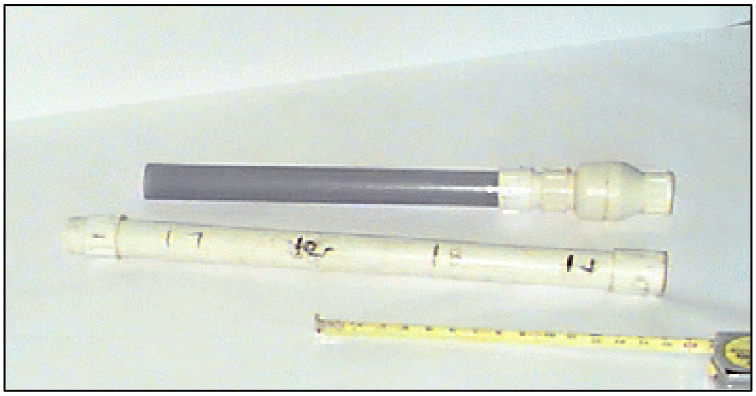


Figure 2.1. Push-core sampler.

Survey and Sample Locations

The coverage of the multi-beam survey is shown in Figure 2.2. It extends from about 2 miles north of the diversion channel to about 2.25 miles south of the diversion channel. It also extends into West Bay to the extent allowed by the water depths in the Bay.

ADCP surveys were conducted in an area extending from the Venice Louisiana area, River Mile 12.1, to just south of Cubits Gap, River Mile 2.6 (Figure 2.3). The locations of the survey transect lines are shown in Figures 2.4 through 2.19. In the figures (with the exception of Figure 2.5 which shows the general locations of the areas surveyed on April 22 and 23), ADCP survey transect numbers are given on each survey line. The designation of the survey line and the name of the ADCP raw data file for the ADCP survey transect numbers are given in Appendix B. ADCP surveys were conducted on March 10 and 11, 2009 (Figure 2.4), April 22 and 23, 2009 (Figures 2.5-2.9), May 5 and 6, 2009 (Figure 2.10), May 29 and 30, 2009 , (Figures 2.22 and 2.12), June 16 and 17, 2009 (Figures 2.13 and 2.14), July 21 and 22, 2009 (Figures 2.15 and 2.1619) and September 23 and 24, 2009 (Figures 2.17 and 2.18).

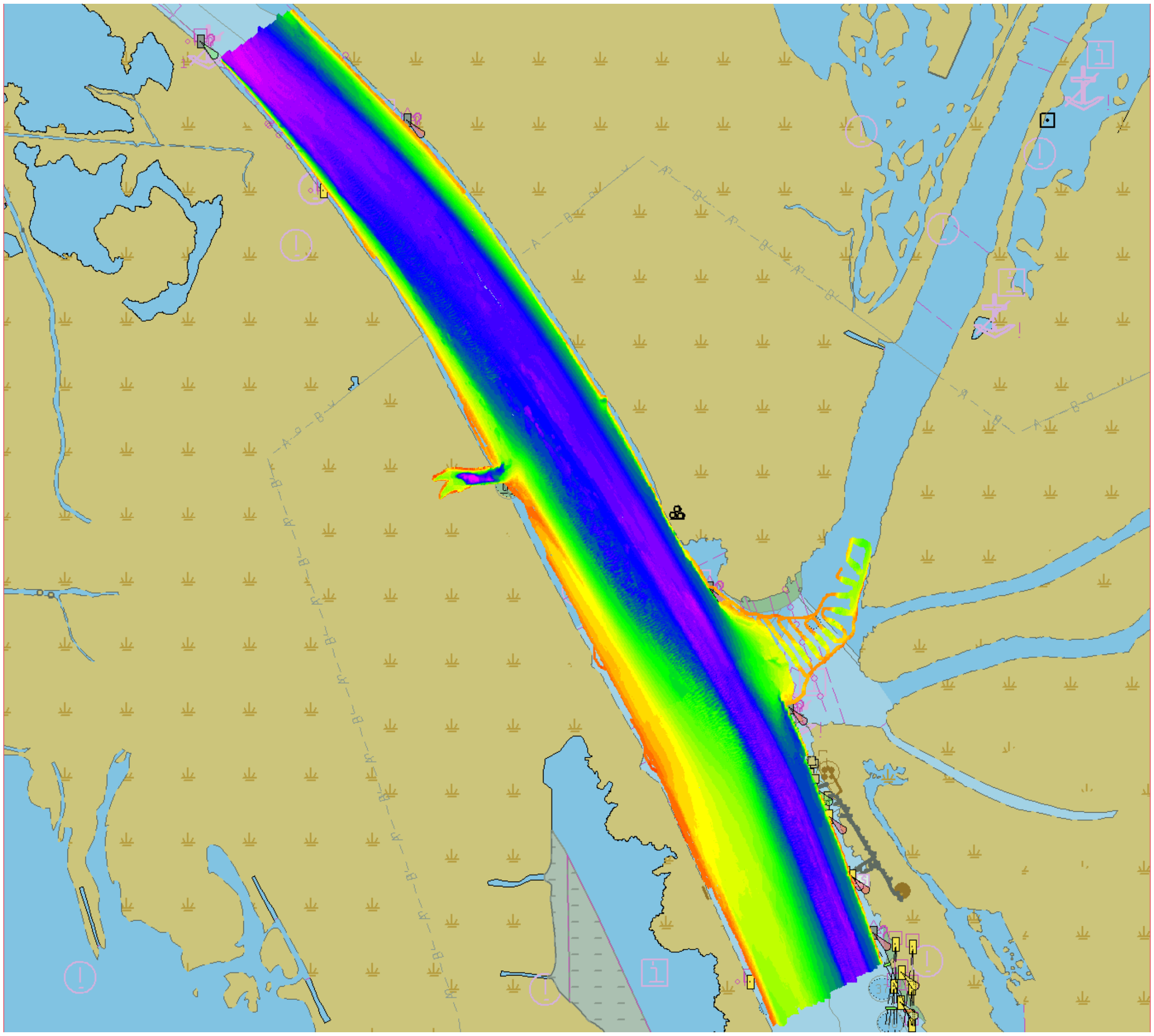


Figure 2.2. Multi-beam survey coverage.

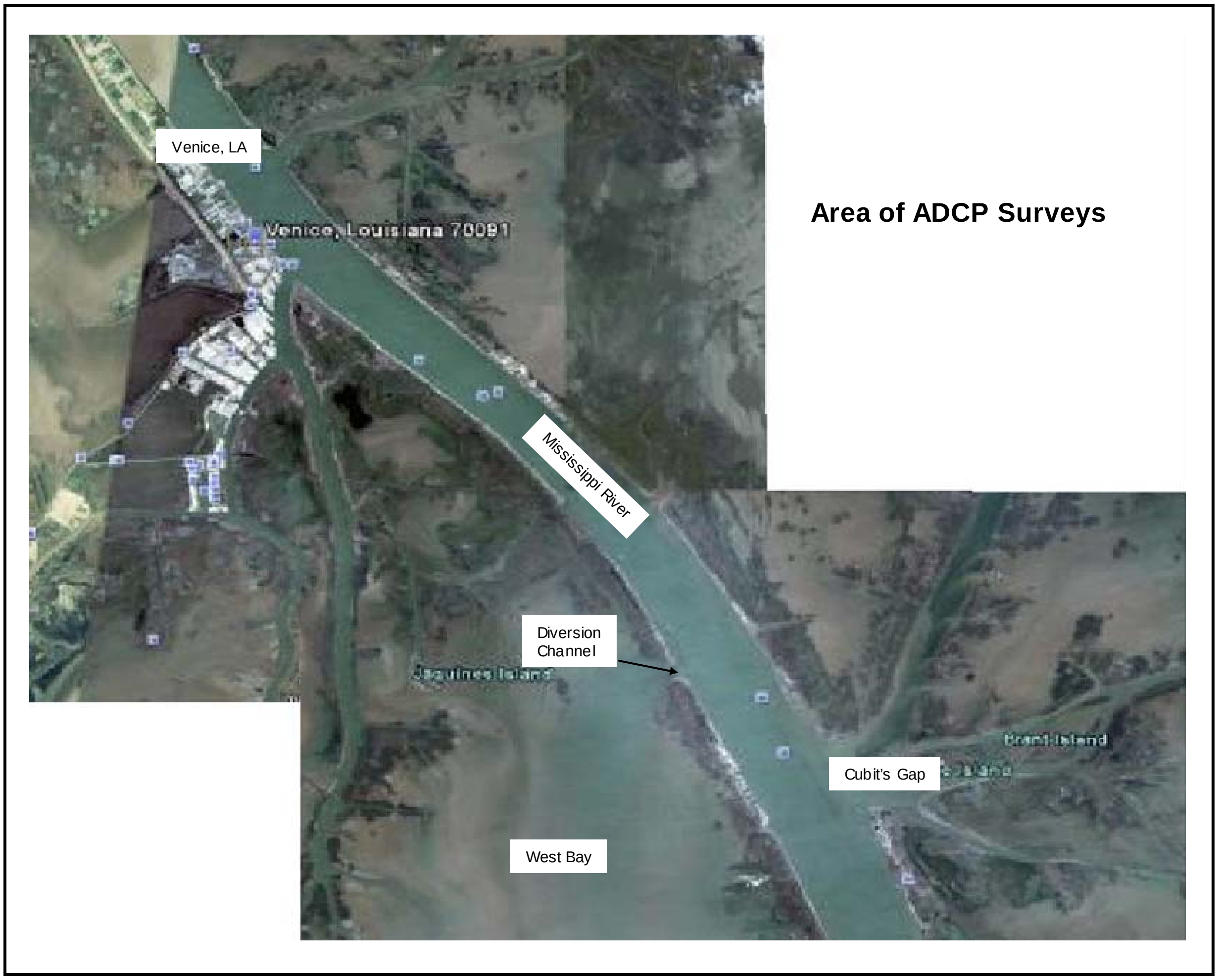


Figure 2.3. ADCP survey area.

March 10-11, 2009

Figure 2.4. ADCP survey transects on March 10 and 11, 2009.

Area 1 – April 22-23, 2009

Area 2 – April 22-23, 2009

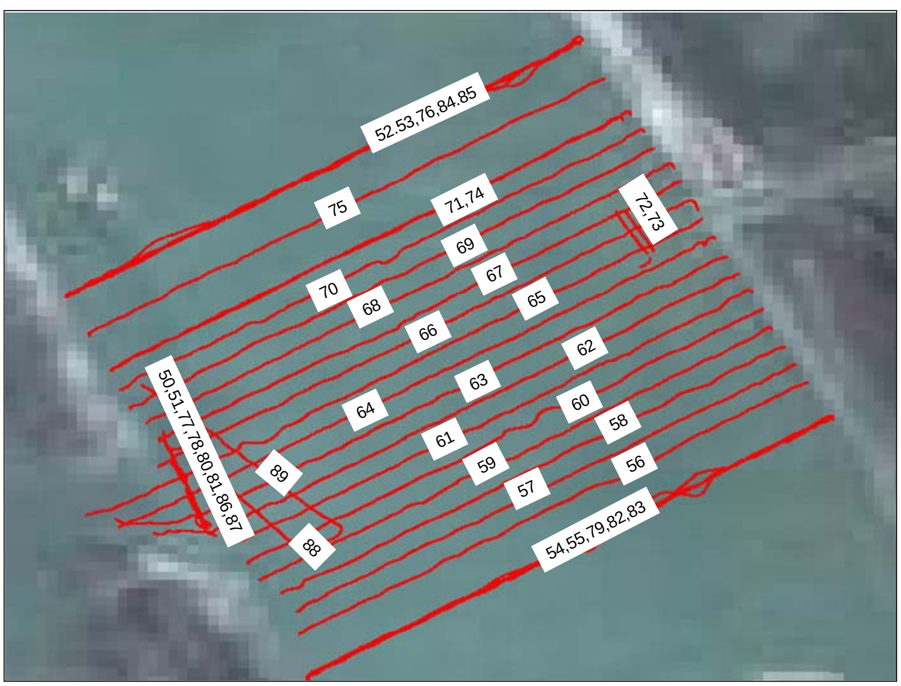
Area 3 – April 22-23, 2009

Area 4 – April 22-23, 2009

Figure 2.5. Transect areas during the ADCP survey on April 22 and 23, 2009.

Area 1 – April 22-23, 2009

Figure 2.6 ADCP survey transects on April 23, 2009 in Area 1.



Area 2 – April 22-23, 2009

Figure 2.7. ADCP survey transects on April 22 and 23, 2009 in Area 2.

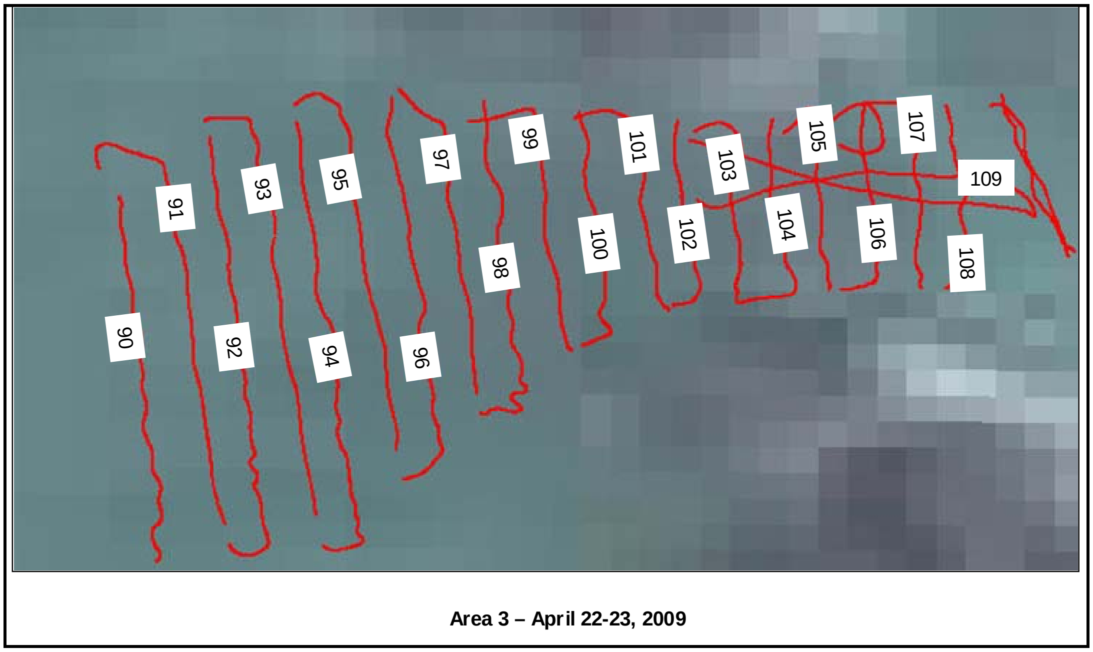


Figure 2.8. ADCP survey transects on April 22, 2009 in Area 3.

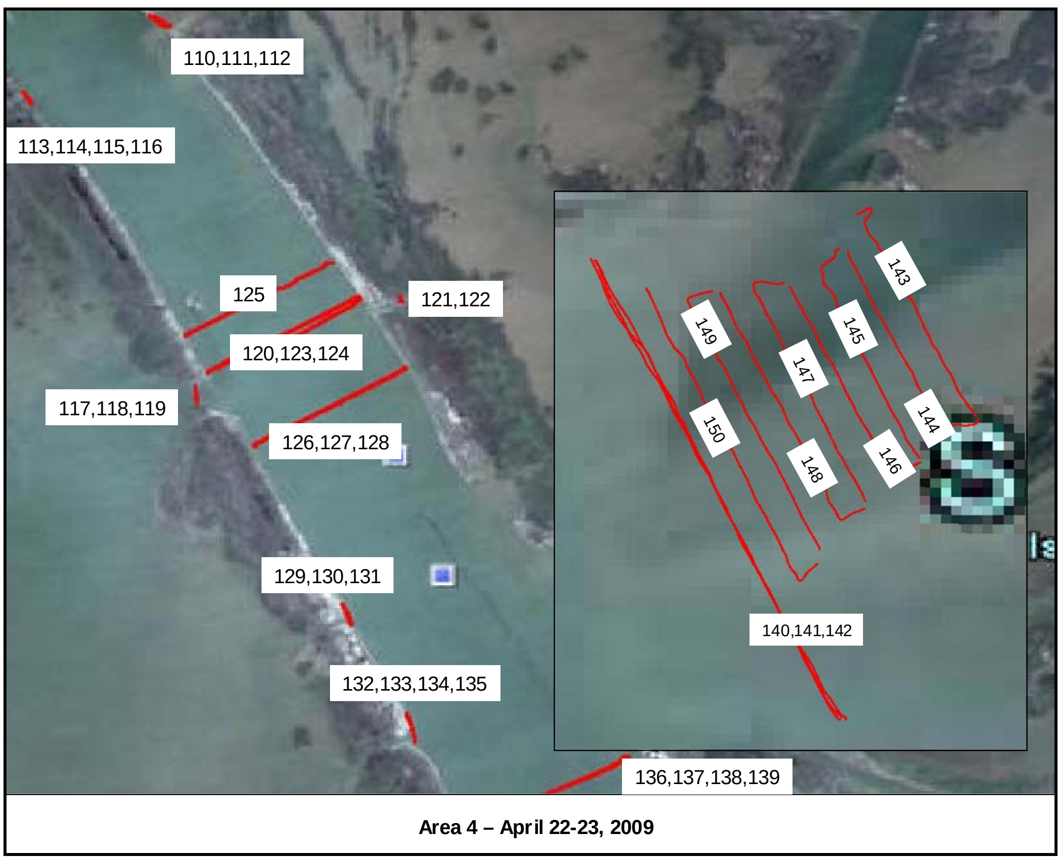


Figure 2.9. ADCP survey transects on April 23, 2009 in Area 4.

May 5-6, 2009

Figure 2.10. ADCP survey transects on May 5 and 6, 2009.

May 30, 2001

Figure 2.11. ADCP survey transects on May 30, 2009.

Figure 2.12. ADCP survey transects on May 29 and 30, 2009.

Figure 2.13. ADCP survey transects on June 17, 2009.

June 16-17, 2009

Figure 2.14. ADCP survey transects on June 16 and 17, 2009.

July 21-22, 2009

Figure 2.15. ADCP survey transects on July 21, 2009.

Figure 2.16. ADCP survey transects on July 21 and 22, 2009.

Figure 2.17. ADCP survey transects on September 24, 2009.

Figure 2.18. ADCP survey transects on September 23 and 24, 2009.

The locations of the suspended sediment samples, OBS measurements, and salinity measurements are shown in Figures 2.19 and 2.20. The locations of the push- cores and the bottom drag samples are shown in Figures 2.21-2.23. The latitudes and longitudes for the locations shown in the Figures 2.19 and 2.26 are in Appendix C, and the locations shown in Figures 2.21-2.24 are in Appendix D.

Chronology of Events

Field Activities

Field activities began on March 9, 2009 and were ended on September 25, 2009. They are summarized in Tables 2.1-2.7.

Figure 2.19. Locations of suspended sediment samples, OBS measurements, and salinity measurements near Venice, LA.

Figure 2.20. Locations of suspended sediment samples, OBS measurements, and salinity measurements.

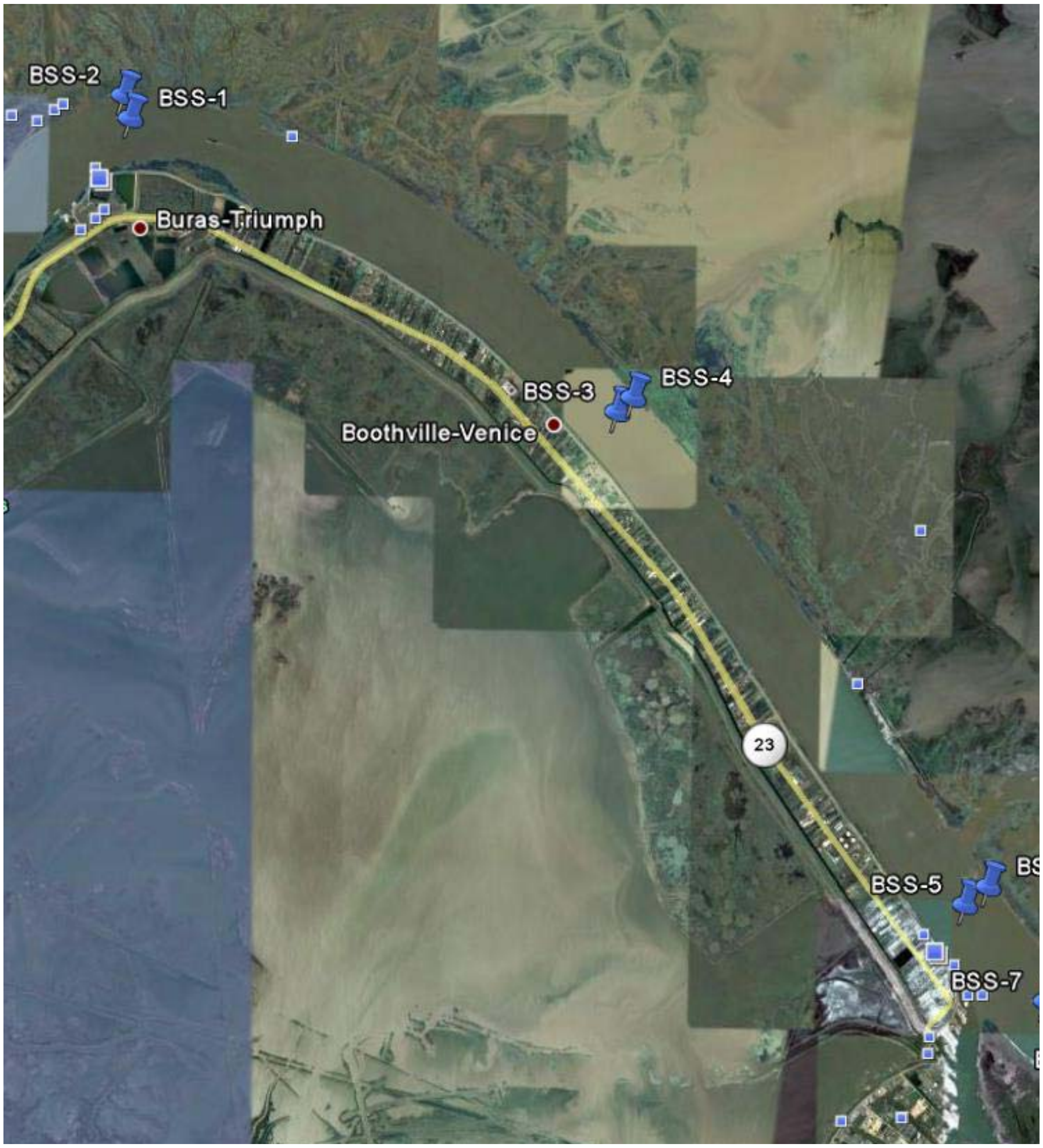


Figure 2.21. Locations of bottom drag samples north of Venice, LA.

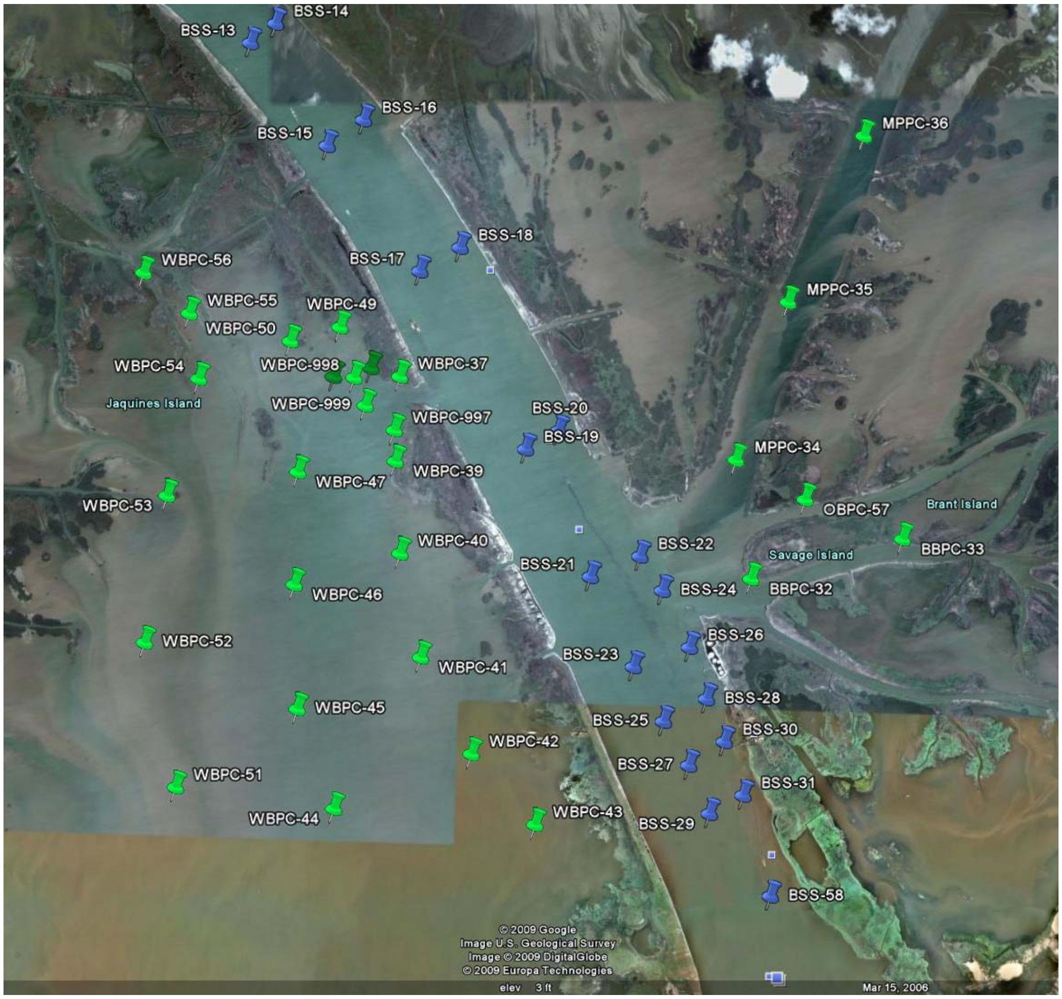


Figure 2.22. Locations of the bottom drag samples and push-cores between Venice, LA and the diversion channel. The push core are denoted samples are noted with the green pins while the bottom drag are noted with the blue pins.

Figure 2.23. Locations of the bottom drag samples in Southwest Pass.

Table 2.1. Field activities during trip 1a on March 9-12, 2009.

Date	Activities
March 9	John Bull, Chris Callegan, Mike Kirklin, Jim Leech and Dave Perky deployed to Venice, LA with the survey vessels Mr. George and Mr. Dave.
March 10	John Bull, Mike Kirklin and Jim Leech collected 26 bottom drag samples from the Mr. Dave along the Mississippi River starting south of Cubit's Gap to approximately 5 miles north of Venice, LA. Chris Callegan and Dave Perky collected nine push cores and conducted ADCP surveys in the diversion channel and West Bay using the Mr. George.
March 11	The Mr. Dave collected additional bottom drag samples in the vicinity of the diversion channel and in Cubit's Gap. The Mr. George conducted ADCP surveys north and south of the diversion channel and in Cubit's Gap.
March 12	John Bull, Chris Callegan and Mike Kirklin deployed with the Mr. George and Mr. Dave to another job location. Jim Leech and Dave Perky finished collecting push-core samples in West Bay using a rented air boat. After collecting the push cores, Leech and Perky returned to Vicksburg.

Table 2.2. Field activities during trip 1b on April 22-24, 2009.

Date	Activities
April 22	John Bull, Chris Callegan, Mike Kirklin, Pat McKinney and Dave Perky deployed to Venice, LA with the survey vessels Mr. George and Mr. Dave. John Bull, Mike Kirklin and Dave Perky collected 30 P-61 water samples using the Mr. Dave. Chris Callegan and Pat McKinney conducted an ADCP survey using the Mr. George.
April 23	John Bull, Chris Callegan, Mike Kirklin, Pat McKinney and Dave Perky deployed to Venice, LA with the survey vessels Mr. George and Mr. Dave. John Bull, Mike Kirklin and Dave Perky collected 29 P-61 water samples using the Mr. Dave. Chris Callegan and Pat McKinney conducted an ADCP survey using the Mr. George.
April 24	John Bull, Chris Callegan, Mike Kirklin, Pat McKinney and Dave Perky returned to Vicksburg.

Table 2.3. Field activities during trip 1c on May 4-7, 2009.

Date	Activities
May 4	Chris Callegan, Jesse Chism, Mike Kirklin and Dave Perky deployed to Venice, LA with the survey vessels Mr. George.
May 5-6	Chris Callegan, Jesse Chism, Mike Kirklin and Dave Perky collected 148 P-61 water samples and conducted an ADCP survey using the Mr. George.
May 7	Departed from Venice, LA and went to Morgan City, LA for another project.

Table 2.4. Field activities during trip 2 on May 28-June 1, 2009.

Date	Activities
May 28	Chris Callegan, Mike Kirklin and Dave Perky deployed to Venice, LA.
May 29	Chris Callegan, Mike Kirklin and Dave Perky conducted 6 ADCP transect surveys, made OBS and salinity measurements and collected 65 P-61 samples using the Mr. Dave.
May 30	Chris Callegan, Mike Kirklin and Dave Perky conducted 34 ADCP transect surveys, made OBS and salinity measurements and collected 20 P-61 samples using the Mr. Dave.
May 31	Chris Callegan, Mike Kirklin and Dave Perky collected 17 bottom drag samples along Southwest Pass.
June 1	Chris Callegan, Mike Kirklin and Dave Perky returned to Vicksburg

Table 2.5. Field activities during trip 3 on June 15-18, 2009.

Date	Activities
June 15	Mike Kirklin, Dave Perky and Terry Waller deployed to Venice, LA.
June 16	Mike Kirklin, Dave Perky and Terry Waller conducted 27 ADCP transect surveys and collected 60 P-61 samples using the Mr. Dave.
June 17	Mike Kirklin, Dave Perky and Terry Waller conducted 35 ADCP transect surveys and collected 21 P-61 samples using the Mr. Dave.
June 18	Mike Kirklin, Dave Perky and Terry Waller returned to Vicksburg.

Table 2.6. Field activities during trip 4 on July 20-24.

Date	Activities
July 20	Chris Callegan, Mike Kirklin and Dave Perky deployed to Venice, LA with the Mr. George. They collected 20 suspended sediment samples from water pumped up from 7 ft depth at the Cypress Cove Marina.
July 21	Chris Callegan, Mike Kirklin and Dave Perky conducted 45 ADCP transect surveys, collected 42 P-61 samples, and made 3 CTD and OBS casts using the Mr. George.
July 22	Chris Callegan, Mike Kirklin and Dave Perky conducted 20 ADCP transect surveys and collected 119 pumped suspended sediment samples using the Mr. George.
July 23	Chris Callegan, Mike Kirklin and Dave Perky collected 45 bottom drag samples using the Mr. George.
July 24	Chris Callegan, Mike Kirklin and Dave Perky returned to Vicksburg.

Table 2.7. Field activities during trip 5 on September 21-25.

Date	Activities
Sept. 21	Chris Callegan, Tony Jackson and Dave Perky deployed to Venice, LA with the Mr. George.
Sept. 22	Chris Callegan, Tony Jackson and Dave Perky collected 47 bottom drag samples in Southwest Pass using the Mr. George.
Sept. 23	Chris Callegan, Tony Jackson and Dave Perky collected 92 suspended sediment samples, conducted 23 ADCP transects surveys, and made 13 CTD and OBS casts using the Mr. George.
Sept. 24	Chris Callegan, Tony Jackson and Dave Perky collected 36 suspended sediment samples, conducted 28 ADCP transects and made 17 CTD and OBS casts using the Mr. George. Tony Jackson returned to Vicksburg with the samples.
Sept. 25	Chris Callegan and Dave Perky returned to Vicksburg.

Data Processing and Analysis

Processing Steps

OBS and salinity measurements

The OBS with salinity and pressure sensors was suspended approximately 0.5 ft above the P-61 suspended sediment sampler. When the suspended sediment sample was taken at 1 ft, the OBS was out of the water. For that reason, in the tables of OBS results in Appendix D, the time and OBS measurements near the 1-ft depth are for readings taken coincidently near 1-ft depth when the system was being lowered or raised from some deeper depth.

Laboratory analysis for suspended sediments:

Suspended sediment concentrations (SSC): Each sample for SSC was shaken to re-suspend particles and then poured into a 1L graduated cylinder to record the volume. The samples were then transferred into a ground glass vacuum filtration system (8-lb vacuum maximum) and drawn through pre-weighed, 90 cm diameter, glass fiber filter with 0.7μm particle retention. The sample bottles, graduated cylinders, and filter towers were rinsed several times with distilled water to make sure that all particles were introduced to the filter. The filters were then dried in a low temperature oven overnight at approximately 50˚C. The filters were then re-weighed and SSC was calculated for each sample. The SSC's for each sample are reported in Appendix G.

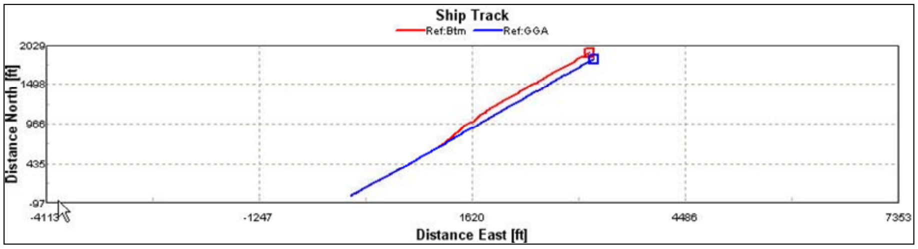
Suspended sediment grain size analysis: The laser diffraction technique was utilized to analyze suspended sediment samples. A Coulter LS100 particle size analyzer was used for samples collected prior to the July, 2009 sampling trip. Samples collected in July and September were analyzed for grain size with a Malvern Mastersizer 2000. Pre-treatments of samples prior to analysis by the laser were consistent throughout all sampling trips. Prior to analysis a dispersant agent (sodium meta-phosphate) was added to each sample bottle to bring the concentration to approximately 1-2 g/L, sonicated for 60 seconds, and passed through a 850 μm (#20 ASTM) sieve to remove any debris from the sample. Each sample was cycled through the laser at least three times and an averaged size distribution was reported. The grain size distributions for the suspended sediment samples are reported in Appendix _.

Laboratory analysis of the bottom samples

Within West Bay and parts of Cubit's Gap bottom samples were collected via 1.5" push cores. Bottom samples for the main stem of the river were collected via bottom drag. All the push cores were extruded and sectioned at 1cm intervals, but only the top 1cm was analyzed for this work. As with the suspended sediment samples, the bottom samples were analyzed for grain size distribution through laser diffraction. Samples collected prior to July were analyzed with the Coulter LS100 and those collected after were analyzed with the Mastersizer 2000. Prior to introduction to the laser all bed samples were introduced to and suspended in a solution of sodium meta-phosphate (1-2g/L) for at least 5 hrs. Samples were then sonicated and passed through a 850 μm (#20 ASTM) sieve to remove any large debris from the sample. No sediment grains were ever observed to be retained in the sieve for all samples. Each sample was cycled through the laser at least three times and an averaged size distribution was reported. The grain-size distributions of the bottom samples are in Appendix H.

Data Return and Assessment of Data Quality

During the trip to West Bay on April 22 and 23, 2009, the orientation of the current meter mounted to the survey vessel changed. Figure 2.24 shows a comparison between the ship track using GPS and the ship track using bottom track in ADCP transect 52 (Figure 2.7), which was the forth transect run on the first day of the survey (a total of 121 transects were run during the two days), and ADCP transect 84 (Figure 2.7), made along the same line the next day. In transect 52, the tracks are in close agreement and the Q's are 499387 ft^3/s using bottom track, and 526,705 ft^3/s using GPS, a 5 percent difference. In transect 84, the tracks diverge widely, and the Q's are 484,719 ft^3/s using bottom track, and 287,959 ft^3/s using GPS, a 68 percent difference. This large discrepancy is the result of the current meter changing orientation in its mount. The value of the orientation can be changed during post processing of the ADCP data. This was done for all ADCP data obtained during this trip. After substituting new orientation values during post processing, the discharges using the GPS reference are 507,132 ft^3/s for transect 52 and 517,015 ft^3/s for transect 84, a 2 percent change from one day to the next. It is believed that following this post processing that the discharge measurements are as accurate as those taken on the other trips when there were no problems with the ADCP mount.



ADCP transect 52

ADCP transect 84

Figure 2.24. Comparison of bottom-track ship track (red line) and GPS ship track (blue line) on April 23, 2009 (ADCP transects 52 and 84).

Not all transects were made with quality control suitable for the best-possible quality discharge measurements. When making discharge measurements, the survey vessel was held at the start of the transect line, at a position where the distance to the edge of the channel was known and there were at least two cells of valid data, for ten ensembles. The transect line was then crossed at the slowest possible speed, until a position at the end of the transect line was reached where the distance to the edge of the channel was known and there were at least two cells of valid data. The vessel was then held there for ten ensembles. The process was then immediately repeated going in the opposite direction (in most cases) across the transect line. Some transect lines were run only to measure the current velocities along the transect. For these lines, estimating the discharges in the unsurveyed sections of the channel between the ends of the transect lines and the edges of the channel was not important and no special steps were taken at the start and end of the lines. In Appendix F, the discharge measurements along lines surveyed primarily for velocity measurements are marked with an asterisk.

Measuring discharges into West Bay was particularly challenging because of the complexity of the flow near the diversion channel. Lines that were too far out in the Mississippi River from the diversion channel were affected by current eddies in the region of the channel. Likewise lines too far into West Bay from the diversion channel were affected by the complexity of the flow in the Bay. In Appendix F, Table F1, the transect lines WBD and 5, 6, 7 and 8, when surveyed as discharge lines, are considered the most accurate for discharge from the Mississippi River into West Bay.

Also very challenging were the discharge measurements into secondary channels off the Mississippi River. The flow is these channels was low, the depths were shallow (meaning there were very few good velocity cells under the boat), and maneuvering in the channels was difficult. Based on the poor repeatability of discharge measurements, the accuracies are thought to be poor (Appendix F, Table F6).

During the last trip, when ADCP surveys were conducted on September 23 and 24, 2009, there was a problem with the navigation. For an unknown reason, the position data had shifts in it during the transects. The measured current directions are clearly incorrect because the heading information is inaccurate. However, when referenced to bottom track, the discharges appear to be correct. Whereas, all discharges in Appendix F before September are calculated from being referenced to GPS track to eliminate any possibility that movement of bottom sediments could affect discharge measurements, the discharges for September 23 and 24, 2009 are calculated from being referenced to bottom track. The river flow in September was very low and bottom movement may have also been very low during the trip.

There are a few suspended sediment samples that have abnormally high sediment concentrations that may be the result of the P-61 sampler hitting the bottom and causing bottom material to be suspended and sampled. Figure 2.25 shows suspended sediment concentrations along Transect Line R-5.2, just north of the diversion channel, were this obviously happened. With the exception of Station A, the near-bottom concentrations range from 111 to 261 mg/l, however, at Station A, the concentrations jump from 148 mg/l for the sample at 22.5 ft depth, to 580 mg/l for the bottom sample at 30 ft of depth. However, other cases are suspect, but not clearly incorrect. Figure 2.26 shows a case where the same thing may or may not have happened at Station B.

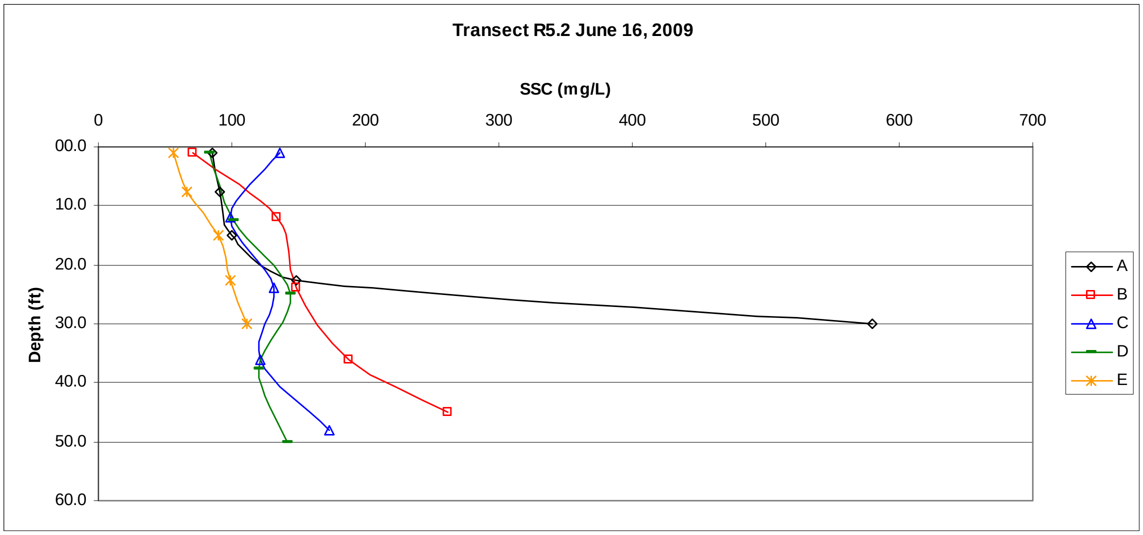


Figure 2.25. Suspended sediment concentrations sampled along Transect Line R-5.2 on June 16, 2009.

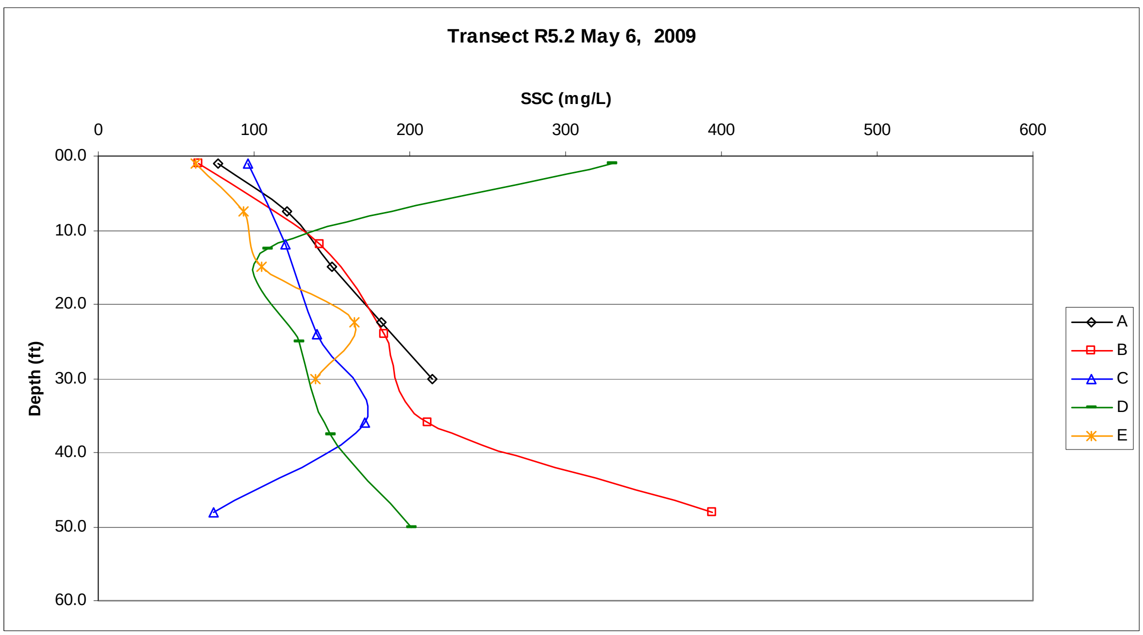


Figure 2.26. Suspended sediment concentrations sampled along Transect Line R-5.2 on May 6, 2009.

Analysis

ADCP measurements of discharges are given in Appendix F. Discharges across current transect lines that are representative of transport from the Mississippi River into West Bay, are given in Table F1. Discharges across current transect lines crossing the Mississippi River north of the diversion channel, representative of transport coming down-river into the area of the channel, are given in Table F2. Discharges across current transect lines crossing the Mississippi River south of the diversion channel, representative of transport coming down-river immediately after the area of the channel, are given in Table F3. Discharges across current transect lines crossing Cubit's Gap, representative of transport from the Mississippi River into Cubit's Gap, are given in Table F4. Discharges across current transect lines crossing the Mississippi River south of Cubit's Gap are given in Table F5. Discharges across current transect lines that are representative of transport into secondary channels off the Mississippi River are in Table F6, while those across secondary channels in Cubit's Gap are in Table F7. Discharge measurements in the vicinity of Venice, LA, are in Table F8.

Discharges across survey lines in the Mississippi River immediately north of the diversion channel, discharges into the diversion channel, and discharges across survey lines in the Mississippi River immediately south of the diversion channel were analyzed. The results are in Table 2.8. The discharges into West Bay through the diversion channel are given as percentages of the discharges in the river across the survey lines immediately north of the diversion channel. The amounts of unaccounted for discharges (i.e., the failures to achieve perfect mass balance in the control volume that includes the diversion channel) are also given as percentages of the discharges in the river across the survey lines immediately north of the diversion channel. The flows through the secondary channel immediately across the river from the diversion channel are not taken into account because they were measured as having negligible effects on the overall mass balance. Due to the fact that the required discharge measurements are not all at the same time, and in fact in a couple cases were only acquired over two days, tidal elevation changes and temporal discharge differences could affect the mass balances. The measures of the inabilities to achieve mass balance are an indicator of the reliability of the discharge measurements into West Bay through the diversion channel.

The same analyses of discharges through a control volume that includes Cubit's Gap were performed. The results are in Table 2.9. During the April 22 and 23, 2009 survey, ADCP transects were made all the way across Cubit's Gap west of the secondary channels. In Table 2.9 the discharge shown as being through Cubit's Gap during this survey is the average of the measured discharges for the survey line that went across the Gap. During the May 29 and 30, and the June 16 and 17

Table 2.8. Discharges through the control volume that includes the diversion channel.

Survey Dates	April 22 and 23, 2009	May 5 and 6, 2009	May 29 and 30, 2009	June 16 and 17, 2009	July 21 and 22, 2009	September 23 and 24, 2009
Discharge north of the channel	550,738 ft^3/s	500,448 ft^3/s	740,062 ft^3/s	568,041 ft^3/s	311,852 ft^3/s	331,732 ft^3/s
Discharge into the channel	46,514 ft^3/s	42,011 $f t^3/s$	68,373 ft^3/s	52,252 ft^3/s	28,724 ft^3/s	31,357 ft^3/s
Discharge south of the channel	509,966 ft^3/s	454,715 ft^3/s	675,834 ft^3/s	485,332 ft^3/s	256,360 ft^3/s	279,250 ft^3/s
Percentage discharge into the channel	8.4%	8.4%	9.2%	9.2%	9.2%	9.5%
Percentage of unaccounted discharge	1%	-1%	1%	-5%	-9%	-6%

2009 surveys, transects across Cubit's Gap were not made, but unlike the April 22 and 23, 2009 survey, transects across each of the secondary channels off Cubit's Gap were made. In Table 2.9, the discharges through Cubit's Gap for these surveys are the sum of the average discharges through the secondary channels. During the July 22 and 23, 2009 and the September 23 and 24, 2009 surveys, ADCP transects across Cubit's Gap, and across each of the secondary channels off Cubit's Gap were made. In July the total measured discharge going through the secondary channels is 19.7 percent lower than that measured going through Cubit's Gap. In September, it is 7.4 percent lower. These results for July and September indicate that there is significant discharge in Cubit's Gap that is across areas too shallow to survey, and that the percentages of discharge through Cubit's Gap in May and June, which are based on the flows through the secondary channels, are low. However, the percents of discharge unaccounted for in May and June (2 and -4 percent) don't support this conclusion. It may be that in May and June, when the river flows were much greater than in July and September, the deeper depths allowed greater survey coverage in the secondary channels in Cubit's Gap. A careful review of the measurements during July 23 and 23, 2009, did not reveal a reason for the large percentage of unaccounted for discharge (33 percent).

Table 2.9. Discharges through the control volume that includes Cubit's Gap.

Survey Dates	April 22 and 23, 2009	May 29 and 30, 2009	June 16 and 17, 2009	July 22 and 23, 2009	September 23 and 24, 2009
Discharge north of Cubit's Gap	509,966 ft^3/s	675,834 ft^3/s	485,332 ft^3/s	237,569 ft^3/s	271,518 ft^3/s
Discharge through Cubit's Gap	80,945 ft^3/s	126,132 $f\ t^3/s$	87,884 ft^3/s	41,209 ft^3/s	35,189 ft^3/s
Discharge south of Cubit's Gap	443,033 ft^3/s	560,997 ft^3/s	378,873 ft^3/s	273,710 ft^3/s	229,120 ft^3/s
Percentage discharge into the channel	15.9%	18.7%	18.1%	17.3%	13.0%
Percentage of unaccounted discharge	3%	2%	-4%	33%	-2%

Analyses of the discharges through a control volume that surrounds Venice, LA are given in Table 2.10. The control volume is seen in Figure 2.11 as defined by the four transect lines in the Figure 2.11. The lines are across the Mississippi River in the northern part of Venice, across the River south of Venice, and in the channels that lead away from Venice to the east and west. The discharges for July 21 have an unusually large unaccounted for percentage. It is believed that a significant amount of discharge through the channel to the west was missed because the survey transect line was short.

Table 2.10. Discharges through the control volume that includes the south part of Venice, LA.

Date	Discharge from the north	Discharge to the east	Discharge to the west	Discharge to the south	Unaccounted discharge
May 30, 2009	986,538 ft^3/s	110,632 ft^3/s	102,551 ft^3/s	782,242 ft^3/s	1%
June 17, 2009	669,118 ft^3/s	72,226 ft^3/s	74,294 ft^3/s	555,939 ft^3/s	5%
July21, 2009	234,775 ft^3/s	52,198 ft^3/s	28,908 ft^3/s	196,168 ft^3/s	18%
September 23, 2009	388,628 ft^3/s	18,956 ft^3/s	34,509 ft^3/s	315,781 ft^3/s	-5%

Plots of the median grain size (D50) for the push-cores taken in West Bay and Cubits gap are shown in Figures 2.27 and 2.28. They show two distinctly different mixtures of types of materials in both areas. A mixture of fine material with mean D50 values of 26.4 microns in both West Bay and Cubit's Gap, and a mixture of fine sand-size material with a mean D50 value of 158.3 microns in West Bay.

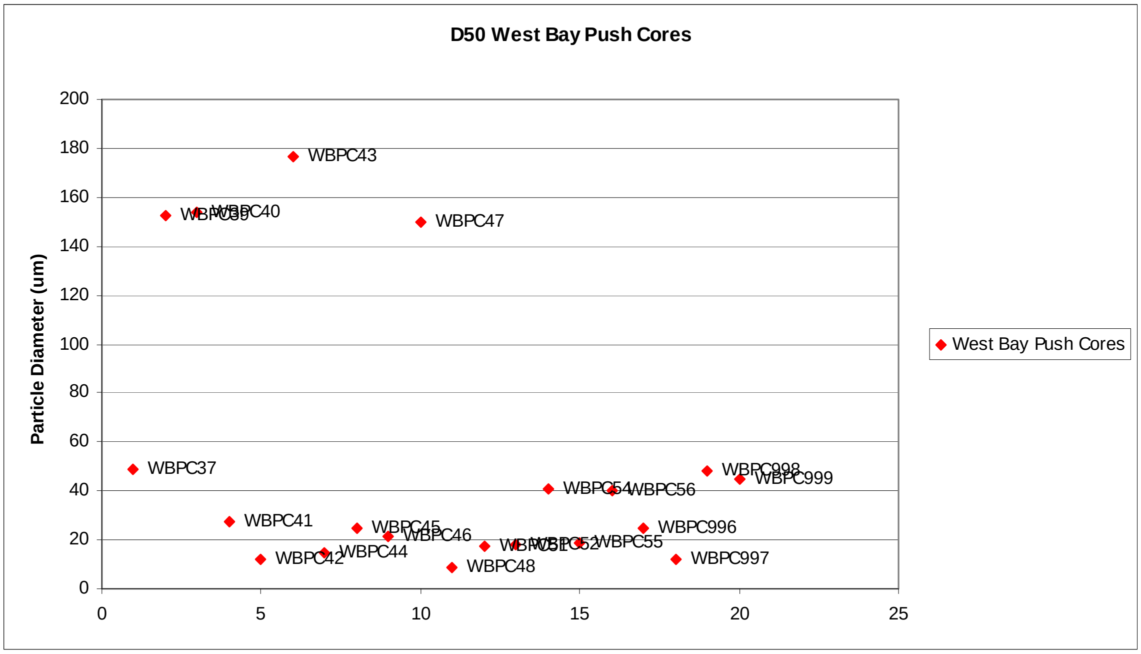


Figure 2.27. D50 values for the push-cores taken from West Bay.

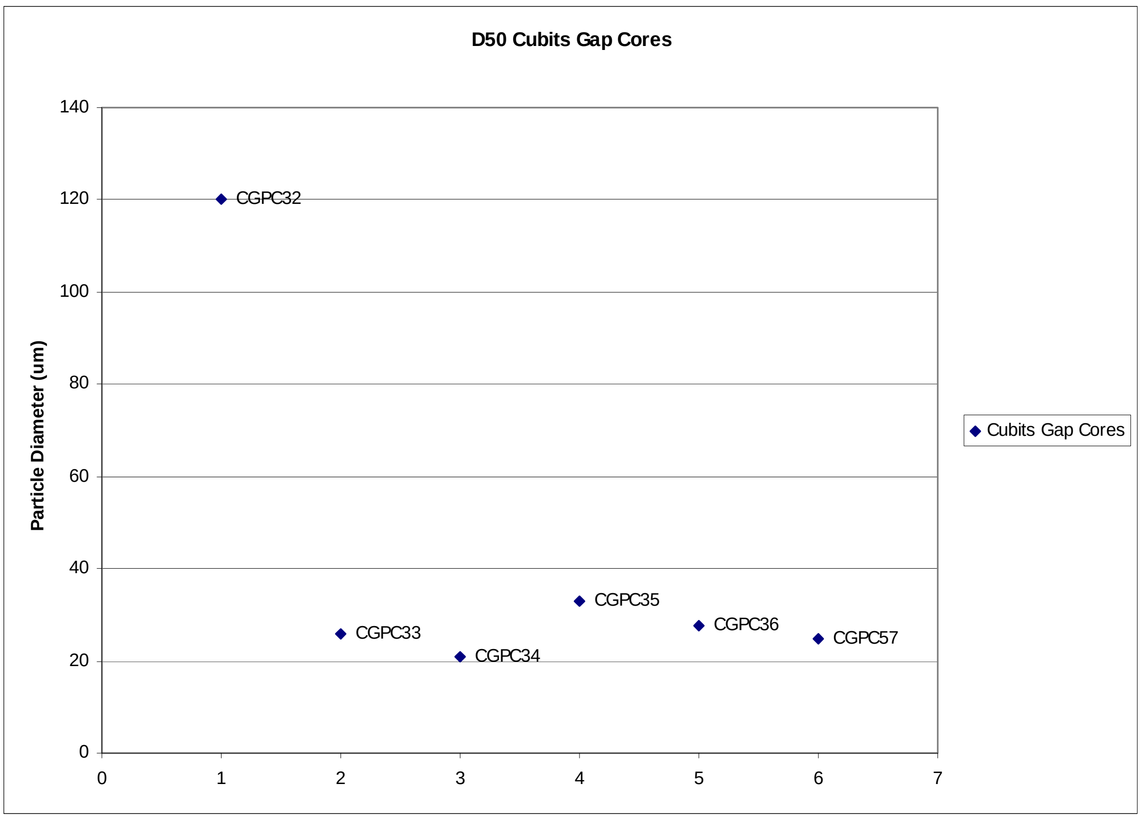


Figure 2.28. D50 values for the push-cores taken from Cubit's Gap.

In Cubit's Gap, there is only one sample with a mixture of fine sand-size material (D50 value of 120.3 microns) while there are four locations with sand-size material in West Bay. Two of the four push-core locations having sand-size material are near the diversion channel. However, the other two are roughly a half mile south of the channel on the eastern side of the bay nearest the Mississippi River and may be primarily dredged material from the river placed in West Bay.

Tables of the grain-size distributions of the bottom drag samples are given in Appendix H. Going down-river, the samples from the west side of the Mississippi River are more fine-grained than the samples from the east side of the river, until the sample line across the river just north of Cubit's Gap (samples 19 and 20, Figure 2.22). Figure 2.29 shows an example of this, where the grain size distribution for the finer sample 15, on the west side of the river, is plotted with the grain size distribution of the coarser sample 16, directly across the river on the east side (Figure 2.22). Starting with samples 19 and 20 just north of Cubits Gap and going down-river to Southwest Pass, the trend is reversed. In this region the samples from the west side of the river are coarser than those from the east side of the river. Overall, as is the case in West Bay, the D50 (plotted in Appendix H) values show two distinct types of bottom material in the Mississippi River, sand-size material, with a mean D50 value of 185.0 microns, a little coarser than the mean value of 158.3 microns found in West Bay, and fine material about the same size as that found in West Bay with a mean D50 value of 22.3 microns. Figure 2.30 shows the D50 values throughout West Bay and Cubits Gap.

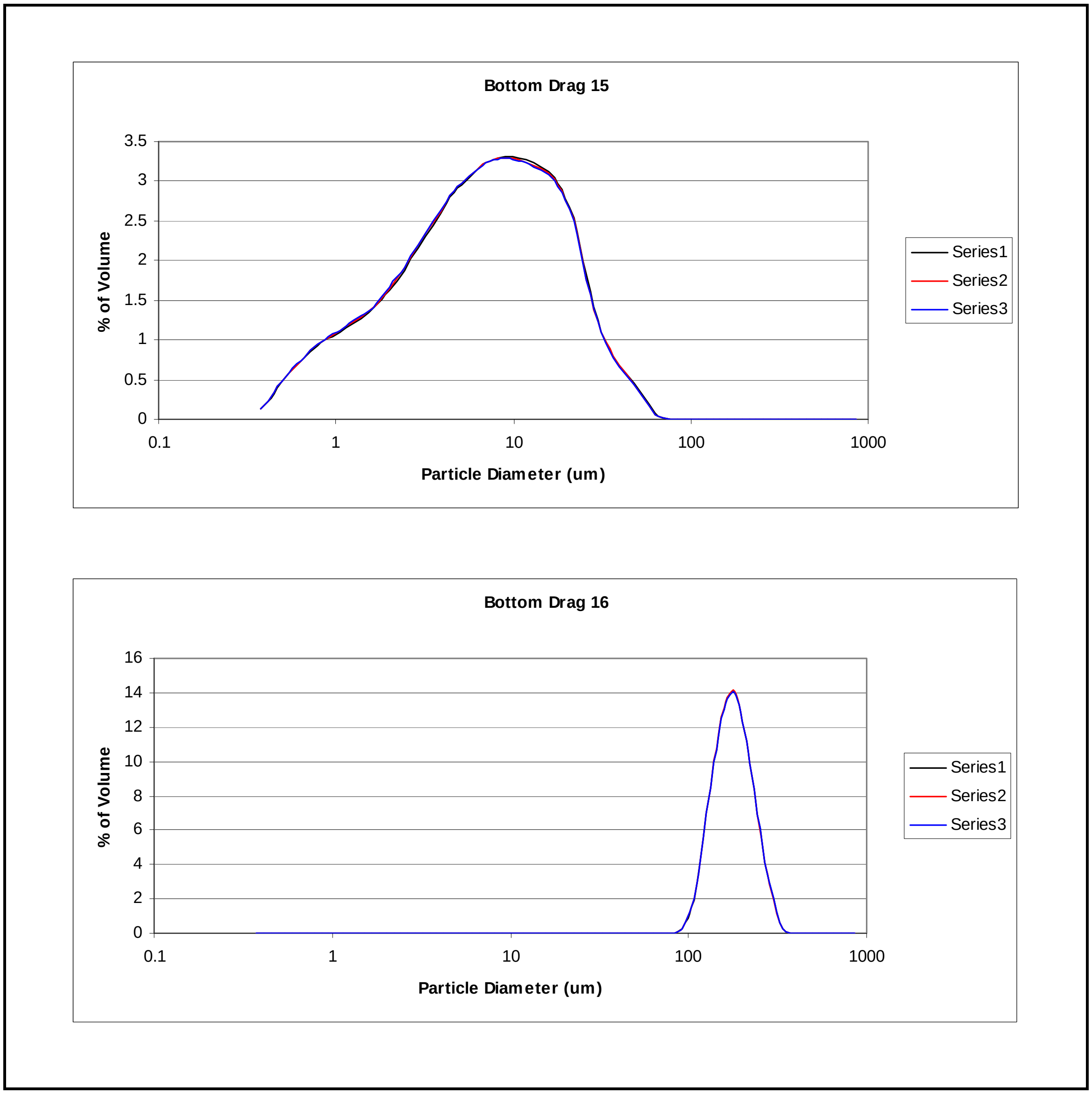


Figure 2.29. Grain size distributions for bottom drag samples 15 and 16.

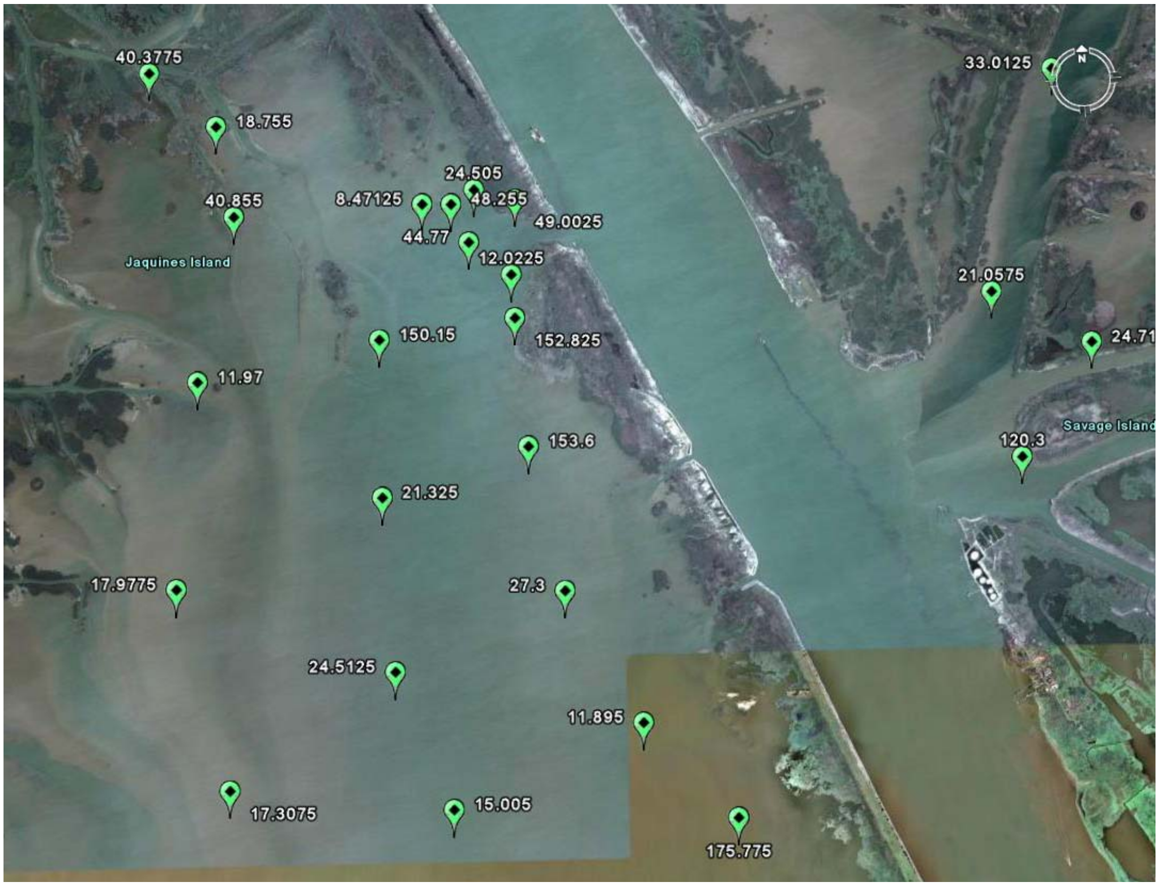


Figure 2.30. Map of D50 values in West Bay and Cubits Gap.

Cross sections of horizontal current velocities during the 3D current survey are plotted in Appendix E. Figure 2.31 shows a cross section of vertical current velocities measured along three consecutive ADCP transects across the same survey line done on April 23, 2009 in the throat of the diversion channel. The transect numbers are 117, 118 and 119 (Figure 2.9). The cross sections are displayed from south (right side) to north (left side) across the channel, so that they are viewed as looking from the Mississippi River into West Bay. The figure shows an area of downward (negative – blue to purple colors) current speeds from 120 to about 180 ft across the channel, and an area of upward (positive- yellow to red) current speeds at about 270 ft across the channel. Figure 2.32-2.34 show the 3D flow patterns inside the West Bay Diversion Cut. Figure 2.32 is a depth average velocity plot of all the 3D velocity lines collected during the April survey. Notice the flow patterns in the cut itself. By depth averaging the entire water column the eddy pattern is diminished. That pattern is more evident when you look at the surface currents and bed currents in Figures 2.33 and 2.34. There is an eddy in the flow in the shallow water on the north side of the diversion channel.

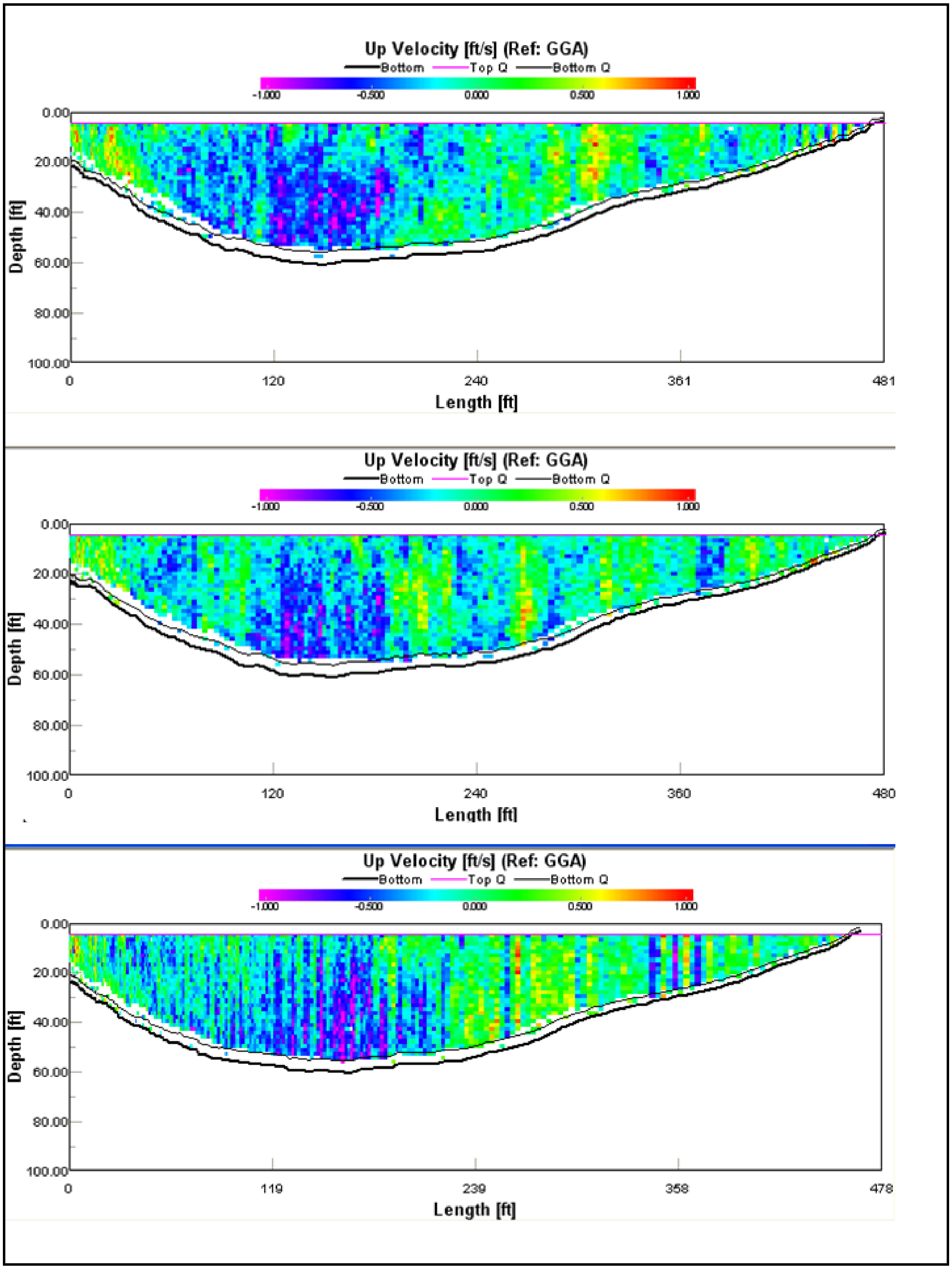


Figure 2.31. Vertical current velocities across the diversion channel on April 23, 2009.

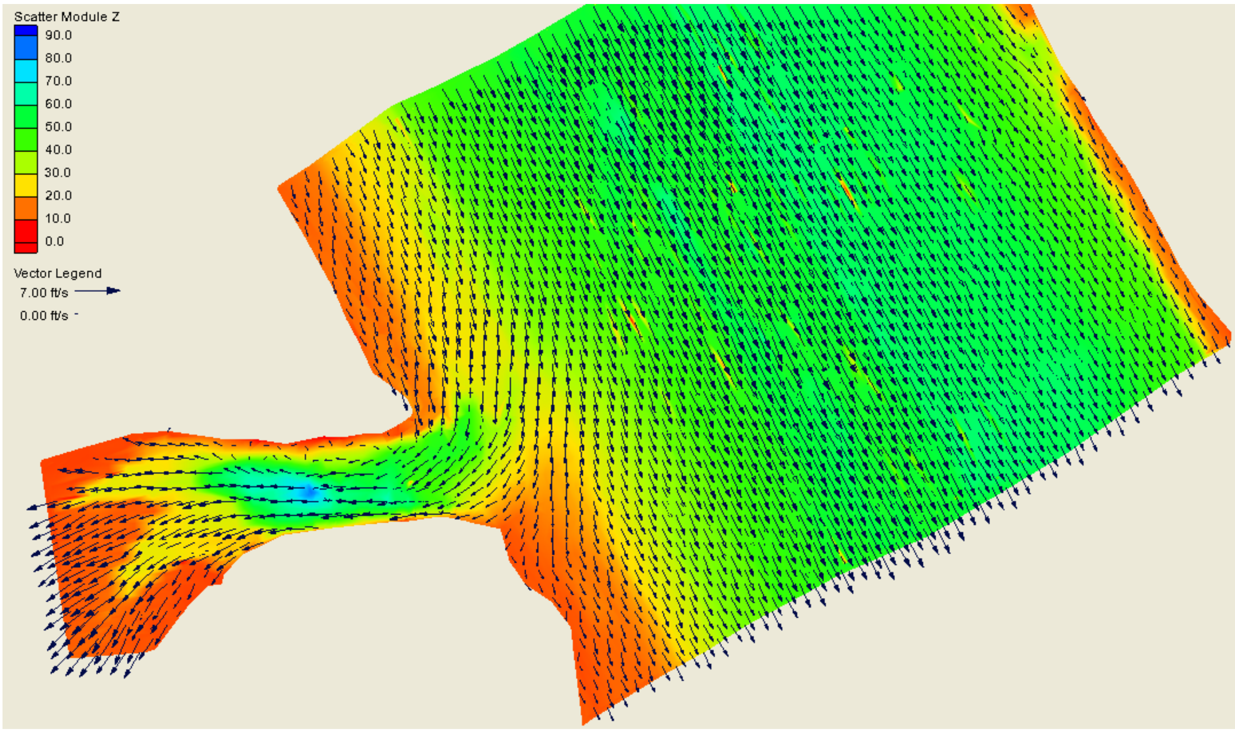


Figure 2.32. Depth Averaged 3D flow measurements from the April 23, 2009 trip.

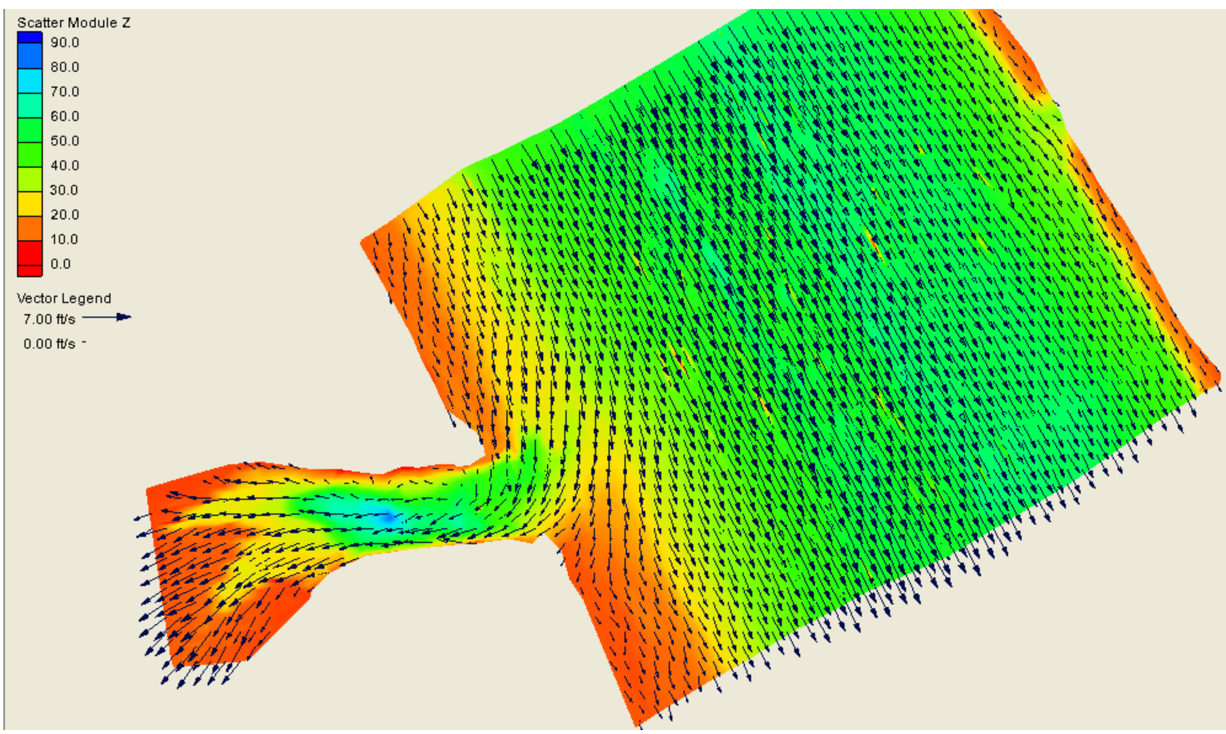


Figure 2.33. Surface Velocities of the 3D flow measurements during April 23, 2009 trip.

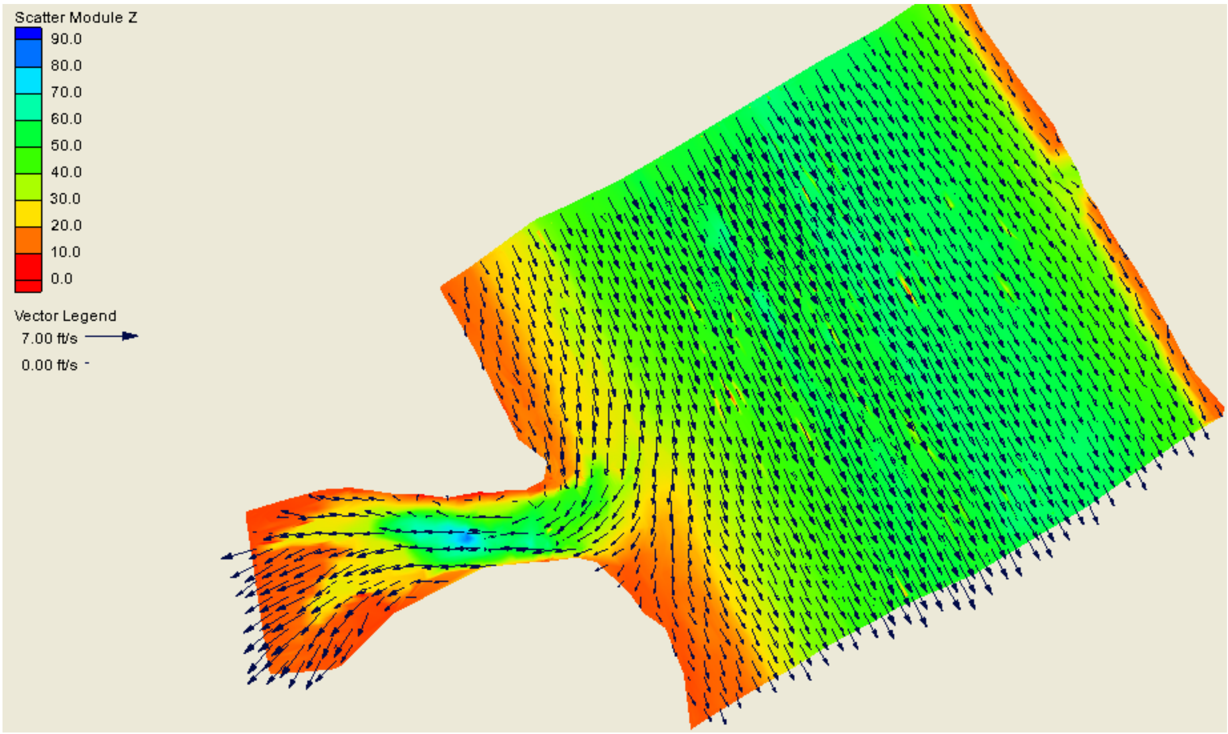


Figure 2.34. Bottom Velocities of the 3D flow measurements during April 23, 2009 trip.

The CTD casts made on May 29 and 30, 2009, when the discharge north of the diversion channel was 740,062 ft3/s shows no indication of a salt wedge. On July 21, 2009, when the discharge is 311,852 ft3/s, it is present at 46.74 ft depth with a salinity of 28.71 PSU, at survey transect line R-5.2 (the one immediately north of the diversion channel). No CTD casts were made further up river from R-5.2 on July 21. On September 23 and 24, when the discharge is 331,732 ft3/s, it is present as far north as survey transect line R-12.1 (north of Venice) at 52.12 ft depth with a salinity of 2.56 PSU. During this survey it was measured at R-5.2 with a salinity of 5.49 PSU at a depth of 33.79 ft and 22.68 PSU at a depth of 46.33 ft.

ADCP back scatter calibration to suspended sediment concentration data is the means by which sediment flux calculations were made to determine the suspended sediment transport rates out the various diversions along the main Mississippi River from river mile 12.1 to river mile 2.6. The method of calibration has been developed over several years of application. It involves the relationship between the distribution function of the acoustic backscatter energy values and the calibration TSM, Total Suspended Sediment Concentration, distribution function. The ideal calibration TSM data set needs to be collected across the cross sections where ADCP transects are collected. The range of acoustic back scatter energy values is from 0 to 256. Several representative ADCP transects are read and the energy values are counted over the range of 0 to 256 to create the distribution function for the acoustic backscatter. The same process is done for all of the TSM samples, each time a concentration value occurs then a count value is added to a distribution function. The whole premise for the calibration is that the two distribution functions are related for that particular stage. After the two distribution functions are populated, then the value for each function in one percent increments are paired. These paired values are regressed against each other to define a calibration curve between the two data sets. Usually a second order polynomial fit gives r squared values greater than 0.96. That calibration curve is only good for the stage in which it was collected because the relationship of the acoustic backscatter energy to TSM is a function of the material characteristics in suspension. As the source, size distribution and concentration change with the hydrograph then the backscatter distribution function will change and take a slightly different shape.

The next step in the calibration process is the conversion of the acoustic backscatter data to TSM values. The calibration equation is applied to the ASCII ADCP data to convert backscatter to TSM values. We have noticed that the conversion of backscatter data closer to the bed usually dose not match as well as we would like. Usually it tends to over estimate the profile as it approaches the bottom. We have devised a method that is applied to the converted ASCII files that fits a Rouse profile through the concentration data as it approaches the bed. A maximum concentration value has to be supplied by the user to tell the method where to start applying the rouse profile algorithm to the concentration profile. This value is derived from the actual sample data. The choice of this value is an iterative process to try to achieve the closest fit to the actual field samples.

During the samples collection operation two physical samples were collected at each point in the water column. One sample was analyzed for TSM while the other sample was analyzed for grain size distribution. In addition to the sample data ADCP velocity and backscatter data was collected during the entire sampling operation. These backscatter data were converted to TSM values for the entire sampling period. The converted TSM values at the specific depth elevation were extracted to compare to the actual physical samples. This comparison showed how well the calibration process worked. If the converted data near the bed was too high as compared to the sample data then we would increase the value of the pick point in applying the Rouse profile in the conversion process. The process might be repeated several times until the best fit was achieved.

Once the backscatter data is converted to the best of our ability the next step in the flux calculation process begins. The ADCP collects velocity data as the boat is driven across the channel. The collection rate of the instrument is fixed and the vertical spacing of data in the profile is fixed but the speed of the vessel as it moves across the channel can vary slightly as different flow conditions arise. Therefore the cells or bins can vary in length as the boat moves across the cross section. In addition to the velocity data for each cell, we now have TSM values for each cell through the calibration process. We take the dot product of the water flux with the concentration at each cell to determine the sediment flux through that cell. This process is done throughout the entire profile at which time the values are summed for the entire cross section. The resultant value is in mg/sec which is then converted to tons/day for the cross section. The tables in Appendix I show the flux values for all of the survey trips using two methods of calculations.

After the first review session with the pier reviewers we decided to make and additional calculation of suspended flux using a method called the moving boat method. This method does not use the converted acoustic backscatter to make the flux calculation but instead a mean concentration from the suspended sediment samples taken at each cross section. This concentration is used with the individual q-values calculated throughout the water column. The fluxes for each bin are summed as you move across the cross section to give a total flux for the cross section. The percentages of the different size classes for the suspended sediment are then used to determine fluxes by size class for each cross section. The moving boat method gave slightly larger suspended flux values as expected since the whole cross section is treated with one mean concentration value. This method does not capture the cross sectional variability that we know exists. We mainly did this exercise to prove to ourselves that we were in the right ball park for the flux calculation. Appendix I shows these differences from the two methods.

Summary and Conclusions

A field data collection program was conducted in the lower Mississippi River from Venice to Head of Passes, in Southwest Pass, in West Bay and in Cubit's Gap form March 9, 2009 to September 25, 2009. It produced the following data to improve definition of boundary conditions for one-dimensional and multi-dimensional models, and for calibrating and verifying model results:

a. A bathymetric base map of the Mississippi River channel in the vicinity of the diversion entrance channel and through the diversion entrance channel into West Bay to the extent that water depths in the Bay allow.

b. Current speeds and directions across transects of the Mississippi River in the vicinity of the diversion, and across the diversion entrance, as well as acoustic backscatter intensity measurements across the same transects.

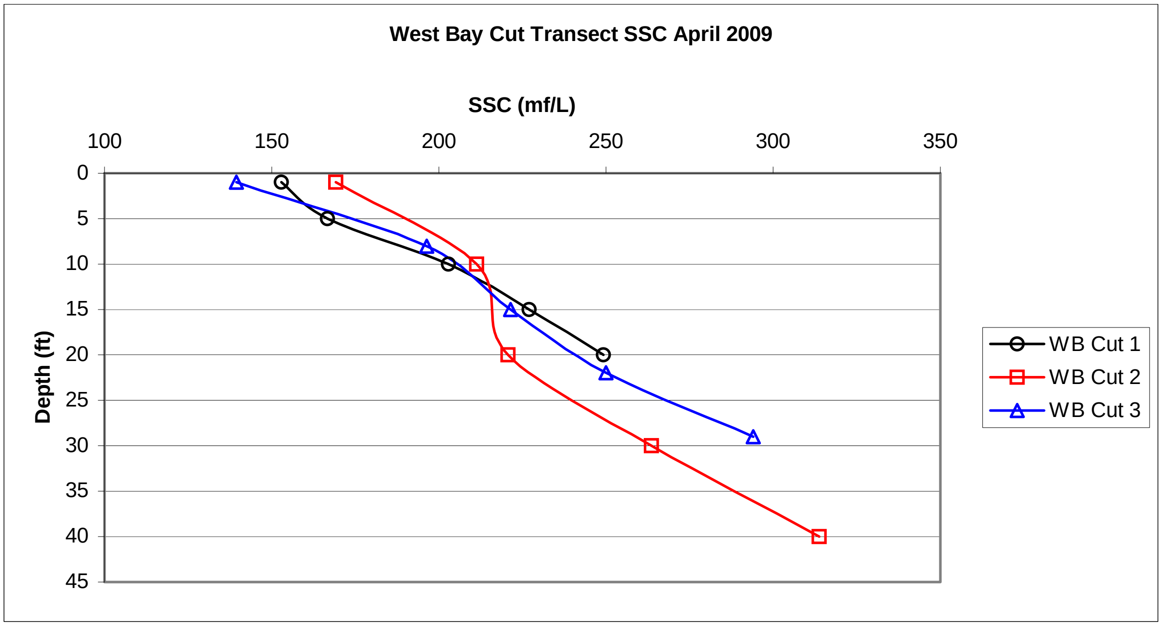
c. Suspended sediment concentrations and suspended sediment types (percent sand and fines) at horizontal and vertical sample locations along the ADCP transects.

d. Optical backscatter and salinity measurements along the ADCP transects.

e. Bottom-sediment types and grain-size distributions at selected locations in the Mississippi River and West Bay.

An iterferometric (phase measuring) swath sonar survey conducted prior to the start of the field measurement program produced a bathymetric map determined to be adequate for the purposes of this study. It extends from about 2 miles north of the diversion channel to about 2.25 miles south of the diversion channel, and into West Bay to the extent allowed by the water depths in the Bay.

The diversion channel diverts 8.4 to 9.5 percent of the flow in the Mississippi River into West bay. Cubit's Gap diverts 13.0-18.7 percent of the flow in the river. There are significant vertical current velocities in the diversion channel. An eddy in the flow was observed in the shallow water on the north side of the diversion channel. The concentration profiles shown in Figure 2.35 show that there is difference of approximately 150mg/l in the maximum concentration from the main river to the West Bay Cut. This observation is for only one event but similar trends exist for different stages of the hydrograph.



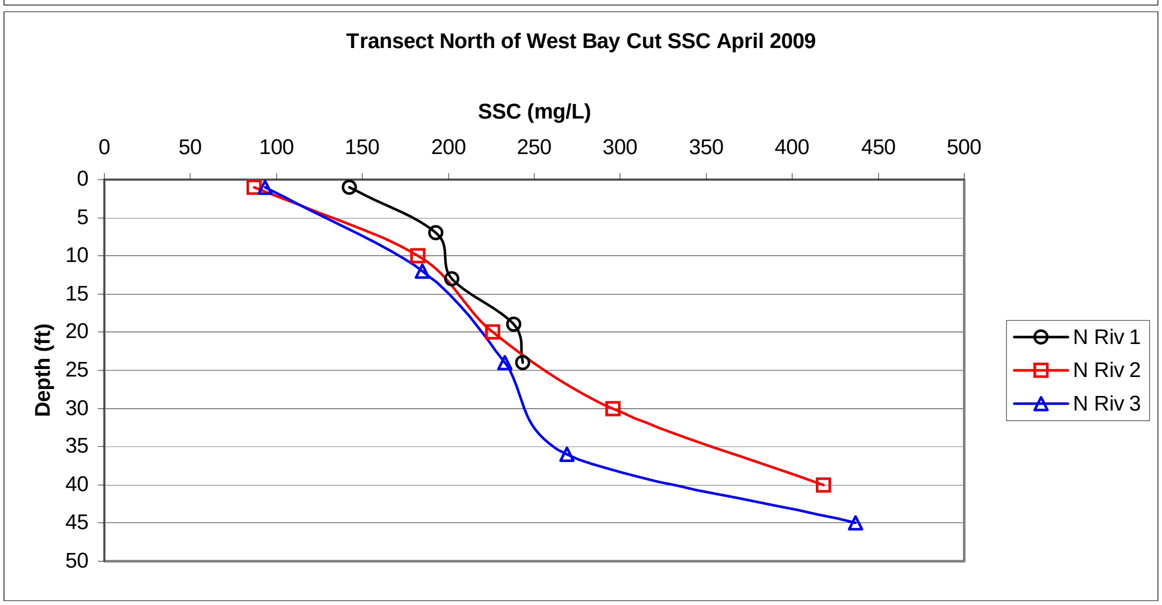


Figure 38 Concentration Profiles for north of the diversion cut RM 5.2 and the Diversion Cut

Suspended Sediment Concentration Method Comparison

The concentration values calculated from the ADCP Backscatter data are very similar to the actual measured values for each trip. They tend to be slightly lower than the mean measured values. That could account for the slightly lower back scatter flux calculations when comparing to the flux measurements from the moving boat method. Figure 2.36 shows the relationship between the measure and the calculated TSM values which gives confidence to the further analysis.

	Depth Averaged SSC of all Transects (mg/L)					
	April 22-23, 2009	May 5-6, 2009	May 29-30, 2009	June 16-17, 2009	July 20-23, 2009	Sept 22-24, 2009
Measured SSC	224.0819	151.0722	237.4138	122.53	34.97071	30.00211
ADCP SSC	208.6755	159.1197	208.0234	131.1978	31.98384	26.98762

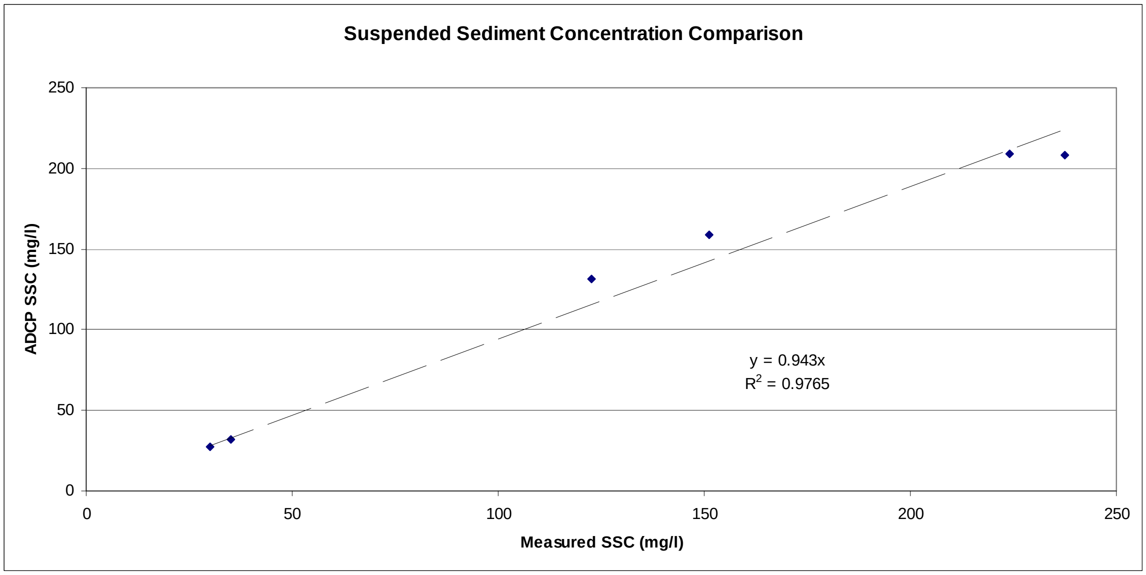


Figure 2.36. Average TSM values compared to Average TSM from Back Scatter Data

These two multi-beam surveys of the West bay diversion before and after the high water event in Late may show that the Cut is eroding more in the vicinity of lines 7—14 (Figures 2.37 and 2.38). The red erosion area has increased in size and the green area has split to for a y pattern. The cross section lines cut through the two surveys show this erosion and deposition along the north side of the cut (Figures 2.39 and 2.40). These results are very similar to the patterns shown in the 2D and 3D model. (The orientation of the cross section graphs is the north bank on the left side of the plot looking out the diversion cut.)

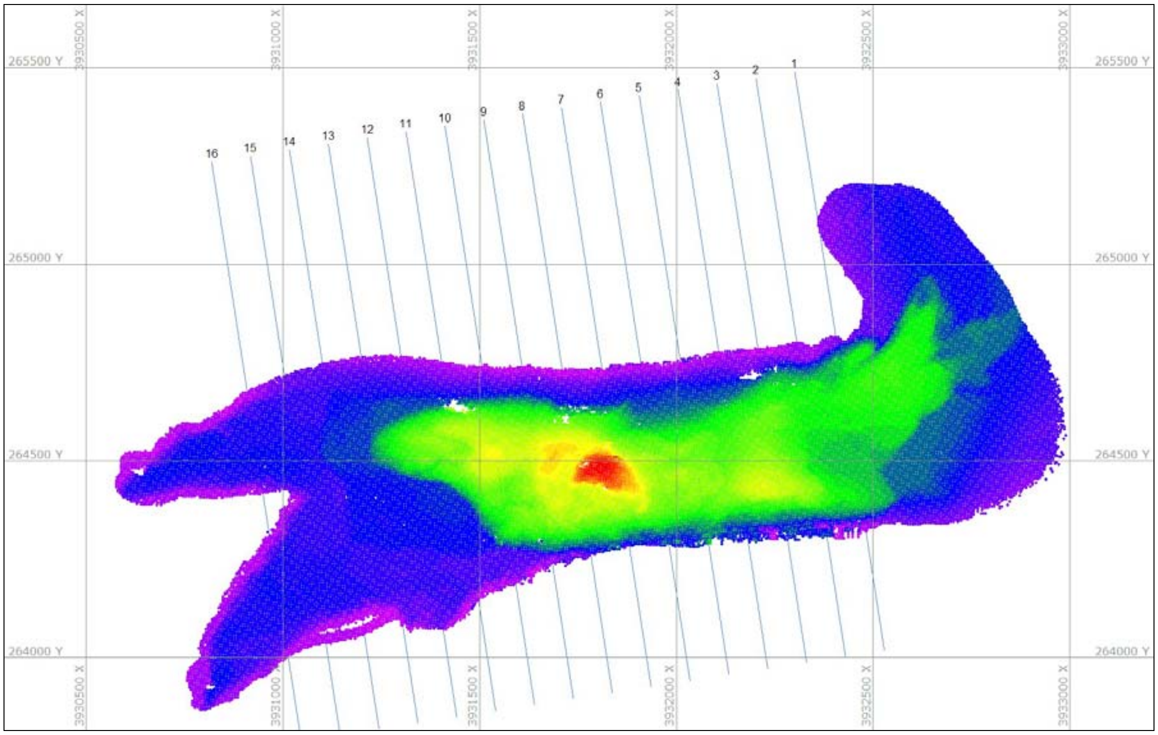


Figure 2.37. April Multi-beam Survey of the Diversion Cut.

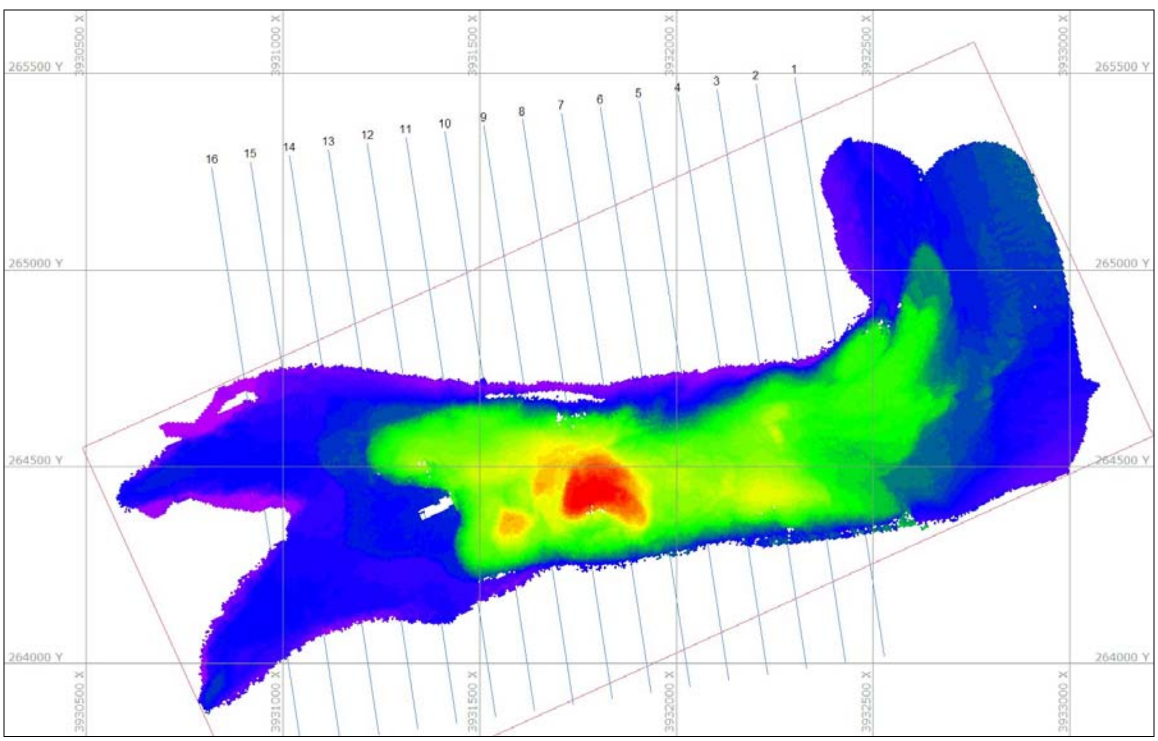


Figure 2.38. August Multi-beam Survey of the Diversion Cut.

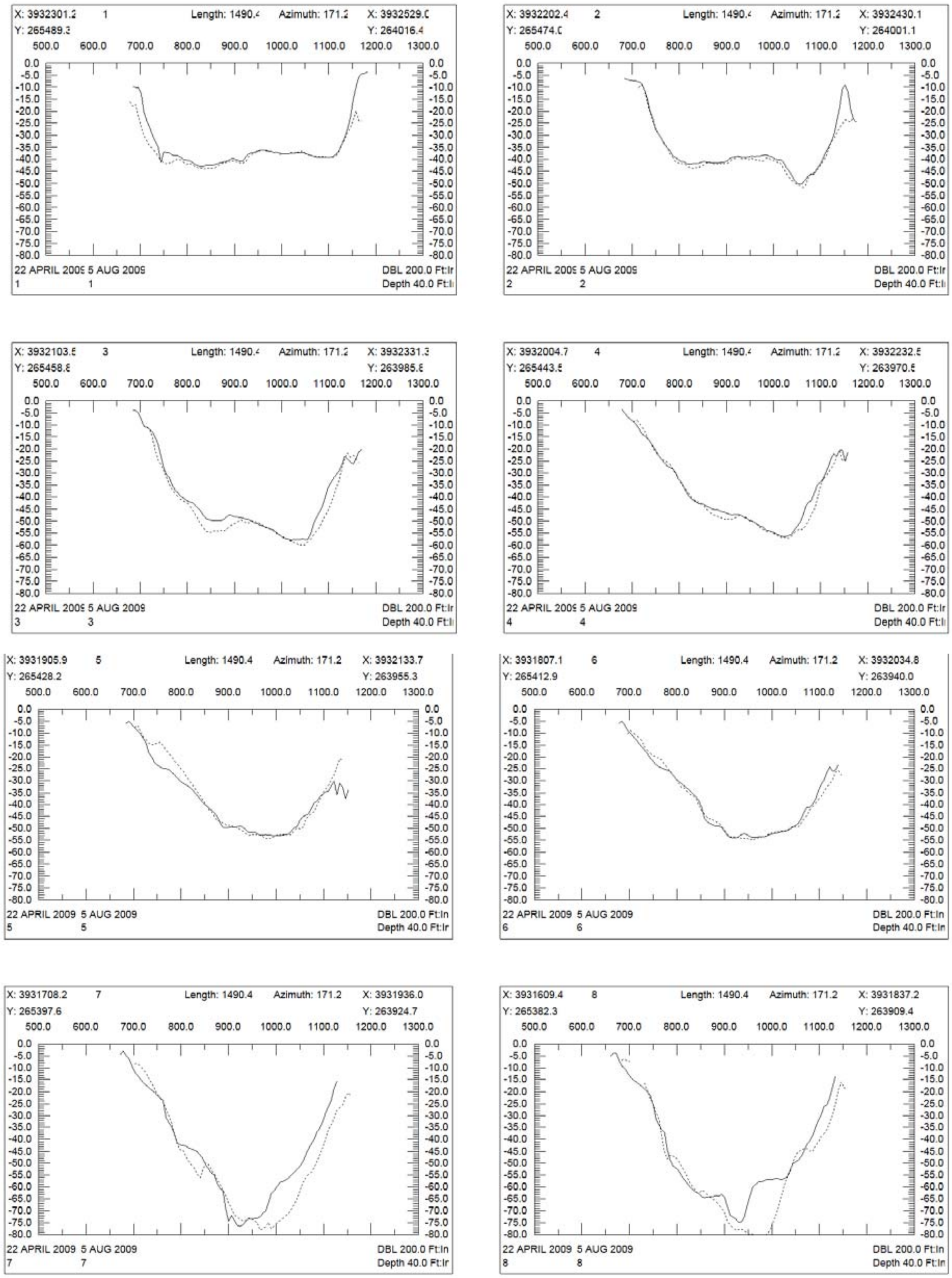


Figure 2.39. Cross Section Plots of the multi-beam surveys Lines 1-8.

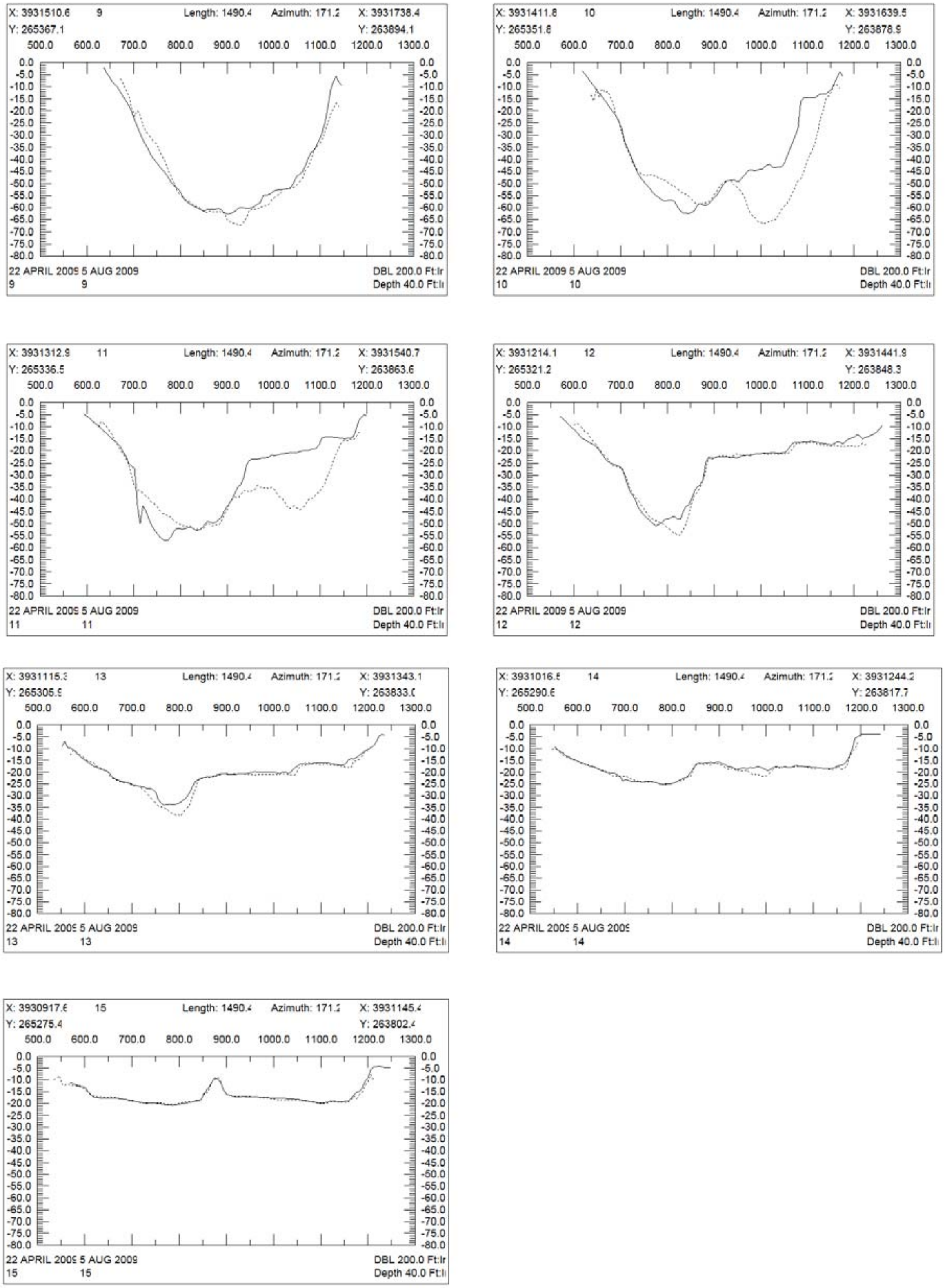


Figure 2.40. Cross sections of the Multi beam Survey Lines 9-15.

3 Geomorphic Assessment

Purpose of Geomorphic Assessment

The dominant morphological processes at work in the lower Mississippi River and delta system can operate over very large spatial and temporal scales. There are many factors, both natural and man induced, that can contribute to these processes. The effects of large floods and storms, changing sediment loads and characteristics, channel maintenance activities, dredging practices, diversions (natural and man-made), subsidence and relative sea level rise are just a few such factors. In terms of temporal scales that are typically associated with river morphology, the diversion at West Bay has been operating for a very short time period. The determination must be made as to what degree the observed shoaling at the Pilottown anchorage area is a result of large-scale, long-term river adjustments, or a direct result of the impacts of the West Bay diversion. It is therefore important to identify the long-term morphological trends that are occurring in this reach of the river and to evaluate the observed shoaling at the Pilottown anchorage area with regard to these trends. These morphological trends are determined by means of a geomorphic assessment.

The geomorphic assessment brings together all the known information and data about the river reach, and provides a description and understanding of if/how the lower Mississippi River has changed in a historical perspective. Methods and tools used in the geomorphic assessment include analysis of channel geometry data, stage and discharge data, dredging records, sediment data, and natural events and anthropogenic influences. Each section of the geomorphic assessment provides an incremental contribution to the overall understanding of the dominant processes that have shaped and formed the system.

The results of the analyses are integrated with the overall objectives of documenting the historic trends and changes in hydrology, sedimentation, and channel geometry for the lower Mississippi River, summarizing the local changes observed in the Pilottown anchorage since construction of West Bay diversion, and evaluating the impacts of the diversion with regard to the historic trends.

Often times the results of a particular analysis may conflict with the results of other analyses. Therefore, it is important to interpret results of all analyses in an integrated manner in order to achieve the most accurate description of the dominant processes that have influenced channel development in the study area.

It is also important to remember that a geometric analysis of this nature focuses on observed data which gives a description of specific channel conditions representative of a given point in time. Any observed change from one time period to another is a cumulative response resulting from all influencing forces acting on the system during that span of time. Careful engineering judgment must be exercised when attributing an observed system response to a specific cause or event, because the response may be due to multiple factors with varying degrees of influence.

In addition, the geomorphic assessment can provide information of baseline conditions necessary for development, application and accurate interpretation of numerical model results.

Description of Geomorphic Assessment Tasks

The detailed geomorphic assessment was conducted for the lower Mississippi River from Belle Chase (RM 75.0 AHP) to East Jetty in Southwest Pass (RM 18.5 BHP). The assessment focused on the time period from 1960 to the present. The specific tasks of the geomorphic assessment include:

- Geometric Data Analysis
- Gage/Discharge/Sediment Data Analysis
- Dredge Records Analysis
- Historic Events Timeline Analysis
- Integration of Results

Geometric Data Analysis

The purpose of the geometric data analysis is to document the changes in channel dimension, pattern and profile of the lower Mississippi River within the study reach. A comprehensive database of channel geometry data was compiled from historic comprehensive hydrographic surveys of the lower Mississippi River as well as channel condition surveys collected by MVN in support of the annual channel maintenance program for the lower Mississippi River. The comprehensive hydrographic surveys generally provide full coverage of the study area, whereas the channel condition surveys generally cover from the upper limit of the Pilottown anchorage area to East Jetty in Southwest Pass. These surveys will be the basis of the geometric data analysis for the Mississippi River channel, with emphasis on the vicinity of West Bay diversion and the Pilottown anchorage area.

The types of analyses conducted as part of the geometric data analysis are as follows:

- Cross section comparisons. Channel cross sections were compared at selected locations for sequential hydrographic surveys to determine scour and shoaling trends. These comparisons include a qualitative evaluation along the full extent of the cross section for all cross section locations in the study area, and a quantitative evaluation of a 500 foot section westward of the Pilottown anchorage area line for cross sections located within the anchorage area limits. Locations of the selected cross sections are presented in a later section that presents the procedures and results of the geometric data analysis in detail.

- Volumetric computations. The study area was partitioned into reaches, and each reach was defined by a specific area over which volumetric changes between sequential hydrographic surveys were computed. These reach areas vary in length, with the more detailed reaches located within the Pilottown anchorage area. Average bed elevation changes were computed for each reach from the computed volumetric changes and the surface area of each reach. Details of the reach locations are presented later in the geometric data analysis section.

- Channel pattern analysis. Contours of the -45 foot channel bed elevations were computed for each hydrographic survey and used to determine the channel location. The channel locations were compared for all surveys to determine any trends in channel pattern and channel widths.

Gage/Discharge/Sediment Data Analysis

The purpose of gage, discharge and sediment data analysis is to evaluate existing data to determine how the distribution of flow in the outlets within the study area has changed over time, and how these trends have impacted the morphology of the lower Mississippi River. Historic discharge data published by MVN and non-published post-construction data at the West Bay diversion collected by MVN were obtained to form a discharge database for this analysis. Discharge data were collected for Baptiste Collette, Grand Pass, West Bay diversion, Cubits Gap, Southwest Pass, South Pass and Pass a Loutre. In addition, discharge data were collected for Tarbert Landing and Venice on the Mississippi River. Sediment data obtained include bed material and suspended sediment data at Tarbert Landing and Belle Chase on the Mississippi River. Suspended sediment data was collected as part of this overall study at West Bay diversion and other distributaries in the vicinity. However, there are no earlier data for determining historic trends in sediment transport in the diversions. The data collected for this study was used primarily for the numerical model investigations.

Dredge Record Analysis

Dredge records were obtained from MVN and analyzed to determine trends in dredging requirements in the lower Mississippi River and Southwest Pass. Total dredge volumes were available by year, and are representative of the total dredging requirements for the reach from Venice, LA to the outlet of Southwest Pass. Daily dredge records for each dredge contract could not be obtained; therefore no information on the location, amount and time of specific dredge quantities could be determined. In addition to the dredge records, grain size analyses of dredge material grab samples were available for many of the dredge contracts.

Historic Events Timeline Analysis

A tabulation of historic events pertaining to the lower Mississippi River was compiled by MVN and provided as part of the geomorphic assessment. The document provided information on river engineering activities that have occurred in the study area since 1960, including changes to navigation channel maintenance, enlargement of passes and diversion construction. This information, along with information on significant flood and storm events, was used to improve the interpretation of results of the other analyses and to gain a better understanding of the geomorphology of the lower Mississippi River.

Integration of Results

This task will integrate the results from all of the analyses conducted as part of the geomorphic assessment, and will be the basis for formulating study conclusions. The results from each analysis will be evaluated with respect to the results of the other analyses to establish the trends in river morphology and sedimentation from a historic perspective as well as for the post-West Bay construction time period. The integrated results will be evaluated to determine if observed shoaling trends in the Pilottown anchorage area are within the influence of large-scale, long-term morphological changes occurring within the study reach, or a specific result of the impact of West Bay diversion. It should be noted that conflicting results are a possibility; therefore, all results are evaluated in an integrated manner to arrive at the most accurate and complete assessment.

Review and Discussion of Data

The analyses of the geomorphic assessment were conducted with historic data from the study area, and the accuracy and value of the results is larger dependent on the quality and availability of the data. Data obtained for this geomorphic assessment include comprehensive hydrographic surveys encompassing the entire study area, channel condition surveys covering the reach from Venice downstream to East Jetty, discharge measurements for the main river and the passes, dredge records and dredge material grab sample gradations, and suspended and bed material sediment data. Due to the breadth of the study time period (approximately 50 years), the format of the data ranges from hard copy maps and published data tables to digital maps and XYZ datasets. All data were evaluated for quality assurance, and obvious errors were corrected when sufficient justification existed.

Comprehensive Hydrographic Surveys

Comprehensive hydrographic surveys of the Mississippi River have been collected by MVN, approximately one survey per decade. The surveys cover the Mississippi River for the entire MVN district area from Black Hawk, LA to Head of Passes, and include survey data for Southwest Pass, South Pass and Pass a Loutre. The surveys generally cover from waters edge to waters edge, and are collected along survey ranges at approximately two-tenths of a mile interval. Bathymetry data are expressed as elevation relative to a specified vertical datum.

The 5 comprehensive surveys used in the geomorphic assessment were 1961-1963, 1973-1975, 1983-1985, 1991-1992 and 2003-2004. It should be noted that each survey period spans several years, and the survey data may have been collected at any point within that time span.

The data for the comprehensive surveys were obtained from MVN. The data for all surveys except the 2003-2004 survey were provided in DGN files, and the 2003-2004 survey was provided in XYZ digital format. All survey data were brought into a GIS database and a triangulated irregular network (TIN) was developed for each survey. Typically, TINs are best developed from data points that are uniformly distributed over the area. In the case of the comprehensive surveys, the data exist in a straight line along each survey range. This is less than ideal for TIN development; however, the survey ranges were close enough together that the TIN surface was considered satisfactory for all areas except the extreme edges of the survey. Contours were developed from each TIN and were compared to the contours on the hard copy maps of the survey. Data value errors were quickly identified based on obvious contour disagreement, and corrections to the survey data were made based on the published hard copy map values.

Channel Condition Surveys

Channel condition surveys are collected by MVN on a regular basis for the area from Venice to East Jetty. These surveys are collected to evaluate the condition of the navigation channel and to determine maintenance dredging requirements. For the geomorphic assessment a channel condition survey was selected for October of each year from 1990 to 2008. The October period was selected because it corresponds to the start of a water year, and conditions are generally representative of a complete annual hydrologic cycle. Since these surveys are collected by MVN for the purpose of monitoring of the navigation channel, the spatial coverage of the surveys usually does not extend from waters edge to waters edge. In addition, the upstream extent of the survey coverage is variable from survey to survey, ranging typically from the upstream limit of the Pilottown anchorage area to near Venice. These surveys were provided by MVN in DGN files and XYZ format. The data for these surveys are also collected along survey ranges, so the density of survey data is similar to that of the comprehensive surveys. The survey data were brought into the GIS database, TINs were developed, contoured, and checked for errors. In addition to the annual October surveys obtained, post-flood surveys for the 1997 and 2008 floods were also obtained, as well as pre-storm and post-storm surveys for Hurricane Katrina in 2005.

Horizontal and Vertical Datum

The horizontal datum for the comprehensive surveys is NAD27 and NAD83, and the vertical datum includes Mean Sea Level Datum, NGVD29 and NAVD88. For the channel condition surveys, the horizontal datum is NAD83 and the vertical datum is Mean Low Gulf (MLG). In order to compare data from surveys of different datum, all survey data were projected to the NAD83 horizontal datum. The coordinate system for the survey data is State Plane Louisiana South.

Vertical control in the study area is a very complex issue due to such factors as subsidence and sea level rise. Complicating the matter is the fact that 3 different vertical datum are present in the survey data. Considering the significant time span of the survey data used in this study, it is expected that vertical controls and gages in the area have most likely been adjusted several times. In the case of the comprehensive survey data, the gages used to reduce the raw survey data are not known, and temporal adjustment of the data were not attempted. The channel condition surveys are tied to known gages, and the vertical consistency for these surveys is believed to be reasonable. A 2002 survey of various monuments in the Mississippi River delta area was provided by MVN. This survey provided elevation references in NGVD29, NAVD88 and MLG for the tidal benchmark at Venice (087 0849A). These elevations were used to determine a relationship between the vertical datum, and corrections were applied to correct all survey elevations where required to NAVD88. The corrections to convert NGVD29 and MLG to NAVD88 were -1.19 feet and -1.90 feet, respectively.

Survey Data Uncertainty

Hydrographic survey data collected over a time span of over 40 years and referenced to multiple datum are likely subject to potential error and uncertainty, originating from both equipment accuracy and collection methodology. The hydrographic surveys conducted in the early years of the study period were taken with single beam fathometers and without GPS position control, whereas the more recent surveys, although still collected with a single beam fathometer, utilize GPS positioning for more horizontal accuracy. Single beam fathometers typically have accuracy within 0.5 feet for depths encountered within the study area. In addition, the earlier survey data points were digitized from hard copy maps, thus potentially introducing digitizing and data entry error in both horizontal position and elevation. Also, the vertical datum correction relationship used to convert survey data to NAVD88 was determined from a single tidal bench mark, and may not be representative of the entire study area. All data were carefully checked to ensure their accuracy and viability for use in this study. Regardless, it is understood that potential inaccuracies and uncertainty are still present within the dataset. This uncertainty is likely more prevalent in the earlier comprehensive hydrographic surveys of the 1960s through 1980s. Data from the channel condition surveys, being more recently collected with more modern equipment and referenced to a single horizontal and vertical datum, should contain less uncertainty and error in comparison. Although no formal attempt was made to quantify the uncertainty of the hydrographic survey data, the vertically adjusted data are thought to be within +/- 1 foot and are sufficient for the types of trend analyses conducted as part of the geomorphic assessment.

Discharge Measurements

Discharge measurements collected at irregular time intervals by MVN and published annually in the *Stages and Discharges of the Mississippi River and Tributaries in the New Orleans District* from 1960 until 1998 were obtained for use in this study. Discharge measurements were obtained for the main river as well as all distributaries within the study reach, although yearly data were not always available. Additional data were obtained from MVN that included substantial measurements collected since the construction of the West Bay diversion for purposes of monitoring the development of the diversion. Discharge measurements made prior to approximately 1995 were conducted using a current meter for point velocities along verticals. More recent discharge measurements were collected using acoustic doppler current profiler (ADCP) technology.

Geometric Data Analysis and Results

The geometric data analyses were conducted with the comprehensive and channel condition hydrographic survey data adjusted to horizontal NAD83 State Plane Louisiana South and vertical NAVD88. All computations and results presented are in English units unless specifically stated otherwise.

Cross Section Analysis. The locations of the cross sections used in this analysis are shown in Figures 3.1 through 3.4. The cross sections are orientated from left to right looking downstream. The cross sections were generated in the GIS system and used to extract the bathymetry data for each hydrographic survey. It should be noted that cross sections RM 75.0 AHP to RM 15.0 AHP are available only for the comprehensive hydrographic surveys, since the channel condition surveys did not cover that area. The extracted bathymetric data for all surveys available at each cross section were plotted for comparison and to determine any trends in channel dimension change. The comparison plots for all cross sections are presented in Plates XX-XX of Appendix J.

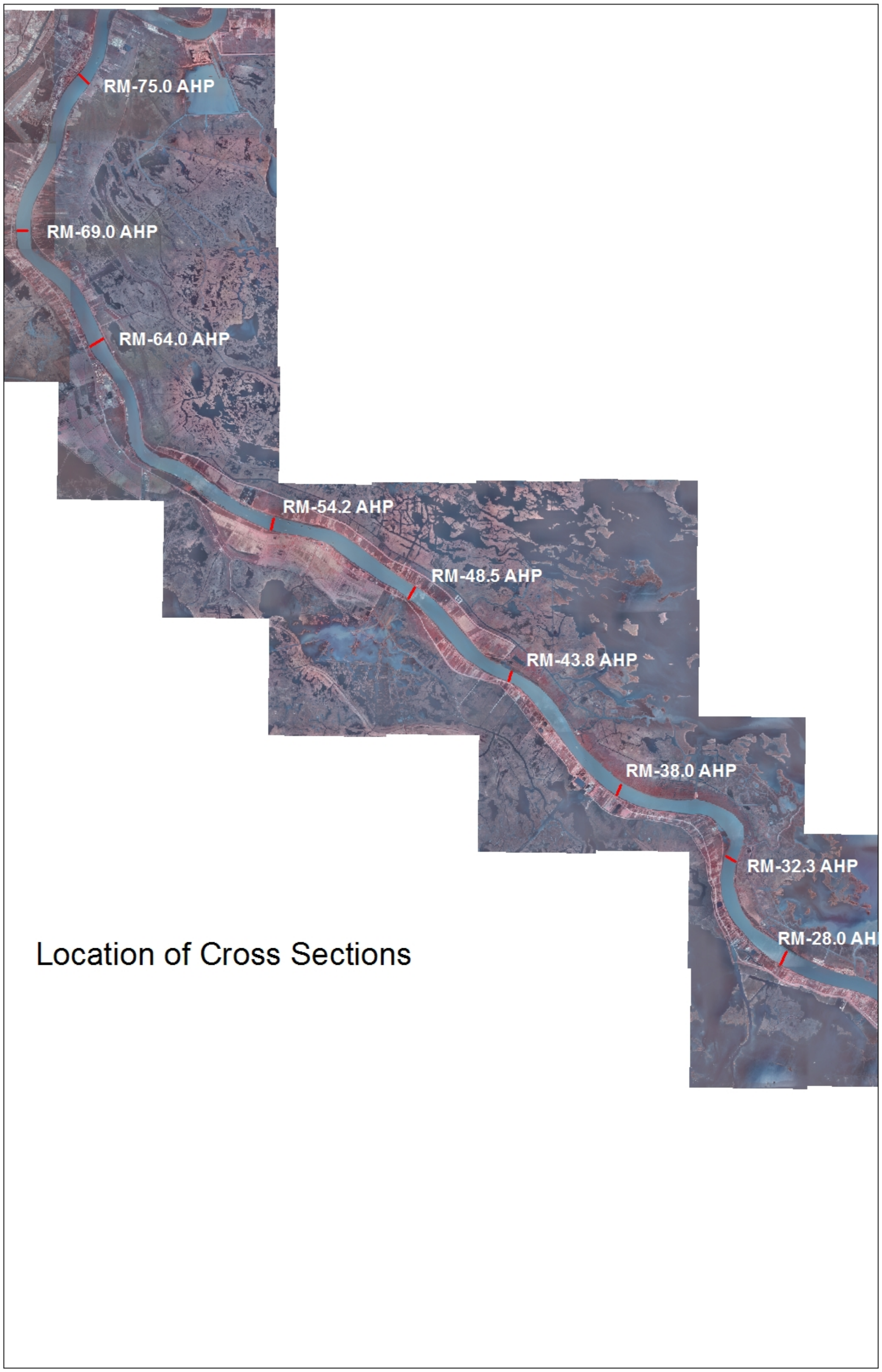


Figure 3.1. Cross section locations, RM 75.0 AHP to RM 28.0 AHP.

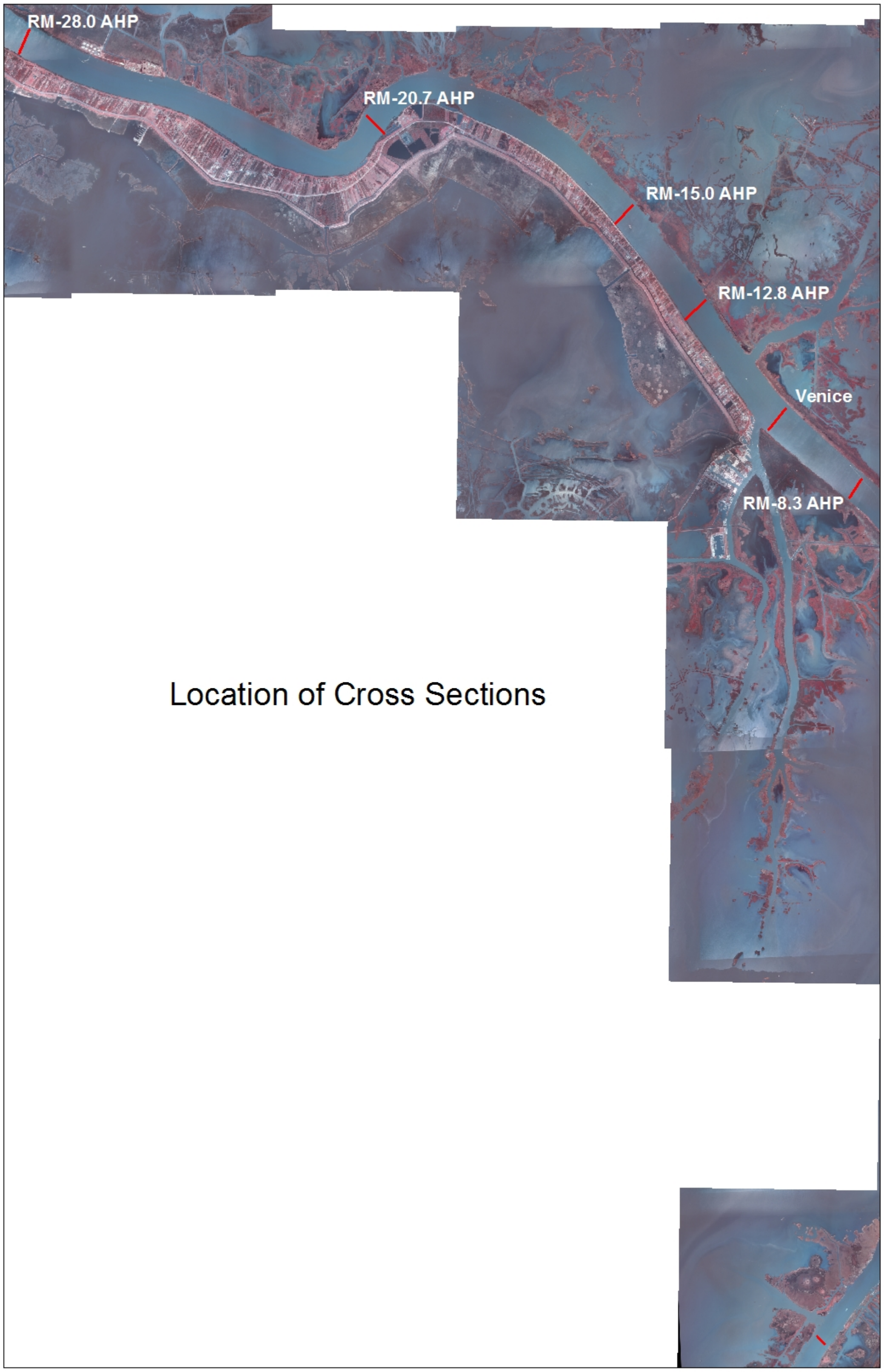


Figure 3.2. Cross section locations, RM 28.0 AHP to RM 8.3 AHP.

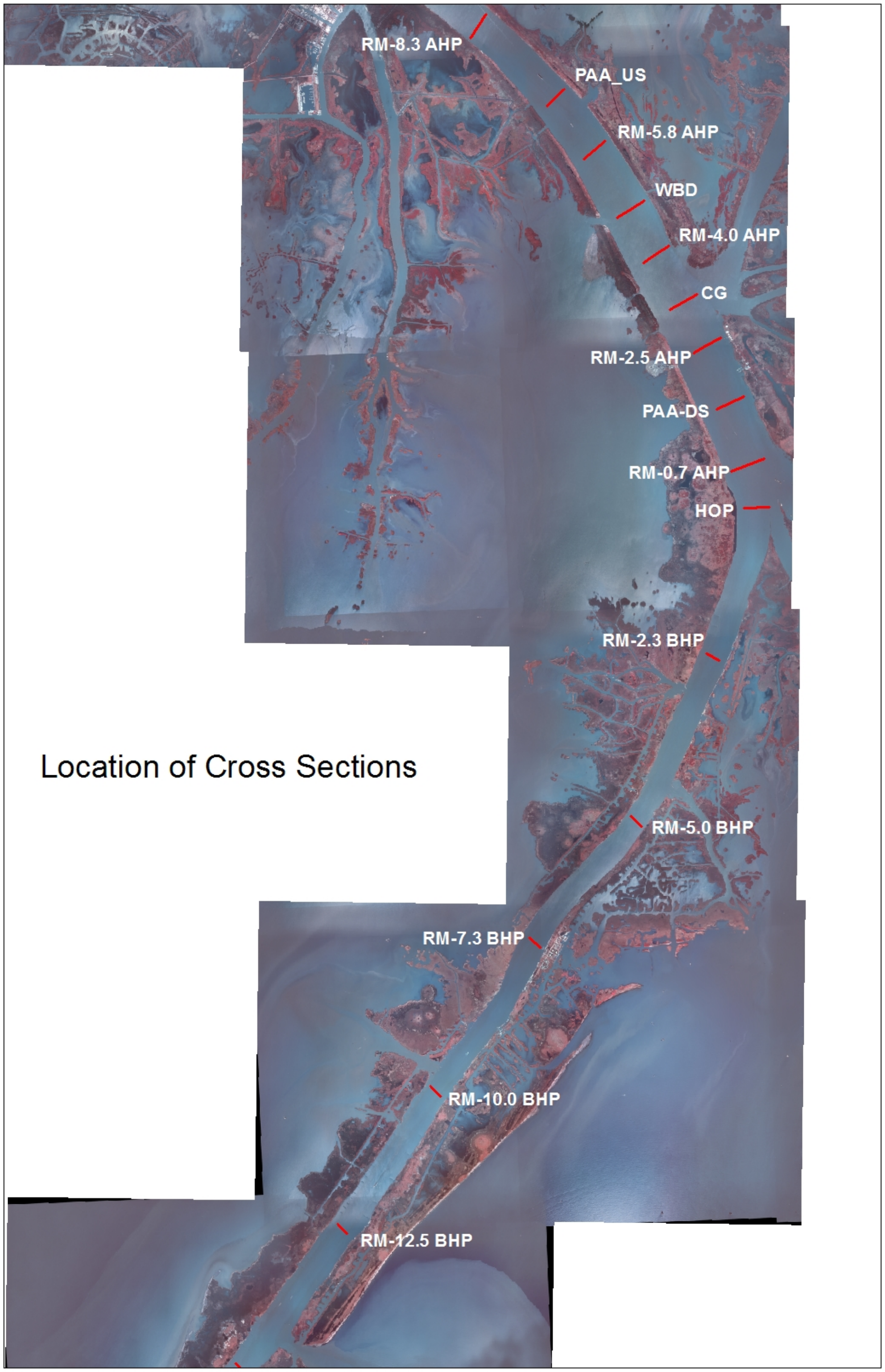


Figure 3.3. Cross section locations, RM 8.3 AHP to RM 12.5 BHP.

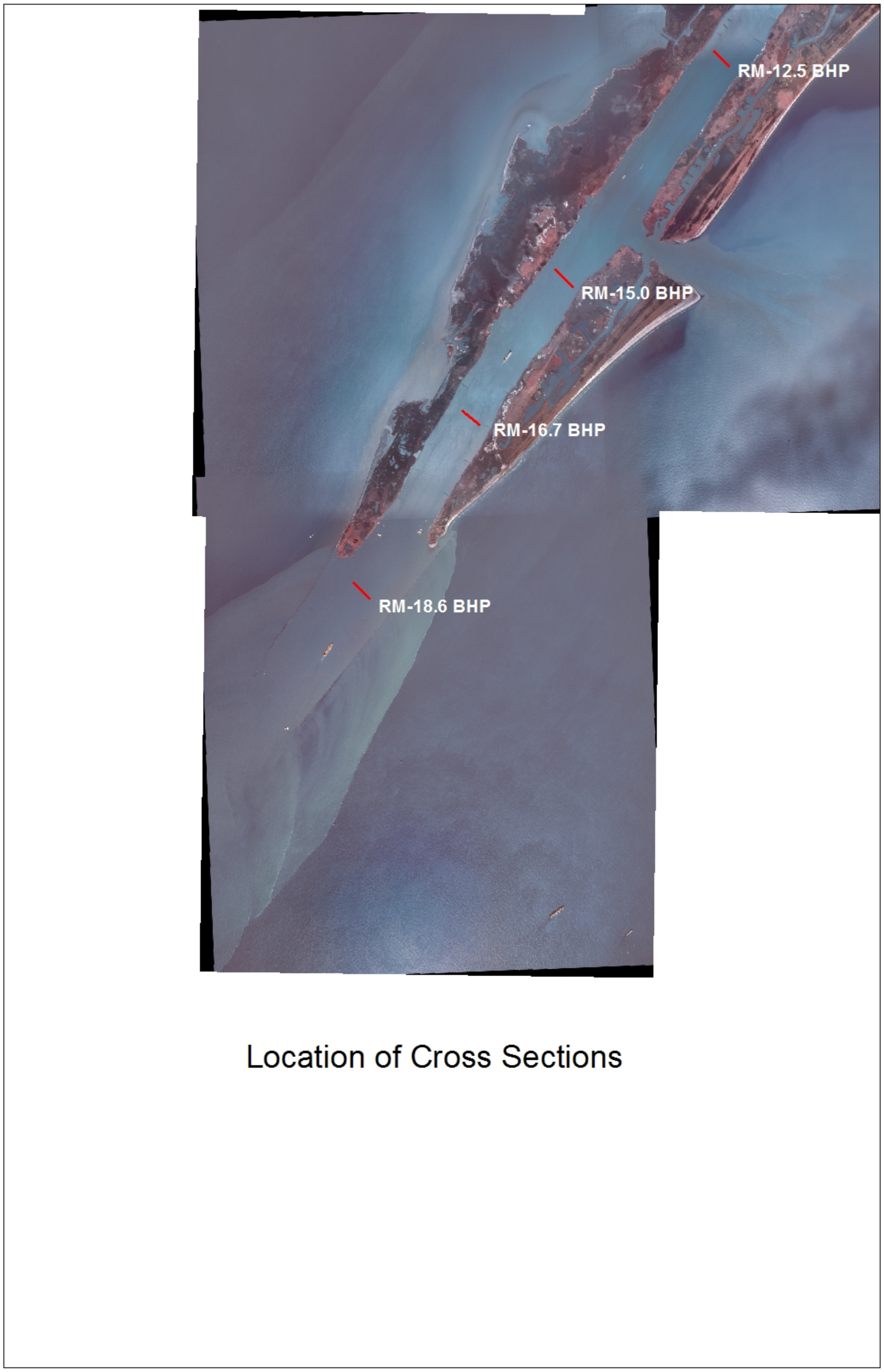


Figure 3.4. Cross section locations, RM 12.5 BHP to RM 18.6 BHP.

The comparison plots for cross sections RM 75.0 AHP through RM 12.8 AHP indicate variability across the channel, both at the thalweg and along the point bar, of sometimes 5 to 10 feet, but channel shape in general is fairly consistent. For example, Figure 3.5 shows the cross section comparisons for RM 75.0 AHP, which is at the upstream limit of the study area near Belle Chasse. There is variability in the thalweg channel over the survey period of approximately 8 feet and a deepening of the upper half of the point bar on the right side of the channel of approximately 15 feet.

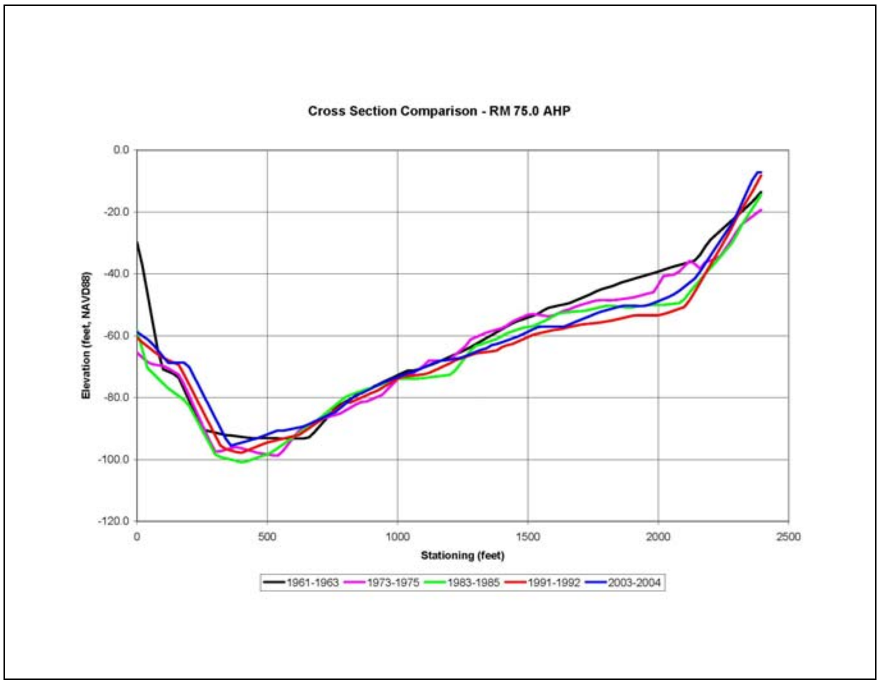


Figure 3.5. Cross section comparison plot for RM 75.0 AHP.

The deepening of the thalweg channel seems to occur over the 1970s and 1980s surveys which cover a time period of generally higher flow on the river (floods of 1973, 1975, 1979, 1983), but depths recover such that the more recent channel of 2003-2004 is little different than the 1961-1963 channel. The same pattern can be seen on the point bar side of the channel, but the channel remains overall deeper in this area. The same trend is observed for RM 69.0 AHP.

The comparison plot for RM 64.0 AHP shown in Figure 3.6 indicates a case where a change in cross section shape occurs. In general, the thalweg channel deepens over time, the lower portion of the point bar becomes shallow over time, and the upper portion of the point bar deepens over time. The thalweg channel deepens after the 1960s survey, most likely in response to construction of the Belair revetment subsequent to that survey.

Figure 3.7 indicates an example of significant shift in the channel dimension as observed at RM 43.8 AHP. This plot shows a significant shift of the channel towards the right descending bank, along with significant filling along the point bar area on the left side of the channel. The high degree of variability in this comparison suggested potential data inaccuracy. However, inspection of the hard copy maps of the surveys revealed that this section is at the location of the Point Michael revetment, and prior to the construction of the revetment approximately 200-300 feet of foreshore was present along the right descending bank. Through erosion of this foreshore, the channel shifted toward the right bank until the revetment was constructed. As the channel shifted to the right the point bar along the left side of the channel responded by filling. Note that there is a slight overall reduction in thalweg depth over the survey time period.

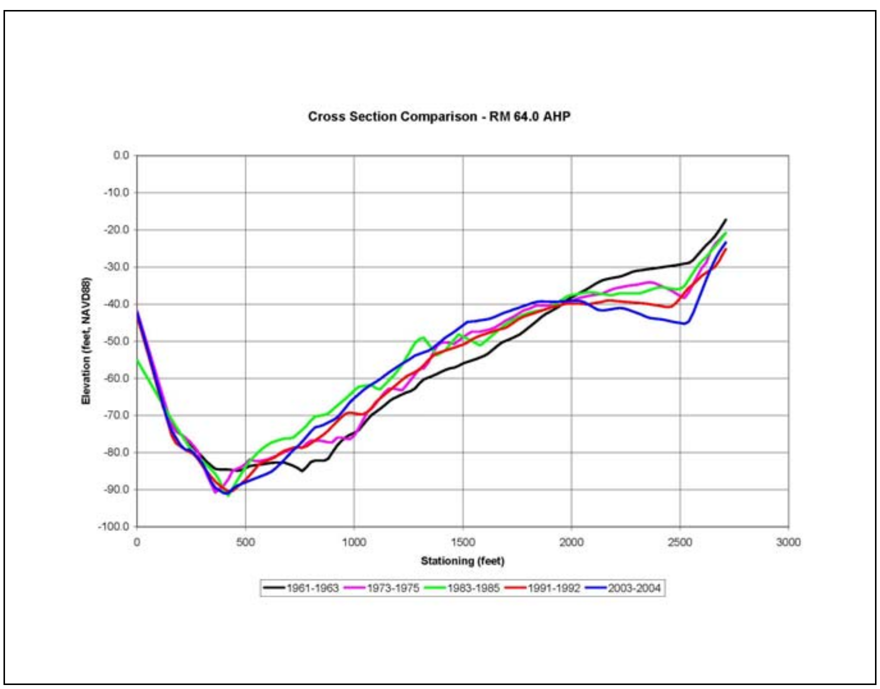


Figure 3.6. Cross section comparison for RM 64.0 AHP.

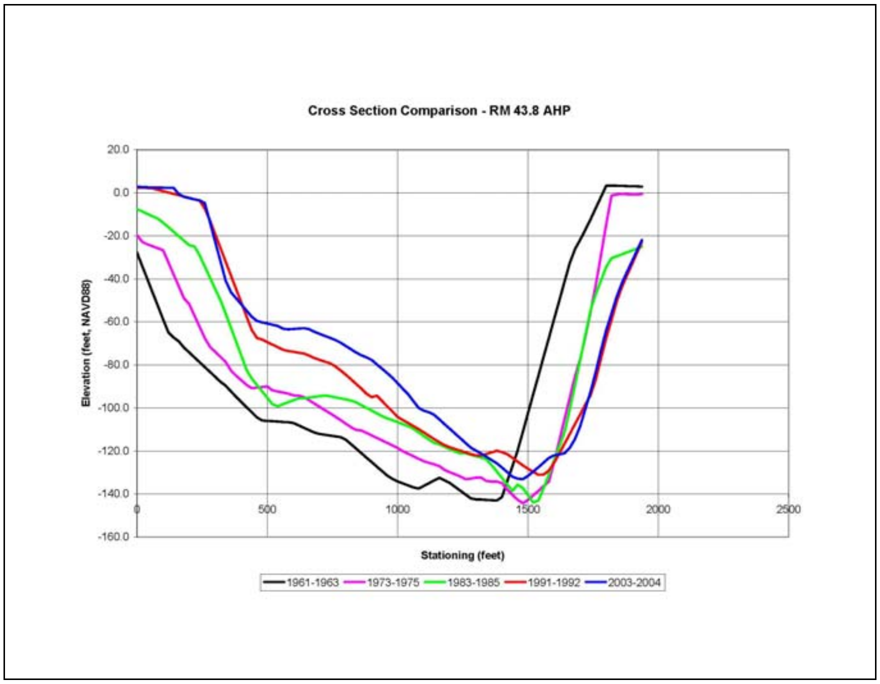


Figure 3.7. Cross section comparison for RM 43.8 AHP.

Cross section comparisons at RM 28.0 AHP through RM 12.8 AHP indicate a general deepening of the thalweg channel occurred after the 1960s survey. However, for all the other surveys there is a noted consistency and very little observed changes or trends between successive surveys. This may suggest potential inaccuracies with the 1960s survey data, but most likely represents changes due to revetment construction in that time period. Outside of the 1960s survey, there has been little appreciable change from the 1970s to the present. Figure 3.8 shows the cross section comparison for RM 12.8 AHP, which is located in a crossing just upstream of Baptiste Collette. This section also contained data from a few channel conditions surveys which extended that far upstream. Overall, the channel has deepened from the 1960s through the 1980s, but depths were generally reduced in subsequent surveys.

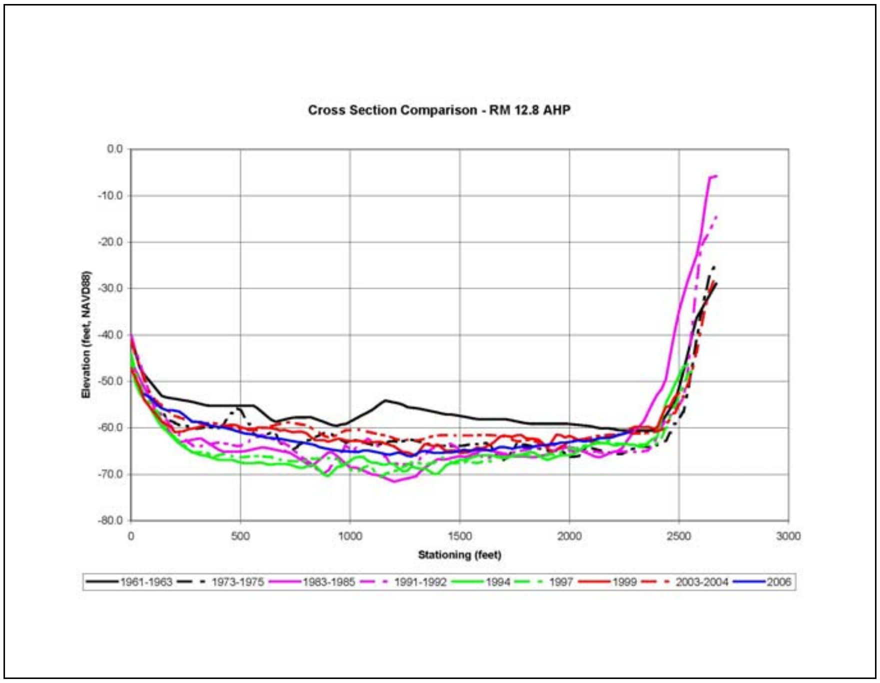


Figure 3.8. Cross section comparison for RM 12.8 AHP, just upstream of Baptiste Collette.

Analysis of the cross sections from RM 75.0 AHP to RM 12.8 AHP reveals that the general trend in channel dimension has been a slight deepening to no significant change in the depth of the thalweg channel. Changes in channel shape due to point bar shifting and possible response to revetment construction were noted, but overall the shape of the channel cross section has been fairly consistent.

However, the above mentioned trend observed from RM 75.0 AHP to RM 12.8 AHP reverses for the cross sections from Venice downstream to approximately Cubits Gap, shifting to a trend where the depth of the Mississippi River channel has been reduced over the study time period. Figure 3.9 illustrates the observed changes in channel dimension for the cross section at Venice, which is just downstream from Grand Pass. There is a dual phase shift observed here, with a general decrease in thalweg depth and a shift in thalweg location toward the right descending bank (toward Grand Pass). The overall decrease in depth is approximately 18-20 feet, and the shift in channel location is approximately 500 feet toward the right descending bank. These changes result in a channel with a more uniform depth and shape. The thalweg channel location and depth for the 1961-1963 and 1973-1975 surveys is fairly consistent, and the shift begins prior to the 1980s survey. This roughly corresponds to the time period for enlargement of the passes at Baptiste Collette and Grand Pass, as more flow is being carried by the distributaries.

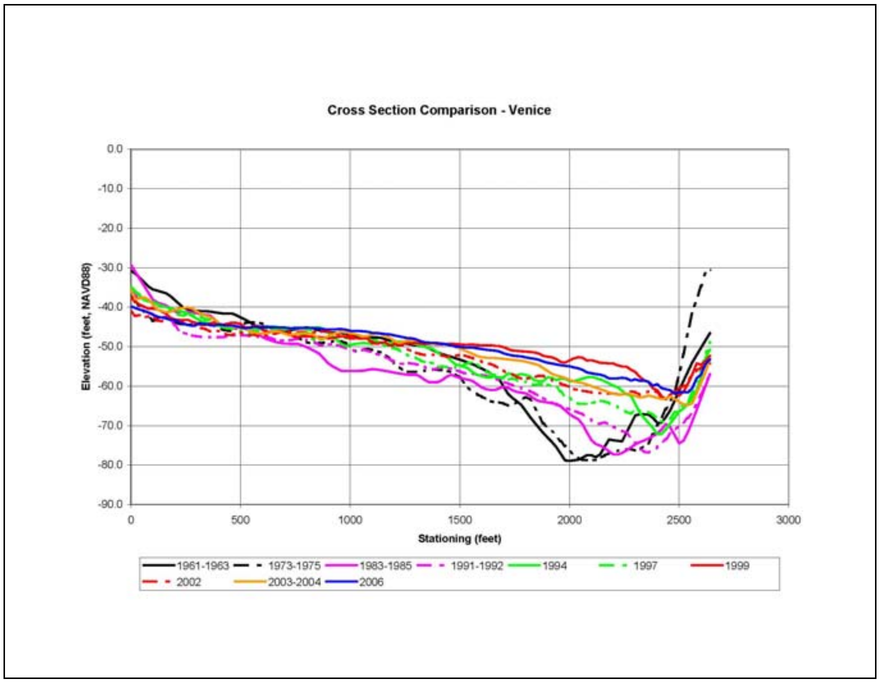


Figure 3.9. Cross section comparison at Venice, just downstream of Grand Pass.

Cross section comparisons for RM 8.3 AHP to RM 5.8 HP indicate a general decrease in thalweg channel depth of 15 to 20 feet over the time range of the surveys. A slight shift in thalweg channel location can also be detected, as illustrated in Figure 3.10 for the cross section at the upstream limit of the anchorage area. The cross section comparison shows that in addition to the decrease in depth there has been a slight shift in thalweg location of approximately 400-500 feet toward the right descending bank. This occurs in an area where the river channel is crossing from the right descending bank below Venice to the left bank upstream of Cubits Gap. It can be seen that the thalweg channel for current conditions is actually located within the upstream portion of the anchorage area. A similar trend is observed for RM 5.8 AHP. Note that the location of the Pilottown anchorage area line between the anchorage and the navigation channel is shown on this and all plots for cross sections located within the anchorage area. This line was determined from MVN plan drawings for the current Pilottown anchorage area dredging contract which indicated the horizontal coordinates of the line. The coordinates were entered into the GIS system, and the intersections of the anchorage area line and the cross sections were determined.

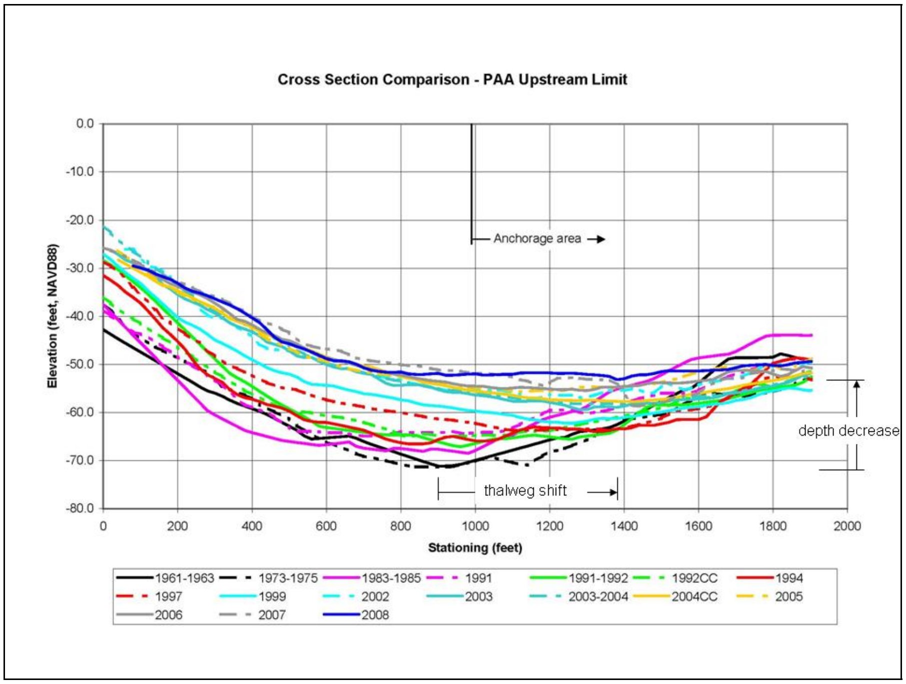


Figure 3.10. Cross section comparison for cross section located at the upstream limit of the Pilottown anchorage area.

The cross section comparison shown in Figure 3.11 for the section located at West Bay diversion (WBD) shows that a deeper thalweg channel existed along the left descending bank in the 1960s survey timeframe, and the elevation on the point bar along the right descending bank was actually as high or higher than current elevations. The cross section from the 1970s survey indicates that the channel had changed significantly, most likely in response to the 1973 flood. The deep portion of the channel had filled, and the point bar slope had been degraded by approximately 10 feet. Since the 1970s survey time there has been a general decrease in thalweg channel depth of approximately 20 feet and a filling along the point bar area of 10 to 15 feet. A similar pattern is observed at RM 4.0 AHP.

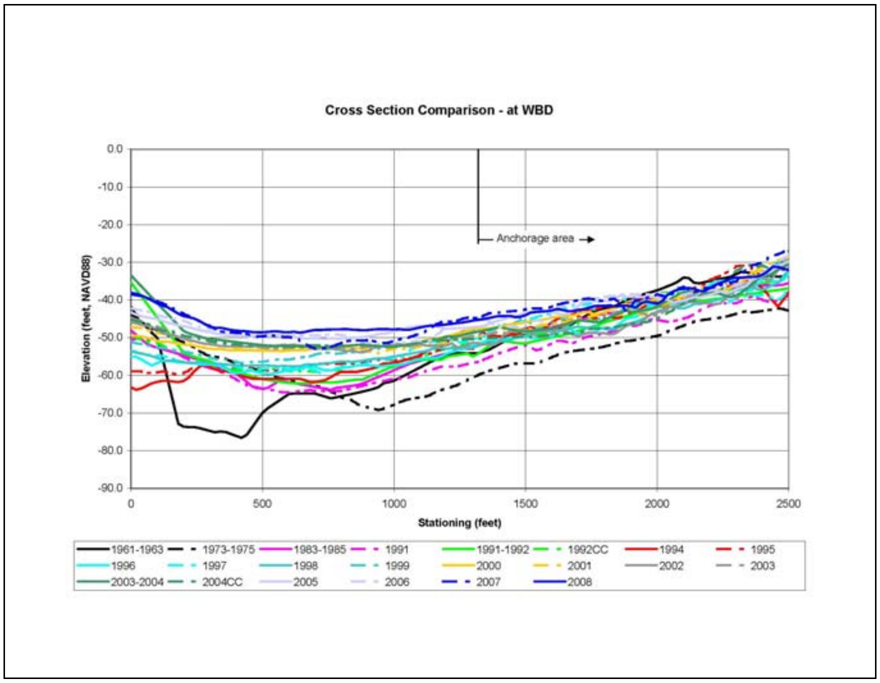


Figure 3.11. Cross section comparison for section located at West Bay Diversion.

Beginning at the cross section located at Cubits Gap, a channel that is significantly influenced by dredging for navigation can be seen. Figure 3.12 illustrates the information for the cross section located at Cubits Gap. Observed change between the 1960s survey and the 1970s survey once again indicates scour along the right side of the channel within the anchorage area of 5 to 8 feet, resulting in a channel that has significantly more depth than for current conditions. The 1970s survey indicates a more uniform depth across the section. This was also true for the 1980s survey, which indicated significant filling in the thalweg channel to approximately elevation -44 feet NAVD88. At first this was believed to be erroneous data; however, examination of the hard copy survey maps revealed that the data are accurate. Maintenance of the navigation channel to -45 feet MLG began in the late 1980s. All surveys subsequent to that time indicate that the channel dimension and shape is shifting from a fairly uniform depth to more of a bendway-type section with an entrenched channel along the left descending bank and a developing point bar along the right side of the channel.

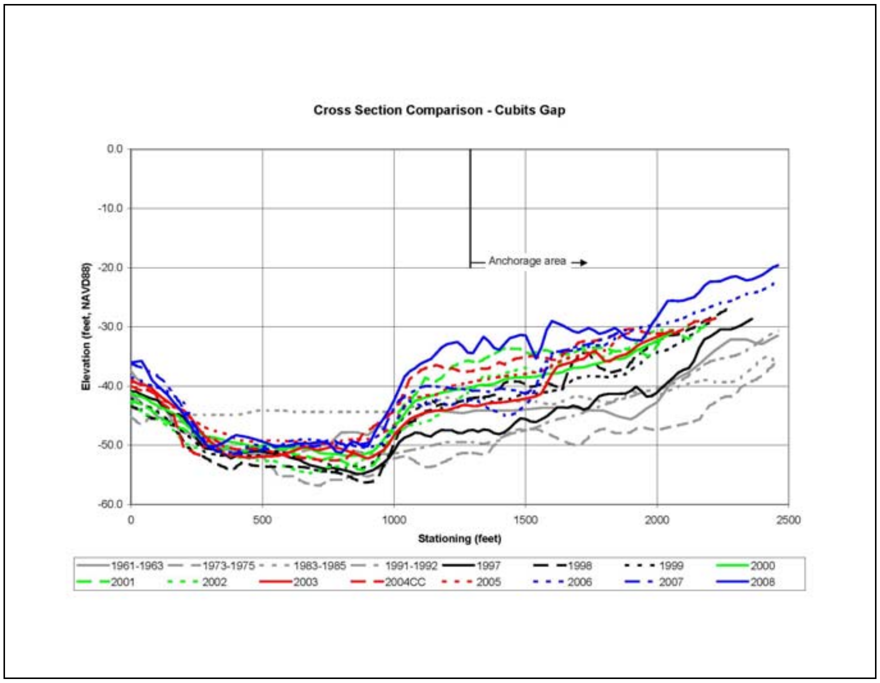


Figure 3.12. Cross section comparison for section located at Cubits Gap.

The cross sections are presented with a different legend scheme in order to distinguish any trends associated with the construction of the West Bay diversion. The six channel condition surveys prior to construction are shown in black and red, while the 6 post-construction surveys are shown in red and blue. Earlier surveys are shown in grey for reference. The plot indicates there is fluctuation in channel elevation within the anchorage area, but that the trend has been a reduction in depth for the period prior to and after West Bay diversion construction. As much as 12 to 15 feet of filling occurred in the anchorage area from the 1970s survey to the construction of the diversion. Since the time of construction, as much as 10 feet of filling has occurred. The thalweg channel is obviously strongly influenced by dredging, and depths tend to fluctuate within a 5 foot range. No real trends can be determined within the thalweg portion of the channel.

Figure 3.13, which shows the cross section comparisons for RM 2.5 AHP, illustrates the degree of channel change that has occurred at this location during the study time period. In fact, the 1960s survey shows that the thalweg channel was actually westward of the anchorage area line, and depths were uniform across the section for the 1970s and 1980s surveys. From the 1960s survey until the construction of West Bay approximately 12 to 15 feet of deposition occurred within the anchorage area, corresponding with the development of an entrenched navigation channel along the left descending bank and a developing point bar along the right descending bank. Since construction of the diversion approximately 3 to 5 feet of deposition has occurred in this area. Similar trends are observed for the cross section at the downstream limit of the anchorage area.

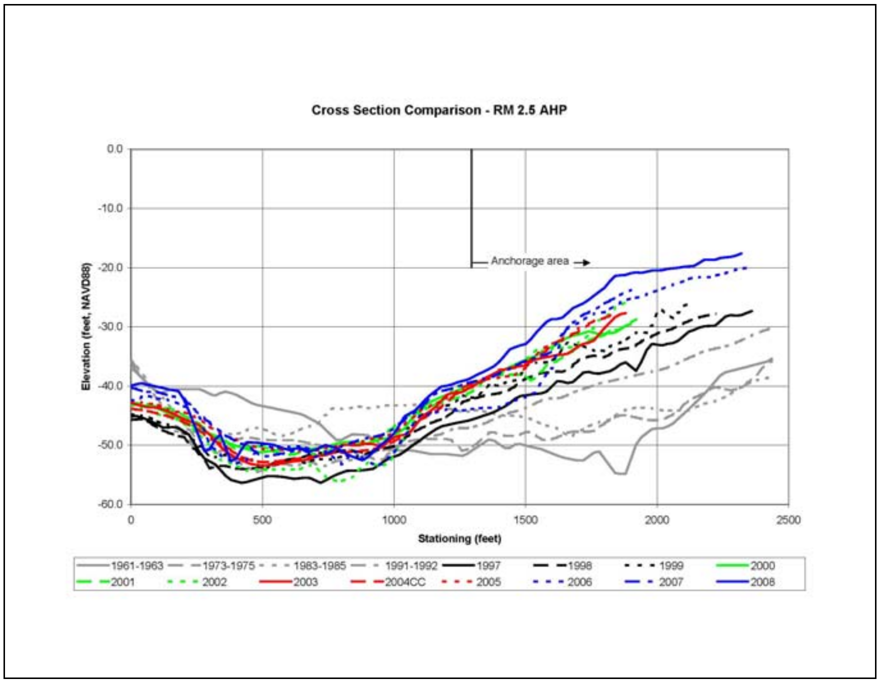


Figure 3.13. Cross section comparison for RM 2.5 AHP.

For the Mississippi River channel from the downstream limit of the anchorage area to Head of Passes, dredging for the -45 foot navigation channel dominates. This is seen in Figure 3.14 for the cross section comparison at RM 0.7 AHP. For the surveys that precede the change to the -45 foot navigation channel the thalweg channel is shallower and the channel at the point bar along the right descending bank is approximately 10 feet deeper. It can be seen that the point bar is almost fully developed to the current conditions by the 2003-2004 comprehensive survey. Very little additional filling has occurred in this area since the construction of the diversion. It should be noted that few of the channel condition surveys extend far enough to the right to capture the full point bar.

Similar conditions are observed for the section at Head of Passes, with the exception that the channel location changes as the channel shifts westward to enter Southwest Pass.

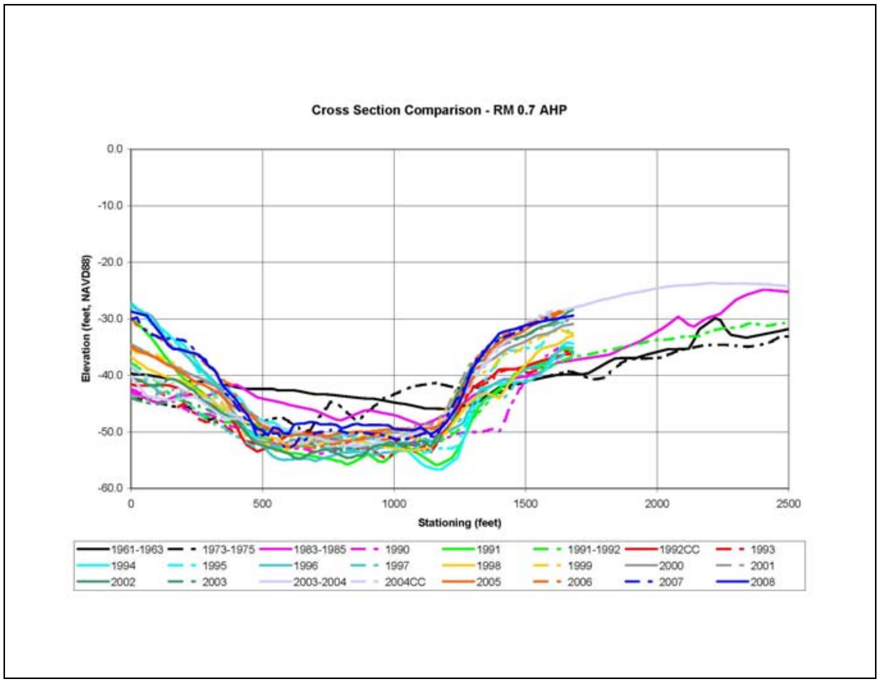


Figure 3.14. Cross section comparison for RM 0.7 AHP.

For the cross sections within Southwest Pass, the channel is completely dominated by dredging. No trends can be discerned, other than the existence of a shallower channel prior to the -45 foot navigation project. Cross section comparisons for RM 10.0 BHP and RM 18.6 BHP are shown in Figures 3.15 and 3.16 as examples. Note that the 1980s comprehensive survey data was not available in digital format for Southwest Pass

The overall assessment based on the comparison of the cross sections is that the general trend for the Mississippi River upstream of Venice has been no appreciable change to a slight increase in channel depth over time. The river thalweg channel observed in the 1960s time period is generally shallower than the current river depths. A shift in this trend appears to occur in the reach from Venice to Cubits Gap. Beginning at Venice, the cross section analysis indicates a trend of reduced depths over time. Depth reductions as much as approximately 20 feet have occurred in the reach over the study time period. The location of the channel crossing has also experienced a general shift toward the right descending bank during this time. The channel in the vicinity of the anchorage area and West Bay diversion appears to have been filling during the period before and after construction of the diversion; however, determination of rates is problematic due to the variability in the survey data. For the reach from Cubits Gap to Head of Passes the channel is heavily influenced by dredging for maintenance of the navigation project. For survey periods after the change to the -45 foot navigation project, the thalweg channel is entrenched along the left descending bank, and the point bar along the right descending bank is actively developing. There appears to be very little impact on the point bar development in the downstream portion of the anchorage area due to construction of the diversion. From Head of Passes to East Jetty the channel is dominated by navigation dredging, and no real trends can be determined other than the channel prior to the -45 foot project was more shallow than the current channel.

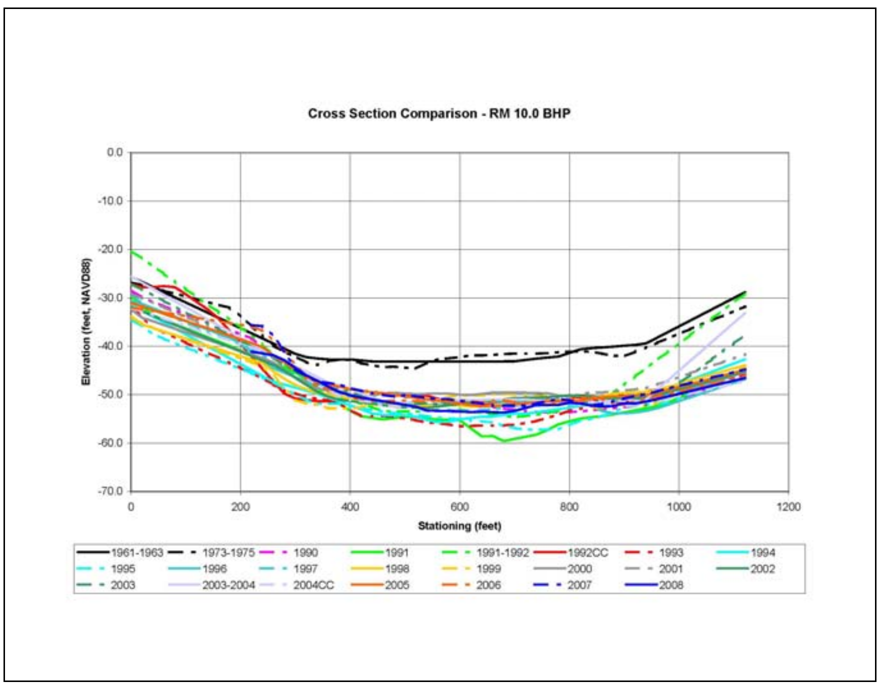


Figure 3.15. Cross section comparison for RM 10.0 BHP.

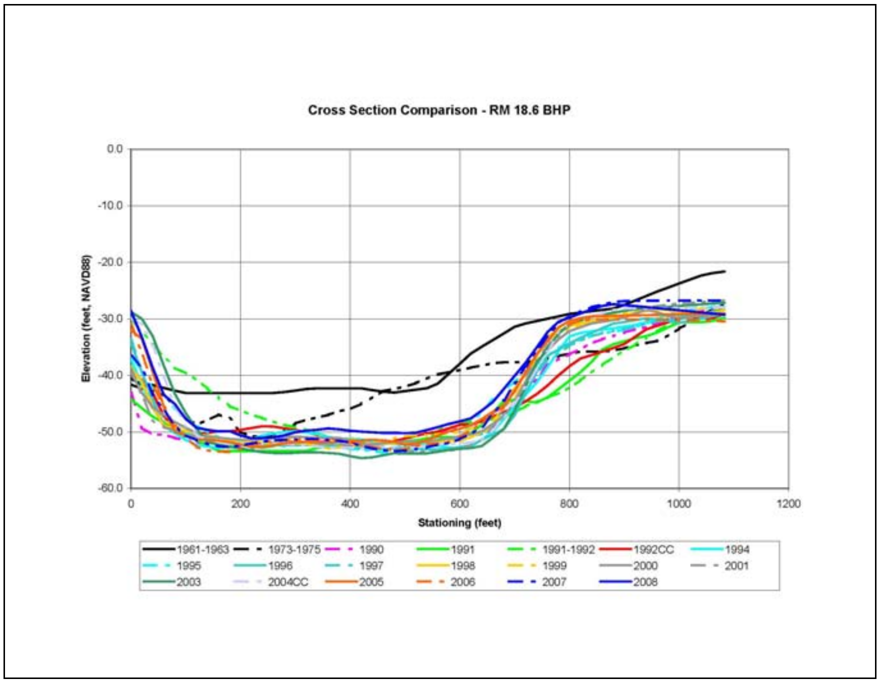


Figure 3.16. Cross section comparison for RM 18.6 BHP.

Average Channel Bed Elevations

The comparison of cross sections from the comprehensive and channel condition surveys provides a means for a qualitative assessment of the observed trends in channel depths and dimension for the Mississippi River within the study reach. However, it is difficult due to the variability at each cross section and from survey to survey to quantify the observed changes. It was necessary to establish a means to quantify the observed changes within the anchorage area in order to evaluate the impacts of the diversion. To quantify the observed changes, the average channel bed elevation was computed over the portion of the cross section extending 500 foot westward (towards the right descending bank) from the anchorage area line. This analysis was conducted only for the cross sections within the anchorage area. The computed average bed elevations for each cross section were then plotted versus time to determine if any trends in channel dimension are present. This method provides for better visualization of channel depth trends that are specific to the anchorage area.

The plot of average channel bed elevation for the cross section at the upstream limit of the anchorage area is shown in Figure 3.17. Note that the comprehensive surveys and the channel condition surveys before and after construction of the diversion are plotted separately. The reason for this is that the channel condition surveys are representative of year to year changes, whereas comprehensive surveys reflect decadal changes. In years where data exists for both survey types, differences in average bed elevation can be seen between the surveys. This is primarily due to the fact that the comprehensive survey data may have been collected at any time within the survey period, whereas the channel condition surveys were collected during October of each year.

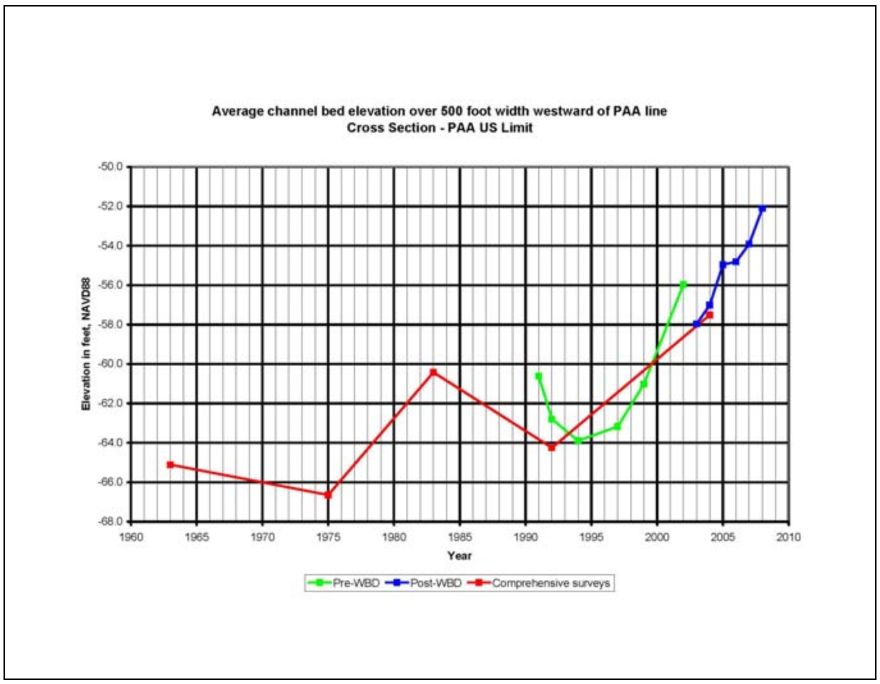


Figure 3.17. Comparison of average channel bed elevation for cross section located at the upstream limit of the Pilottown anchorage area.

The plots for the comprehensive surveys and the pre-construction channel condition surveys indicate a slight increasing trend in channel bed elevation, although with some variability. The post-construction surveys indicate a steady trend in increasing channel bed elevation, with a yearly change of approximately 1.1 feet.

The average bed elevation plot for the cross section at RM 5.8 AHP is shown in Figure 3.18. Average bed elevations for all three survey types are highly variable at this cross section, most likely due to the channel crossing that occurs in the upper anchorage area. Note that the average channel bed elevations prior to diversion construction were almost the same as current elevations. No definitive trends in channel bed elevation could be determined.

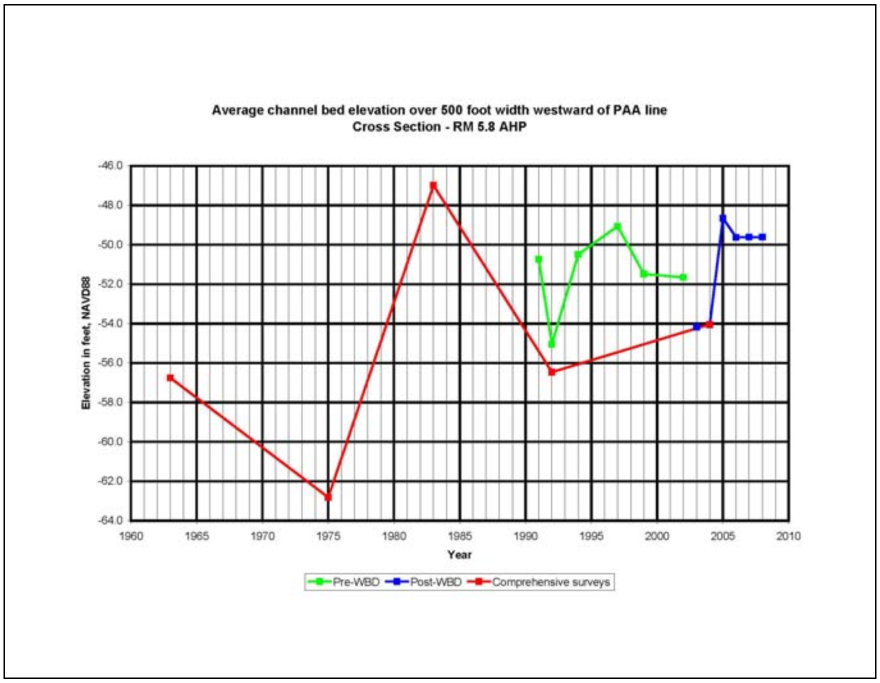


Figure 3.18. Comparison of average channel bed elevation for cross section located at RM 5.8 AHP.

The average channel bed elevations for the cross section located at the West Bay diversion are plotted in Figure 3.19. The plot for the comprehensive surveys indicates no real trend over the period. The pre-construction channel condition surveys display a slight trend of increasing channel bed elevation, although there is significant fluctuation in the data. The overall trend is approximately 0.25 feet annually. The post-construction channel condition survey plot indicates a trend of increasing channel bed elevation, with an average rate of 1.2 feet per year. This data indicates that there is a potential increase in the rate of deposition for the post-construction time period.

The average bed elevation plot for the comprehensive surveys for RM 4.0 AHP shown in Figure 3.20 indicates no discernable trend. However, the plots for the pre- and post-construction channel condition surveys display a clear trend in increasing bed elevation. The yearly rate of change for the pre-construction period and post-construction period is fairly similar, with the exception of the 2002 survey that indicates a significant and uncharacteristic scour of the bed.

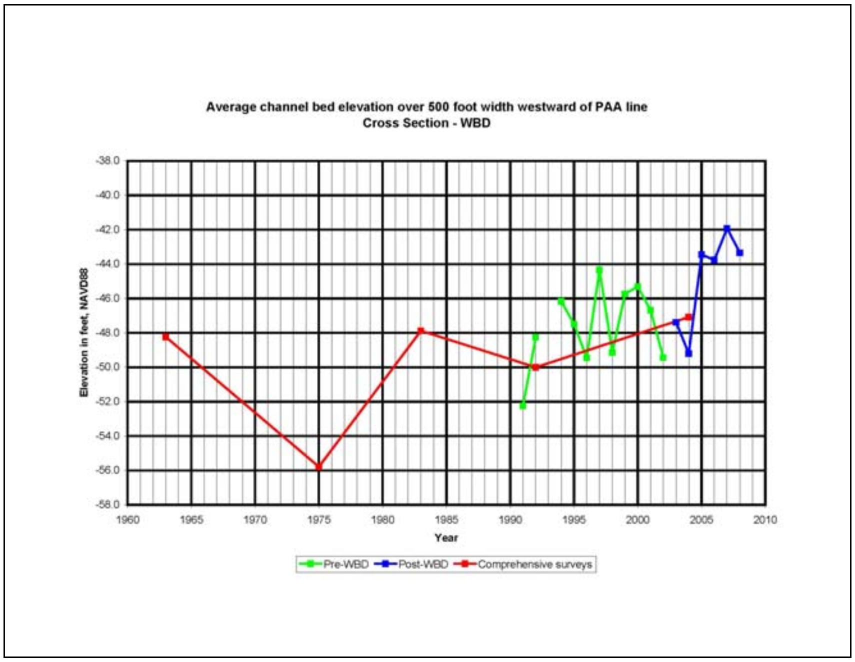


Figure 3.19. Comparison of average channel bed elevation for cross section located at West Bay diversion.

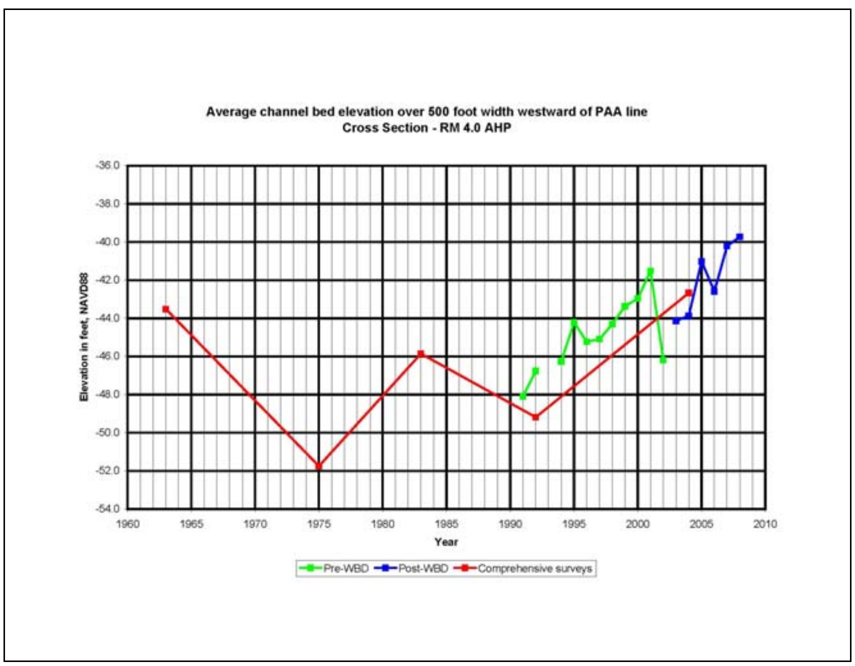


Figure 3.20. Comparison of average channel bed elevation for cross section located at RM 4.0 AHP.

Figure 3.21 shows the average bed elevation plots for the cross section at Cubits Gap. The plot for the comprehensive surveys indicates a slight trend of increasing bed elevation from the 1990s survey to the 2000s survey, but no real trend from the 1960s survey to the 1990s survey. The plot for the pre-construction channel condition surveys indicates an overall increasing bed elevation trend at a rate of approximately 1 foot per year. The post-construction channel condition surveys indicate a similar trend of approximately 0.9 feet per year, although there is significant variability. The impact of the 2003 and 2006 dredging in the anchorage area can been observed in this plot.

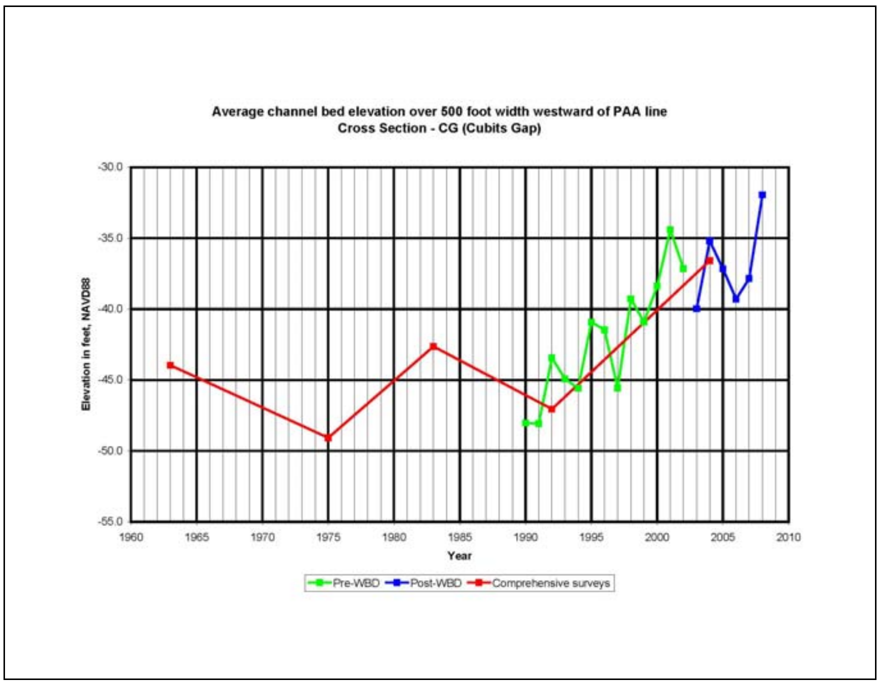


Figure 3.21. Comparison of average channel bed elevation for cross section located at Cubits Gap.

The trends in average bed elevation change for the cross sections located at RM 2.5 AHP and the downstream limit of the Pilottown anchorage area (PAA-DS) are very similar, as seen in Figures 3.22 and 3.23. As can be seen in the plot for the comprehensive surveys for RM 2.5 AHP in Figure 3.22, a steady increase in average channel bed elevation has occurred over the time period. The yearly rate of change is approximately 0.4 feet. For the pre-construction and post-construction channel condition surveys, a similar trend is observed, with a yearly rate of change for both plots of approximately 0.7 feet per year. In Figure 3.23, an overall trend of increasing channel bed elevation can be seen from the comprehensive surveys. For the channel condition surveys, a similar trend can be seen for both the pre-construction and post-construction surveys. The linear trend indicates an approximate rate of change of 0.5 feet per year for each.

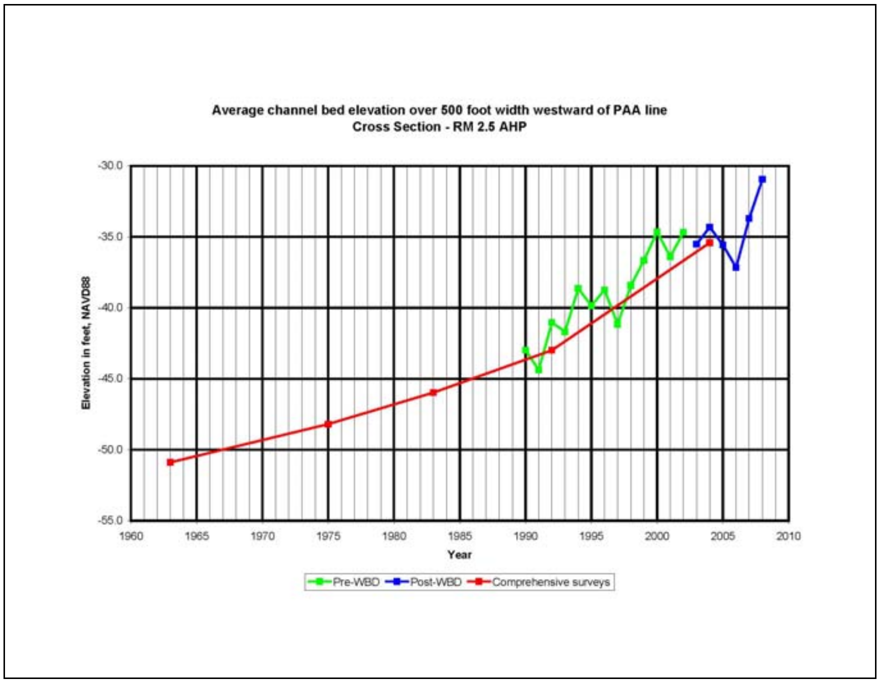


Figure 3.22. Comparison of average channel bed elevation for cross section located at RM 2.5 AHP.

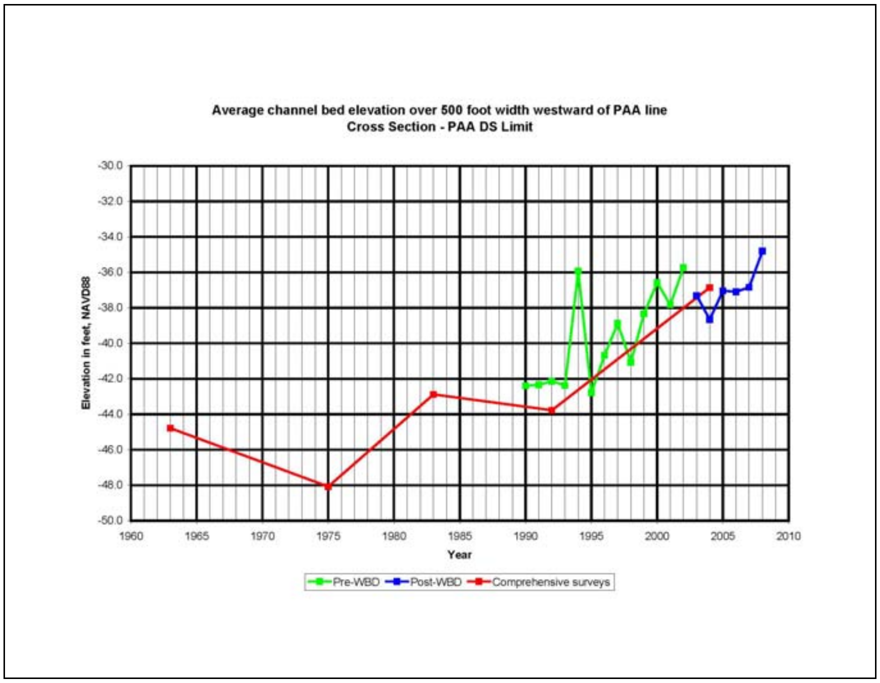


Figure 3.23 .Comparison of average channel bed elevation for cross section located at the downstream limit of the Pilottown anchorage area.

The average bed elevation analysis provides a method to attempt to quantify the rates of change observed for a specific section of each cross section located within the anchorage area. Based on this analysis, it appears that the channel bed elevation in the anchorage area has, in general, been increasing over the study time period. It does appear that there is a notable difference in the pre- and post-construction rates of channel bed elevation change in the vicinity of the diversion channel. For the cross section at the diversion the yearly rate of average bed elevation increase for the post-construction time period is approximately 3 times as great as the rate for the pre-construction time period. This possible effect of the diversion does appear to be limited to the vicinity near the diversion. Comparison of the average channel bed elevations for the cross sections from Cubits Gap to the downstream limit of the anchorage area indicates no discernable change in the rate of deposition relative to the construction of the diversion. This suggests that the diversion has had no appreciable impact of deposition rates in the lower portion of the anchorage area.

Analysis of Flood and Hurricane Impacts

Surveys following the floods of 1997 and 2008 and Hurricane Katrina in 2005 were analyzed to determine the degree of impact due to extreme hydro-meteorological events. For the floods of 1997 and 2008, surveys that were analyzed are the October survey preceding the spring flood event, the survey collected 2 to 3 weeks after the flood peak, and the following October survey. For Hurricane Katrina, the surveys that were compared are the pre-storm survey of early August 2005, the mid-September 2005 survey, and the October 2005 survey. Channel condition surveys were used for all these comparisons. The plots are shown in Plates XX-XX of Appendix J.

Cross section comparisons for the floods of 1997 and 2008 indicate that large magnitude floods of this nature result in substantial changes that are often irregular in pattern. The flood peaks produce sufficient stream power to move the bed sediments through the river channel in large waves, resulting in a noticeably remolded channel perimeter. Figures 3.24 and 3.25 illustrate the impact of the 1997 flood for the cross sections at RM 5.8 AHP and Cubits Gap. Figure 3.24 illustrates that at RM 5.8 AHP slight filling in the thalweg channel and considerable deposition on the point bar occurred due to the flood. Interestingly, approximately half of the flood deposits on the point bar had been eroded by the following October. Figure 3.25 shows that at Cubits Gap very little change in thalweg depth occurred, but significant erosion along the point bar in the anchorage area took place. It is interesting that deposition in the anchorage area occurred at one point, but erosion occurred at a location not much farther downstream. This may be indicative of the large sand waves that can be generated during large flood events. Figure 3.26 shows the changes that occurred at RM 10.0 BHP as a typical example for Southwest Pass. The plot indicates that both erosion and deposition occurred over as much as a 5 foot vertical range at this location.

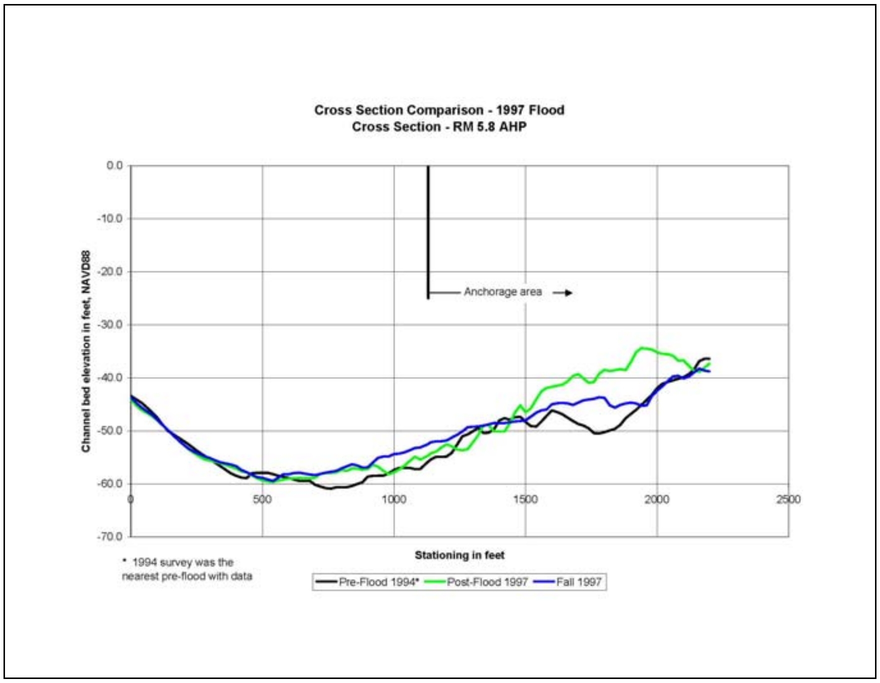


Figure 3.24. Cross section comparisons for 1997 flood for cross section located at RM 5.8 AHP.

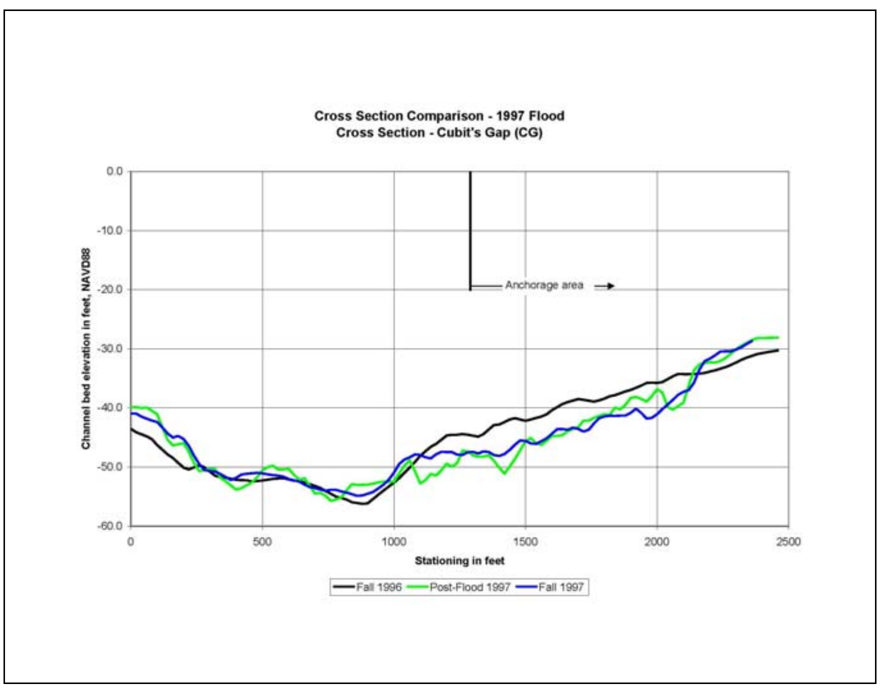


Figure 3.25. Cross section comparisons for 1997 flood for cross section located at downstream limit of Pilottown anchorage area.

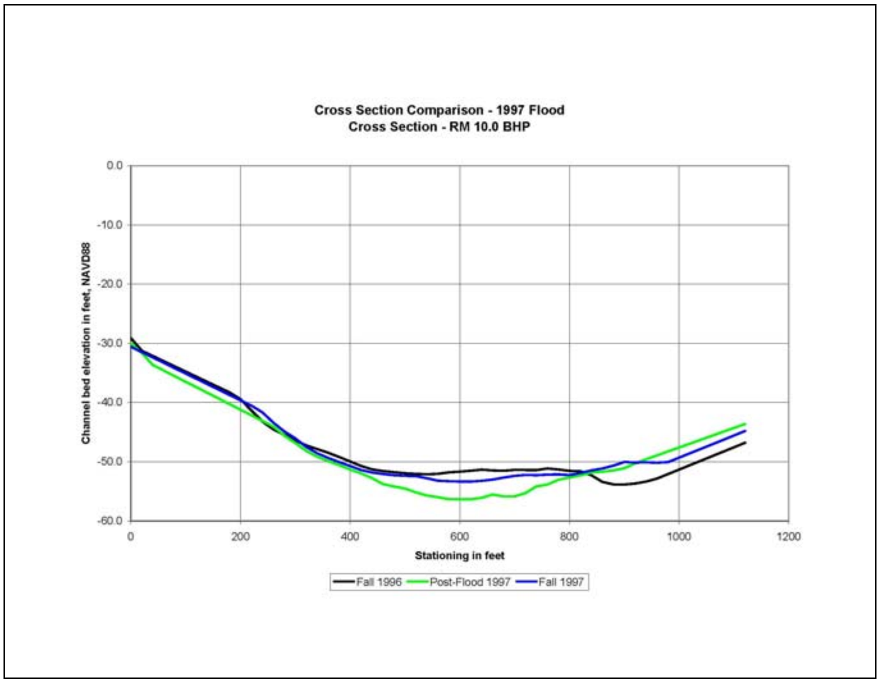


Figure 3.26. Cross section comparisons for 1997 flood for cross section located at RM 10.0 BHP.

Figures 3.27 and 3.28 illustrate the observed impacts on channel dimensions resulting from the flood of 2008. Figure 3.27 shows the cross section comparisons for the section located at the West Bay diversion. The surveys indicate a slight filling within the thalweg channel, and 3 to 5 feet of erosion in the anchorage area adjacent to the navigation channel. Two to 3 feet of deposition occurred farther upslope on the point bar. The October 2008 survey indicates that the anchorage area adjacent to the channel had almost completely refilled with sediment by the following autumn. Figure 3.28 shows the observed changes at Cubits Gap for the 2008 flood. It can be seen that 6 to 8 feet of sediment deposition occurred along the edge of the navigation channel and the anchorage area. The shape and elevation of the channel within the anchorage area for the pre-flood survey (October 2007) is indicative of the effects of the 2006 anchorage area dredging effort. This suggests that deposition from the 2008 flood effectively negated the dredging effort in this location. The conditions in the following October has not changed significantly since the post-flood survey, except for removal of flood deposited material from the channel. Figure 3.29 shows the changes that occurred at RM 5.0 BHP as an example of the typical changes observed within Southwest Pass for the 2008 flood. The plot indicates scour of the channel, as much as 10 feet, occurred during the flood, but most of the scoured area had refilled by the following autumn.

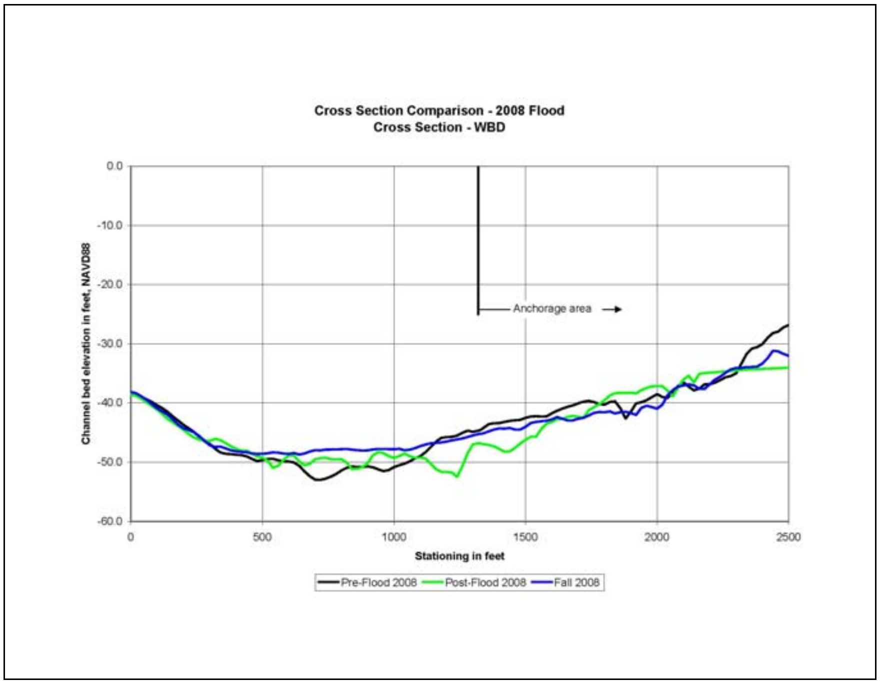


Figure 3.27. Cross section comparison for 2008 flood for cross section located at West Bay diversion.

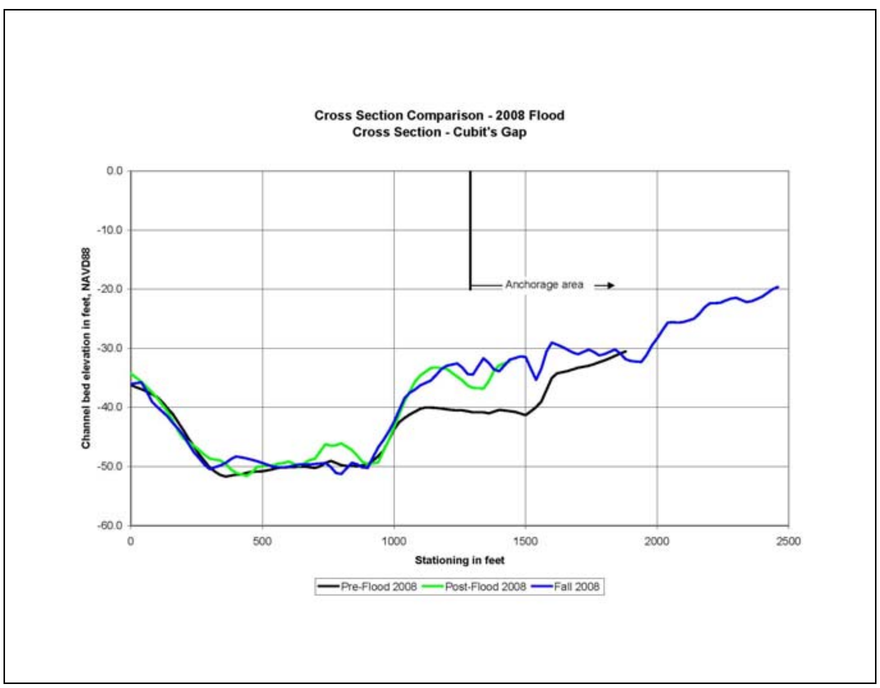


Figure 3.28. Cross section comparison for 2008 flood for cross section located at Cubits Gap.

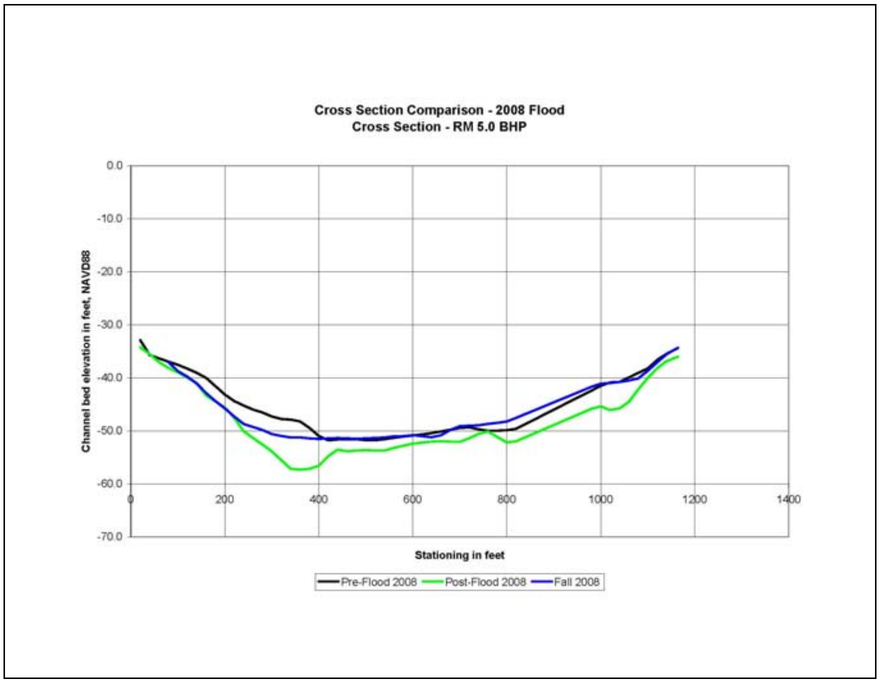


Figure 3.29. Cross section comparison for 2008 flood for cross section located at RM 5.0 BHP.

The cross section comparisons for Hurricane Katrina in 2005 indicate that a general deposition of sediment occurred in the area. The deposition pattern was fairly uniform, with slightly more deposition observed in the channel than along the point bar within the anchorage area. Depths of deposition range from approximately 2 feet in the upstream anchorage area to approximately 5 feet in Southwest Pass near East Jetty. The survey comparisons also indicate a portion of the deposited material was either dredged or scoured away within a couple of months after the storm. Figure 3.30 shows the observed changes at the cross section at West Bay diversion. Approximately 2 feet of deposition occurred in the thalweg channel, but less in the anchorage area. The cross section comparisons in Figure 3.31 indicate a similar deposition pattern at Cubits Gap, with 2 to 3 feet of filling in the channel and approximately 1 foot of deposition within the anchorage area. Figure 3.32 illustrates the typical changes observed at Head of Passes. The trends observed from Head of Passes to East Jetty indicate deposition in the channel during the storm and scour (dredging?) of storm deposits during the ensuing few months. In general, approximately 3 to 5 feet of sediment deposition occurred during the storm in Southwest Pass, with the amounts increasing with proximity to the gulf. Deposition patterns were very uniform across the section. Removal of the deposited material in the months after the storm resulted in a restoration of 30 to 50 percent of the pre-storm channel geometry. Figure 3.33 shows the cross section comparisons for RM 18.6 BHP at East Jetty.

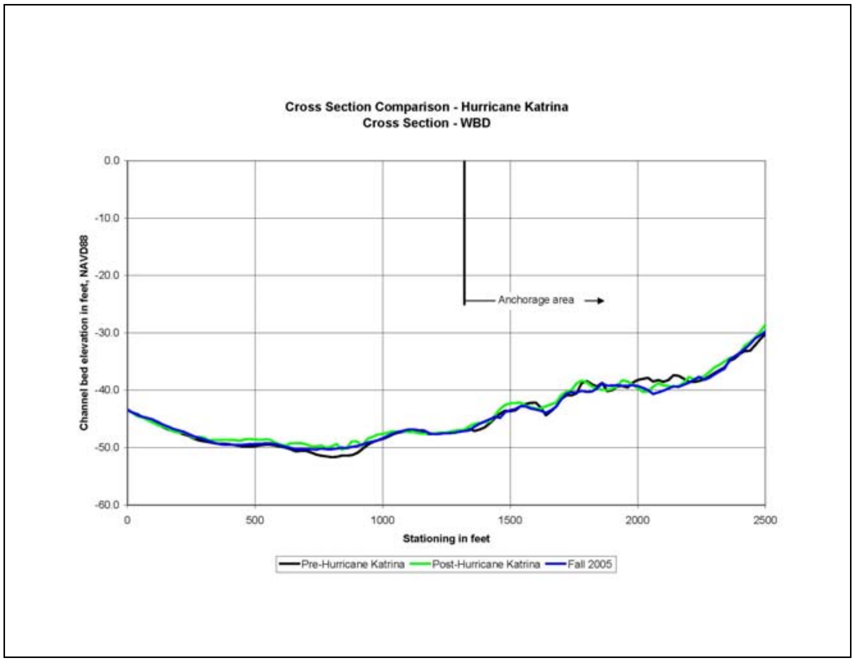


Figure 3.30. Cross section comparison for Hurricane Katrina for cross section located at West Bay diversion.

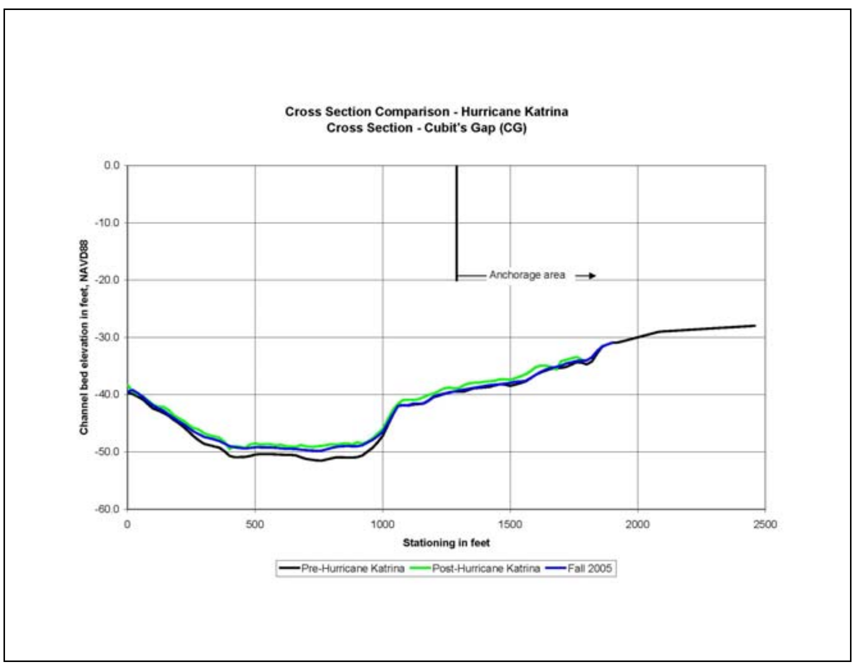


Figure 3.31. Cross section comparison for Hurricane Katrina for cross section located at Cubits Gap.

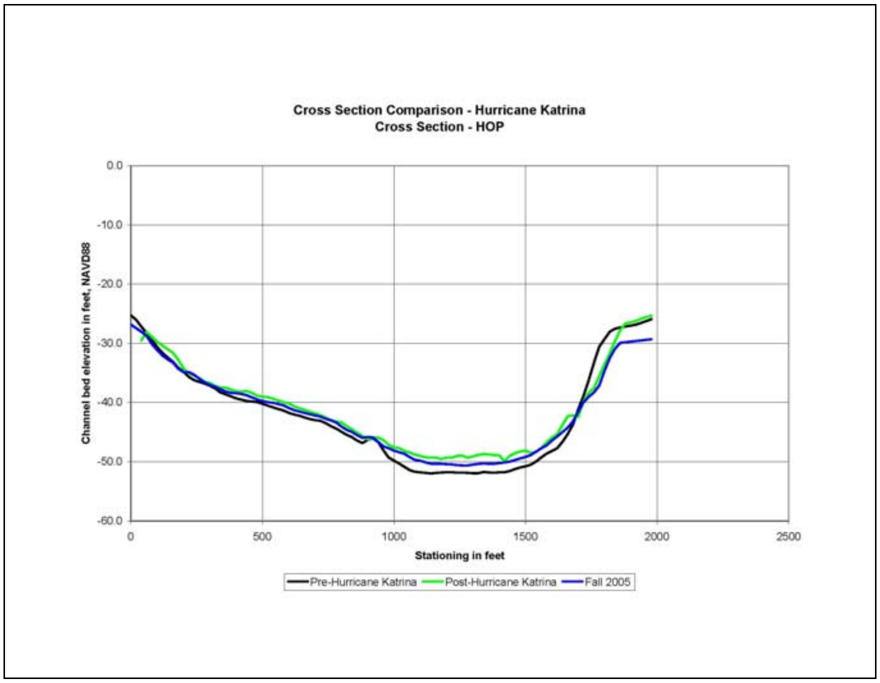


Figure 3.32. Cross section comparison for Hurricane Katrina for cross section located at Head of Passes.

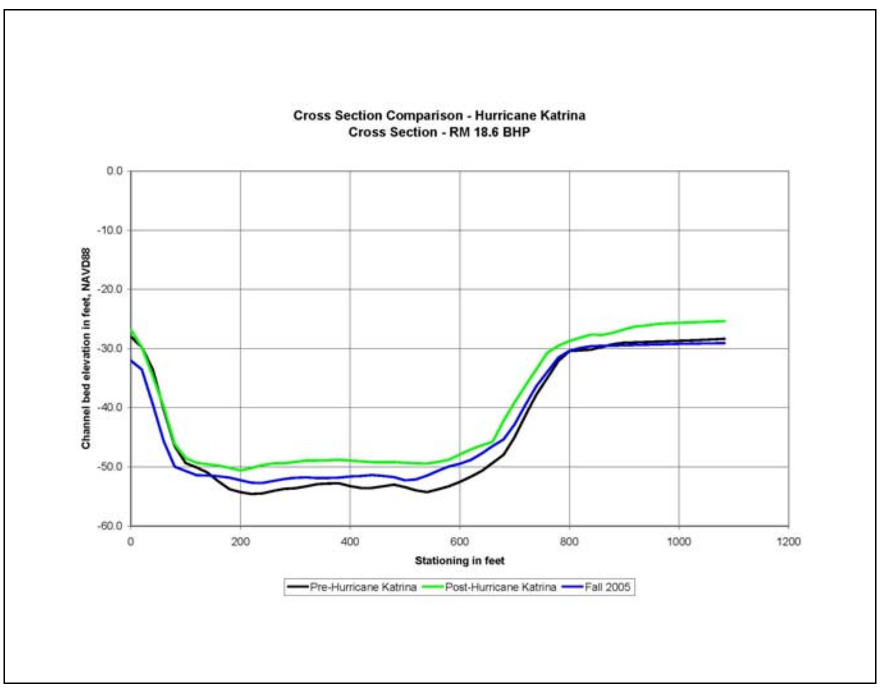


Figure 3.33. Cross section comparison for Hurricane Katrina for cross section located at RM 18.6 BHP.

The analysis of the cross section comparisons for the spring floods of 1997 and 2008 and for Hurricane Katrina in 2005 reveals that major flood events can significantly alter and remold the channel of the lower Mississippi River and Southwest Pass. Cross section comparisons indicate the flood events can both scour and deposit sediments in both the thalweg channel and along the point bar. In general there is no discernable pattern or trend in the scour or deposition, although deposition in the thalweg channel typically occurs. The stream power associated with large floods mobilizes the channel bed material and moves it downstream in waves, resulting in a reworked channel perimeter. As was shown in Figure 3.28, approximately 6 to 8 feet of sediment deposition occurred in the anchorage area at Cubits Gap during the 2008 flood, effectively filling the area dredged in the 2006 anchorage area dredge work. In contrast to the effects of the major floods, the effects of Hurricane Katrina appear to be primarily depositional, and the pattern of deposition is generally uniform with greater deposition in the thalweg channel and less deposition along the point bar in the anchorage area. Depths of sediment deposition increase in the downstream direction and are greatest near the gulf. The cross section comparisons indicate that the material deposited during the storm is removed in the weeks following the storm, either by dredging are natural erosion. It should be noted that these patterns and trends could be different for a storm that approaches the Mississippi River delta on a different track than that of Hurricane Katrina.

Cross Section Analysis with Focus on West Bay Diversion Construction

A cross section analysis that focused primarily on determining trends in the near term before and after construction of West Bay diversion was conducted. This analysis addressed the periods 5 years prior to and subsequent to diversion construction and evaluated the maximum extent of the channel bed elevation during those periods. This analysis does not attempt to determine rates of change during these time periods, but rather looks at the maximum extent of the location of the channel bed within the periods. The plots for this analysis show the range of channel bed extent within the anchorage area for the 5 year pre-construction period shaded in red, and the maximum extent for the post-construction period shaded in blue. This shaded range in effect creates an envelope that describes the maximum extent the channel bed has increased from a given point in time. The survey prior to the pre-construction period is plotted in black to indicate the baseline condition for this analysis (1998 survey for most plots, but the 1997 survey whenever the1998 survey is missing). All the comprehensive surveys prior to diversion construction are shown as a reference of the overall changes that have occurred during the study period.

Figure 3.34 shows the plot for the cross section located at the upstream limit of the anchorage area. The plot shows that the channel bed in the vicinity of the anchorage area increased approximately 8 feet during the pre-construction period and approximately 4 to 5 feet during the post-construction period. It should be noted that the maximum bed elevation extent may be based on a survey from any year within the time period, and not necessarily the last year of the time period. For example, the maximum extent of the channel bed for the pre-construction period occurred prior to 2003 (solid red line), indicating scour had actually occurred prior to diversion construction. This illustrates the dynamic nature of the river system in this area and underscores the necessity to consider long-term trends in the interpretation of results. In general, the plot indicates the maximum extent of channel bed elevation has not increased by a disproportionate amount since the construction of the diversion.

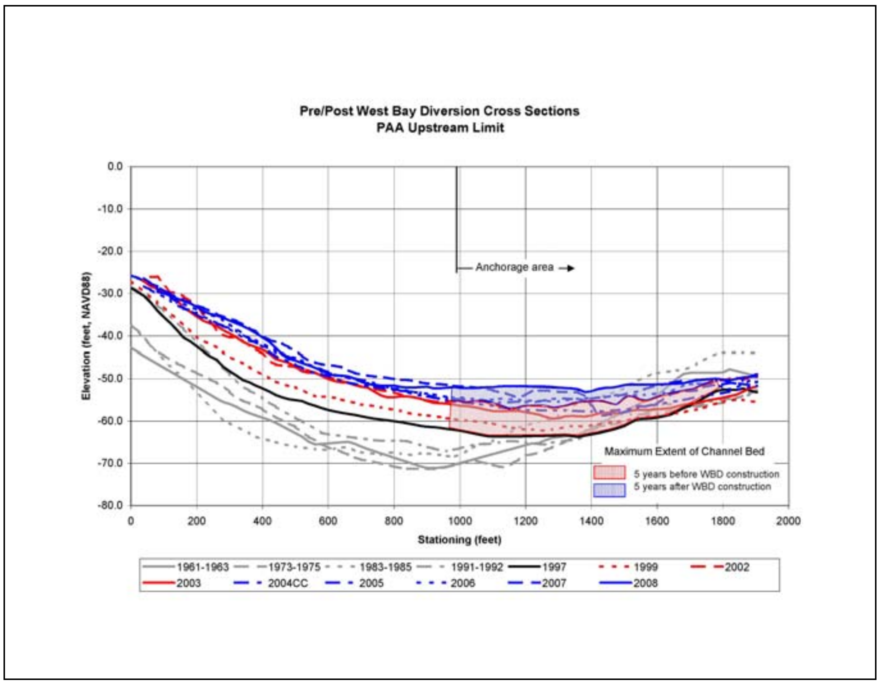


Figure 3.34. Maximum extent of channel bed elevation before and after West Bay diversion construction at upstream limit of anchorage area.

The plot for the cross section located at RM 5.8 AHP is shown in Figure 3.35. The plot indicates that the increase in the extent of maximum channel bed elevation is generally the same for pre- and post-construction periods. However, the curve for the 1997 survey (solid black line) indicates that the channel bed in the anchorage area was actually higher in 1997 than at any other time during the 5 year pre-construction period. This cross section is located where the river channel is crossing from the right descending bank to the left descending bank, and the resulting survey, which may result in varying bed locations. Also, it should be noted that no surveys for 2000 and 2001 are plotted due to missing data.

Figure 3.36 shows the plot for the cross section located at the West Bay diversion. Note that the extent of maximum channel bed elevation does not change disproportionally from the pre- to post-construction period. An interesting observation here is that the curve for the 1960s comprehensive survey indicates the point bar within the anchorage area was at a similar elevation then as for current conditions.

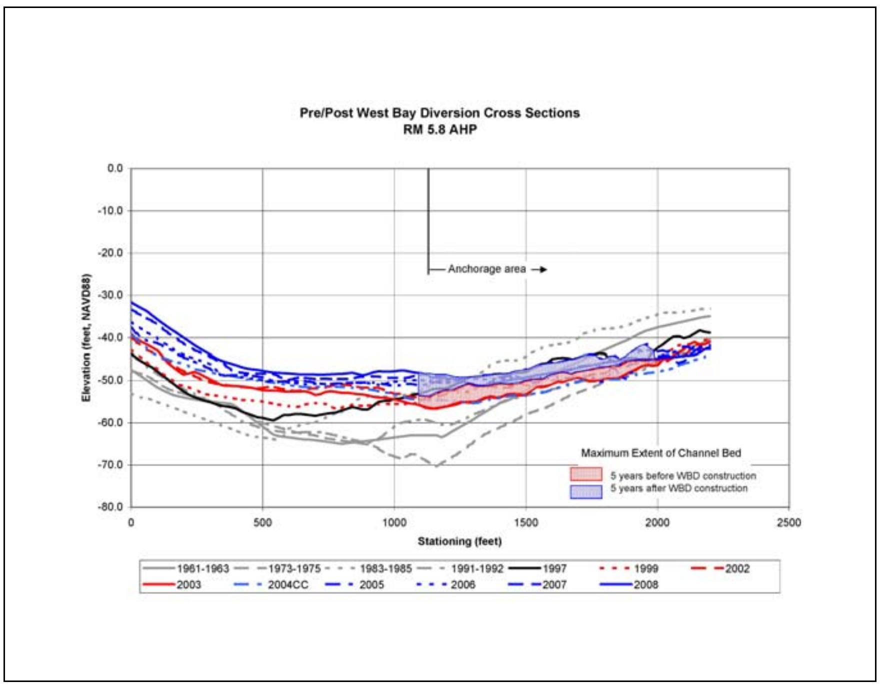


Figure 3.35. Maximum extent of channel bed elevation before and after West Bay diversion construction at RM 5.8 AHP.

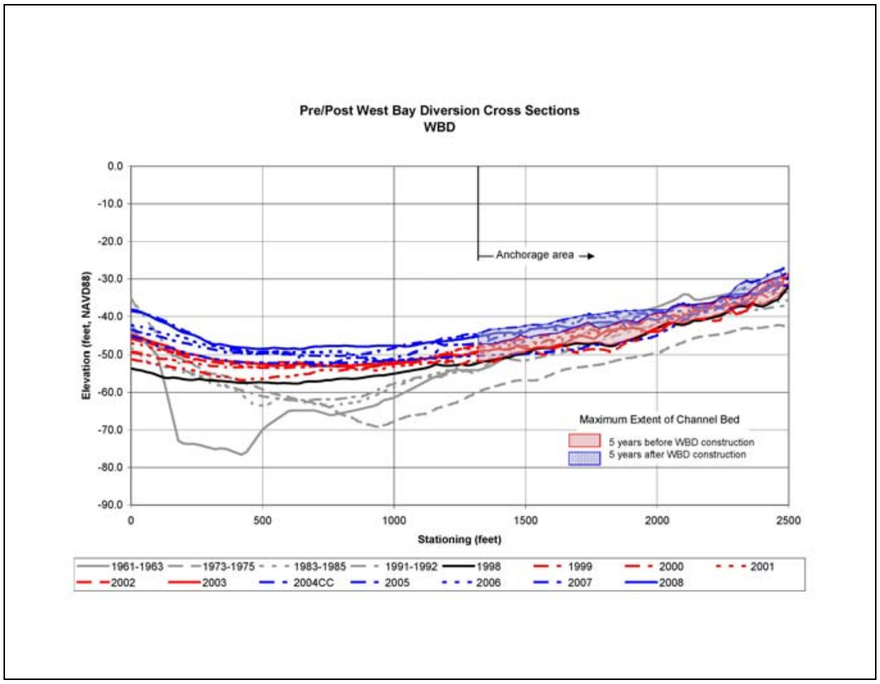


Figure 3.36. Maximum extent of channel bed elevation before and after West Bay diversion construction at West Bay diversion.

The plot of maximum extent of channel bed for the cross section located at RM 4.0 AHP is shown in Figure 3.37. The plot indicates that range of channel bed extent for the pre- and post-construction period is similar for the anchorage area adjacent to the channel, but increases in difference the farther toward the right descending bank.

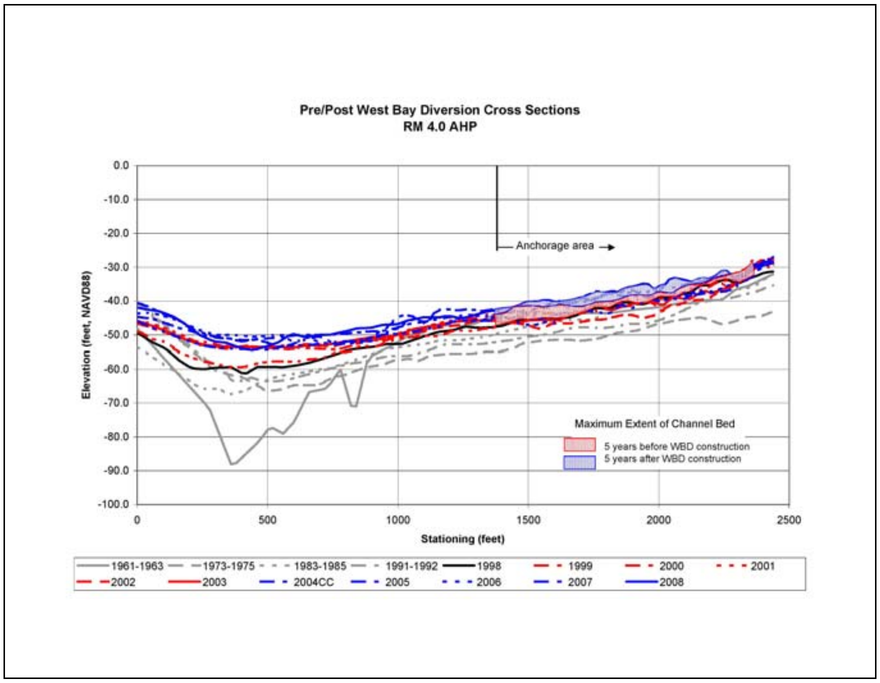


Figure 3.37. Maximum extent of channel bed elevation before and after West Bay diversion construction at RM 4.0 AHP.

The plot for the cross section located at Cubits Gap shown in Figure 3.38 illustrates some interesting aspects of the dynamic degree of channel bed fluctuation that can occur in the study area. The plot indicates that the maximum extent of channel bed elevation for the anchorage area adjacent to the navigation channel for the pre-construction period was almost that of the post-construction period. The degree of fluctuation appears more for the post-construction period in the portion of the anchorage area toward the right descending bank. It appears that the point bar in the anchorage area adjacent to the navigation channel had significantly developed at some point prior to the diversion construction, as high as elevation -33 feet NAVD88. What is remarkable is that the point bar has rapidly redeveloped after each of the anchorage area dredging events in 2003 and 2006. The changes in this area since the 2006 dredge event are extreme, perhaps as a result of the 2008 flood. Regardless, the surveys indicate that the river tends to rapidly reestablish the point bar in this area after a dredging event, rendering the effects of the dredging very short lived.

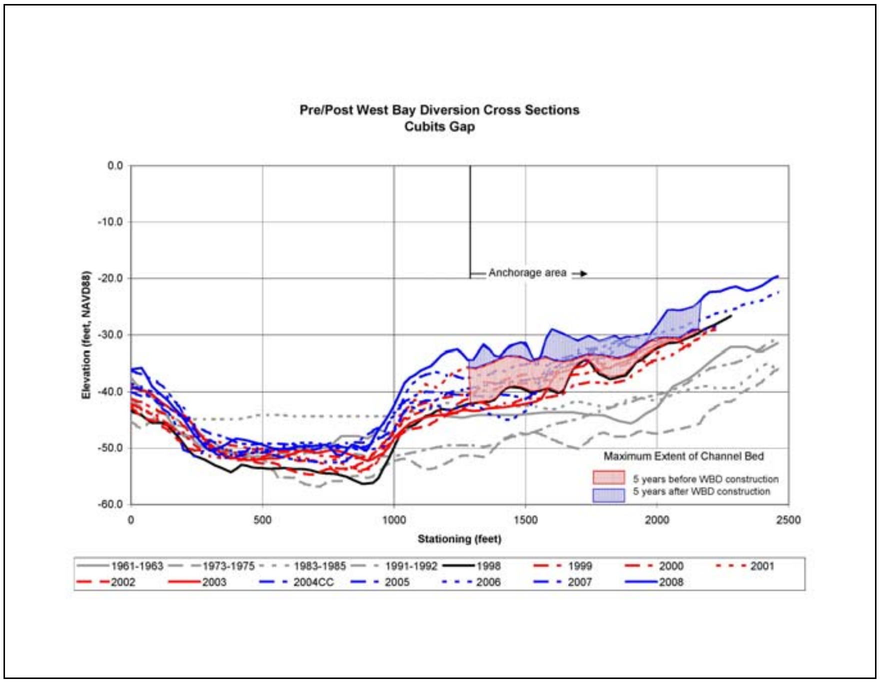


Figure 3.38. Maximum extent of channel bed elevation before and after West Bay diversion construction at Cubit's Gap.

The plots of maximum extent of channel bed for the cross sections located at RM 2.5 AHP and the downstream limit of the anchorage area are shown in Figures 3.39 and 3.40, respectively. For the section at RM 2.5 AHP, the maximum extent of the channel bed within the anchorage area adjacent to the navigation channel for the post-construction period essentially the same or slightly more than the pre-construction period, but increases for the portion of the anchorage area nearer to the right bank. For the section at the downstream limit of the anchorage area there appears to be very little increase in the extent of maximum channel bed for the post-construction period compared to the pre-construction period. This suggests that potential impacts of the diversion construction on shoaling conditions in the lower end of the anchorage area are minimal.

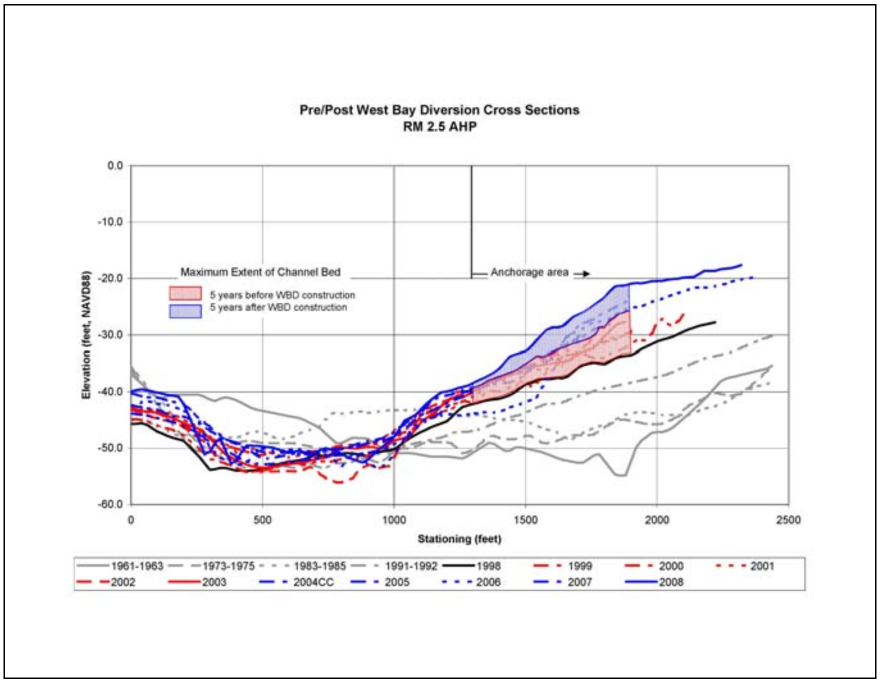


Figure 3.39. Maximum extent of channel bed elevation before and after West Bay diversion construction at RM 2.5 AHP.

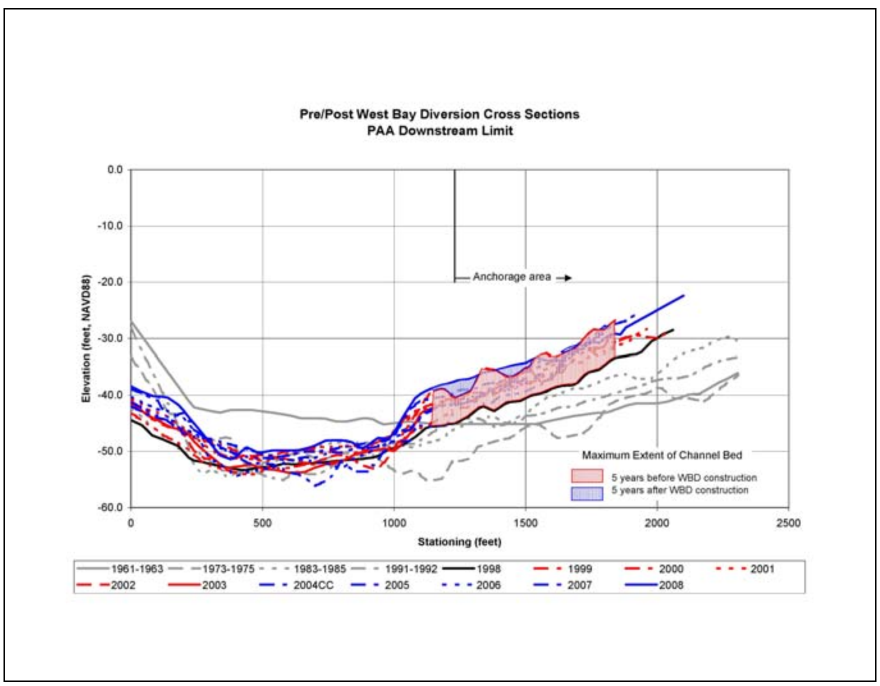


Figure 3.40. Maximum extent of channel bed elevation before and after West Bay diversion construction at downstream limit of anchorage area.

The intent of this analysis was to determine the extent of the maximum channel bed elevation in the anchorage area that was achieved during the 5 year periods before and after construction of the diversion. Variability in the surveys for these time periods yields results that are somewhat inconclusive. The primary conclusion from this analysis is that the maximum channel bed elevation in the anchorage area downstream of Cubits Gap for the pre- and post-construction time periods is very similar.

Volumetric Analysis

The cross section analysis of the preceding section was based on survey data extracted along a single cross section line, and the data are assumed to be representative of the average channel bed conditions within that local area. However, irregularities and undulations certainly exist in the channel bed, and cross section data may sometimes be influenced by these irregularities and not be completely representative of the average channel bed in the area. For instance, cross section data in an area where large sand waves or dunes have been formed by a recent flood event may reflect the crest of a sand wave or the trough of the wave. Analysis of survey data over a larger area will tend to average out these irregularities and will be perhaps more representative of the average channel bed from a spatial perspective.

The study area was divided into reaches for the volumetric analysis. These reaches range in length from as much as 15 miles in the upstream study area to less than 1 mile in the anchorage area. The reaches upstream and downstream of the anchorage area were constructed with the GIS system and were arranged to cover the channel area roughly within the -20 foot contours. Reaches within the limits of the anchorage area were constructed in parallel segments, with one segment covering the navigation channel portion and a parallel segment covering the anchorage area. The anchorage area segment covers a width of approximately 500 feet westward of the anchorage area line. The reach descriptions and limits are presented in Table 3.1 and the locations are shown in Figures 3.41 through 3.43.

Table 3.1. Limits and description of reaches for volumetric analysis.

Reach Name	RM Limits	Description
Reach1	75.0-64.0 AHP	Belle Chasse to near Alliance
Reach2	64.0-48.5 AHP	Near Alliance to West Point a la Hache
Reach3	48.5-38.0 AHP	West Point a la Hache to Port Sulphur
Reach4	38.0-28.0 AHP	Port Sulphur to Sunrise
Reach5	28.0-15.0 AHP	Sunrise to Duvic
Reach6	15.0-10.3 AHP	Duvic to Grand Pass
Reach7	10.3-6.7 AHP	Grand Pass to U/S Limit PAA
Reach8	6.7-4.7 AHP	U/S Limit PAA to West Bay Diversion (channel)
PAA1a	6.7-5.8 AHP	U/S Limit PAA to RM 5.8 AHP (anchorage)
PAA1b	5.8 -4.7 AHP	RM 5.8 AHP to West Bay Diversion (anchorage)
Reach9	4.7-3.2 AHP	West Bay Diversion to Cubits Gap (channel)
PAA2a	4.7-4.0 AHP	West Bay Diversion to RM 4.0 AHP (anchorage)
PAA2b	4.0 -3.2 AHP	RM 4.0 AHP to Cubits Gap (anchorage)
Reach10	3.2-1.6 AHP	Cubits Gap to D/S Limit PAA (channel)
PAA3a	3.2-2.5 AHP	Cubits Gap to RM 2.5 AHP (anchorage)
PAA 3b	2.5-1.6 AHP	RM 2.5 AHP to D/S Limit PAA (anchorage)
Reach11	1.6-0.0 AHP	D/S Limit PAA to Head Of Passes
Reach12	0.0-5.0 BHP	1st quarter Southwest Pass
Reach13	5.0-10.0 BHP	2nd quarter Southwest Pass
Reach14	10.0-15.0 BHP	3rd quarter Southwest Pass
Reach15	15.0-18.5 BHP	4th quarter Southwest Pass (end at East Jetty)

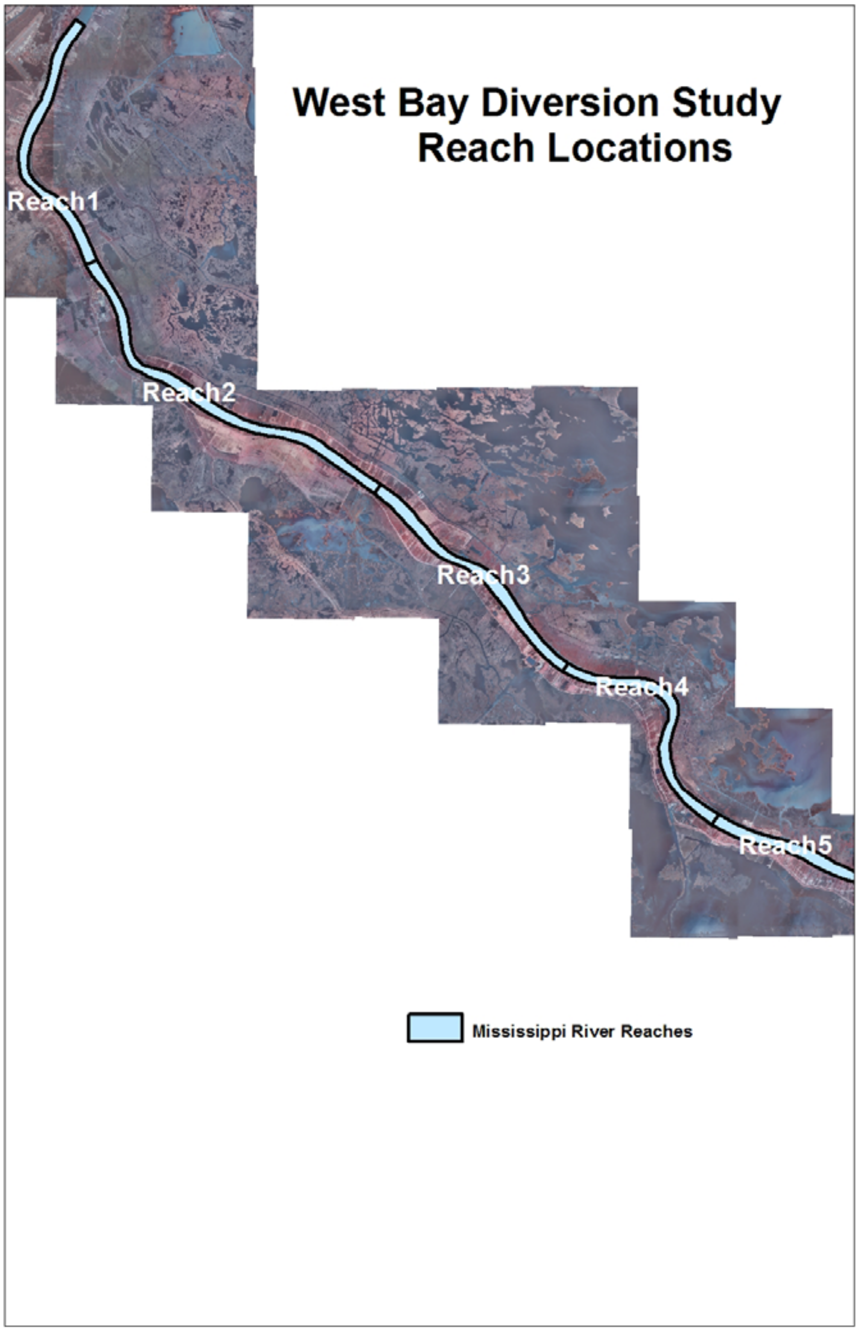


Figure 3.41. Location of Reaches 1-5.

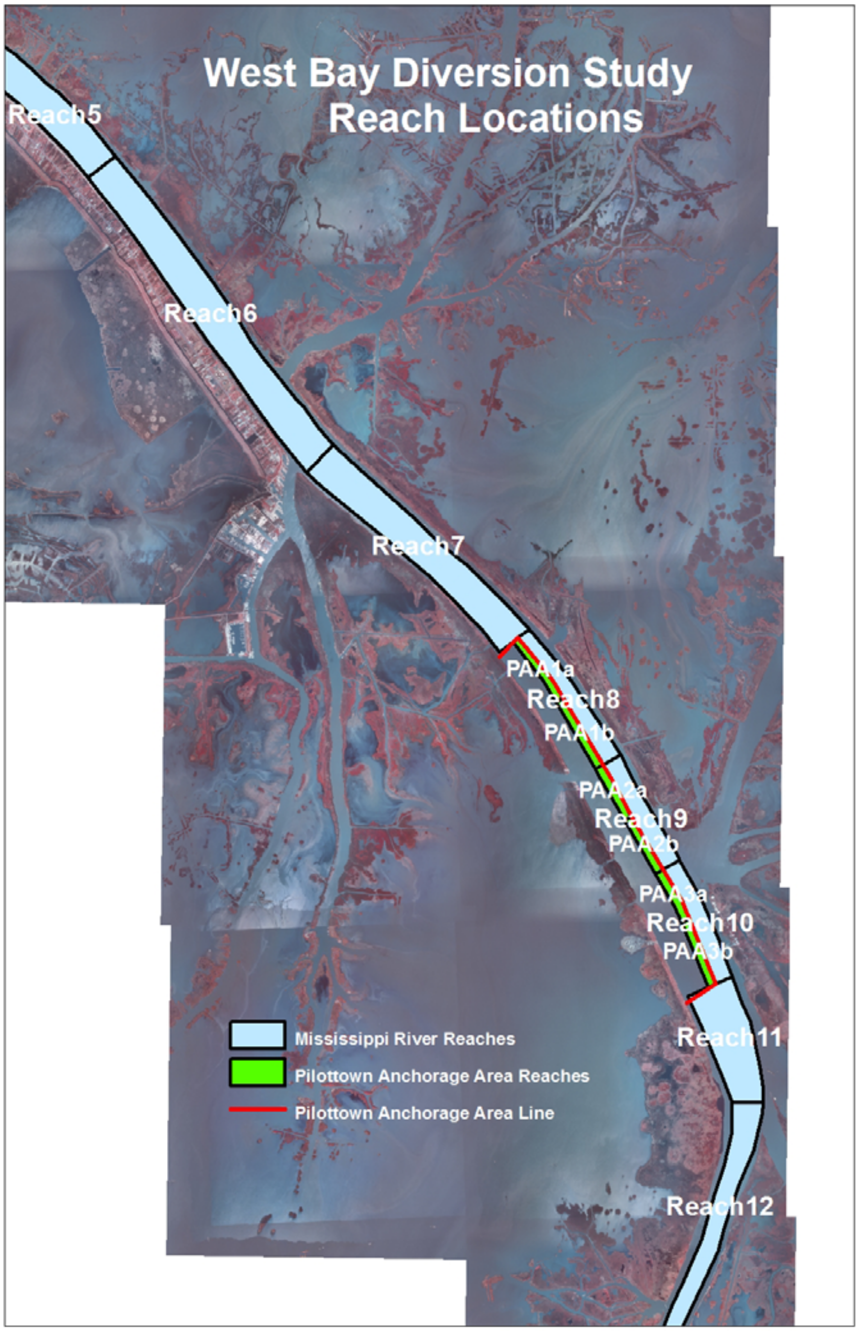


Figure 3.42. Location of Reaches 6-11 and anchorage area reaches.

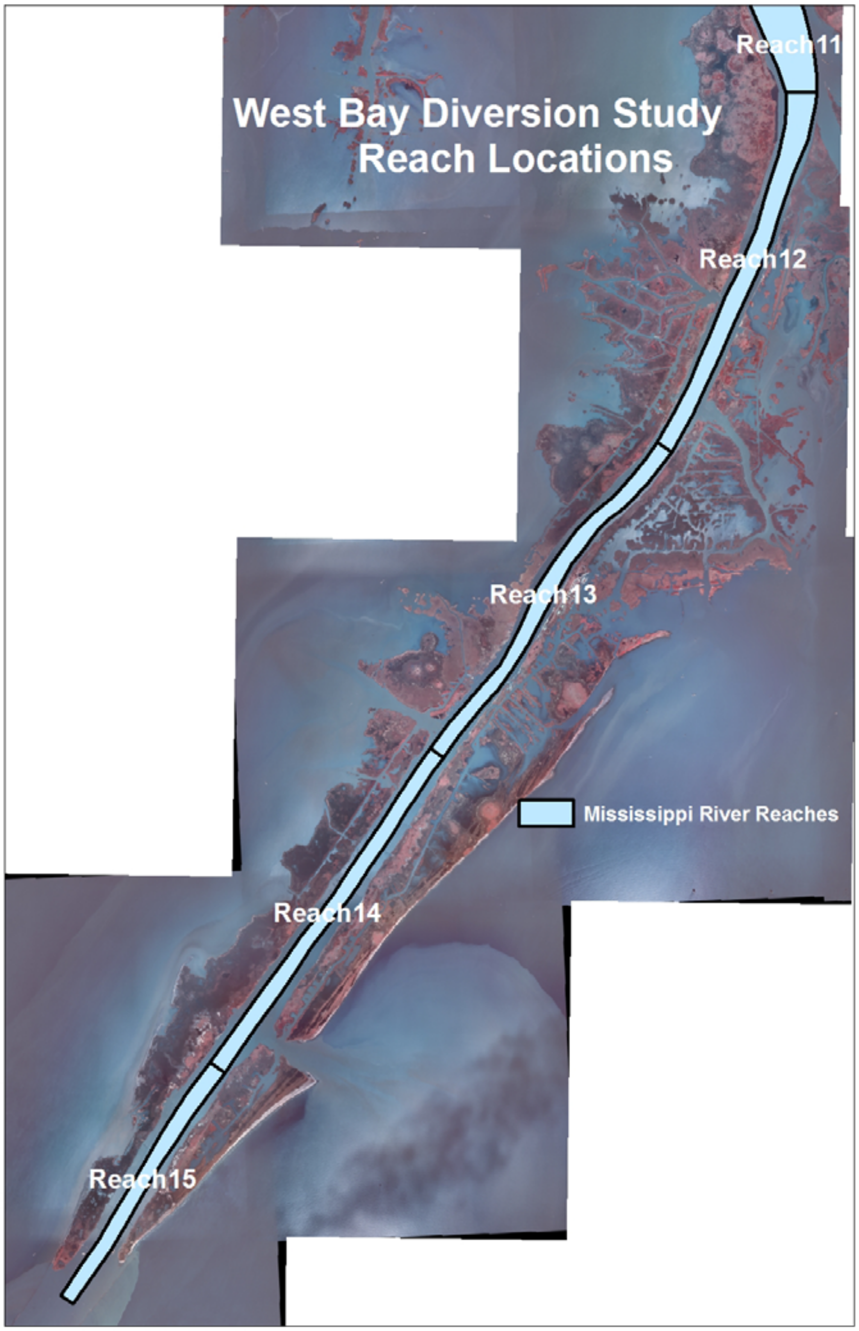


Figure 3.43. Location of Reaches 12-15.

GIS tools were used to calculate the volume from the survey TINs for each reach, and the volumes of successive surveys were subtracted from each other to determine volumetric changes from survey to survey. The volumetric change for each reach was converted to an average bed displacement by dividing the volumetric change by the surface area of the reach. The average bed displacement is proportional to and varies as the volumetric change since the surface area for each reach is a constant. The average channel bed displacements computed from the comprehensive surveys were converted to an annual average channel bed displacement by dividing by the number of years between successive surveys. The annual average channel bed displacements were then plotted to determine the trend of average channel bed change for the reach. The annual bed displacement plots are shown in Plates XX-XX of Appendix K. The plots for Reaches 1 through 7 are based solely on the comprehensive hydrographic surveys because coverage for channel condition surveys did not extend that far upstream. The plots for Reaches 11 through 15 and the anchorage area Reaches PAA1a through PAA3b are based on the yearly channel condition surveys. The plots for Reaches 8 through 10 are based on both surveys.

For Reaches 1 through 6, the reaches located upstream of Venice, the yearly average bed displacement between surveys ranges from 0 to almost 0.5 feet. In general, there is no discernable trend or pattern, with negative (scour) and positive (deposition) displacements occurring randomly between survey periods. The one except is Reach 3, which showed a consistent negative bed displacement from survey to survey. The annual average bed displacement plot for Reach 5 (RM 28.0-15.0 AHP) is shown in Figure 3.44 as an example for these reaches.

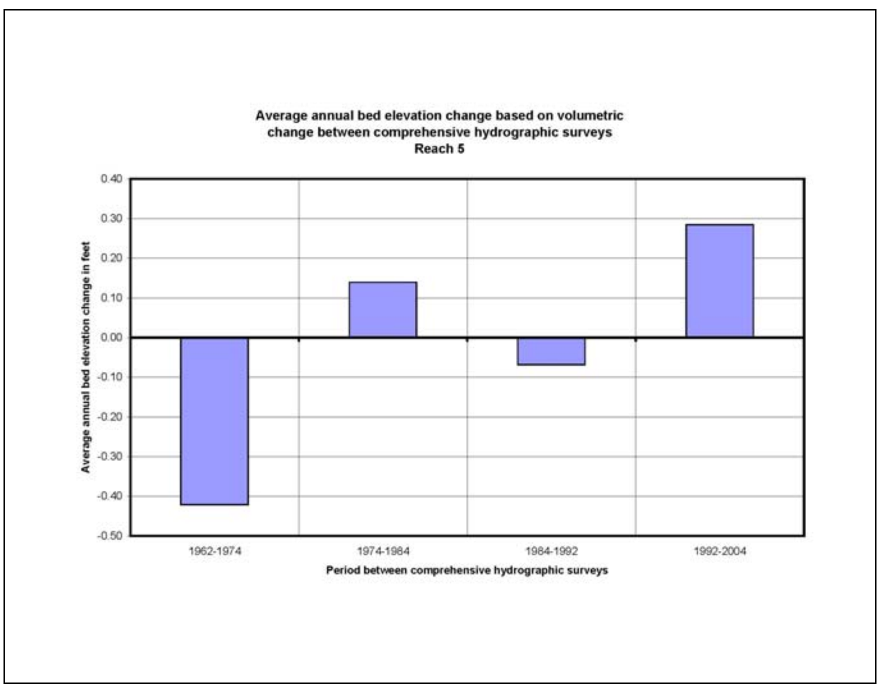


Figure 3.44. Annual average channel bed displacement between comprehensive survey periods for Reach 5.

For Reaches 7 through 9, the reaches from Venice to Cubits Gap, the annual average channel bed displacement indicates a fairly consistent pattern of positive displacement (deposition) between survey periods. This is consistent with the trend observed in the cross section analysis for this area. The plots for Reaches 7 through 9 are shown in Figures 3.45 through 3.47, respectively. At Reach 7, a negative annual displacement occurred annually for the period between the 1960s and 1970s comprehensive surveys, but a positive annual displacement was observed for all successive survey periods. For Reaches 8 and 9, positive annual displacement of the average channel bed occurred for all survey periods, although the displacement for Reach 8 during the 1960s to 1970s survey period was essentially zero. These plots indicate a trend of channel deposition within these reaches. For Reaches 8 and 9 the annual average bed displacement rate for the period between the 1990s and 2000s surveys is several times greater than other survey periods.

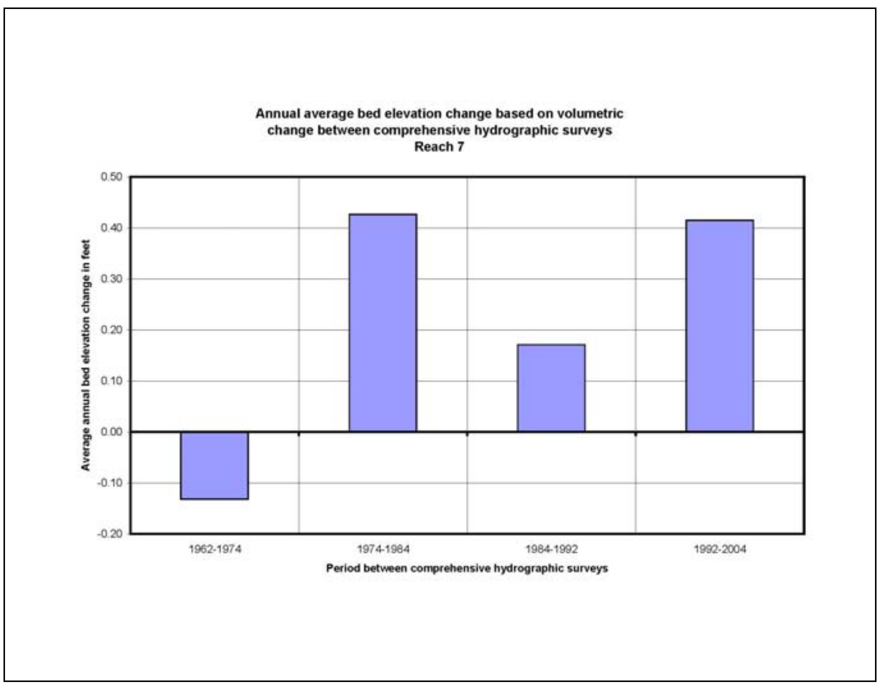


Figure 3.45. Annual average channel bed displacement between comprehensive survey periods for Reach 7.

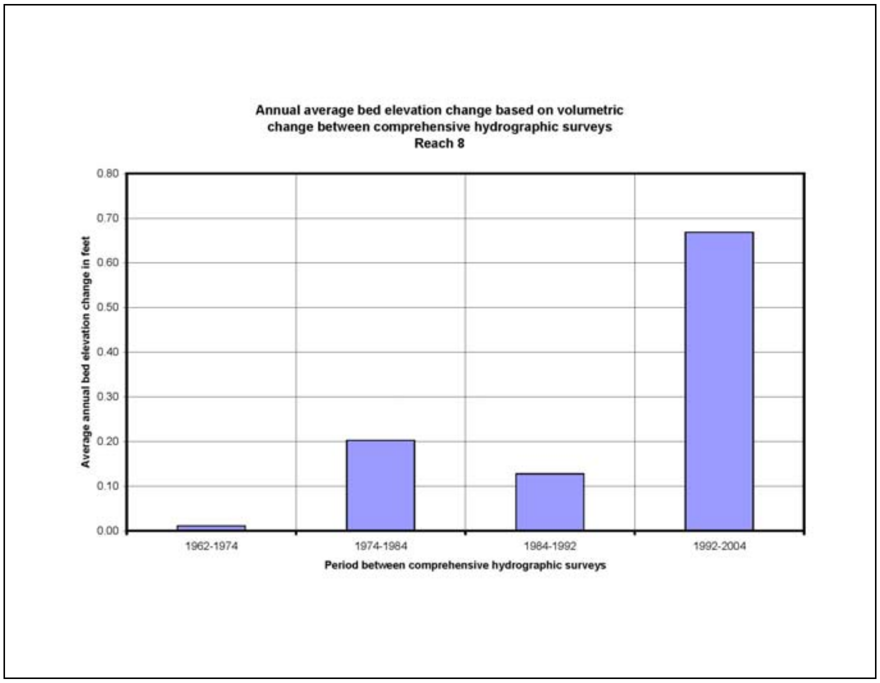


Figure 3.46. Annual average channel bed displacement between comprehensive survey periods for Reach 8.

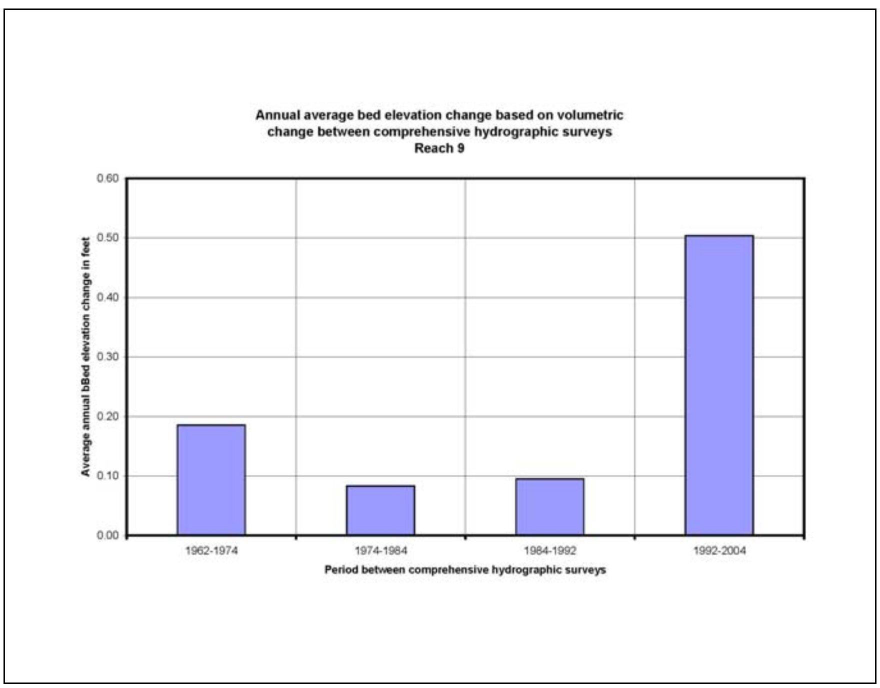


Figure 3.47. Annual average channel bed displacement between comprehensive survey periods for Reach 9.

Channel condition survey coverage also existed for Reaches 8 and 9. Yearly average channel bed displacements were computed based on these surveys and are shown in Figures 3.48 and 3.49, respectively. Although some yearly surveys are missing, the general trend in positive displacement (deposition) is similar to the trend observed from the comprehensive surveys.

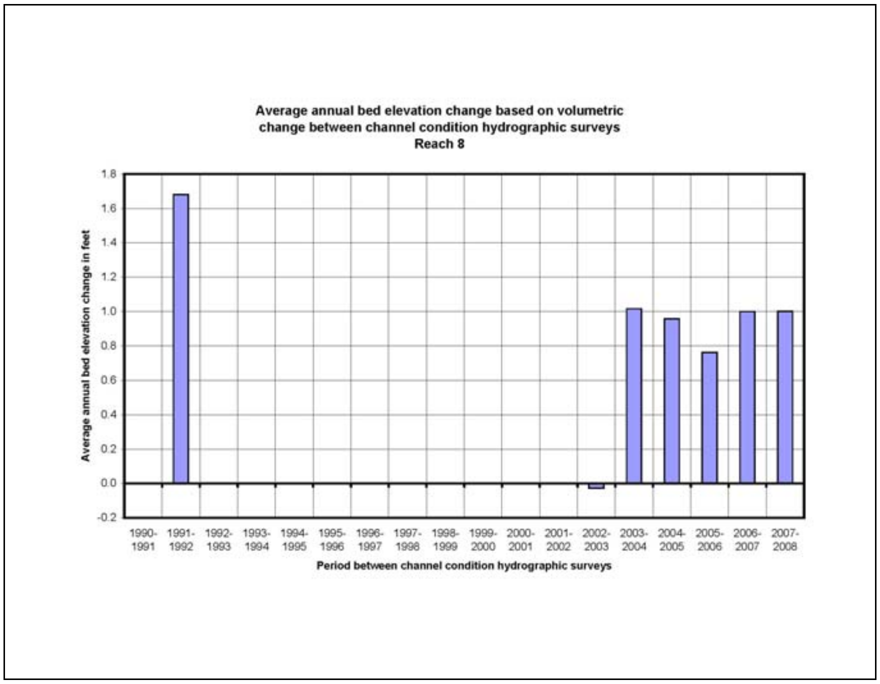


Figure 3.48. Annual average channel bed displacement between channel condition survey periods for Reach 8

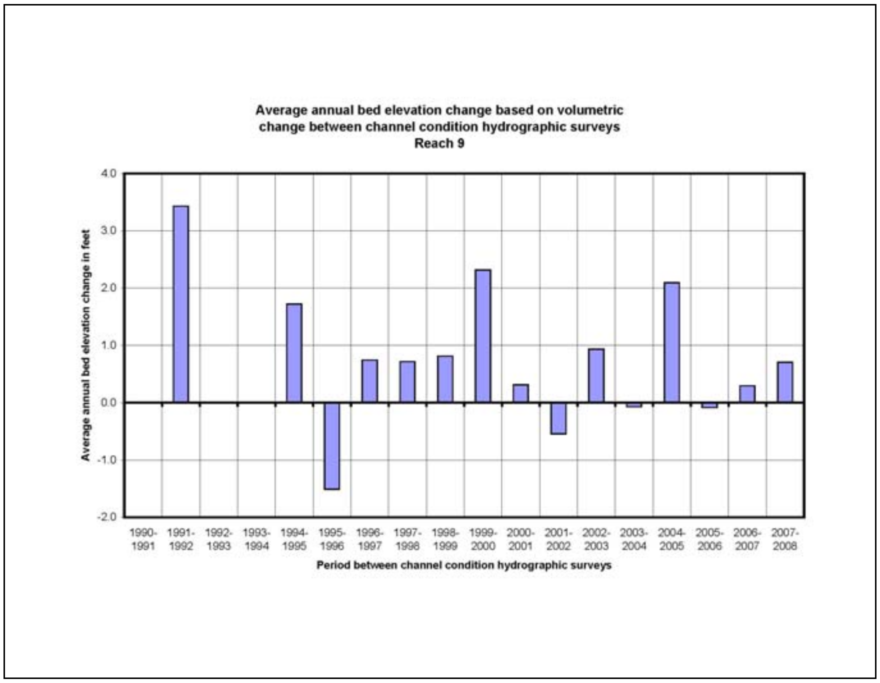


Figure 3.49. Annual average channel bed displacement between channel condition survey periods for Reach 9.

Beginning at Reach 10 and continuing through Southwest Pass to Reach 15, the river channel is dominated by dredging for navigation, and thus the annual average channel bed displacement data display a more random fluctuation between positive and negative displacement. No discernable trends can be identified for these reaches. The plot for Reach 12 in Southwest Pass is shown in Figure 3.50 to illustrate the random displacement values resulting from regular maintenance dredging.

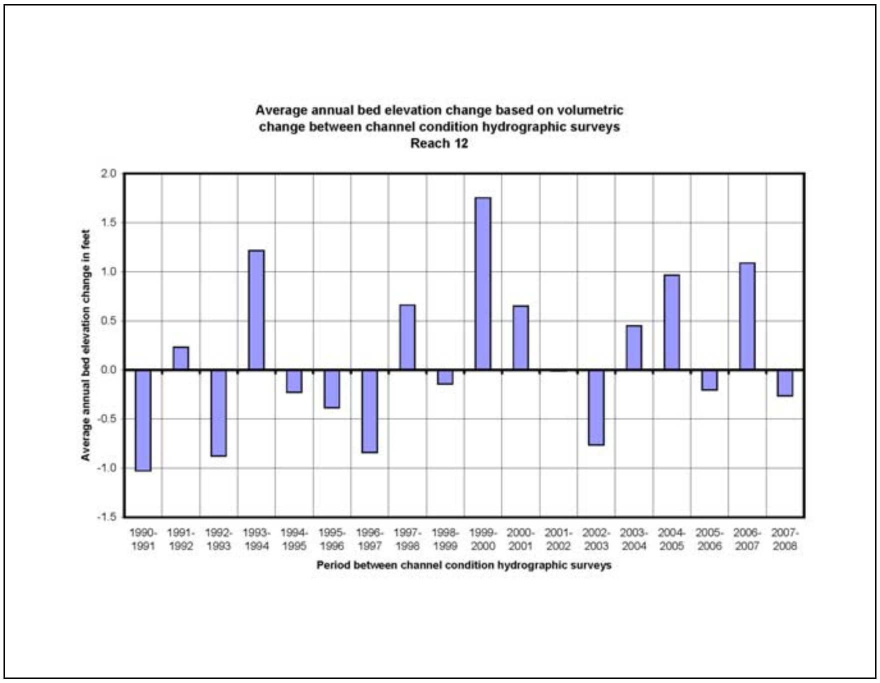


Figure 3.50. Annual average channel bed displacement between channel condition survey periods for Reach 12

The average channel bed displacements for the reaches upstream of Cubits Gap were summed to determine the cumulative bed displacement between the 1960s survey and the 2000s survey. Only reaches above Cubits Gap are presented since these reaches are not modified by navigation dredging.

Table 3.2. Cumulative average channel bed displacement over 1960s to 2000s comprehensive survey period for Reaches 1 through 9.

Reach	Average channel bed displacement (ft)
Reach 1	-2.8
Reach 2*	-4.1
Reach 3*	-4.3
Reach 4	0.6
Reach 5	-0.8
Reach 6	-3.4
Reach 7	9.0
Reach 8	11.2
Reach 9	9.9

* 2003-2004 survey data missing in these reaches. Cumulative displacement does not include average displacement from 1991-1992 survey to 2003-2004 survey

Note that the trend for the reaches above Venice (Reaches 1-6) is for little change to slight negative bed displacement, whereas for the reaches below Venice the trend is for significant positive bed displacement. This agrees well with the findings from the analysis of cross section data within this area.

The reaches within the Pilottown anchorage area were constructed with a width of approximately 500 feet, which extends from the anchorage area line westward towards the right descending bank. This results in narrower reaches than the other reaches of the analysis. The reasons for this are the 500 width nearest the anchorage area line is representative of the area of the anchorage area that requires dredging and is typically utilized by the shipping industry. In addition, channel condition surveys rarely extend to the waters edge, and a 500 foot width ensures that full survey coverage is available for each reach. A detailed map of the anchorage area reaches is shown in Figure 3.51.

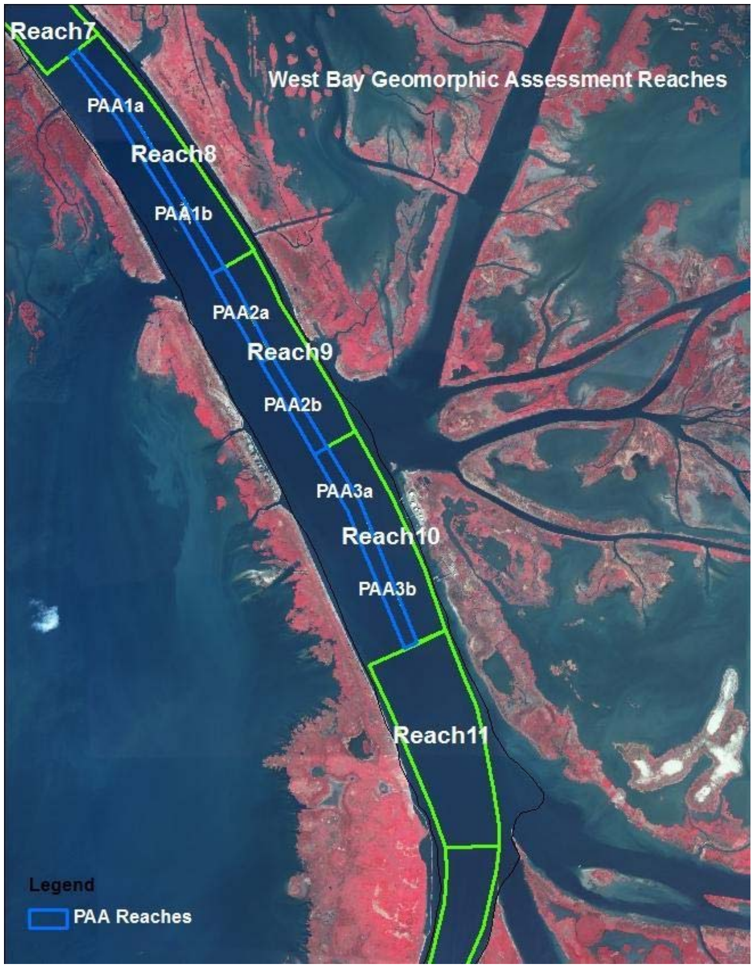


Figure 3.51. Location of Pilottown anchorage area reaches.

The volumetric change between comprehensive survey periods was computed for each anchorage area reach (PAA reach) and was converted to an average channel bed displacement by dividing the volume by the surface area of each reach. The displacements were converted to an annual displacement by dividing by the number of years between each survey. These annual average bed displacements for the PAA reaches are shown in Figure 3.52.

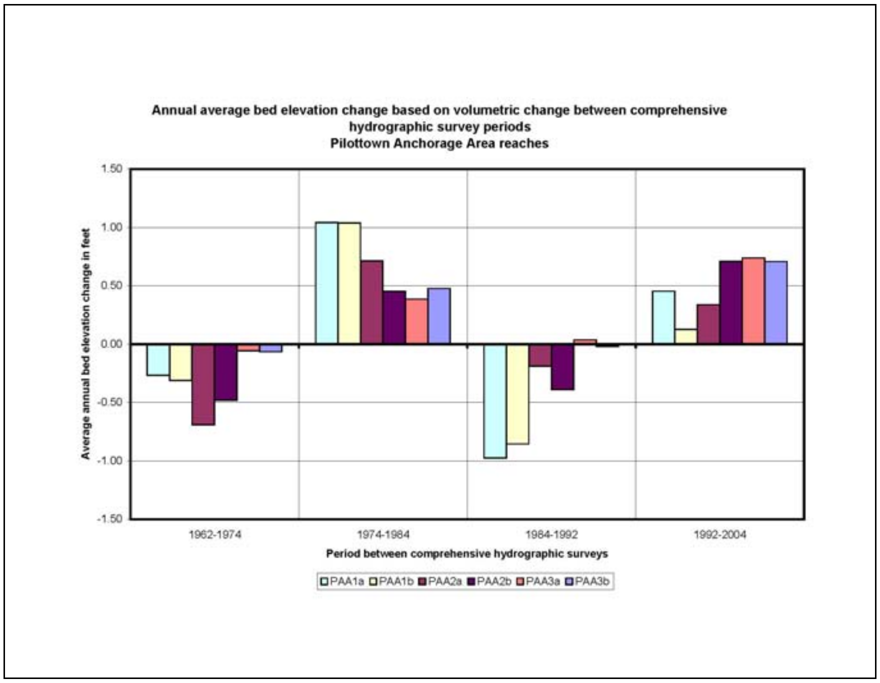


Figure 3.52. Annual average channel bed displacement based on comprehensive hydrographic surveys for the Pilottown anchorage area reaches.

It is difficult from these results to discern any definitive trends in average channel bed displacement for the PAA reaches. For the 1960s through 1970s and 1980s through 1990s survey periods, the trend for Reaches PAA1a through PAA2b was negative displacement, but was basically no change for Reaches PAA3a and PAA3b. Also, the overall trend for Reaches PAA3a and PAA3b, the most downstream reaches, indicates from little change to positive displacement for all survey periods. No other discernable trends can be detected.

The average channel bed displacements for each reach were summed to determine the cumulative displacement over the entire period of comprehensive surveys. The results are presented in Table 3.3. The results indicate that the overall trend was been for positive (deposition) displacement over the entire survey period. In addition, there appears to be a spatial trend as well, as the displacements for Reaches PAA3a and PAA3b (reaches downstream of Cubits Gap) are much greater than the other reaches.

Table 3.3. Cumulative average channel bed displacement over 1960s to 2000s comprehensive survey period for PAA reaches.

Reach	Average channel bed displacement (ft)
PAA1a	4.9
PAA1b	1.3
PAA2a	1.4
PAA2b	4.2
PAA3a	12.3
PAA3b	12.3

The average channel bed displacements determined from the channel condition surveys for the periods before and after construction of West Bay diversion are shown in Figures 3.53 and 3.54, respectively. For the pre-construction time period shown in Figure 3.53, no real trends can be determined. Similar to the results from the comprehensive surveys, the trend for Reaches PAA3a and PAA3b is from little change to positive bed displacement. For the post-construction time period shown in Figure 3.54, the data for the years 2002-2003 and 2005-2006 seem to indicate the anchorage area dredging events that occurred in 2003 and 2006. For the other yearly periods, the results are variable but tend to indicate a general trend in positive average channel bed displacement.

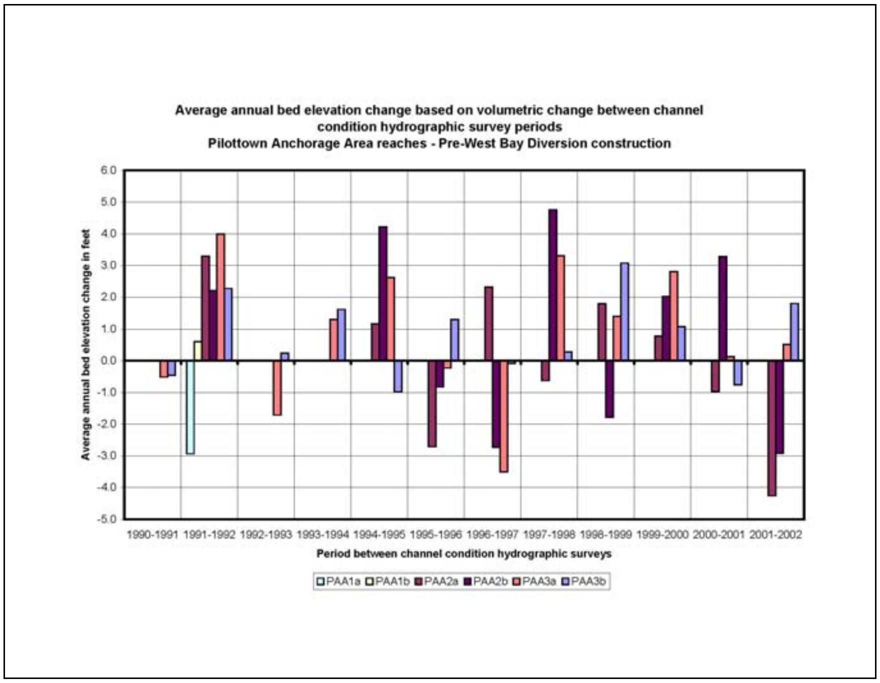


Figure 3.53. Average channel bed displacement based on pre-construction channel condition surveys for Pilottown anchorage area reaches.

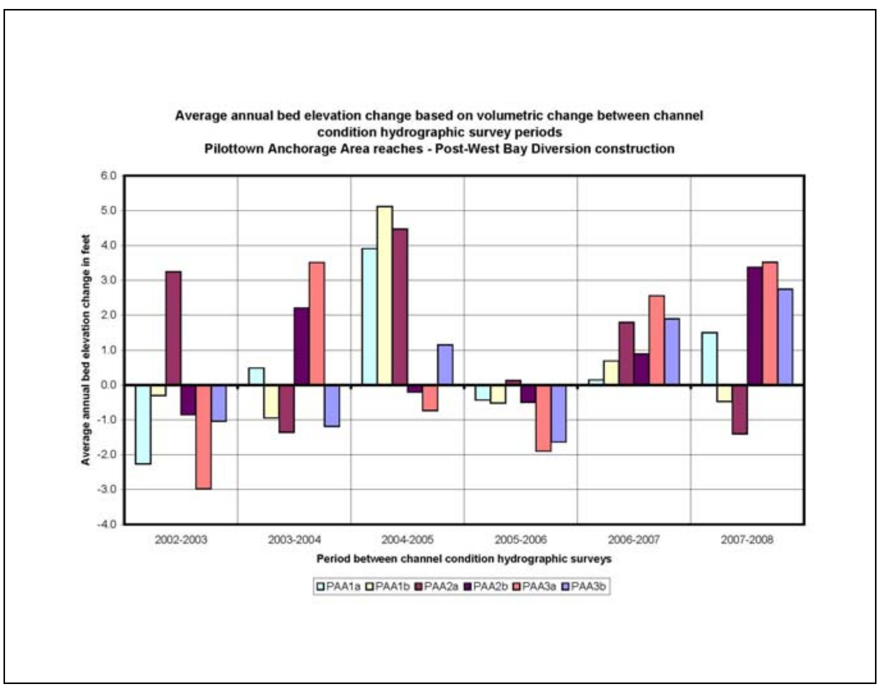


Figure 3.54. Average channel bed displacement based on post-construction channel condition surveys for Pilottown anchorage area reaches.

As mentioned in the above discussion of the volumetric analysis, the volumes determined from each survey period were converted to an average channel bed elevation by dividing the volume by the surface area of each reach. These elevations represent the average channel bed surface over the entire reach area. Average channel bed elevations were determined from the comprehensive surveys and the channel condition surveys, and are presented in Figures 3.55 and 3.56.

The plots of the average channel bed elevations for the comprehensive surveys shown in Figure 3.55 indicate some fluctuation from survey period to survey period, but display an overall general increase in channel bed elevation. Also, the plot illustrates how the average channel bed elevation increases from the upstream to the downstream reaches, indicating that the downstream portion of the anchorage area is significantly shallower than the upstream portion. Similar trends are observed from the plot of the channel condition surveys shown in Figure 3.56. In general, the overall trend has been an increase in average channel bed elevation over time, and a deeper channel in the upstream portion of the anchorage area than in the downstream anchorage area. The curve for Reach PAA2a, the reach immediately downstream of West Bay diversion, does indicate a slight increase in the rate of bed elevation change observed after the construction of the diversion in 2003. A similar increase is noted for Reaches PAA1a and PAA1b in 2005. The plots for Reaches PAA3a and PAA3b indicate no discernable difference in the rate of average bed elevation before and after diversion construction.

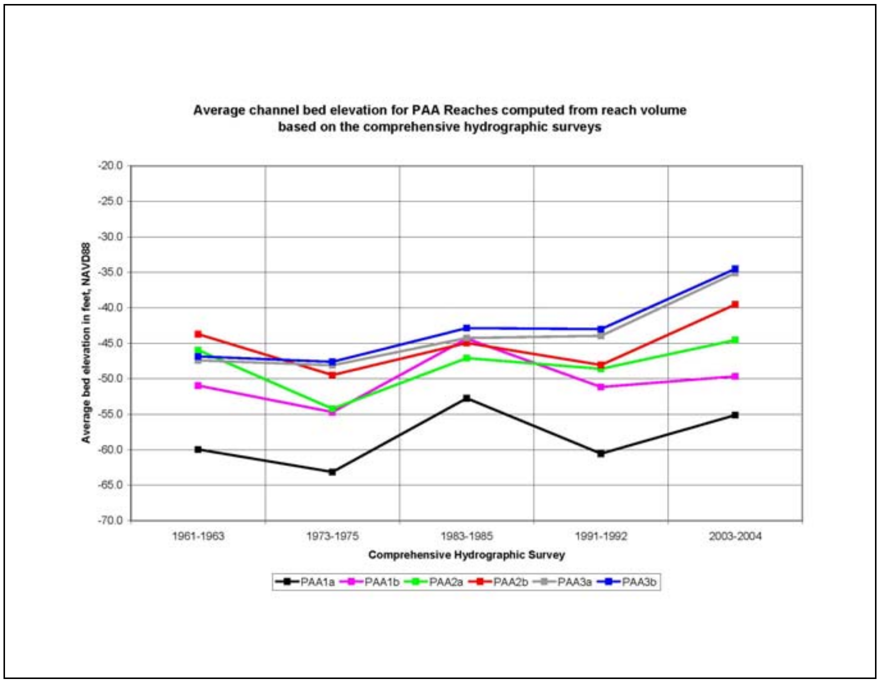


Figure 3.55. Average channel bed elevation computed from volume based on comprehensive surveys for Pilottown anchorage area reaches.

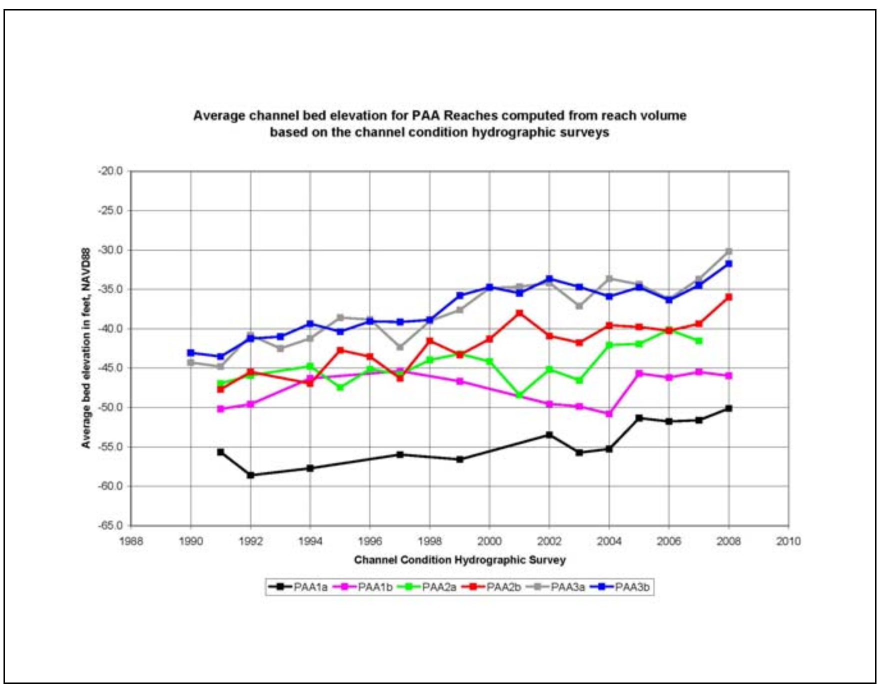


Figure 3.56. Average channel bed elevation computed from volume based on channel condition surveys for Pilottown anchorage area reaches.

In summary, the results of the volumetric analysis indicate that the trend for the reaches upstream of Venice has been from little change to a slight decrease in the average channel bed elevation. A shift in this trend is observed for the reaches downstream of Venice to Cubits Gap, where the trend has been for a significant increase in channel bed elevation. This agrees well with the results from the cross section analysis. For the reaches within the Pilottown anchorage area, the results also indicate a general increase in channel bed elevation over time. The cumulative change in average channel bed elevation determined from the comprehensive surveys is shown to be approximately 3 times greater for reaches in the downstream portion of the anchorage than reaches in the upstream portion. Also, the results indicate that the channel is significant deeper in the upstream portion of the anchorage area than in the downstream portion. A slight increase in the rate of change from the pre- to post-construction periods for Reach PAA2a downstream of the diversion was observed. The rate of change in average channel bed elevation for Reaches PAA3a and PAA3b in the downstream portion of the anchorage area appears unaffected by construction of the diversion.

Channel pattern analysis

The comprehensive survey TINs were contoured and the -45 foot contour tracings were plotted to describe the general location of the river channel within the study area. The channel location tracings were qualitatively analyzed to determine any trends in channel migration over time. The channel location tracings for the comprehensive surveys are shown in Figures 3.57 through 3.59.

The tracings from the comprehensive surveys indicate that the channel location has been very consistent over time, and no major shifts in pattern are noted. This is not surprising, as the channel has been effectively locked in place with revetments. The sinuosity of the Mississippi River in the study area is very minor, and only slight variations in channel location are observed within the top banks. For the reach of the river upstream of Venice, the channel location has been extremely consistent. Channel widths at the -45 foot contour are 80 percent or more of overall top bank widths. Beginning downstream of Venice, a slight alternating point bar pattern can be observed. In addition, the channel downstream of Venice generally appears to be narrower than the channel upstream of Venice. Downstream of Venice, the channel is located along the right descending bank and a point bar is present along the left descending bank. Analysis of cross sections in this area also indicates these features. Channel width at the -45 foot contour is approximately 50 percent of the top bank width at this location. The river channel continues along the right descending bank until a crossing begins in the vicinity near the upstream limit of the anchorage area. The crossing occurs as the channel passes through the upstream portion of the anchorage area, and a point bar begins to develop along the right descending bank. The channel shifts to the left descending bank in the vicinity between West Bay diversion and Cubits Gap, and remains along the left bank until it shifts westward to enter Southwest Pass. Within Southwest Pass the channel location varies little, indicative of the effects of regular navigation dredging in the pass.

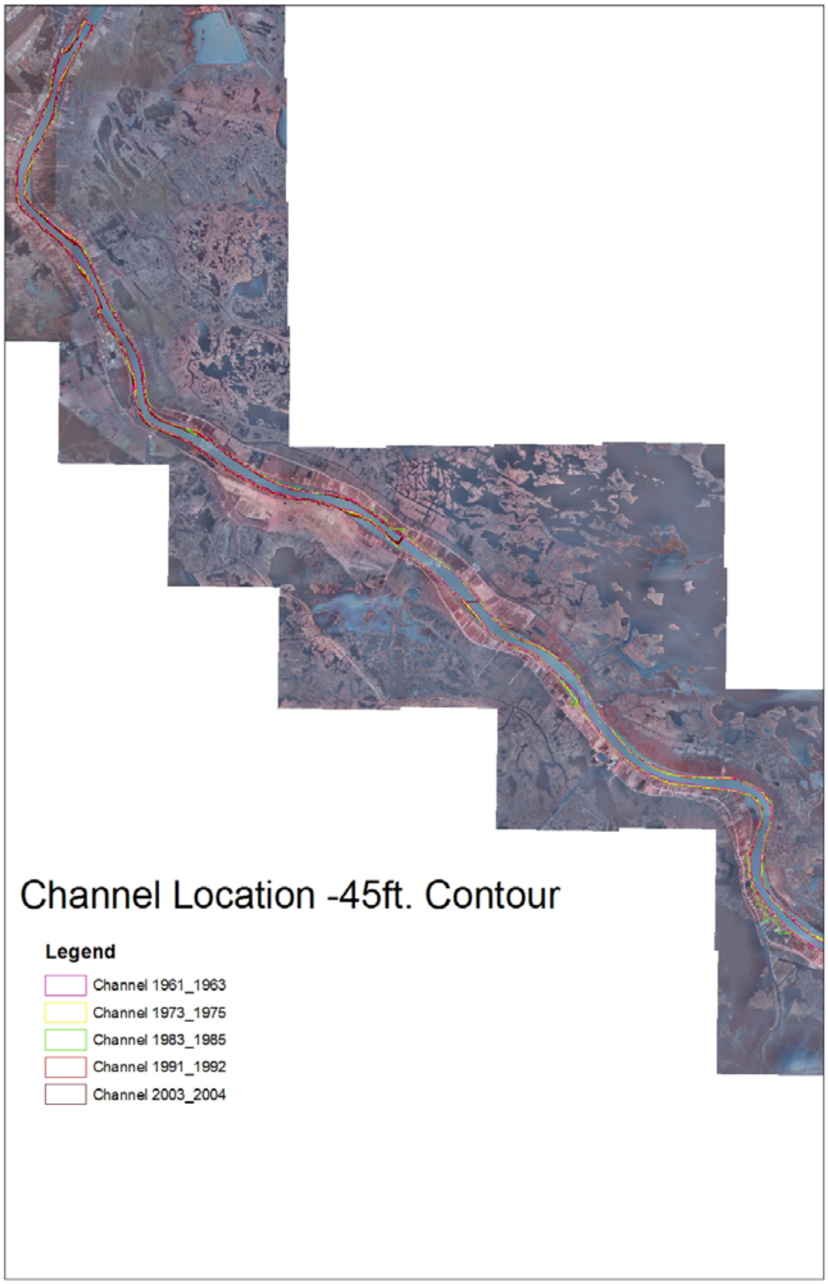


Figure 3.57. Channel location tracings of the -45 ft contour based on the comprehensive surveys from Belle Chase to near Venice.

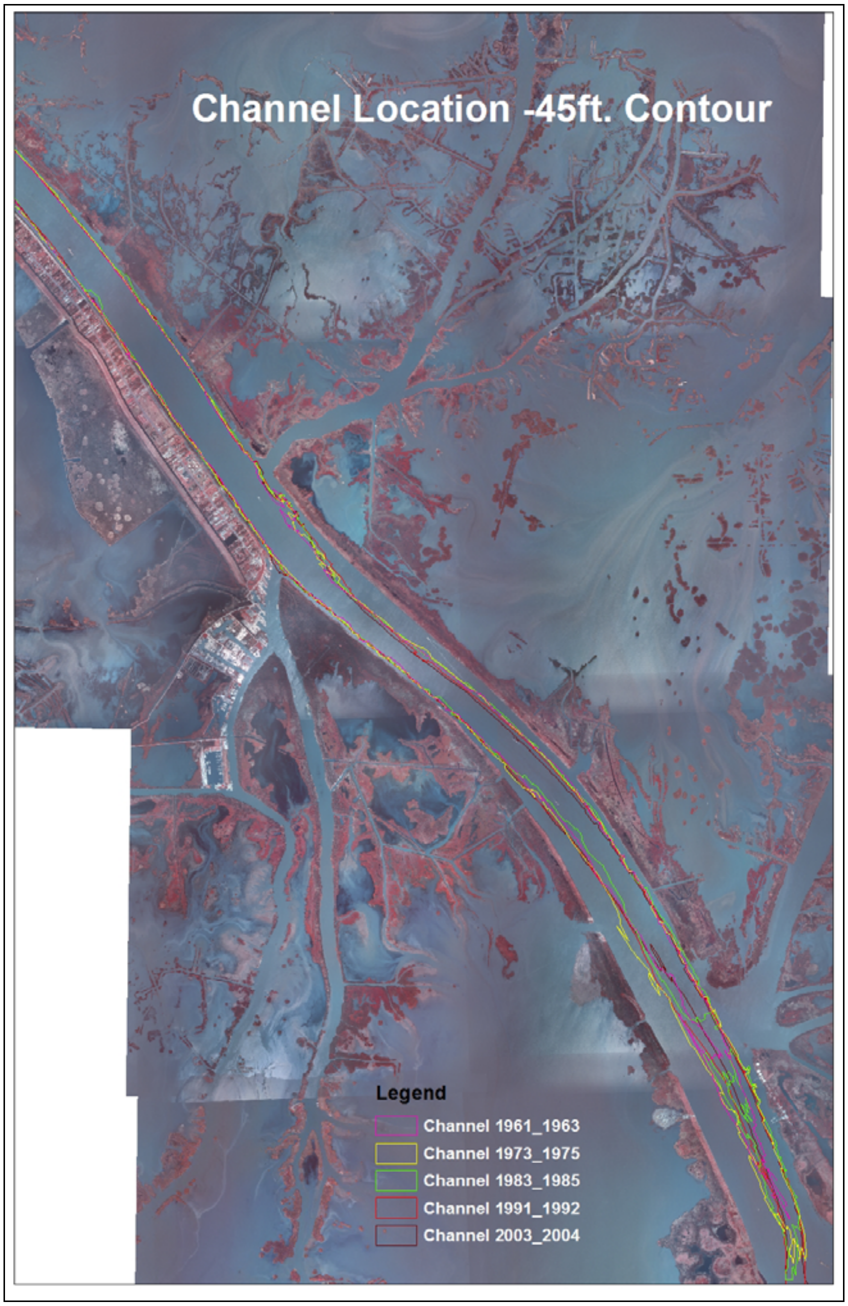


Figure 3.58. Channel location tracings of the -45 foot contour based on the comprehensive surveys from Venice to near Head of Passes.

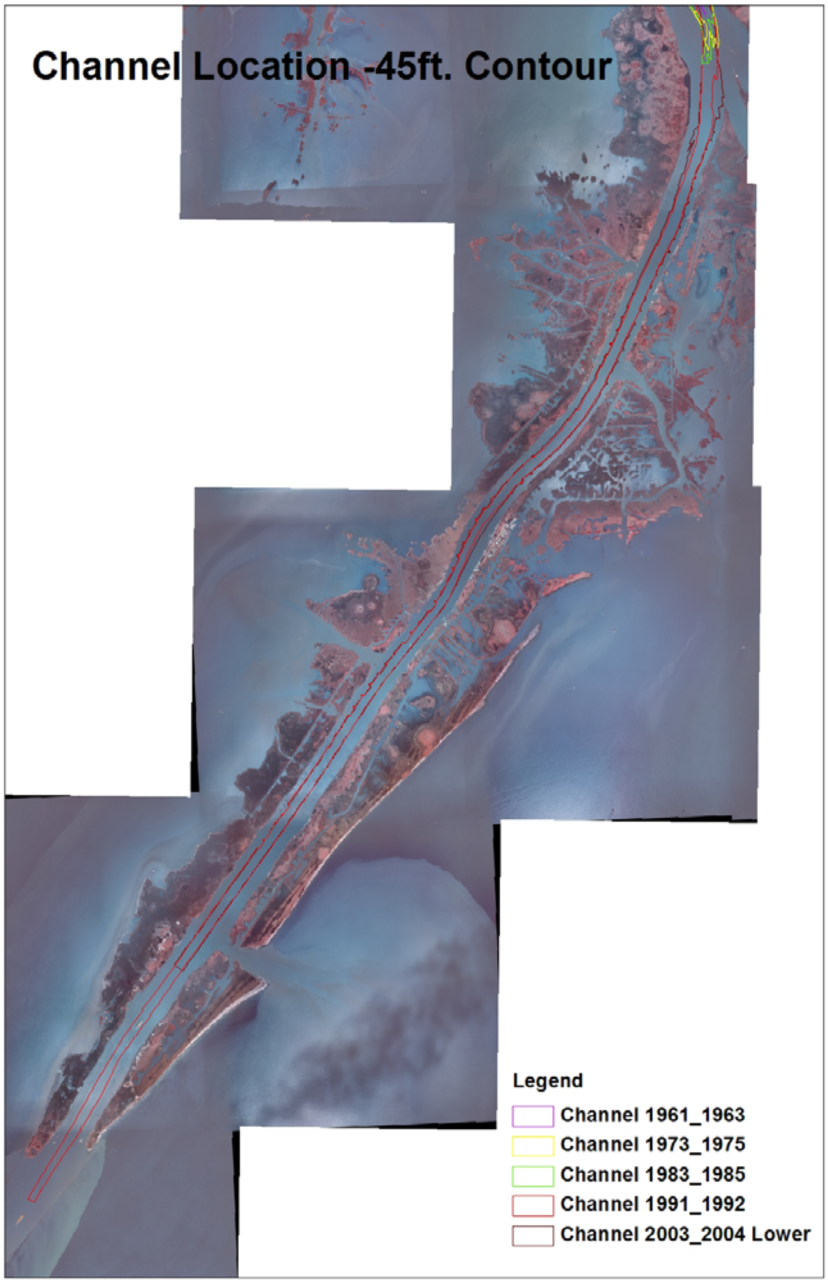


Figure 3.59. Channel location tracings of the -45 ft contour based on the comprehensive surveys from Head of Passes to East Jetty.

Channel location tracings based on the -45 ft contour were also developed from the channel condition surveys. These tracings are limited to the reach of river downstream of Venice. The tracings indicate the alternating point bar sequence downstream of Venice to Head of Passes. It is noteworthy to point out the significant extent of the point bar along the right descending bank that completely encompasses the anchorage area. The point bar pattern extends from approximately RM 5.5-6.0 AHP to near Head of Passes. The channel downstream of Cubits Gap is narrow and fairly consistent in width and location, as would be expected in a reach that is heavily influenced by maintenance dredging. Downstream of Cubits Gap, the channel width is only 25 to 30 percent of the top bank width. Channel tracings upstream of Cubits Gap indicate significant variability in channel width, as much as 500 to 750 feet. In addition, the channel tracing for the 2008 survey indicates that the channel has narrowed from West Bay diversion to Cubits Gap. Closer inspection of the tracings reveals that narrowing has occurred since the construction of the diversion. Since this is not an effect of maintenance dredging in the area, the narrowing is most likely attendant to the development of the anchorage area point bar and may be influenced by the diversion. The plot of the channel location tracings from the channel condition surveys are shown in Figures 3.60 and 3.61.

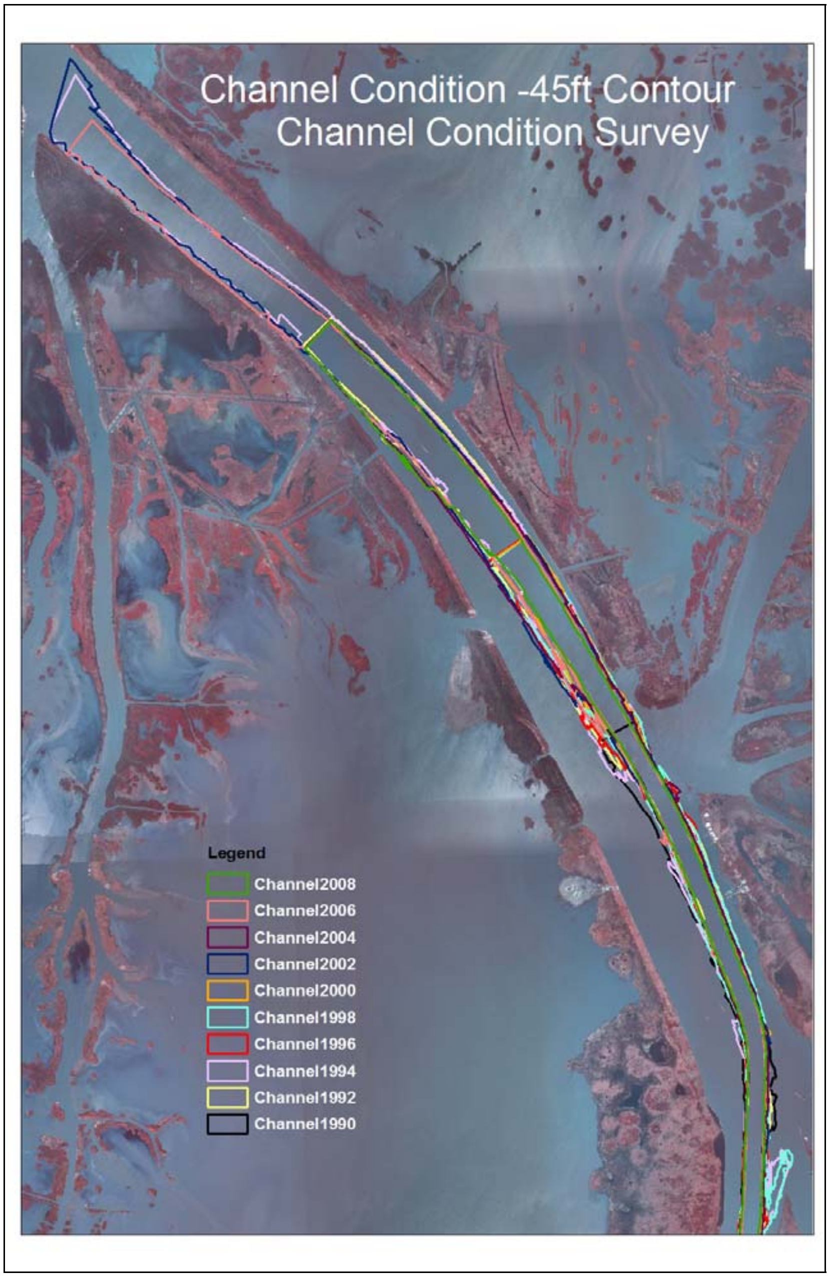


Figure 3.60. Channel location tracings of the -45 foot contour based on the channel condition surveys from Venice to Head of Passes.

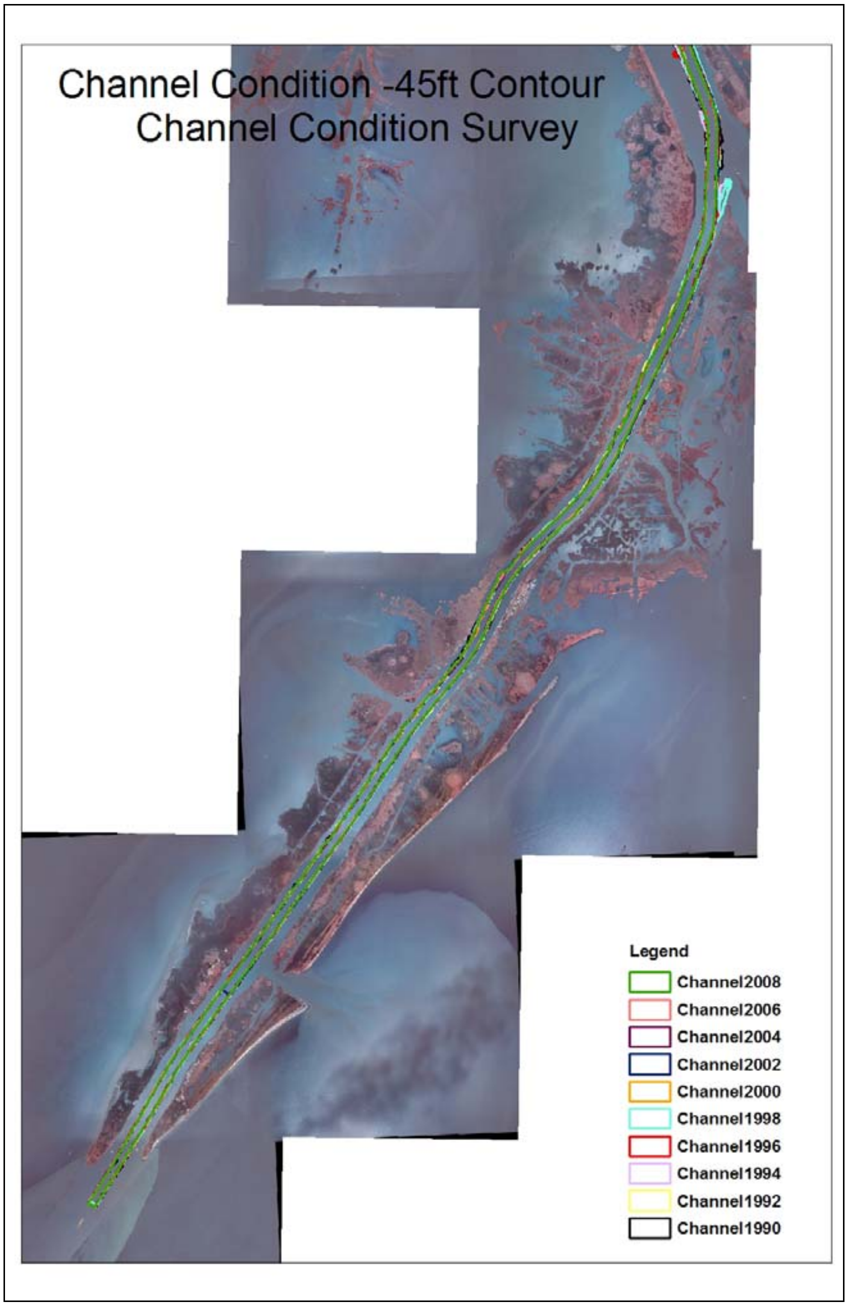


Figure 3.61 Channel location tracings of the -45 foot contour based on the channel condition surveys from Head of Passes to East Jetty

As seen in the channel location tracings from both the comprehensive and the channel condition surveys, the channel downstream of Venice follows an alternating point bar sequence. Channel widths in the reach from the diversion to Cubits Gap have generally decreased over time. To gain a sense of this change, the channel width for each comprehensive survey was measured at each cross section within the anchorage area, and the width as a percentage of the 2003-2004 width was computed. The results are shown in Figure 3.62. As can be seen, the widths are consistent at cross section locations in the upstream portion of the anchorage area. However, the widths at cross section locations from RM 4.0 AHP to the downstream limit of the anchorage area indicate that channel widths from earlier surveys are as much as 250 percent greater than the 2003-2004 width. A trend can also be seen as the width percentage steadily decreases from the 1970s survey period, indicating that the channel width in the vicinity of Cubits Gap was decreasing prior to diversion construction.

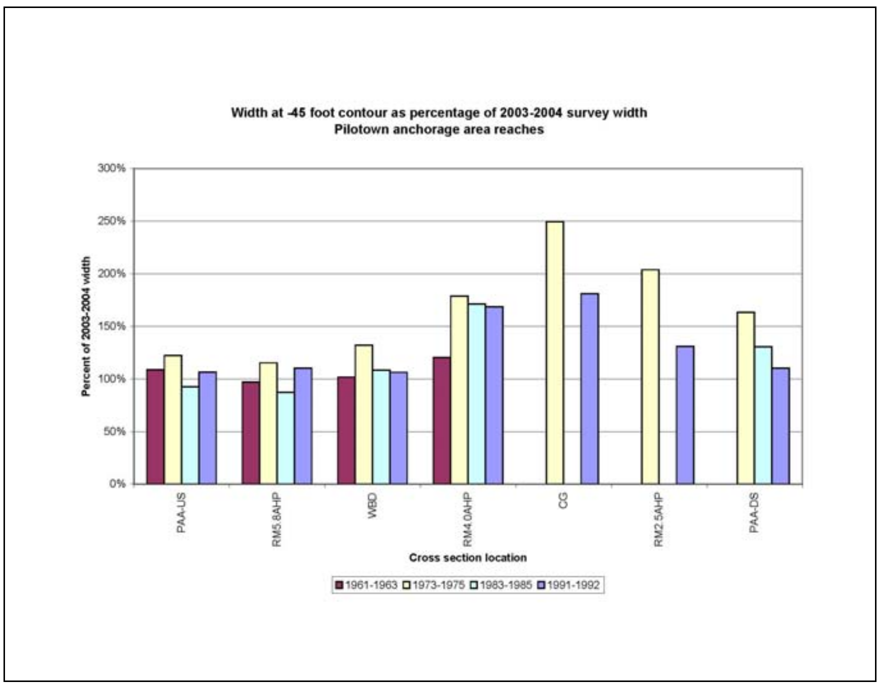


Figure 3.62. Channel widths at the -45 foot contour as a percentage of 2003-2004 width for cross sections located within the Pilottown anchorage area.

Channel widths at the -45 foot contour were also measured from the channel condition survey channel tracings. The widths for the cross sections within the anchorage area were plotted as shown in Figure 3.63. The plot indicates that the channel widths for the cross sections located at Cubits Gap, RM 2.5 AHP and PAA-DS have steadily decreased by as much as 500 feet. No change in the trend of width reduction associated with construction of the diversion can be detected.

The curves for the sections at WBD and RM 4.0 AHP indicate that channel width has decreased from 750 to 1000 feet from the early 1990s to 2008, with approximately 50 percent of the change occurring after the opening of the diversion. Channel widths for cross sections at the upstream end of the anchorage area and RM 5.8 AHP indicate a slight trend of decreasing width over time.

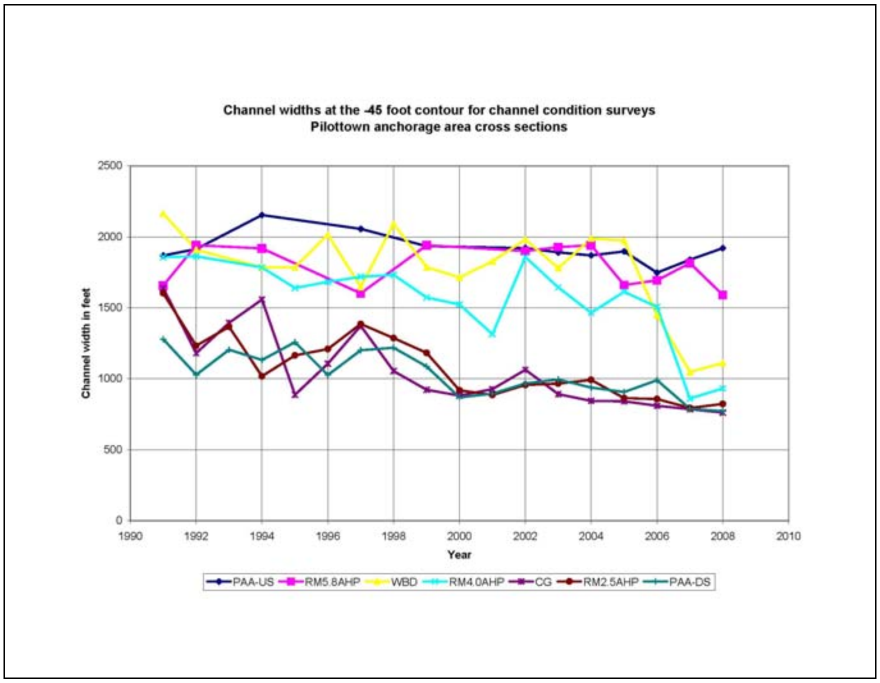


Figure 3.63. Channel widths at the -45 foot contour based on channel condition surveys for cross sections located in the Pilottown anchorage area.

In summary, the channel pattern analysis results indicate that the location of the river channel has been very consistent over time in the study area. No trends in major channel pattern shifts are evident. In the river reach downstream of Venice, an alternating point bar sequence exists. In addition, the channel also seems to narrow downstream of Venice. Temporal change in channel width through narrowing was noted. Channel widths in the vicinity of Cubits Gap based on the comprehensive surveys have decreased 100 to 150 percent from the 1970s survey period to the 2000s survey period. Data from the channel condition surveys indicates that channel widths upstream of Cubits Gap have decreased as well. Data at cross sections in the vicinity of the diversion indicate that approximately half of a 750 to 1000 foot width decrease occurred after opening of the diversion.

Gage/Discharge/Sediment Data Analysis and Results

Discharge Data Analysis

Discharge observation data for the Mississippi River, distributaries and passes in the study reach were obtained from MVN published reports and databases. The historic discharge data in the published reports contained miscellaneous measurements at various stations for the years 1960 through 1998. Published measurements were obtained for the Mississippi River at Venice, Baptiste Collette, Grand Pass, Cubits Gap, Southwest Pass, South Pass and Pass a Loutre. From the MVN databases, discharge measures at the above mentioned stations plus West Bay diversion were obtained. Computed daily discharge at Tarbert Landing was also obtained. These discharge data were analyzed to determine the distribution of flow for the passes, distributaries and diversions in the lower Mississippi River, and to determine if any trends or changes in flow distribution can be observed.

Computations were made for the discharge of the passes and distributaries as a fraction of the discharge at Venice and at Tarbert Landing. Tarbert Landing discharge was used because daily discharge was available that more readily corresponded to the dates of the discharge measurements of the distributaries. The discharge fraction values were plotted to determine if any changes to the capacities of the distributaries has occurred over the study period.

The discharge for Baptiste Collette and Grand Pass as a fraction of discharge at Venice and Tarbert Landing is shown in Figures 3.64.and 3.65, respectively. As can be seen in Figure 3.64 the percentage of the Mississippi River discharge carried by Baptist Collette and Grand Pass is very similar throughout the study time period. The percent of flow in the 1960s was approximately 3 to 4 percent of Venice discharge, and the percentage began increasing in the 1970s to approximately 10 to 12 at the present time. Figure 3.65 indicates a similar trend as a percentage of Tarbert Landing, ranging from 3 to 4 percent at the beginning of the study period to 8 to 10 percent for current conditions.

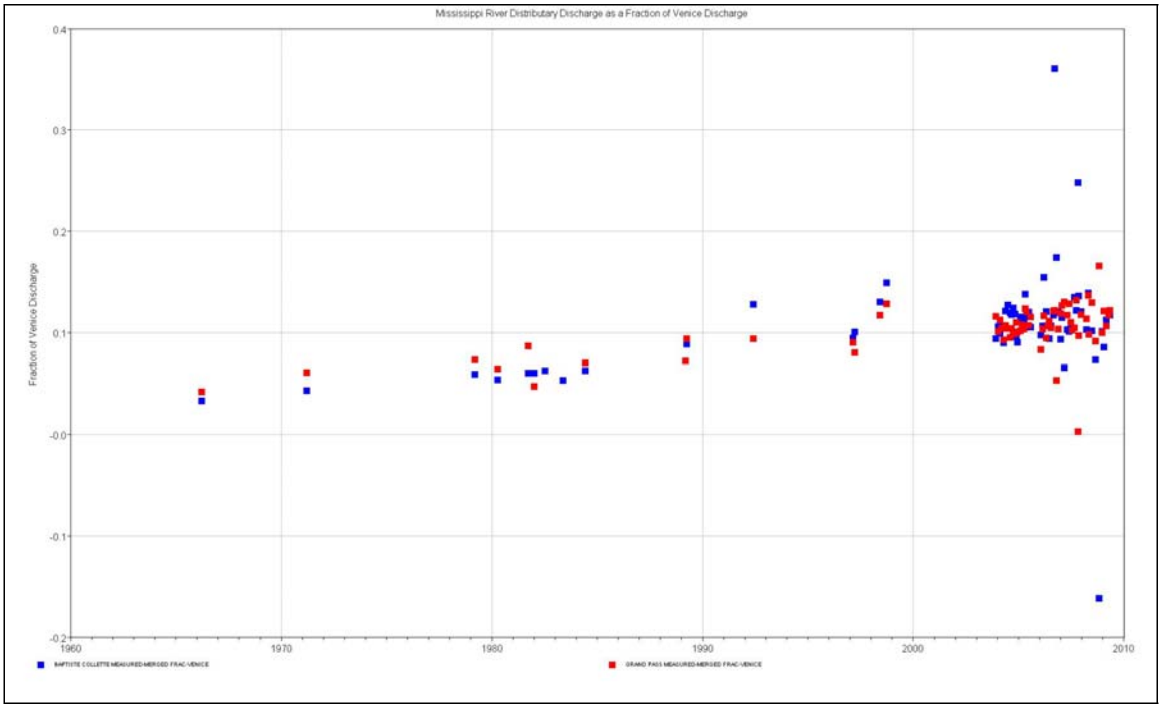


Figure 3.64 .Discharge at Baptiste Collette and Grand Pass as a fraction of Venice discharge.

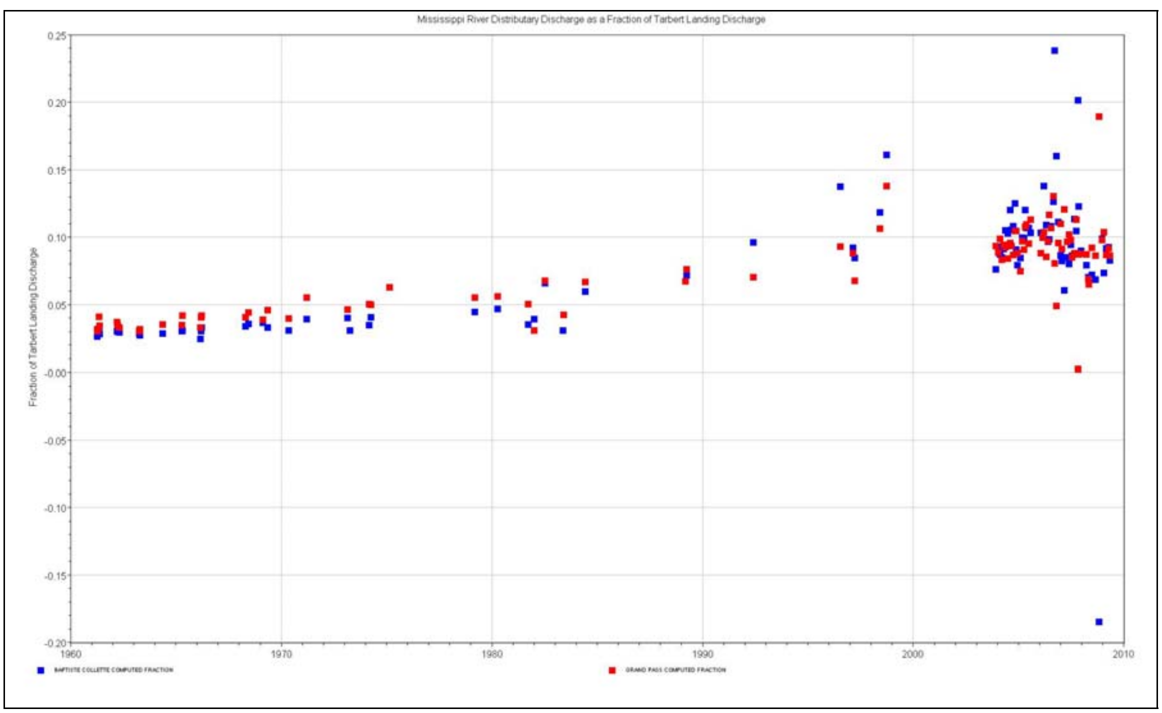


Figure 3.65. Discharge at Baptiste Collette and Grand Pass as a fraction of Tarbert Landing discharge.

From the plots it appears that the change in flow percentage was minimal until the mid-1980s, when the rate of change seemed to increase. This most likely correlates with the enlargement projects for Baptiste Collette and Grand Pass that occurred in the mid to late 1970s. In addition, data from a 1939 study of the Mississippi River passes indicates that the percent of flow for these outlets in the 1930s was similar to the percentage at the beginning of the study period. The report (MVN, 1939) states that as a percentage of the mean discharge at New Orleans, Baptist Collette was carrying approximately 2 percent and Grand Pass (referred to as The Jump) was carrying approximately 3 percent. Although stated as a percentage of New Orleans discharge rather than Venice discharge, this historic data indicates that there had been little change in the flow distribution for these outlets from the 1930s until the 1960s.

The discharge for Cubits Gap and West Bay diversion as a percentage of discharge at Venice and Tarbert Landing is shown in Figures 3.66 and 3.67. As a percentage of Venice discharge, Cubits Gap has carried approximately 15 percent of the Mississippi River discharge until the construction of the diversion in 2003. At that time, there appears to be a steady decrease to approximately 10 to 12 percent for current conditions. The data for West Bay diversion indicates that the diversion was carrying approximately 2 percent of the discharge immediately after construction, and has increased to approximately 7 to 8 percent for current conditions. It is logical that the percentage at Cubits Gap, or other outlets located downstream of West Bay, would adjust to offset the increase in percent for West Bay as the diversion developed. As a percentage of Tarbert Landing discharge, the discharge at Cubits Gap was approximately 10 to 12 percent, with perhaps a slight increase to 13 to 14 percent prior to construction of West Bay. Since then a reduction of approximately 10 percent has occurred.

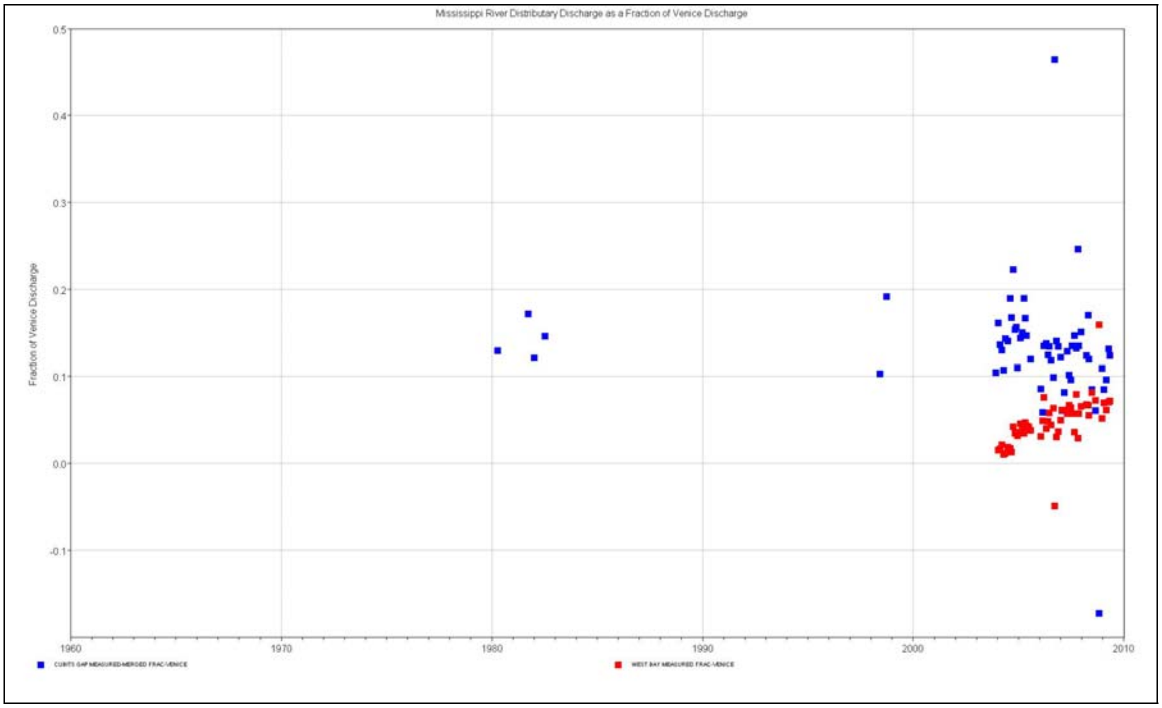


Figure 3.66. Discharge at Cubits Gap and West Bay diversion as a fraction of Venice discharge.

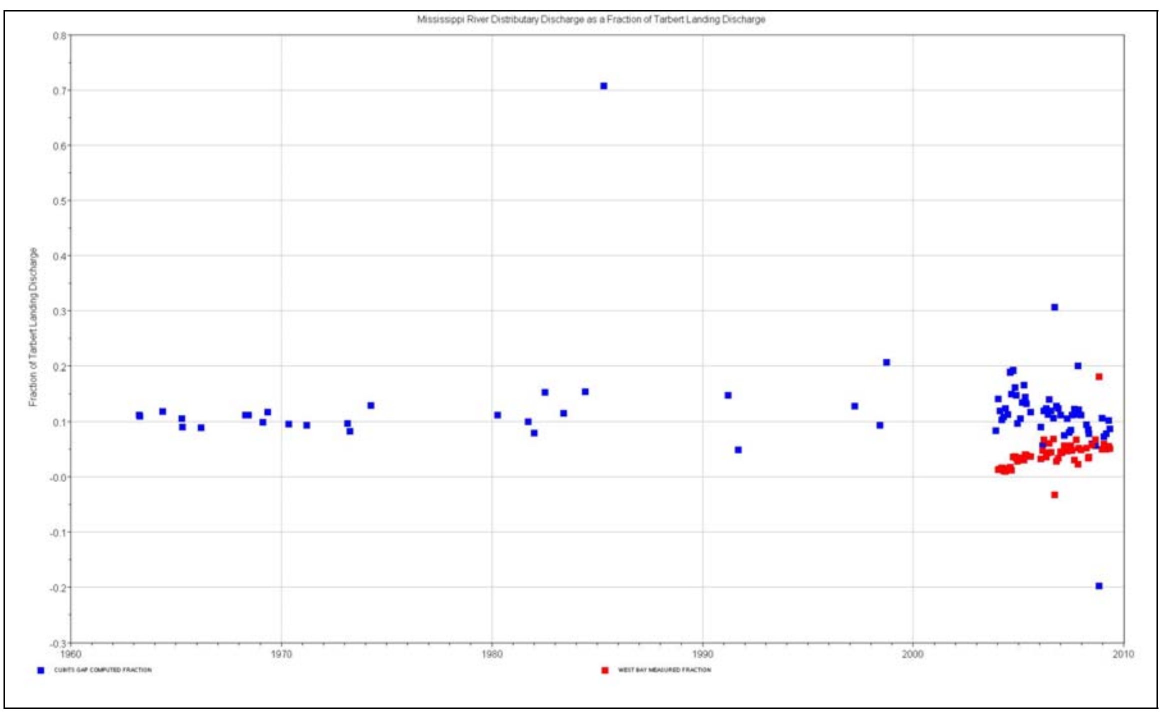


Figure 3.67. Discharge at Cubits Gap and West Bay diversion as a fraction of Tarbert Landing discharge.

The capacity of Cubits Gap as a percentage of New Orleans mean discharge reported by MVN (1939) is approximately 13 percent, indicating little change in the capacity of this outlet prior to the study period.

The capacity of Southwest Pass, South Pass and Pass a Loutre as a percentage of discharge at Venice and Tarbert Landing is shown in Figures 3.68 and 3.69. These plots indicate that the greatest change in flow capacity of all the outlets in the Mississippi River delta vicinity occurred at Pass a Loutre. The plots indicate that the outlet capacity as a percentage of Mississippi River flow for Southwest Pass and Pass a Loutre were very similar at the beginning of the study period, approximately 30 percent. The percent for South Pass was approximately 14 to 16 percent. Beginning in the 1970s until the mid-1990s a decreasing trend in distribution percentage for Pass a Loutre occurred. Distribution percentage for this outlet decreased to approximately 12 percent. The percentage for South Pass also decreased slightly during this time, and at present the percentage for South Pass and Pass a Loutre is very similar. The data for Soutwest Pass indicate that the percentage for this outlet was been fairly constant over the study period, although there is considerable scatter in the data. The capacity of Southwest Pass as a percentage of Mississippi River discharge is approximately 28 to 30 percent in the beginning of the study period and increases to approximately 35 to 40 percent for current conditions. This increase is most likely associated with the increase in the navigation project depth from -40 to -45 feet MLG that occurred in the late 1980s.

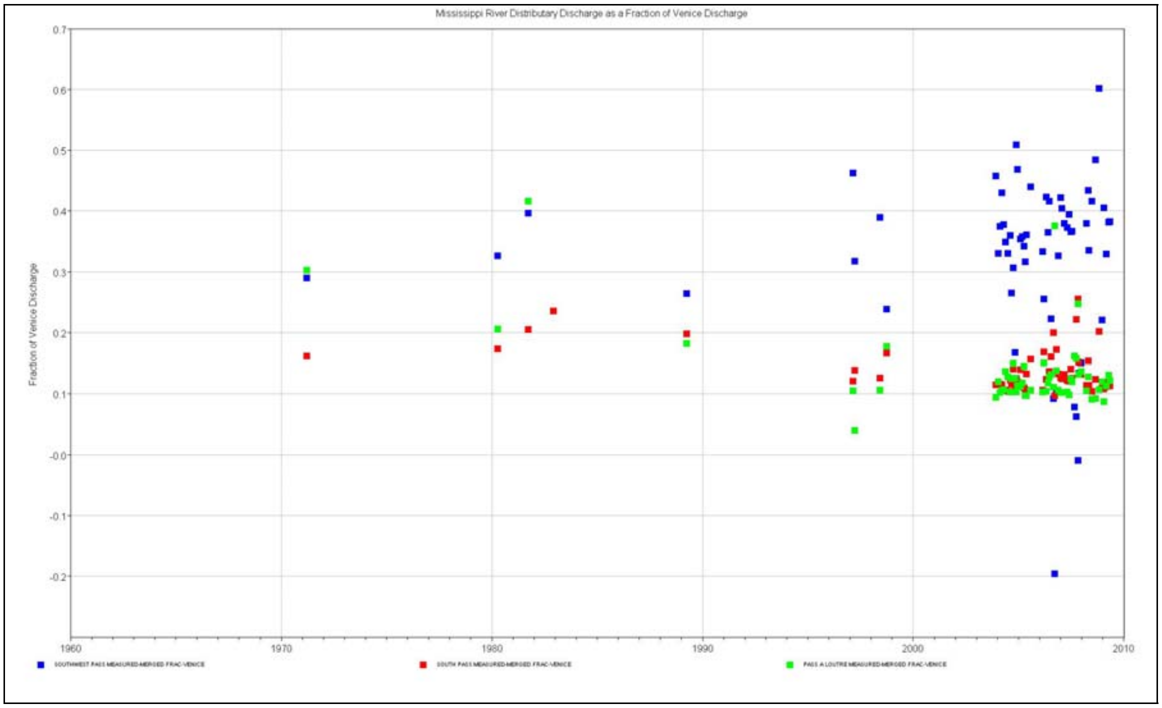


Figure 3.68. Discharge at Southwest Pass, South Pass and Pass a Loutre as a fraction of Venice discharge.

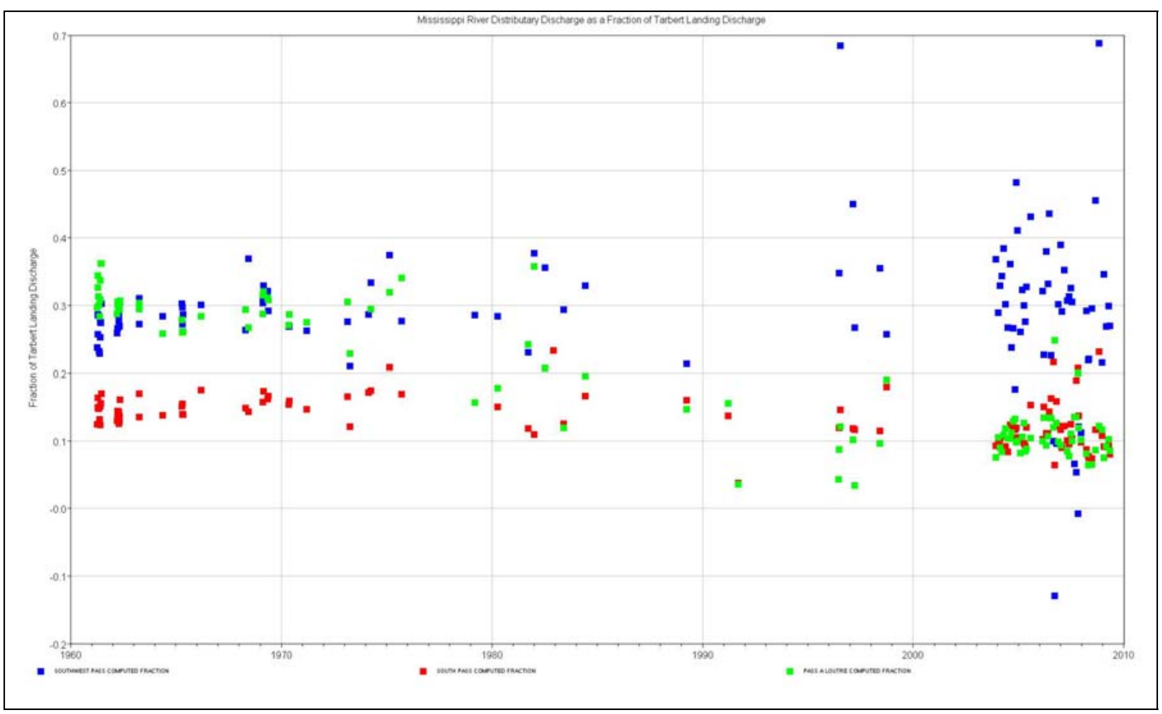


Figure 3.69. Discharge at Southwest Pass, South Pass and Pass a Loutre as a fraction of Tarbert Landing discharge.

MVN (1939) states that the capacity of Southwest Pass, South Pass and Pass a Loutre as a percentage of New Orleans mean discharge was 31, 14 and 36 percent, respectively. This indicates that the percentage of Pass a Loutre may have decreased slightly from the 1930s until the 1960s, while the percentage for Southwest Pass and South Pass were fairly consistent over that time period.

Capacity as a percentage of Venice discharge for West Bay diversion and outlets downstream were plotted for the post-West Bay construction time period to determine how the capacity of the outlets have changed as the diversion has developed. The percentages of the outlets downstream of the diversion must adjust as the diversion develops and capacity increases. The plot is shown in Figure 3.70. A linear trend line was applied to the data for each outlet to discern the trend in percentage. The trend line for West Bay indicates that the capacity of the outlet as a percentage of river flow has increased from 2 to approximately 7 to 8 percent since the outlet was opened. The percentage for Cubits Gap appears to decrease over the same period by a similar amount. The percentage of South Pass and Pass a Loutre indicate essentially no change over that time period. The percentage for Southwest Pass appears to slightly decrease since diversion construction as well, although the degree of data scatter may bias the trend. From this data it appears that the increase in capacity of West Bay diversion since construction has been offset by a decrease in capacity of Cubits Gap and, to some degree, Southwest Pass.

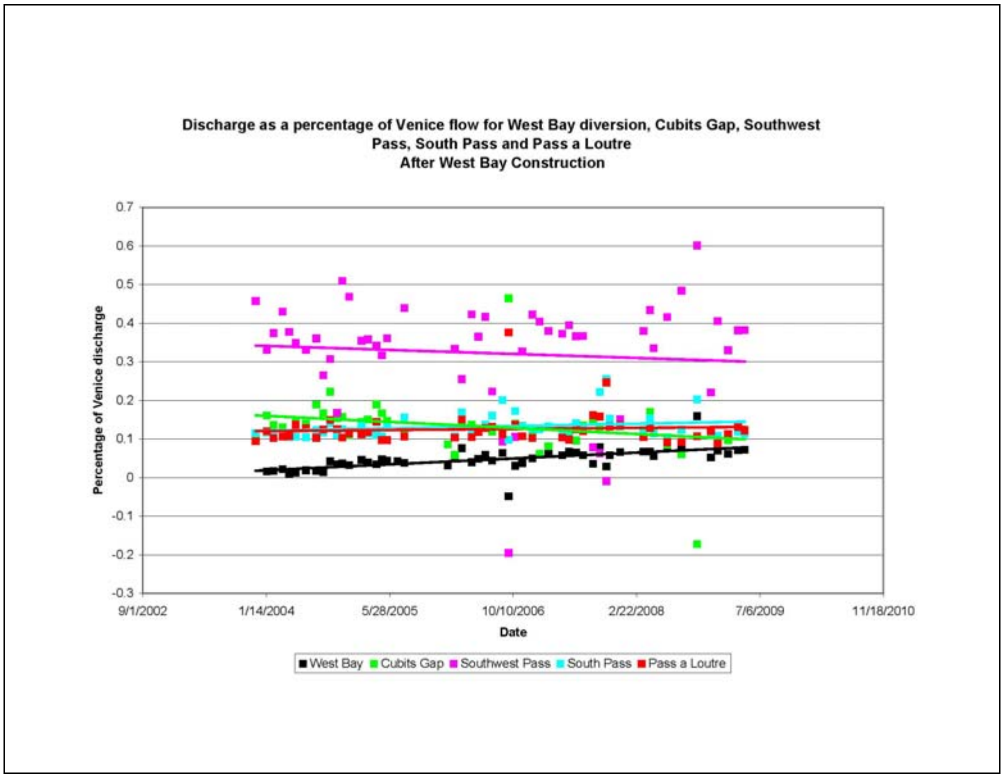


Figure 3.70. Capacity as a percentage of Venice discharge for the outlets downstream of West Bay diversion for the post-construction time period.

Sediment Data Assessment

Sediment data available for the study reach includes historic bed material data and suspended sediment data for the Mississippi River. In addition, suspended sediment measurements were collected as part of this study at West Bay diversion, Baptiste Collette, Grand Pass and Cubits Gap, as well as points on the Mississippi River. Since sediment discharge data for the outlets was limited to the recent measurements collected, no trend analysis or assessment for the outlets was attempted. Rather, the trends in annual suspended sediment and water discharge and the distribution of bed sediments for the Mississippi River are presented to provide a general description of the nature of sediments within the study area. This subject has been investigated by many researchers, therefore reference is made to their work rather than conducting a duplicate effort for this study.

Bed material data for the Mississippi River was collected and analyzed in 1989 by Nordin and Queen (1992). The grain size distribution for the bed material samples by river mile is shown in Table 3.4. The data indicate that the channel bed of the Mississippi River in the study area above Head of Passes is primarily composed of fine sand, with very fine sand and silt also present. Grain size analyses of dredge material grab samples conducted by MVN indicate a similar composition, and will be presented later in this chapter. Bed material samples collected by ERDC in 2009 as part of this study near RM 5.5 AHP and RM 2.5 AHP agree reasonably well with the Nordin data in percentage of medium and fine sand, but generally contain a higher percentage of very fine sand and silt than the Nordin samples. These bed material samples are further discussed in the 1-dimensional model chapter of this report.

Table 3.4. Mississippi River bed material gradations (Nordin and Queen 1992).

Sample Location (1989 River Mile AHP)	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)
75.2	0.13 FS	0.16 FS	0.20 FS
73.1	0.17 FS	0.23 FS	0.34 MS
65.8	0.18 FS	0.22 FS	0.29 MS
63.0	0.34 MS	0.45 MS	0.60 CS
59.0*		0.00	0.02 MSilt
57.0	0.14 FS	0.18 FS	0.23 FS
55.4	0.15 FS	0.19 FS	0.25 FS
52.8	0.17 FS	0.21 FS	0.26 MS
51.2	0.11 VFS	0.14 FS	0.18 FS
47.3	0.15 FS	0.23 FS	0.33 MS
44.8	0.14 FS	0.17 FS	0.20 FS
42.8	0.17 FS	0.23 FS	0.32 MS
40.0	0.12 VFS	0.16 FS	0.20 FS

37.0	0.17 FS	0.21 FS	0.25 FS
35.2	0.18 FS	0.24 FS	0.32 MS
33.0	0.26 MS	0.30 MS	0.36 MS
30.4*	0.01 FSilt	0.14 FS	0.19 FS
26.0	0.17 FS	0.20 FS	0.23 FS
23.9*	0.00	0.02 MSilt	0.07 VFS
21.9	0.15 FS	0.18 FS	0.23 FS
18.0*	0.00	0.00	0.01 FSilt
13.5	0.11 VFS	0.14 FS	0.18 FS
11.9*	0.08 VFS	0.11 VFS	0.15 FS
5.5*	0.13 FS	0.15 FS	0.18 FS
2.8	0.13 FS	0.16 FS	0.20 FS

- Samples that Contain a Significant Amount of Clay and Silt

- Legend: FSilt = Fine Silt MSilt = Medium Silt VFS = Very Fine Sand
  FS = Fine Sand MS = Medium Sand CS = Coarse Sand

Suspended sediment discharge data observed at Tarbert Landing indicate that an overall trend of decreasing suspended sediment discharge has occurred throughout the study period. Demas and Allison (2009) presented that the annual suspended sediment load at Tarbert Landing has decreased by 17 to 20 percent from 1975 to 2006, as shown in Figure 3.71. However, the trend in annual water discharge has experienced little change over the same period, as shown in Figure 3.72. Similar trends in decreasing suspended sediment load have been reported by Horowitz (2009 in press) and Thorne et al (2008).

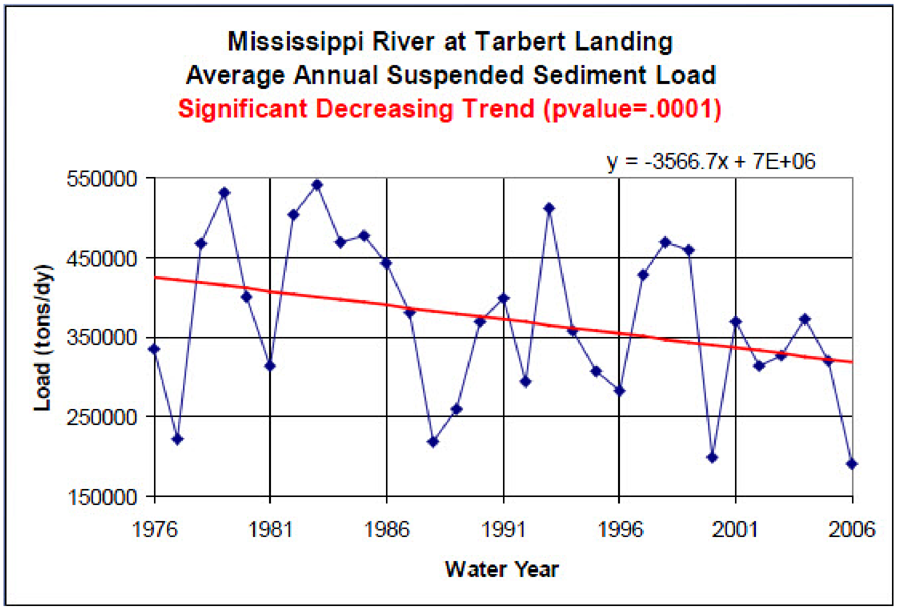


Figure 3.71. Annual suspended sediment load for Mississippi River at Tarbert Landing (after Demas and Allison 2009).

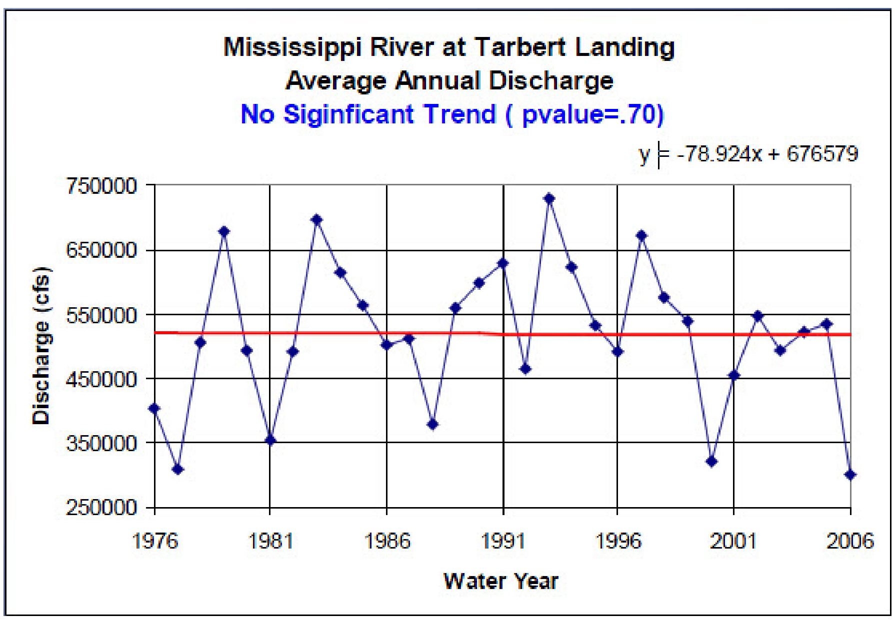


Figure 3.72. Annual water discharge for Mississippi River at Tarbert Landing (after Demas and Allison 2009).

Dredge Data Analysis and Results

Dredge records from the 1970s to the present were obtained from MVN for the purpose of investigating the trends in dredging requirements for the study area. The data include the total maintenance dredge volumes by year for the Southwest Pass reach. MVN defines the Southwest Pass reach as extending from Venice through the entire Southwest Pass. It was originally intended to determine dredge volumes by specific river mile; however, this could not be accomplished for all dredge contracts. Therefore, only a summary of the total dredge volume is presented. Historically, the vast majority of maintenance dredging on the lower Mississippi River has occurred from approximately RM 3.5 AHP to Head of Passes, and throughout the entire Southwest Pass. Minimal dredging has been required in the past between RM 3.5 AHP and Venice.

Total dredge volume by fiscal year dredging contracts for the Southwest Pass reach is shown in Figure 3.73. The plot indicates the probable effects of the floods of the 1970s on maintenance dredging requirements. It is also noted that the dredge volumes since the late 1990s are much less than the long term yearly average for the period. This decrease could possibly be a result of the Mississippi River bank line restoration project of the late 1980s and early 1990s. During this project, the deteriorated bank lines of the Mississippi River and Southwest Pass were restored via foreshore dike construction and hydraulic fill dredged from the channel.

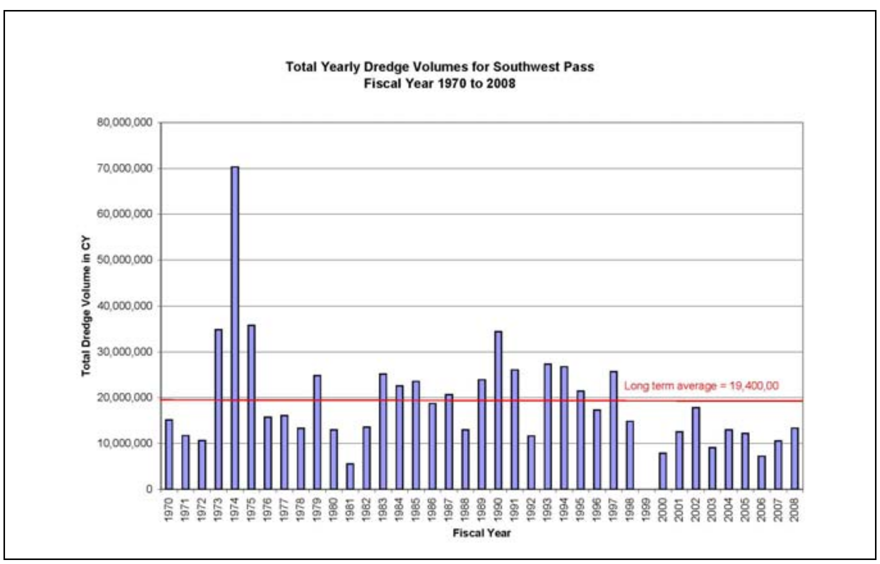


Figure 3.73. Total yearly dredge volumes for Southwest Pass.

Dredge material grab samples from various dredge contracts from 1996 to 2008 were collected and grain size analyses conducted by MVN. This data included grain size distribution and XY coordinates for location of the samples. However, not all sample data contained location coordinates. The data with location coordinates were entered into the GIS system and plotted. The spatial distribution of the D_{50} of the grab samples is shown in Figure 3.74. In general, the D_{50} of the dredge grab samples is fine sand in the vicinity of Cubits Gap, and transitions to very fine sand and some silt between Cubits Gap and Head of Passes. There are some instances of D_{50} in the silt class at and upstream of Cubits Gap. Throughout Southwest Pass, the D_{50} of the dredge material grab samples is primarily very fine sand and silt/clay. No grab samples with a D_{50} of medium sand were observed. These grab sample data included samples collected as part of the initial dredging of the Pilottown anchorage area in 2003. These samples all indicate a D_{50} of fine sand.

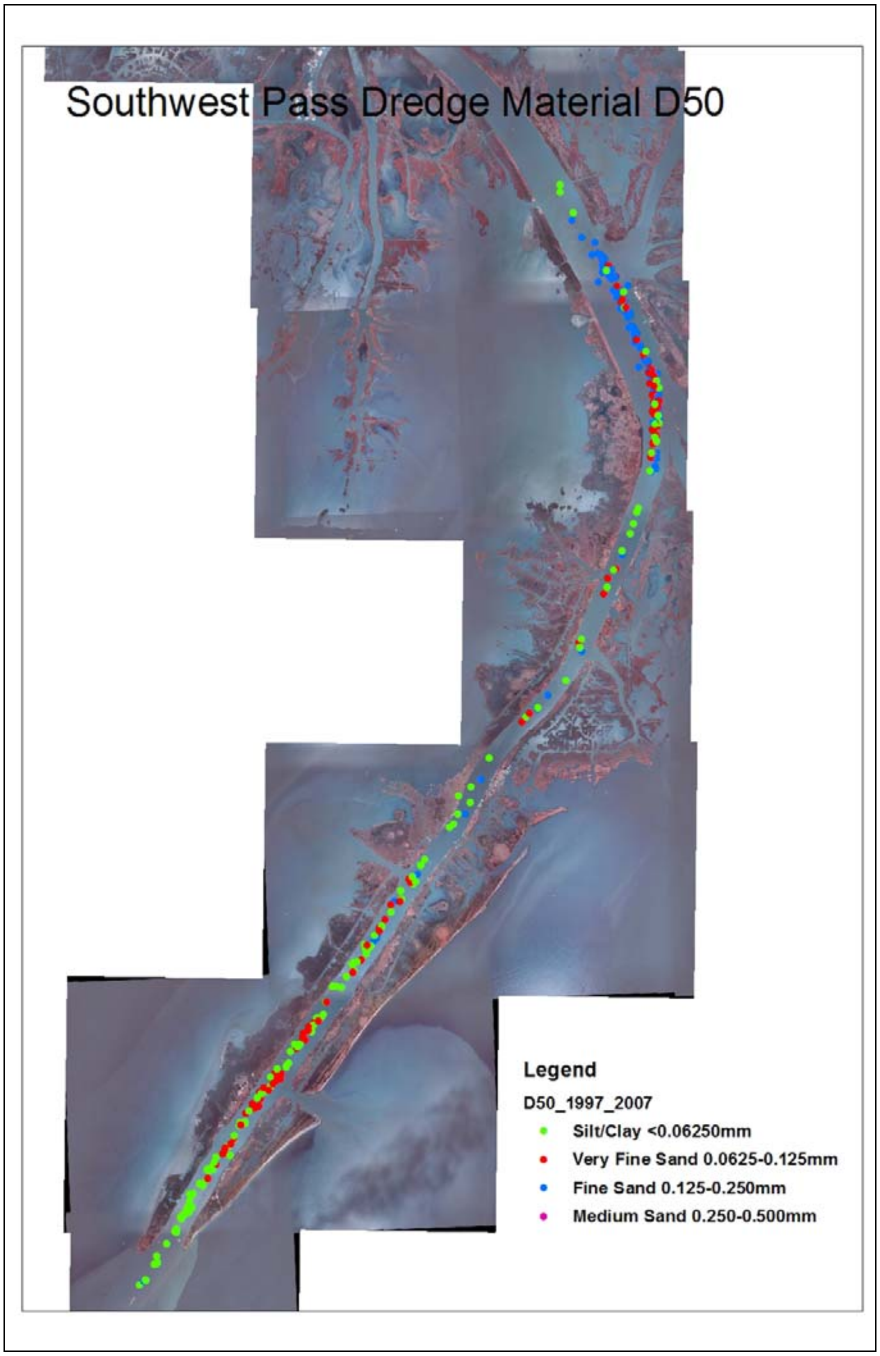


Figure 3.74. Dredge material grab sample location and D_{50} grain size.

Historic Events Timeline

A comprehensive report of the events that have transpired in terms of river engineering, channel maintenance and other man-induced activities for the study area was compiled by MVN and is included as part of this report in Appendix L. The information in this summary provides background information that is essential for an accurate interpretation of the results of the various analyses conducted in the geomorphic assessment. The report covers the principle river engineering activities that have occurred from 1960 to the present. Four significant events are detailed in the report that are believed to at least contribute in some degree to the river channel morphology observed over the study period: 1) deepening of the navigation project from -40 feet MLG to -45 feet MLG, 2) enlargement projects on Baptiste Collette and Grand Pass, 3) river bank line restoration projects and 4) construction of West Bay diversion.

Deepening of Navigation Project

As stated in the events summary, the navigation project as authorized in 1960 provided a channel to a depth of -40 feet MLG and 1000 feet wide from New Orleans to Head of Passes. The authorized channel for Southwest Pass was for the same depth but at a width of 800 feet. Deepening of the navigation project to -45 feet MLG was authorized by PL 99-88 (Aug 1985) and WRDA 1986. In addition to deepening the navigation channel, the width of the channel from New Orleans to RM 17.5 BHP was reduced from 1000 feet to 750 feet. Dredging to achieve the new depth was conducted in 1987 and occurred from RM 3.5 AHP to the gulf.

Possible effects of the deeper and narrower navigation channel were observed in the geometric data analysis, primarily from Cubits Gap downstream. In this reach of the river that is heavily modified by regular maintenance dredging, the channel is firmly entrenched along the left descending bank of the river. In this reach, the point bar along the right descending bank appears to have developed significantly. This has resulted in a channel cross section shape typically observed in a bend of a river, with a narrow, deep thalweg channel and a well-defined point bar. Comprehensive hydrographic surveys prior to the deepening project indicate that the channel section in this reach was wider than the present day channel.

Enlargement of Baptiste Collette and Grand Pass

Projects to enlarge the outlets of Baptiste Collette and Grand Pass were constructed in 1978-1979. These projects included dredging of the channel and construction of jetties.

The possible effects of these projects can be noted in the increase in discharge capacity as a percentage of Mississippi River flow for the outlets. Capacity percentages for the outlets were approximately 3 to 4 percent each in 1960, and have increased to approximately 8 to 10 percent each at current conditions. This increase in capacity seems to correspond in time to the enlargement project construction. This change has resulted in an increase in the combined distribution percentage for these outlets from 6 to 8 percent to 16 to 20 percent. Although the effects of this change are difficult to determine without numerical modeling, the increase in flow percentage is likely to increase deposition potential in the river downstream of the outlets.

River Bank Line Restoration

Restoration of deteriorated river bank lines was approved in 1985 and project construction conducted from 1986 to 1991. The purpose of the restoration project was to construct foreshore dike along the deteriorating bank line and replenish the area behind the dikes with hydraulic fill borrowed from the river channel.

The effect of the bank line restoration was to prevent river flow over the banks and to confine the flow within a well defined channel. This resulted in increased velocities in the river channel. Dredge records indicate a general reduction in maintenance dredging has occurred from the late 1990s to the present. The restoration project was possibly a contributor to this observed reduction in maintenance dredging.

Construction of West Bay Diversion

Construction of West Bay diversion was completed in 2003 at RM 4.7 AHP. The initial diversion channel was constructed to a capacity of 20,000 cfs, requiring the dredging of approximately 655,000 CY (gross). In addition, the anchorage area was dredged as part of the construction of the diversion. Approximately 735,000 CY (gross) was removed from the anchorage area downstream of the diversion channel in the shallow draft portion of the anchorage area. In 2006, a second dredging event for the anchorage area was conducted, resulting in the removal of approximately 1.88 million CY (gross). Of this total, 640,000 CY (gross) were removed from the deep draft portion of the anchorage area upstream of the diversion, and 1.24 million CY (gross) were removed from the shallow draft portion of the anchorage area downstream of the diversion. A third dredging event for the anchorage area will be conducted in 2009.

Results from the gage/discharge data analysis indicate that the percentage of Mississippi River flow distribution for West Bay diversion at time of construction was approximately 2 percent, but has increased to approximately 7 to 8 percent. It is probable that the diversion has had an impact on the morphology of the river, in a manner similar to that resulting from the enlargement of Baptiste Collette and Grand Pass. As the diversion capacity has increased, capacity of outlets downstream from the diversion must likewise decrease based on continuity of flow. This cumulative change in flow distribution has most likely had an impact on deposition trends in the river downstream of the diversion. Geometric data analyses indicate that the point bar was developing and had significantly developed prior to diversion construction. The fact that dredging was required in the anchorage area at the time of diversion construction indicates that the point bar had developed sufficiently to prior to construction of the diversion. However, determining if and/or how the development of the point bar has been affected specifically by the diversion is difficult with this type of analysis. Numerical model investigations conducted as part of this study will aid in identifying potential impacts specific to the diversion.

Integration of Results and Conclusions

Integration of Results

Results from the various analyses conducted as part of the geomorphic assessment were integrated in order to formulate conclusions that best describe and explain the cause and effect of the overall morphological trends observed in the study area. The integration process takes the results from a given analysis and interprets the results in relation to the results of all analyses. In doing so, definitive trends can be established and areas of conflicting results can be identified. In addition, the results of the geomorphic assessment will be integrated with the results of the other aspects of this overall study to determine a comprehensive assessment of the anchorage area and the potential impacts of West Bay diversion on induced shoaling.

The geometric data analyses indicate that in general there has been little change to a slight lowering of the river channel bed upstream of Venice. Results from cross section comparisons and reach average channel bed displacement and elevation comparisons agree reasonably and verify this trend. It should be noted that the geometric analyses for this reach of the river are based solely on comprehensive surveys collected approximately every decade. Observed changes in channel dimension for this reach can reasonably be correlated with revetment construction.

A distinct change in the trend of channel dimension occurs in the vicinity of Venice. Several things occur at this location. First, the main distribution of flow for the lower Mississippi River begins at Baptiste Collette and Grand Pass. The combined distribution of flow as a percentage of Mississippi River discharge for these two outlets has increased from approximately 5 percent to 16 to 20 percent over the study period.

Secondly, an alternating point bar channel pattern is observed. A point bar is located on the left descending bank immediately downstream of Grand Pass. The thalweg channel continues along the right descending bank until approximately the upstream limit of the anchorage area, where a crossing occurs. The thalweg channel shifts toward the left bank as it crosses through the upstream portion of the anchorage area, and is located closely along the left bank at Cubits Gap. A corresponding point bar begins along the right descending bank in the upper portion of the anchorage area, and extends throughout the anchorage area to near Head of Passes.

Thirdly, a trend in reduced river channel depths is observed. Beginning at Venice and continuing to Cubits Gap, a general reduction in channel thalweg depths by as much as 20 feet has occurred over the study period. This trend is identified at individual cross sections and over reach average areas. There is a degree of variability in the data, particularly associated with the occurrence of large floods; however, the overall trend is one of general depth reduction. The effect of regular maintenance dredging is evident beginning at Cubits Gap and proceeding downstream to Head of Passes and throughout Southwest Pass. Due to the continual modification of the channel from maintenance dredging in this area, no definitive trends can be determined other than changes in depth that transpired as a result of the navigation channel deepening project.

The point bar that is located on the right descending bank within the anchorage area limits is very extensive, and the development of the bar has had a major impact on conditions within the anchorage area. From a qualitative assessment of cross section survey data, the point bar has been actively developing for years prior to construction of West Bay. Survey data indicates that there has been a degree of fluctuation in the vertical extent of the point bar. Some cross sections show that conditions in the anchorage area were actually higher in 1997 than at the time of diversion construction. Also, survey data indicates that the 1973 flood caused significant erosion of the point bar in the upper portion of the anchorage area. The combination of the deep, narrow channel and the well developed point in this area produce a channel shape that is typically observed in sharp river bends. Reach average channel bed displacement determined from the comprehensive surveys indicates the lower portion of the point bar within the anchorage area has increased in elevation 3 times as much as the upper portion of the anchorage area.

The development of the point bar in relation to the construction of West Bay diversion is difficult to accurately quantify. Analysis of average channel bed elevations along a 500 foot section landward (westward) of the Pilottown anchorage area line for cross sections within the anchorage area indicates an increase in post-construction deposition rates for locations at the diversion and downstream to Cubits Gap. For locations downstream of Cubits Gap, no significant change in the rate of deposition relative to diversion construction is observed. Reach average channel bed elevations indicate a similar trend, with an increase in post-construction elevations observed for the reaches in the vicinity of the diversion and downstream to Cubits Gap, but little change in rates for reaches downstream of Cubits Gap.

Indication of the development of the point bar can be seen in the analysis of channel pattern. The channel pattern analysis for the comprehensive surveys indicates that channel widths become narrower downstream of Venice. Since the deepening of the navigation project, the channel width and location downstream of Cubits Gap has been very consistent along the left descending bank, and the point bar on the right descending bank has developed significantly in response. Above Cubits Gap (outside of the dredging influences), channel width based on the channel condition surveys has decreased, with the right side of the channel narrowing toward the left descending bank. This indicates that the point bar on the right descending bank is developing and encroaching to the east. In addition, it appears that the narrowing has increased in the years after diversion construction. Channel widths measured at the cross section locations in the vicinity of the diversion indicate a reduction in channel width of 750 to 1000 feet, with a large percentage of that occurring in the post-construction time period. Width data for cross sections downstream of Cubits Gap do not indicate a change in trend due to diversion construction.

The channel pattern analysis also indicates that the channel width at the -45 foot contour for the river reach immediately above Venice accounts for approximately 80 percent or more of the total top bank width. In the vicinity of the point bar on the left descending bank downstream of Venice, the channel width at the -45 foot contour is approximately 50 percent of the top bank width. Downstream of Cubits Gap the channel width at the -45 foot contour is only 25 to 30 percent of the top bank width, although the channel width is primarily determined by dredging at this location. This channel width pattern is obviously related to the alternating point bar sequence downstream of Venice. The beginning of Mississippi River flow distribution at Venice is believed to be the primary contributor to the development of this pattern.

Distribution of Mississippi River flow through some of the outlets located in the lower river and delta has changed over time. The combined percentage of river flow distributed by Baptiste Collette and Grand Pass has increased from approximately 5 percent to 16 to 20 percent, with the time frame of the increase corresponding to the enlargement of those outlets in the late 1970s. Flow distribution at Pass a Loutre has significantly decreased by as much as 20 to 25 percent beginning in the mid 1970s. The primary cause of this reduction at Pass a Loutre is unclear, but may be associated with the aforementioned changes at Baptiste Collette and Grand Pass, as well as the deepening of the navigation project in Southwest Pass. Flow distribution percentage for West Bay diversion has increased fairly uniformly since construction, from approximately 2 percent to 7 to 8 percent of river flow. The distribution percentage at Cubits Gap has decreased correspondingly, as has possibly the distribution percentage at Southwest Pass. In consideration of the geometric changes in depth and width that occur with the beginning of flow distribution near Venice, it appears that flow distribution through the outlets may be the primary physical agent for the observed morphological change in the study area. Given this, it is reasonable to assume that the construction of West Bay diversion, or any other diversion, will influence the trends of deposition in the anchorage area.

Major floods result in noticeable change to the channel perimeter, and changes are often without a discernable pattern. The flood of 1973 produced significant erosion in the point bar within the upper portion of the anchorage area. Patterns of scour and deposition are often observed for the same cross section. In the case of tropical storms, the effects seem to be more general. Sediment deposition observed during Hurricane Katrina appeared more uniform over the river channel, and deposit depths tended to increase with increasing proximity to the gulf. The track of the storm relative to the river delta most likely affects deposition trends.

Conclusions

The results of the various analyses of the geomorphic assessment were integrated and evaluated using best engineering judgment with regard to long-term morphological trends in the study area, construction of West Bay diversion, and the potential impacts of the diversion on induced shoaling in the Pilottown anchorage area. The following conclusions are presented:

- The lower Mississippi River and delta region is a dynamic system that has experienced significant morphologic adjustment over the study period.

- The river channel upstream of Venice has been generally stable in dimension and pattern over the study period, with essentially no change to a slight increase in channel depth.

- A definitive change in channel trends occurs at Venice. In general, channel depths from Venice to Cubits Gap decrease consistently over the study period. Downstream of Cubits Gap and throughout Southwest Pass the channel is heavily influenced by navigation maintenance dredging. Depth change trends are basically indistinguishable except for increases due to deepening of the navigation project.

- The point bar along the right descending bank that extends throughout the Pilottown anchorage area was developing prior to the construction of West Bay diversion, and would have continued to develop to some degree without construction of the diversion. Development of the point bar downstream of Cubits Gap appears to correspond to deepening of the navigation project.

- Construction of West Bay diversion has most likely resulted in increases in deposition rates in the anchorage area mainly between the diversion and Cubits Gap. Deposition rates in the anchorage area downstream of Cubits Gap indicate little influence due to construction of the diversion.

- The distribution of Mississippi River flow via outlets in the study area is believed to be a major factor in observed channel morphology and deposition trends. It is reasonable to assume that the West Bay diversion affects these trends by contributing to the overall distribution of river flow in the area.

- Identifying and quantifying impacts that are specific to West Bay diversion is difficult using these types of assessments. Changes observed in the geometric data are a cumulative result of all processes and influences such as river hydrology, floods, storms, dredging activities and river engineering projects. Impacts specifically attributable to construction of West Bay diversion are best determined through numerical modeling. Modeling results should be evaluated along with the geomorphic assessment results to achieve the most comprehensive and accurate interpretation of diversion impacts on anchorage area shoaling.

4 1-Dimensional Modeling Analysis

Purpose of 1-Dimensional Analysis

The HEC-6T numerical model software package is being utilized as a part of a multi task evaluation to determine the effects of the West Bay Diversion on sedimentation rates and patterns and dredging requirements in the Pilottown Anchorage Area. The tasks include field data collection, geomorphic assessment, 1-dimensional modeling, and multi-dimensional modeling. The 1-dimensional modeling provides the means of assessing the long term impacts of the diversion as well as providing upstream sediment boundary conditions for the multi dimensional model. Fifty year simulations will be run with the 1-dimensional model. These long term simulations are not possible with multi dimensional models. The results of the 1-dimensional modeling will be integrated with the results of the geomorphic assessment and the multi dimensional models in order to provide a thorough evaluation of the impacts of the West Bay Diversion.

HEC-6T Software Description, Capabilities, Limitations and Requirements

For the West Bay Diversion evaluation, the HEC-6T Sedimentation in Stream Networks software package is being used. The HEC-6T software is an enhanced version of HEC-6, Scour and Deposition in Rivers and Reservoirs. HEC-6 is public domain software maintained by the U.S. Army Corps of Engineers Hydrologic Engineering Center in Davis, California. HEC-6T is proprietary software owned by MBH Software, Inc. of Clinton, Mississippi. The HEC-6T user manual is provided by MBH Software, Inc. once the license to the software has been purchased.

MBH provides the HEC-6T user's manual as a supplement to the HEC-6 user's manual. The HEC-6 user's manual provides the model purpose, philosophy, application, capabilities, theoretical assumptions, and limitations. This manual describes HEC-6 as "a one-dimensional movable boundary open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and/or deposition over moderate time periods, typically years". HEC-6 is designed to simulate long-term trends of scour and/or deposition. Specifically, the HEC-6 sediment transport model calculates water surface and sediment bed surface profiles by computing the interaction between sediment material in the streambed and the flowing water-sediment mixture. HEC-6 is a steady state model that partitions a continuous flow record into a series of steady flows. The HEC-6 user's manual describes the computational process as follows: "For each flow a water surface profile is calculated thereby providing energy slope, velocity, depth, etc. at each cross section. Potential sediment transport rates are then computed at each cross section. These rates, combined with the duration of the flow, permit a volumetric accounting of sediment within each reach. The amount of scour or deposition at each section is then computed and the cross section is adjusted accordingly. The computations then proceed to the next flow in the sequence and the cycle is repeated beginning with the updated geometry." Model output includes computed total sediment discharge passing each cross section and the volume of deposits or scour accumulated at each cross section from the beginning of the simulation.

Model input requirements include channel geometry, upstream boundary conditions, bed gradations, distributary / diversion outflow and sediment concentration, water temperature, downstream boundary conditions, and user specified sediment transport function. Boundary conditions refer to the water and sediment discharges entering the model and to the stage-discharge relationship prescribing the base level of energy. There are three external boundary condition parameters: upstream water discharge, upstream sediment discharge by particle size, and downstream water surface elevation. A two phase calibration is required. The first phase includes the calibration of computed water surface profiles to observed profiles. This is accomplished by running the model in the fixed-bed mode for a range of steady-state discharges. Manning's roughness coefficients are adjusted so that calculated water surface profiles match measured stages at available gage locations. The second phase includes sediment calibration. This can be accomplished by simulating observed erosion and deposition and by simulating measured sediment transport. Also, if dredging records are available, calibration to dredging quantities is an option.

The use of HEC-6T has both advantages and disadvantages. HEC-6T provides 3 primary advantages needed for the evaluation of the West Bay Diversion. Those advantages include:

1. HEC-6T allows for long term simulations where multi dimensional models are limited to much shorter simulations (typically single events to months to possibly 1 year). For the West Bay Diversion evaluation, 50 year simulations will be run.

2. HEC-6T has the ability to simulate dredging activities. Dredging can be specified after any event in the hydrograph. The program will then dredge at every cross section at which the dredging option is prescribed in the geometric

data set. Dredging can be stopped at any time. Two dredging options are provided, the fixed template option and the vessel draft option. The fixed template is when the dredging template is prescribed by a bottom elevation, a starting station and an ending station. When the bed elevation becomes higher than the template bottom, dredging is performed. The vessel draft is where the width of the dredged channel is prescribed by a starting station and an ending station but dredging is triggered with the water depth at the cross section becomes less than the required draft for navigation. The different options cannot be mixed in a single model run.

3. HEC-6T allows for the diversion of both water and sediment and calculates that impact on downstream sediment transport.

The primary disadvantage is that HEC-6T is a 1-dimensional model which means that the model uses average hydraulic and sediment parameters since it is simulating 3-dimensional processes in 1dimension. HEC-6T includes no provision for specifying a lateral distribution of sediment load or bed material gradation across a cross section. Normally, deposition and scour are modeled by moving each cross section point within the movable bed an equal amount (the area that is shifted vertically during each time step due to sediment movement). For this study, an option was selected that preferentially deposits sediment within the dredging template before deposition is distributed over the rest of the moveable bed.

Modeling Approach

For the West Bay Diversion evaluation, a HEC-6T model as developed by the USACE Vicksburg District (MVK) is being used. The MVK HEC-6T model is part of a regional model being developed by funding provided by the Mississippi River and Tributaries (MR&T) Project for the identification of long term channel maintenance sites within the Lower Mississippi River. Since this model was developed for regional use, modifications are required for the West Bay Diversion evaluation. Additional cross sections are required downstream of Belle Chase to adequately define the channel geometry within the study reach. The highest density of channel cross sections is required within the Pilottown Anchorage Area (River Mile 1.5 to River Mile 6.7). An important part of the West Bay Diversion evaluation is the ERDC data collection. The ERDC collected flow diversion, sediment concentration diversion, and bed material gradation data are compared to the existing values contained in the model. If needed, model values are modified. As model input parameters are modified, a continued check on the model calibration is required. That includes water surface profiles, sediment deposition and erosion locations and quantities, dredging locations and quantities, and sediment transport by grain size. Constant subsidence and sea level rise rates were estimated and incorporated into the model. A typical discharge hydrograph which provides a realistic expectation of future flows is selected and duplicated as needed to create a projected 50 year hydrograph. Fifty year downstream water surface elevations are developed that match the time period used in the 50 year discharge hydrograph. The hydrograph is run for 4 alternative scenarios. The first scenario includes no West Bay Diversion and no dredging in the Pilottown Anchorage Area. Dredging in the navigation channel is permitted as needed. An appropriate composite dredging template for the Pilottown Anchorage Area is developed and inserted into the model. This template includes required dredging in both the navigation channel and the anchorage area. The second scenario, no West Bay Diversion but with dredging in the Pilottown Anchorage Area, is run. The West Bay Diversion is inserted into the model. This includes adding the diverted flow and sediment concentration diversion ratios. The composite dredge template is removed and the third scenario (with West Bay Diversion and no dredging in the Pilottown Anchorage Area) is run. For this scenario, dredging, as required, is permitted in the navigation channel. The composite dredge template is inserted back into the model and the fourth scenario, with West Bay Diversion and with dredging in the Pilottown Anchorage Area, is run. Once all the runs are complete, the final step is to compare sediment deposition locations and quantities and dredging locations and quantities through the Pilottown Anchorage Area reach for the four 50 year simulation scenarios to determine the impact that the West Bay Diversion has on the Pilottown Anchorage Area.

MVK Regional HEC-6T Model

The model provided by MVK extends some 455 miles from Vicksburg, Mississippi (River Mile 437.28) to Pilots' Station in Southwest Pass (River Mile -18). The entire model is being used for the West Bay effort but the primary focus is on the Belle Chasse, Louisiana (River Mile 75) to Head of Passes (River Mile 0) reach.

HEC-6T model input requirements include channel geometry, upstream boundary conditions of daily flow and sediment loads, bed material gradations, water temperature, downstream boundary condition of water surface elevation, and the selection of an appropriate sediment transport function. Model channel geometry was derived from the 1992 Mississippi River comprehensive hydrographic survey. The model contains 231 cross sections. The spatial distribution of the cross sections is provided in Table 4.1.

Table 4.1. Spatial Distribution of MVK HEC-6T Model Cross Sections

Reach	No. Cross Sections
Southwest Pass (RM -18 – RM 0 At Head of Passes)	13
Head of Passes (RM 0) to Venice (RM 10.6)	8
Venice (RM 10.6) to Belle Chasse (RM 76)	21
Belle Chasse (RM 76) to Vicksburg (RM 437.28)	189
Total	231

MVK reports that the overbanks were obtained from various sources including hydrographic survey contours, USGS Quad Maps, available Louisiana Digital Orthophoto Quarter Quadrangle (DOQQ) and Light Detection and Ranging (LiDAR), and a previous 1-dimensional model developed in 1983. The New Orleans District reach of the model includes dikes in Southwest Pass and in three channel crossings. The three crossings are Medora Crossing from RM 211 to RM 213, Red Eye Crossing from RM 223 to RM 225, and Smithland Crossing from RM 297 to RM 301. For all dike locations, the channel cross section geometry was adjusted to account for the effects of the dikes.

The upstream model boundary conditions consist of a flow hydrograph and incoming sediment loads. The hydrograph used in the model represents the reported mean daily flow at Vicksburg, Mississippi for the 12 year period extending from 1 October 1990 through 30 September 2002 (water years 1991 – 2002). The incoming sediment load was divided into sands and fine material.

MVK reports that the silt and clay sediment inflow at the upstream boundary of the numerical model was determined from the 1991 – 2002 measured sediment concentrations at Union Point (RM 326.6) and Coochie (RM 317.3). These sampling locations were used instead of Vicksburg and Natchez for three reasons. Those reasons include:

1. The 1992-2002 measured fine sediment concentrations at Vicksburg and Natchez were found to be an order of magnitude less than those fine concentrations reported between 1984 and 1989 at the same gages.

2. The 1992-2002 fine sediment concentrations at Vicksburg and Natchez were inconsistent with downstream measurements for the same time period at Union Point, Coochie, and Tarbert Landing.

3. The Vicksburg and Natchez fine sediment measurements do not include particle size class distributions.

The fine sediment concentrations at Vicksburg were assumed to be the same as those at Union Point and Coochie because, at all three locations, these size classes (clay, very fine silt, fine silt, medium silt, and coarse silt) are wash load.

For the sand grain sizes, MVK reports that the actual sand inflow curves were determined from a combination of calculated sand transport by size class at Vicksburg and measured sand transport by size class downstream at Coochie (RM 317.3) and Union Point (RM 326.6). This methodology was adopted because the size class percentages of the measured suspended load at Vicksburg were not available and the unmeasured load was unknown. The bed material load consists of measured and unmeasured suspended load and the unmeasured bed load. When the calculated load at Vicksburg for a specific size class was greater than the measured load at Coochie and Union Point for that size class, then the calculated load was considered to be bed material load and was used to develop the sediment inflow rating curve at Vicksburg. When the measured load for a specific size class at Coochie and Union Point were greater than the calculated load at Vicksburg, then that size class was considered to be wash load at Vicksburg. The measure size class sediment discharge was increased by 10 percent to account for unmeasured load and was used to develop the sediment inflow at Vicksburg. Using both the calculated load at Vicksburg and the measured load at Coochie and Union Point, sediment inflow values for a range of discharges were developed for each size class. During the calibration phase of the study, it was determined that a portion of the very fine sand class deposited between Vicksburg and Coochie / Union Point. In order to obtain the correct very fine sand transport at Coochie / Union Point, the very fine sand inflow was increased by 33 percent.

Initial bed material gradations in the MVK model were derived from particle size distribution of bed sediments collected along the thalweg of the Mississippi River by Nordin and Queen in 1989. One hundred seventy-six (176) samples were collected between Vicksburg, MS and Head of Passes. Of those samples, 25 were collected between Belle Chasse and Head of Passes. Nordin did not collect any samples in Southwest Pass. The location along with the D_{16}, D_{50}, and D_{84} of each of the Nordin samples within the Belle Chasse to Head of Passes reach is provided in Table 4.2.

Once the Nordin bed material gradations were input into the model, a 2 year discharge of 1,289,000 cfs was run for 30 days. This channel forming discharge allows the model to rework the bed material gradations to those that best represent the channel conditions. These new bed material gradations are then used as the initial gradations for the model.

Other model input requirements include water temperature and the downstream water surface elevations boundary condition. For the regional MVK model, average monthly water temperatures were computed from observed data at Tarbert Landing for the 1992 through 2002 time period. For downstream water surface elevations, monthly average stages for the NOAA gage at Grand Isle East Point were used even though a long term USACE gage exists at East Jetty in Southwest Pass. MVK stage analyses discovered inconsistencies in the reported stages at the East Jetty gage. A comparison of linear regression curves for the gages shows stages at East Jetty to be higher than stages at Head of Passes (RM 0.0) and Venice (RM 10.7) for discharges at Tarbert Landing up to 1,100,000 cfs. The nearest gage with a complete record is the NOAA Grand Isle East Point gage. Stages at this gage correlate well to the short term NOAA gage at Pilots Station in Southwest Pass for 2004 – 2008. Therefore, the 1992 – 2002 stages at Grand Isle East Point were used to determine average monthly stages for the MVK HEC-6T model.

Flow distribution and sediment concentration ratios at each diversion / distributary are input model requirements. Table 4.3 provides the locations of the diversions / distributaries contained in the MVK model. The model simulation period extends from 1991 through 2002. Neither the Davis Pond Diversion nor the West Bay Diversion was included in the model since the Davis

Pond Diversion was not opened until 2002 and the West Bay Diversion was not opened until 2003. For the diversions / distributaries that were included, flow discharge through each diversion / distributary was modeled as a percentage of the discharge in the Mississippi River upstream from that diversion / distributary. When available, the percentages were estimated from measured data. When no measured data was available, the percentage of flow in the diversions was calculated. For the outlets in Southwest Pass, the diverted flow

Table 4.2. Bed Material Sample Locations and Sizes (As Collected By Nordin in 1989)

Sample Location (1989 River Mile)	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)
75.2	0.13 FS	0.16 FS	0.20 FS
73.1	0.17 FS	0.23 FS	0.34 MS
65.8	0.18 FS	0.22 FS	0.29 MS
63.0	0.34 MS	0.45 MS	0.60 CS
59.0*		0.00	0.02 MSilt
57.0	0.14 FS	0.18 FS	0.23 FS
55.4	0.15 FS	0.19 FS	0.25 FS
52.8	0.17 FS	0.21 FS	0.26 MS
51.2	0.11 VFS	0.14 FS	0.18 FS
47.3	0.15 FS	0.23 FS	0.33 MS
44.8	0.14 FS	0.17 FS	0.20 FS
42.8	0.17 FS	0.23 FS	0.32 MS

40.0	0.12 VFS	0.16 FS	0.20 FS
37.0	0.17 FS	0.21 FS	0.25 FS
35.2	0.18 FS	0.24 FS	0.32 MS
33.0	0.26 MS	0.30 MS	0.36 MS
30.4*	0.01 FSilt	0.14 FS	0.19 FS
26.0	0.17 FS	0.20 FS	0.23 FS
23.9*	0.00	0.02 MSilt	0.07 VFS
21.9	0.15 FS	0.18 FS	0.23 FS
18.0*	0.00	0.00	0.01 FSilt
13.5	0.11 VFS	0.14 FS	0.18 FS
11.9*	0.08 VFS	0.11 VFS	0.15 FS
5.5*	0.13 FS	0.15 FS	0.18 FS
2.8	0.13 FS	0.16 FS	0.20 FS

* Samples that Contain a Significant Amount of Clay and Silt
Legend: FSilt = Fine Silt MSilt = Medium Silt VFS = Very Fine Sand
FS = Fine Sand MS = Medium Sand CS = Coarse Sand

percentages were directly related to the widths of the outlets. For the above Venice to Head of Passes reach, the outflow through the diversions was estimated from measured data. For those diversions / distributaries whose flow percentage changed with time, an average percentage for the 1992 – 2002 time period was adopted for the calibration simulations. Flow over the Bohemia Spillway and through the Bonnet Carre' and Morganza Floodways only occurs during flood flows. The diversion percentage of flow over the Bohemia Spillway was calculated. Diversion percentages at Bonnet Carre' and Morganza were assigned in the model to match the operation schedules. The Caernarvon Diversion structure is controlled and its operation is not a direct function of Mississippi River flows. Flow through this diversion was calculated based on the assumption that the gates would remain open during the entire simulation. For the Old River Complex that includes the Auxiliary Structure, Low Sill Structure, Overbank Spillway, and Hydropower Structure, percentages of flow distribution are average discharges for the 1991 – 2002 period of record.

Table 4.3. Diversion / Distributary Locations

Reach	Diversion / Distributary	River Mile
Southwest Pass	Burrwood Bayou	-14.4
	Outlet W-2 and Overbank Flow	-9.8
	Joseph Bayou	-4.5
	Soutwest Pass At Mile 3.0 West	-3.0
Head of Passes to Above Venice	South Pass and Pass a Loutre	0.0
	Cubits Gap and Overbank Flow	3.0
	Grand Pass (The Jump)	10.5
	Baptiste Collette Bayou	11.5
Above Venice to Tarbert Landing	Bohemia Spillway	33 - 45

	Caernarvon Diversion	81.4
	Bonnet Carre' Floodway	127 – 129
	Morganza Floodway	280
Above Tarbert Landing	Old River Complex	311.5 – 316.5

The sediment concentration ratio required by the model is the sediment concentration in the diverted flow compared to the sediment concentration in the river immediately upstream of each diversion. Ratios are input into the model by grain size for a range of flow conditions. The sediment concentrations for the Old River Complex were derived from available measured data. For the remaining diversions / distributaries, estimates of vertical sediment concentration were computed using the Rouse equation. Sediment diversion ratios were calculated for each size class by comparing the average Mississippi River bed elevation with the diversion sill or inlet channel elevation. This methodology accounts for vertical variation in sediment concentration. Typically, inlet channels at diversions are at a higher elevation than the average bed of the river and draw flow from the upper portion of the water column in the river. Coarse sediment concentrations are higher at the bottom of the water column, while fine sediment is more evenly distributed in the water column. Therefore, the concentration diversion ratios will be higher for finer sediment than for coarser sediment.

For the MVK model, the sediment transport function selected was the combined Toffaleti-Meyer-Peter Muller function. With this function, bed load is calculated using the Toffaleti and the Meyer-Peter Muller methods and the larger of the two is used. Suspended bed-material load is calculated using the Toffaleti method. The Toffaleti-Meyer-Peter Muller function is capable of calculating both sand and gravel transport rates by size class. The Toffaleti equation was developed for large, sand bed rivers like the Mississippi River and has been used successfully on previous model studies of the Lower Mississippi River. The Meyer-Peter Muller equation was developed for gravel transport and is important in the regional MVK model to facilitate the transport of gravel size classes known to be in the river bed in the Memphis District reach.

While HEC-6T does not provide for the direct impact of salinity, this impact can be approximated by varying the silt and clay shear threshold deposition coefficients. For the MVK model, the deposition coefficients for both silt and clay were increased downstream of Venice and the coefficient for clay was further increased in Southwest Pass to account for the effects of salinity on sediment deposition. The model allows for varying the threshold coefficients by reach but does not allow for varying the coefficients with discharge or stage. The salinity throughout the Pilottown Anchorage Area (PAA) varies greatly with discharge. During low flow, the salinity is much higher than during high flow periods. The variance is deemed reasonable since the deposition coefficients were determined during model calibration by comparing computed dredge volumes to those reported in Southwest Pass and between Head of Passes and Venice. Therefore, the model accounts for the long term impact of salinity on sediment transport through the reach.

Once the 1-dimensional model has been developed, calibration of both water surface elevations and sediment is required. Water surface elevations are calibrated through channel roughness coefficients. For the MVK model, water surface elevations were calibrated to observed data from 9 gage stations. Table 4.4 identifies the gages and their locations.

Table 4.4. Gage Locations For Water Surface Elevations Calibration

Gage	Location
Venice	RM 10.7
Empire	RM 29.5
West Pointe A La Hache	RM 48.7
New Orleans (Carrollton)	RM 102.8
Reserve	RM 138.7
Donaldsonville	RM 175.4
Baton Rouge	RM 228.4
Bayou Sara	RM 265.4
Red River Landing	RM 302.4

Model roughness coefficients were initially determined in the calibration phase by using the initial cross section geometry with the model in the fixed bed mode. Roughness coefficients were adjusted to regression equations for observed data at each gage. Water surface profiles calculated by the movable bed model for a range of discharges at Tarbert Landing were compared to water surface elevations calculated from the regression equations developed from observed data at each gage. Roughness coefficients determined during the initial fixed bed calibration produced reasonable results during the movable bed simulation.

Sediment is usually calibrated by running a hydrograph for a given period of time and comparing computed sediment transport and bed erosion and deposition locations and quantities to observed values. Also, if dredging is conducted and records are available, calibration to dredging locations and quantities is an option. For the MVK effort, the model was calibrated to observed deposition downstream of the Old River Control Complex and to observed erosion at

Smithland Crossing. The model was also calibrated to measured sediment transport at the Tarbert Landing (RM 306.3) and Belle Chasse (RM 76.0) gages. Calibration also included the simulation of reported dredging volumes in Southwest Pass and Above Head of Passes.

ERDC Modified HEC-6T Model

For the West Bay Diversion evaluation, ERDC used the MVK regional HEC-6T model as the base model. Appropriate modifications were made to the model to accurately depict the West Bay Diversion reach conditions. The first modification included the addition of cross sections through the Belle Chasse to Head of Passes reach to better define the channel geometry through that reach. Table 4.5 presents a comparison of the number of cross sections by reach in the MVK base model and the modified ERDC model. The greatest increase in cross section density occurred in the Head of Passes (RM 0) to Vencie (RM 10.6) reach. This reach includes the Pilottown Anchorage Area and is the primary reach of interest for this study. Cross sections were also added throughout the Venice (RM 10.6) to Belle Chasse (RM 76.0) reach. No cross sections were added in the Southwest Pass (RM -18.0) to Head of Passes (RM 0.0) reach or in the Belle Chasse (RM 76.0) to Vicksburg (RM 437.28) reach.

Table 4.6 provides a comparison of the MVK and ERDC model cross section locations between Head of Passes (RM 0) and Belle Chasse (RM 76). Within the Head of Passes (RM 0) to Venice (RM 10.6) reach, the ERDC model contains 19 cross sections which provide an average cross section spacing of 0.56 miles. The Pilottown Anchorage Area extends from RM 1.5 to RM 6.7. Through that reach, the ERDC model contains 12 cross sections. Eight of those sections are located downstream of the West Bay Diversion. The average cross section spacing through the Pilottown Anchorage Area reach is 0.425 miles. The data for all cross sections added to the model were obtained directly from the 1992 comprehensive hydrographic survey.

Table 4.5. Comparison of Number of Model Cross Sections By Reach

Reach	MVK Model No. Cross Sections	ERDC Model No. Cross Sections
Southwest Pass (RM -18 – RM 0 At Head of Passes)	13	13
Head of Passes (RM 0) to Venice (RM 10.6) Pilottown Anchorage Area (RM 1.5 – RM 6.7)	8 5	19 12
Venice (RM 10.6) to Belle Chasse (RM 76)	21	38
Belle Chasse (RM 76) to Vicksburg (RM 437.28)	159	159
Total	201	229

Table 4.6. Comparison of Model Cross Section Locations (Head of Passes (RM 0) to Belle Chasse (RM 76))

Reach	MVK Model Sections (RM)	ERDC Model Sections (RM)
Head of Passes (RM 0) to Downstream End of Pilottown Anchorage Area (RM 1.5)	0.72	0.72
		0.98
Pilottown Anchorage Area (RM 1.5 to RM 6.7)	1.6	1.6
		1.7
	2.46	2.46
		2.75
		3.36
	3.83	3.83
		4.26
		4.46
		4.9
	5.5	5.5
		6.0
	6.7	6.7

Upstream End of Pilottown Anchorage Area (RM 6.7) to Venice (RM 10.6)	8.1	7.5
		8.1
		8.8
	9.5	9.5
		10.3
Venice (RM 10.6) to Belle Chasse (RM 76)	11.05	11.05
		11.8
	12.5	12.5
		13.4
	14.1	14.1
	15.4	15.4
	17.0	17.0
		18.0
		19.1
		20.0
		21.0

	22.4	22.4
		23.2
	24.0	24.0
		25.0
	26.1	26.1
	24.0	24.0
		25.0
	26.1	26.1
		28.0
		30.0
	32.0	32.0
		33.6
	35.1	35.1
	39.3	39.3
	43.2	43.2
	45.2	45.2
	49.0	49.0
	53.0	51.1

		53.0
	55.0	55.0
	57.0	57.0
		59.0
		60.9
	62.9	62.9
		65.0
		67.0
	69.0	69.0
		71.0
	73.0	73.0
	75.0	75.0

The ERDC field data collection program included the acquisition of flow distribution, suspended sediment concentrations, and bed material gradations within the study reach. In the HEC-6T model, the percentage of flow leaving the river through diversions / distributaries compared to the flow in the river immediately upstream of that diversion / distributary is an input parameter. Therefore, flow distribution measurements were taken in Baptiste Collette Bayou, Grand Pass, West Bay Diversion, Cubits Gap, Mississippi River upstream of Baptiste Collette Bayou, Mississippi River immediately upstream of West Bay Diversion, Mississippi River immediately downstream of West Bay Diversion, and in various small outlets in the bank of the Mississippi River between Venice and Head of Passes. Figure 4.1 is a plot of the flow distributions at Baptiste

Collette Bayou, Grand Pass, West Bay Diversion, and Cubits Gap for the 2003 through 2009 time period as compared to the flow in the Mississippi River at Venice. The plot includes the data collected by the ERDC Coastal and Hydraulics Laboratory as a part of this study along with previous measurements obtained by the New Orleans District (MVN). Review of this data indicates that for most flow conditions, Baptiste Collette and Grand Pass each diverts approximately 10 to 13 percent of the Mississippi River flow at Venice. Cubits Gap diverts approximately 13 to 18 percent of the flow and West Bay Diversion diverts approximately 5 percent of the flow. Figure 4.2 shows the flow distribution at West Bay Diversion by year. This plot shows the increase in flow over time as the West Bay Diversion has enlarged. For the HEC-6T model evaluation, the flow distribution at West Bay was set at the current rate of approximately 7 percent of the Mississippi River flow at Venice.

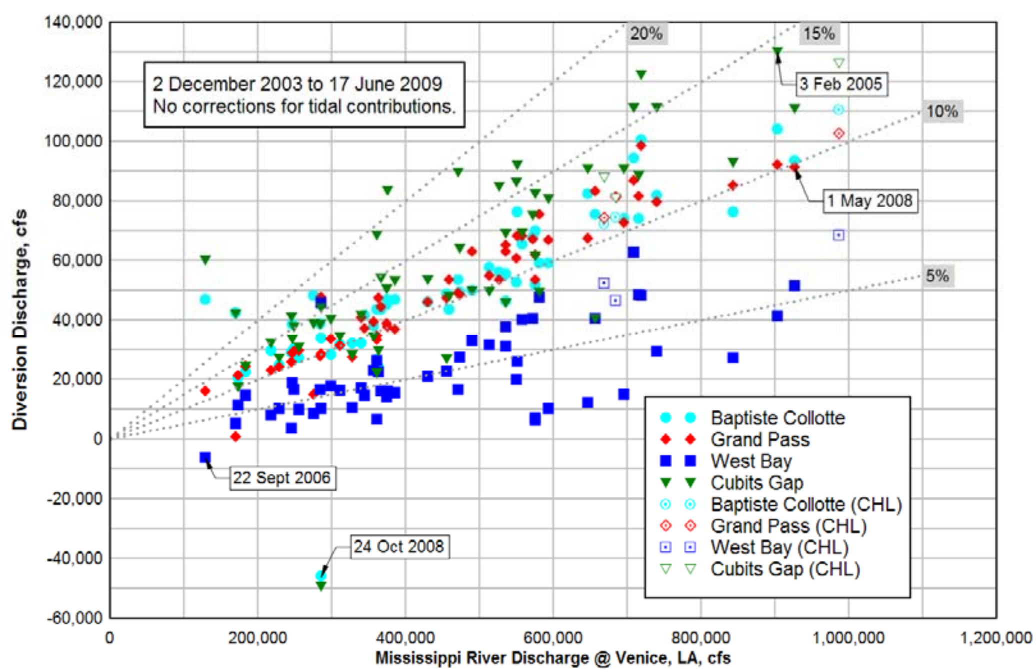


Figure 4.1. Measured Flow Distributions For Baptiste Collette Bayou, Grand Pass, West Bay Diversion, and Cubits Gap (2003 – 2009)

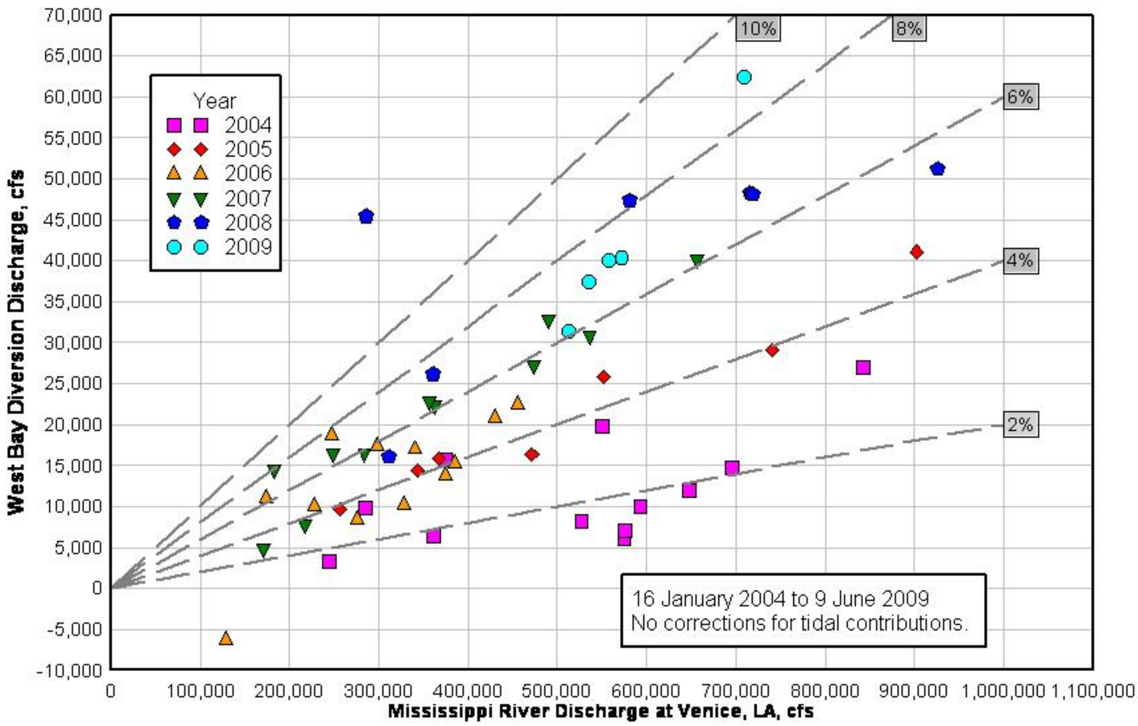


Figure 4.2. Measured Flow Distributions At West Bay Diversion (2004 – 2009)

The ratio of the sediment concentration in the diverted flow to that in the river immediately upstream of the diversion is a model input requirement. The lack of available accurate sediment concentrations for diverted flow has been a weakness of previous 1-dimensional modeling on the Lower Mississippi River. Sensitivity analysis was usually required with sediment diversion concentration ratios varying from 0 to 1. A ratio of 0 means that no sediment is diverted, while a ratio of 1 means that the concentration in the diverted flow is equal to that in the river. The actual concentration ratios usually fall between 0 and 1. MVK reports that for their model, the Rouse equation was used to determine the sediment concentration for the diverted flow. This method estimates diverted sediment concentrations based on the sediment concentration profile in the river and the depth of the diversion inlet verses the average depth of the river. For this study, ERDC Coastal and Hydraulics Laboratory collected suspended sediment measurements at Baptiste Collette Bayou, Grand Pass, West Bay Diversion, and Cubits Gap. Review of the data indicates that to date, not enough data has been collected to accurately define the sediment concentration diversion ratios over a range of flows. Plus, substantial analysis of the data is required to determine a single ratio based on multiple samples. For example, suspended sediment measurements were made for the Mississippi River at Mile 5.2. This site is located immediately upstream of the West Bay Diversion. At that site, suspended sediment samples are collected along 5 verticals across the channel section. At each of those verticals, samples are collected at 5 different depths which results in 25 suspended sediment samples being collected at that location during each sampling trip. In the West Bay Diversion channel, samples were collected along either 2 or 3 verticals at 5 different depths. That results in either 10 or 15 suspended sediment samples being collected in each sampling trip. The model requires a single sediment concentration diversion ratio for each grain size. Therefore, the sediment concentration of each sample must be determined for each grain size and then averaged to determine a single concentration for each sampling trip. A big advantage to the West Bay Diversion evaluation is that multi dimensional modeling is also being conducted. Multi- dimensional models have the ability to compute diverted sediment concentrations. For the West Bay Diversion, the sediment diversion concentration ratios used in the 1-dimensional model were derived from the ADH 2 dimensional model. Figure 4.3 provides the plotted sand size sediment concentration diversion ratios for the West Bay Diversion. This plot represents the rising limb of the 2009 hydrograph and illustrates the complex relationship between diverted sediment concentration, flow, and sediment grain size. The derived values used in the HEC-6T model are provided in Table 4.7 with the diverted flow through West Bay estimated as 7% of the flow passing Venice. For the other diversions in the model, the sediment concentration diversion ratios were determined using the Rouse equation.

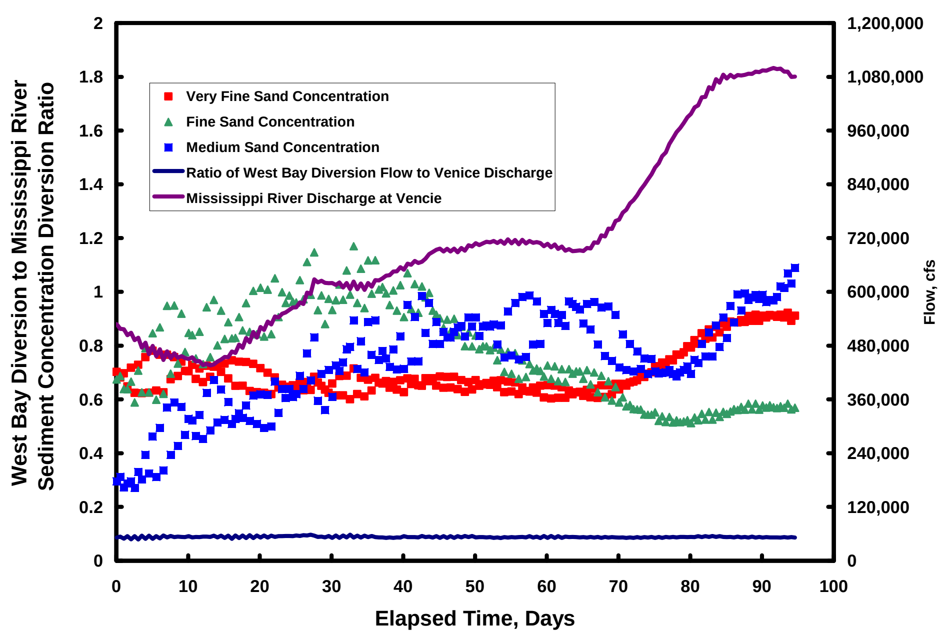


Figure 4.3. Estimated Sand Size Sediment Diversion Ratios for the West Bay Diversion Derived From the ADH 2-Dimensional Model

Table 4.7. West Bay Diversion - Sediment Concentration Diversion Ratios

Diversion Discharge (cfs)	91,000	77,000	49,000	30,800	23,100	1
	Sediment Concentration Diversion Ratio					
Clay	1.0	1.0	1.0	1.0	1.0	1.0
Very Fine Silt	1.0	1.0	1.0	1.0	1.0	1.0
Fine Silt	1.0	1.0	1.0	1.0	1.0	1.0
Medium Silt	1.0	1.0	1.0	1.0	1.0	1.0
Coarse Silt	1.0	1.0	1.0	1.0	1.0	1.0
Very Fine Sand	1.0	0.9	0.65	0.7	0.7	0.0
Fine Sand	0.65	0.57	0.65	0.5	0.5	0.0
Medium Sand	1.0	1.0	0.9	0.5	0.5	0.0

The bed material gradations from the MVK model were derived from running a 2 year frequency discharge through the model for 30 days. This allowed the initial bed gradations derived from the bed material sampling along the thalweg of the Mississippi River as collected by Nordin and Queen in 1989, to rework the bed to gradations produced by the channel forming discharge. As part of the ERDC field data collection program, bed material samples were collected from River Mile 19.6 through Southwest Pass. The grain size distributions for 4 of those sampling sites are presented below. Those sites include BSS-17, BSS- 18, BSS-23, and BSS-26. BSS-17 and BSS-18 are located at RM 5.5, upstream of the West Bay Diversion. BSS-23 and BSS-26 are located at RM 2.5, downstream of the West

Bay Diversion. These sites were selected because a sample was taken by Nordin at these locations, the HEC-6T model includes a cross section at these locations, and because both locations are within the Pilottown Anchorage Area reach. Bed material samples were collected at these sites in March, July, and September 2009. At RM 5.5, BSS-17 is located toward the right descending bank and BSS-18 is located toward the left descending bank. The approximate locations of these sample sites are shown on Figure 4.4. The cross section at RM 5.5 is beginning to resemble a typical channel crossing section with a flatter shape and the thalweg located toward the center of the channel. BSS-17 is located in the anchorage area. Figure 4.5 provides the grain size distribution at Site BSS-17. Figure 4.6 provides the grain size distribution at Site BSS-18. For BSS-17, all three bed material samples collected in 2009 are significantly finer than the sample collected by Nordin. However, the Nordin sample was collected from the channel thalweg and BSS-17 is located more on the adjacent bar. The Nordin sample is 95 percent sand while all three samples collected during 2009 have a much higher concentration of finer material (silt and clay). The sample collected during March is just over 70 percent fine material. Both the sample collected during July and the sample collected in September are approximately 47 percent fine material.

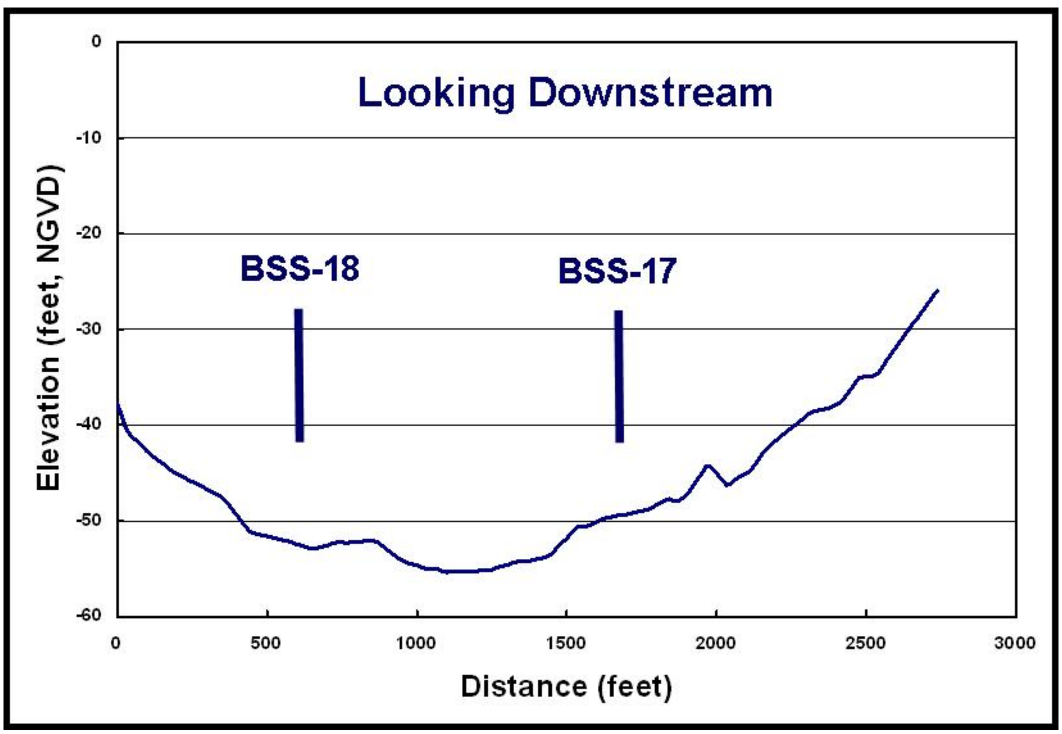


Figure 4.4. Approximate Bed Sample Locations At River Mile 5.5

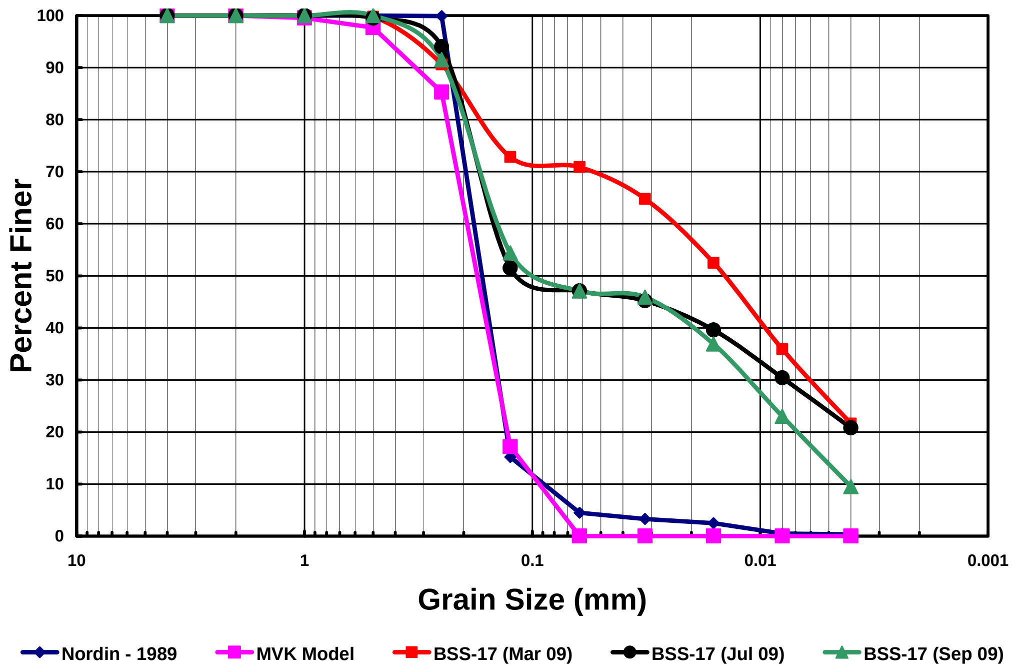


Figure 4.5. Bed Material Gradations At Site BSS-17

For BSS-18, the sampled collected in March replicates the Nordin sample well. As stated, the Nordin sample is 95 percent sand while the BSS-18 sample collected in March is 98 percent sand. The samples collected in July and September are much finer. The sample collected in July is 68 percent fine material while the sample collected in September is 82 percent fine material. The data on Figure 4.6 for BSS-18 indicates a possible seasonal or discharge variation in the grain size distribution.

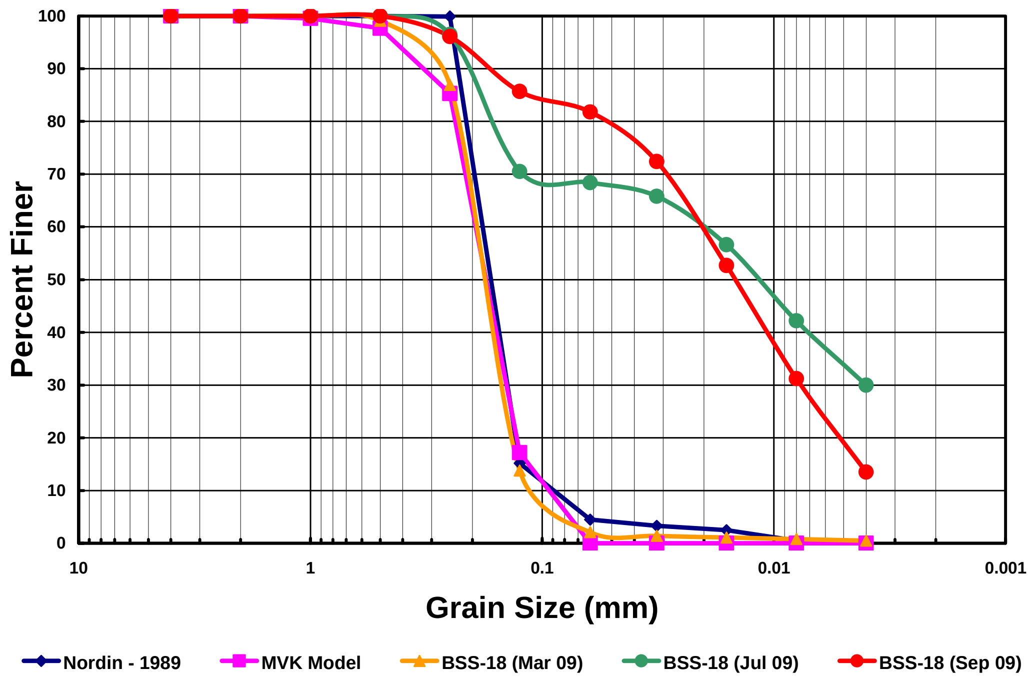


Figure 4.6. Bed Material Gradations At Site BSS-18

At RM 2.5, BSS-23 is located toward the right descending bank and BSS-26 is located toward the left descending bank. The approximate locations of these sample sites are shown on Figure 4.7. The cross section at RM 2.5 has a typical bendway section shape with the thalweg along the outside of the bend and a point bar formation on the inside of the bend. BSS-23 is located in the anchorage area. Figure 4.8 provides the grain size distribution at Site BSS-23. Figure 4.9 provides the grain size distribution at Site BSS-26. For BSS-23, all three bed material samples collected in 2009 are very similar to the sample collected by Nordin even though the Nordin sample was collected from the channel thalweg and BSS-23 is located on the adjacent bar. All samples are between 96 and 99 percent sand.

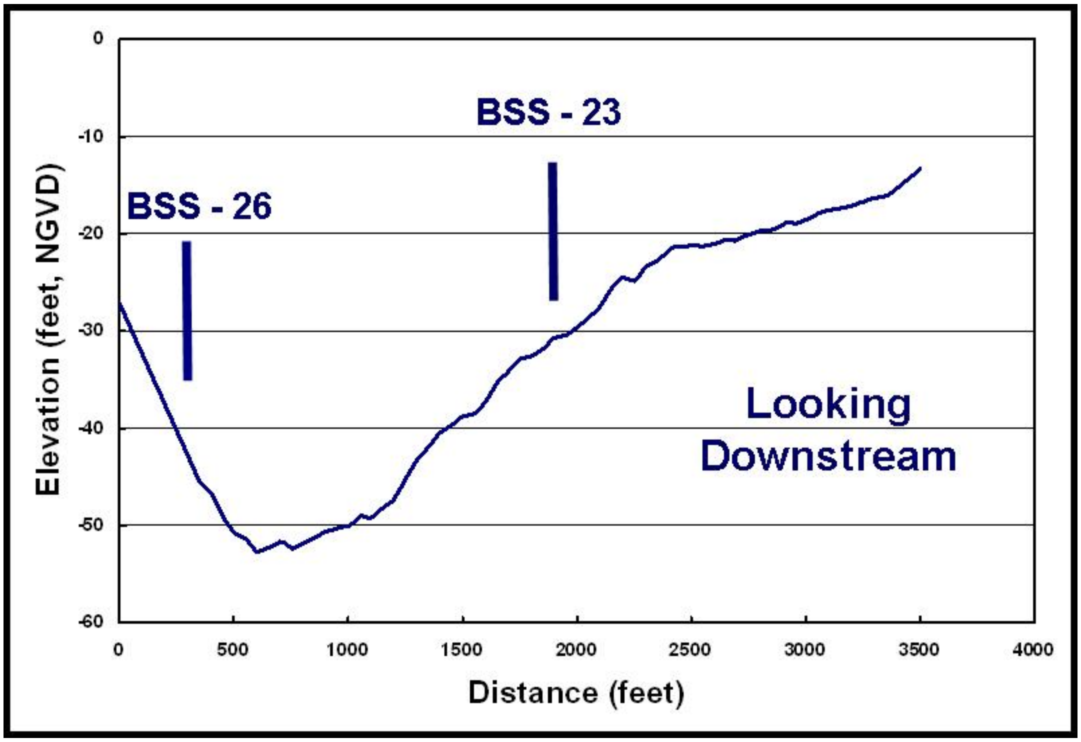


Figure 4.7. Approximate Bed Sample Locations At River Mile 2.5

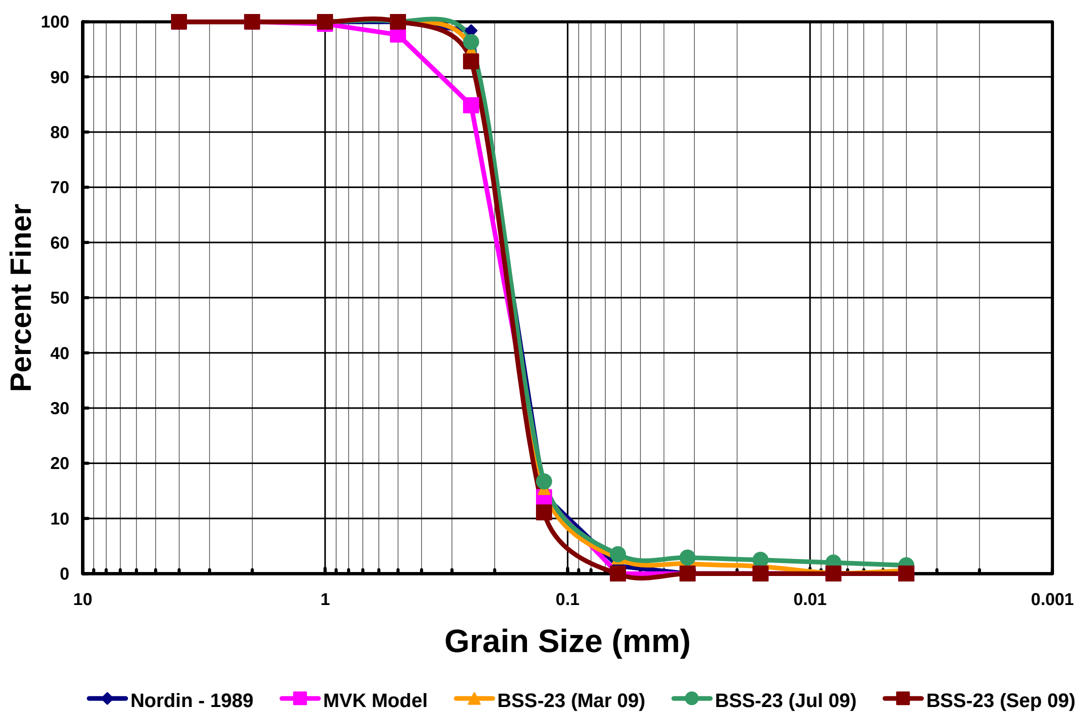


Figure 4.8. Bed Material Gradations At Site BSS-23

For BSS-26, samples were only collected during March and July. The grain size distribution for both of these samples is much finer than the Nordin sample. The March sample is 65% fine material and the July sample is 60 percent fine material while the Nordin sample is approximately 97 percent sand. The data in Figures 4.8 and 4.9 indicate a definite lateral variation in the grain size distribution across the channel at RM 2.5. Due to the variation in the bed material samples, for this effort, bed material gradations in the model were not modified.

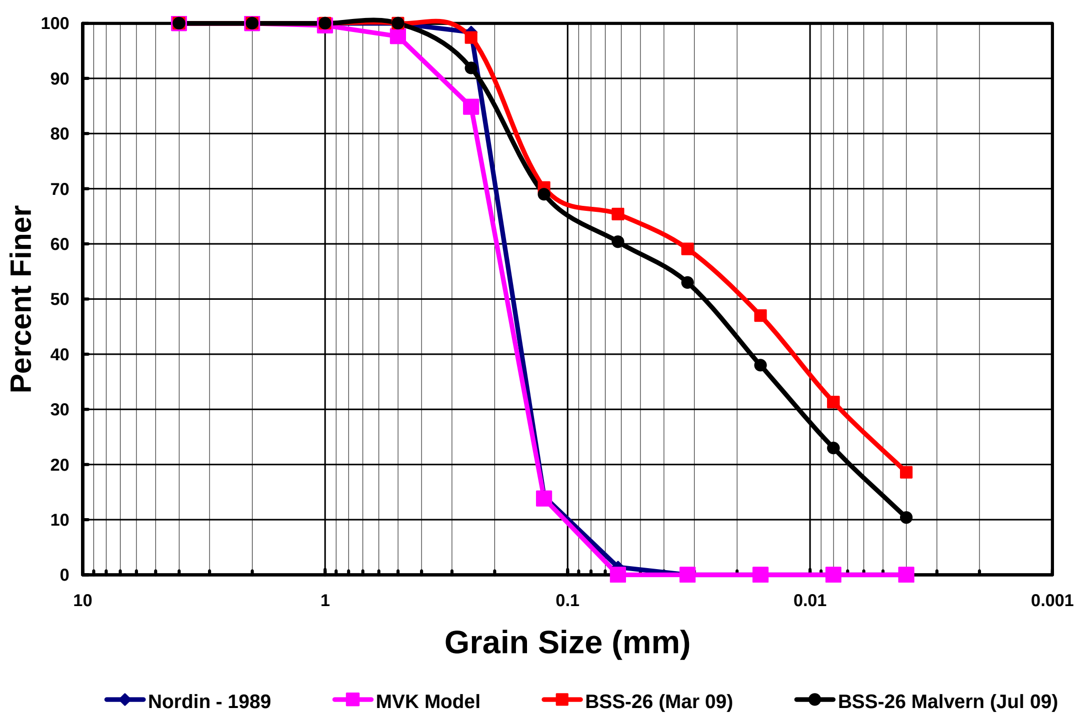


Figure 4.9. Bed Material Gradations At Site BSS-26

In coastal regions, sediment transport in rivers is also influenced by tide and salinity variations. For the MVK model, the downstream boundary condition is average monthly water surface elevation at the NOAA Grand Isle, East Point gage. NOAA reports that the average difference between high and low tides at Grand Isle is approximately 1.05 feet. For the ERDC model, Grand Isle East Point 8:00 AM daily stage is used for the downstream boundary condition. This daily stage over the period of record will vary throughout the daily tidal cycle capturing both high and low tidal conditions. In this domain, tides provide the greatest impact during periods of low flow. During these periods, the river's sediment transport capacity is reduced; however, flow reversals can occur causing the transport of fine grain sediment back into the system and hindering transport of fines out of the system. When said cohesive particles mix with an abundance of ions, due to salinity, flocculation can occur resulting in shoaling. Although sand transport is impeded due to the decrease in fresh water inflow, fine grain sedimentation can actually increase. Here it is important to understand that the model does not account for this process even with the shear stress threshold adjustments.

Since the model channel geometry is referenced to National Geodetic Vertical Datum (NGVD), the downstream boundary water surface elevations must also be referenced to NGVD. NOAA does not report the gage readings at Grand Isle, East Point referenced to any geodetic datum, only to tidal datums. Therefore, a conversion to NGVD is required. NOAA does not provide a conversion for this site. However, previous work has indicated that NGVD at the Grand Isle, East Point gage is equal to the gage reading in mean sea level (MSL) plus 0.8 feet. This corresponds with the conversion utilized by MVK for their model. Figure 4.10 is a conversion furnished by NOAA for a previous ERDC study. Information on Figure 4.9 indicates that NGVD = Mean Tide Level (MTL) + 0.78 feet. According to the Elevation on Station Datum on the NOAA Tides and Currents web site, the difference between MSL and MTL at this gage is 0.01 feet. Adding this difference would be insignificant in a 1-dimensional model, especially given the additional uncertainties in relative sea level rise and subsidence in this area. Therefore, for the ERDC model, 0.8 feet is added to the Grand Isle East Point MSL gage readings to determine the daily downstream water surface elevations.

Figure 4.10. Datum Conversions for the NOAA Gage at Grand Isle East Point, Louisiana

In south Louisiana, both subsidence and sea level rise are significant issues. HEC-6T directly accounts for subsidence. Reported subsidence rates vary from different sources. For the model, subsidence rates were derived from NOAA Technical Report NOS/NGS 50, Rates of Vertical Displacement at Benchmarks in the Lower Mississippi Valley and in the Northern Gulf Region authored by Kirk D. Shinkle (National Geodetic Survey) and Dr. Roy K. Dokka (Louisiana State University) in July 2004. Table 4.8 provides the subsidence rates. Subsidence rates vary from 22 mm/year at RM 22 to 3 mm/year at RM 306. Based on the available data, the subsidence rate at Venice is 16 mm/year. This rate equates to approximately 31.5 inches of subsidence over the 50 year simulations. Subsidence rates in NOAA Technical Report NOS/NGS 50 were computed with an eustatic sea level rise of 1.25 mm/year at Grand Isle. The daily stages were increased at this rate for the 50 year simulations.

Table 4.8. Subsidence Rates Along The Lower Mississippi River

Location	River Mile	Subsidence Rate (mm/year)
Southwest Pass Outlet	-20	16
Venice	10.6	
	11	16
	16	16
	20	20
	22	22
	27	15
	32	12
	35	10
	38	14
	45	13
	49	10
	60	8
	68	7
Belle Chasse	76	
	78	8

New Orleans	102	
	135	9
	216	8
Baton Rouge	230	9
	237	6
	240	4
	266	4
	306	3
Vicksburg	435	
	440	6

The upstream hydraulic boundary condition for the HEC-6T model is water discharge. Water discharge input, in the model, is in the form of a histograph, a time series of inflows of constant or varying durations describing a representative inflow for each event in the series. For these simulations, a typical average daily flow hydrograph was selected and used as a constant duration histograph. This hydrograph includes the 25 year period from 1 January 1984 to 31 December 2008. Figure 4.11 describes the typical hydrograph. The hydrograph shows that during the 25 year period, there are 14 separate flow events that equaled or exceeded the 2 year frequency flow, 6 events that equaled or exceeded the 5 year frequency flow, 3 events that equaled or exceeded the 10 year frequency flow, and 1 event that exceeded or equaled the 20 year frequency flow. The 1984 through 2008 hydrograph also has several low water years such as 1988, 2000, and 2007. The 25 year hydrograph was repeated for the 50 year simulations. One of the unknowns in the modeling effort is the accurate prediction of future stages. Model computed sediment loads, deposition and erosion locations, and trends can vary if larger floods or drier periods occur more frequently than contained in the typical hydrograph.

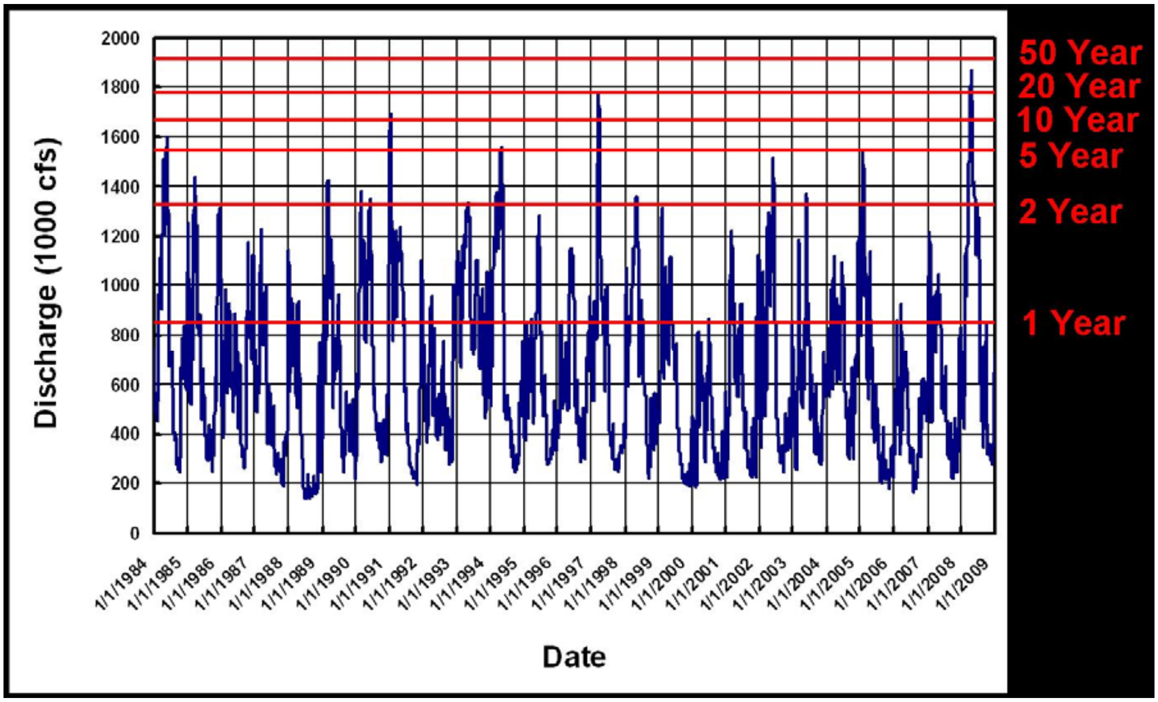


Figure 4.11. Typical Discharge Hydrograph At Vicksburg, MS

Additional model impacts include man induced impacts that includes dredging. HEC-6T allows for dredging of the channel by specifying the bottom elevation and lateral extent of the dredge template. The reach of the Mississippi River through the Pilottown Anchorage Area is unique in respect to dredging requirements. Currently the USACE New Orleans District maintains a 750 foot wide navigation channel. The navigation channel through that reach is dredged to an elevation of -51 feet to accommodate the -45 foot channel plus 6 feet of overdepth dredging / advance maintenance. Parts of the navigation channel, especially the reach from Cubits Gap to Head of Passes require dredging annually or more frequently. A 250 foot wide section of the Pilottown Anchorage Area is dredged to various depths (-48, -44, and -41 feet located as upstream, mid, and downstream respectively) along its length. This dredging is conducted once every 3 years. HEC-6T does not allow for separate dredging templates or for a complex template with varying depths in the template. Therefore, for the West Bay Diversion evaluation, a composite template was developed. This template attempts to simulate the combined navigation channel and anchorage area dredging. Developed by combining the areas of the navigation channel and anchorage area the dredging template uses a composite width. The bottom elevation of the composite template is -50 feet with a bottom width between 940 and 970 feet dependent on the depth of dredging in the anchorage area. This template is used for both simulations where dredging in the Pilottown Anchorage Area scenarios are turned on. For the model both the navigation channel and anchorage area are dredged twice a year, on January 1 and July 1. However, the anchorage area is dredged on a three year cycle. This results in an over estimation of the required dredging, since the model fills the dredge channel before deposition is allowed in the remainder of the channel.

For this effort, the Toffaleti sediment transport function was used. This function was developed for use on large, sand bed rivers like the Mississippi River and has been used successfully on previous 1-dimensional model studies on the Lower Mississippi River.

Discussion of Results

For the West Bay Diversion evaluation, four separate scenarios were modeled. Those scenarios include:

West Bay Diversion Closed and No Dredging Allowed In The Pilottown Anchorage Area

West Bay Diversion Closed and Required Dredging Allowed In The Pilottown Anchorage Area

West Bay Diversion Open and No Dredging Allowed In The Pilottown Anchorage Area

West Bay Diversion Open and Required Dredging Allowed In The Pilottown Anchorage Area

All 4 scenarios included required dredging in the navigation channel. Currently the model behaves appropriately in the area of interest. However; sediment deposition quantities and therefore, dredge quantities in Southwest Pass do not match observed quantities. The model is computing less than observed. However, the model responds well through the other reaches. Thomas and Chang state that computation studies fall into two general categories (Thomas and Chang 2008). Those categories being computational model studies and computational analysis studies. Computational model studies are those for which the model has been calibrated according to formal procedures. Even when a formal calibration is not possible often computational modeling is the best method for analyzing sediment problems (Thomas and Chang 2008). In these cases, model tests are devised so that engineering judgment can be used to assess the credibility of the calculated results. This is what Thomas and Chang term computational analysis studies. For these studies, relative differences in sediment transport loads, sediment deposition, and erosion quantities are computed and will be the case for this modeling effort.

As output, the HEC-6T model provides total sediment loads passing each cross section as well as deposition and erosion locations and quantities. Figure 4.12 is a plot of the total sediment load passing each cross section between RM 80 and RM -20 at the end of the 50 year simulation for each of the 4 scenarios. The total sediment load is the combined sand, silt, and clay loads and is presented as relative load compared to the total sediment load passing RM 12.5. Any downward trend in the plot represents reduced sediment load which would indicate sediment is being diverted and/or sediment deposition is occurring. As the plot shows, the total sediment loads for all 4 scenarios upstream of the West Bay Diversion are extremely similar. The total sediment loads at Belle Chasse (RM 76) are approximately 1.06 times those at RM 12.5. Since there are no major distributaries / diversions between Belle Chasse and RM 12.5, the reduced total sediment loads would indicate that this reach is slightly aggradational. As expected, the first big drop in the total sediment load occurs just upstream of Venice at Baptiste Collette Bayou. At that location, the total sediment load is reduced by 10%. Another 10% reduction occurs at Grand Pass. This indicates that 20% of the total load at RM 12.5 is diverted through Baptiste Collette and Grand Pass. Immediately downstream of Grand Pass, the plot is relatively flat to about Mile 7. From that point downstream to just upstream of the West Bay Diversion, the plot begins to trend downward, indicating sediment deposition is occurring in that reach. For the two scenarios with the West Bay Diversion closed, the plot continues to trend downward to Cubits Gap, indicating that the reach is aggradational even without the West Bay Diversion in operation. For the two scenarios with the West Bay Diversion open, an approximate 7% reduction in the total sediment load is computed at this diversion. For these scenarios, the reach between West Bay Diversion and Cubits Gap trends downward, again indicating sediment deposition through this reach. At Cubits Gap, between 13% and 15 % of the total sediment load is being diverted. In the reach from Cubits Gap to Head of Passes, the plot trends downward approximately 3%. Finally, at Head of Passes, approximately 20% to 25% of the total load is diverted through Pass A Loutre and South Pass.

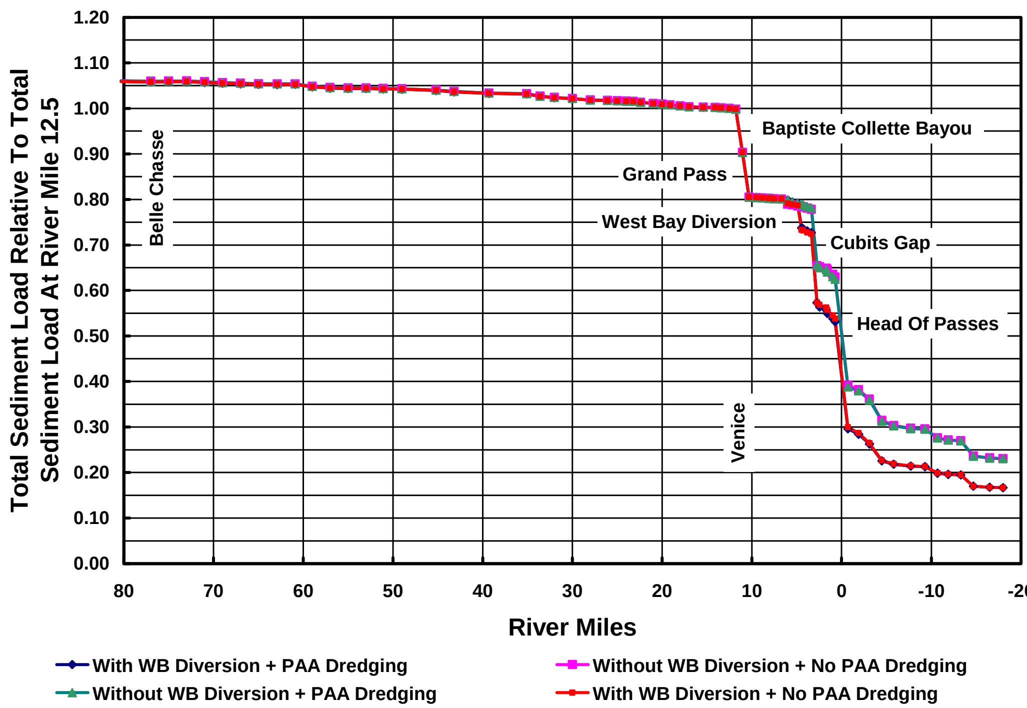


Figure 4.12. Total Sediment Load For The Mississippi River Between RM 80 and RM -20 Relative to Total Sediment Load at River Mile 12.5

Figure 4.12 shows that approximately 46% of the total sediment load at RM 12.5 is diverted or deposited between that location and Head of Passes with the West Bay Diversion open. This value is consistent with but slightly lower than recent suspended sediment load measurements. Only approximately 38% of the total load at RM 12.5 through the same reach is diverted or deposited with the West Bay Diversion closed. Of the 8% difference, only 5% is being diverted and/or deposited at the West Bay Diversion (between cross sections 4.9 and 4.46) while the remaining 3% is deposited and/or diverted downstream above Head of Passes. Note that the deposition rates (line slope between diversions in Figure 4.12) are significantly higher between Cubits Gap and Head of Passes and in the upper reaches of Southwest Pass than in other portions of the model. Deposition rates vary by sediment type. In the model, very little clay is deposited upsteam of Head of Passes while about half of the total sand load at RM 12.5 is diverted or deposited in the reach downstream to Head of Passes. No significant deposition of silt was noted in the model upstream of Baptiste Collette Bayou.

Figures 4.13-4.14 show a comparison of the impacts of the West Bay Diversion on the initial and final (year 50) computed cross-sections at River Mile 3.83 located between West Bay Diversion and Cubits Gap for both dredging scenarios. (This cross-section was selected to illustrate general model behavior in an interesting reach for the purpose of this report. There are significant reach to reach variations in model behavior.) For both dredging scenarios, the simulations with West Bay Diversion open produced significantly greater deposition in the portion of the channel outside the dredging template. (The dredged channel is represented by the horizontal line beginning at about station 51+00 in the year 50 cross-sections.) Subsidence is applied uniformly to all points in the cross-section but the net downward shift is only visible in the figures for the overbank points outside of the moveable bed portion of the channel.

The same cross-section is shown at 10-year intervals for each alternative in Figures 4.15-4.18. The most obvious impact of the West Bay Diversion is that the portion of the cross-section within the dredging template fills to the bottom of the template within the first 10 years of the simulation (Figures 4.17-4.18) whereas complete filling occurs during the second 10 years when the diversion is closed (Figures 4.15-4.16). For the last three alternatives as shown in Figures 4.16-4.18, a new equilibrium bed (minimal change in bed elevation) is established outside of the dredging template during the second 10 years of the simulation. In these 3 alternatives, almost all of the computed deposition is being removed by dredging after year 20. In the first alternative (Figure 4.15), where only the navigation channel is dredged and West Bay Diversion is closed, the equilibrium bed is obtained during the last 10 years of the 50 year simulations. This alternative had the lowest rate of net deposition and dredging, and therefore takes longer to fill to the equilibrium level.

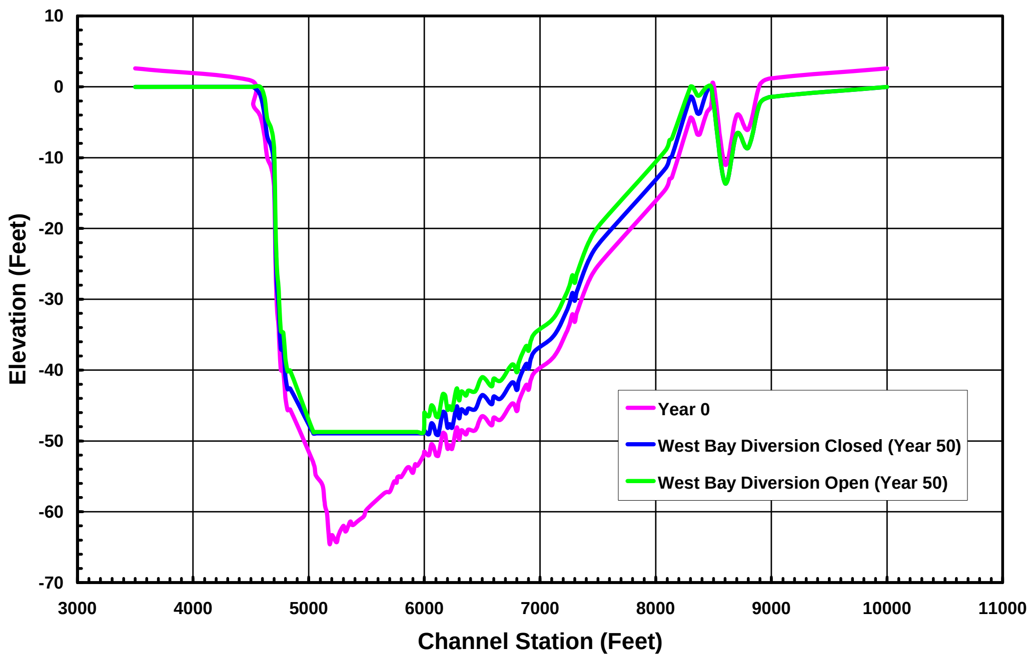


Figure 4.13. Channel Cross Section At River Mile 3.83 At Beginning and End of 50 Year Simulation. Dredging In Pilottown Anchorage Area

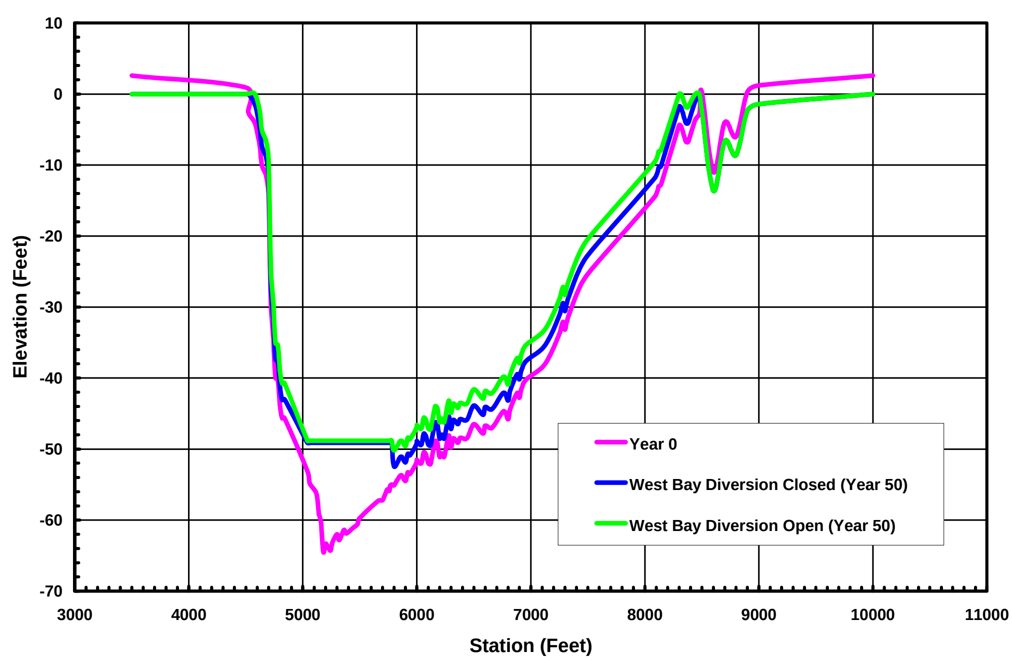


Figure 4.14. Channel Cross Section At River Mile 3.83 At Beginning and End of 50 Year Simulations. No Dredging In Pilottown Anchorage Area

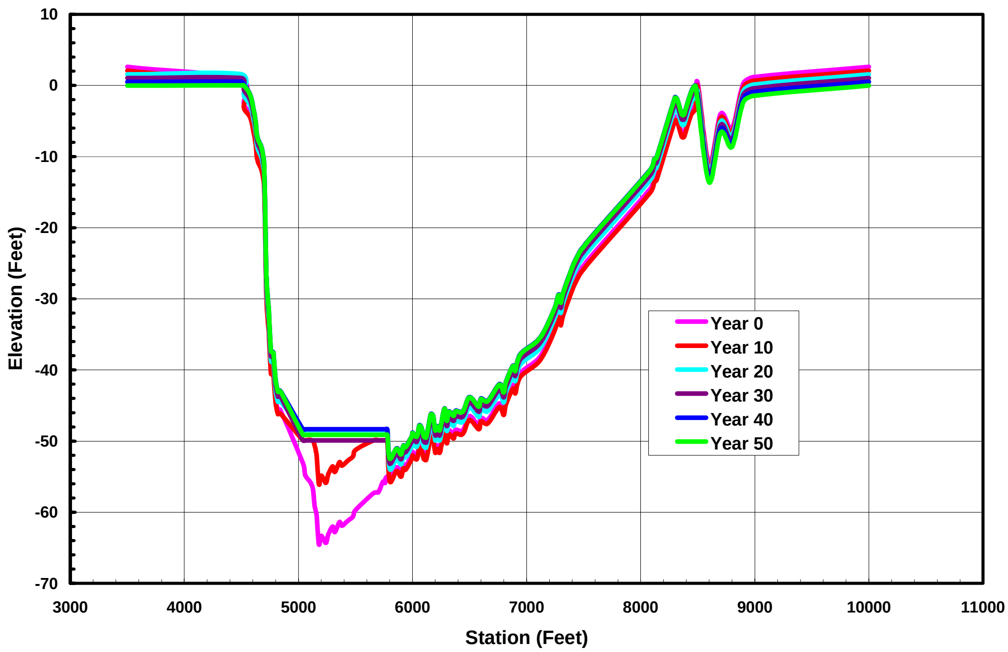


Figure 4.15. Channel Cross Section At River Mile 3.83 In 10 Year Intervals. West Bay Diversion Closed, No Dredging Allowed in PAA

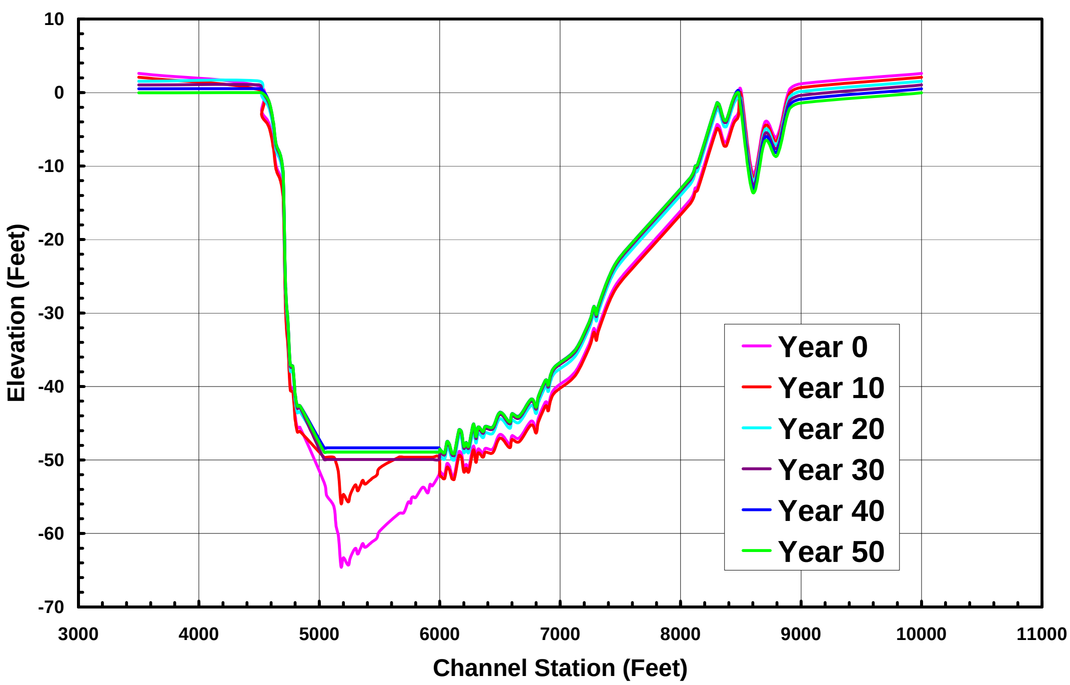


Figure 4.16. Channel Cross Section At River Mile 3.83 In 10 Year Intervals. West Bay Diversion Closed, Dredging Allowed in PAA

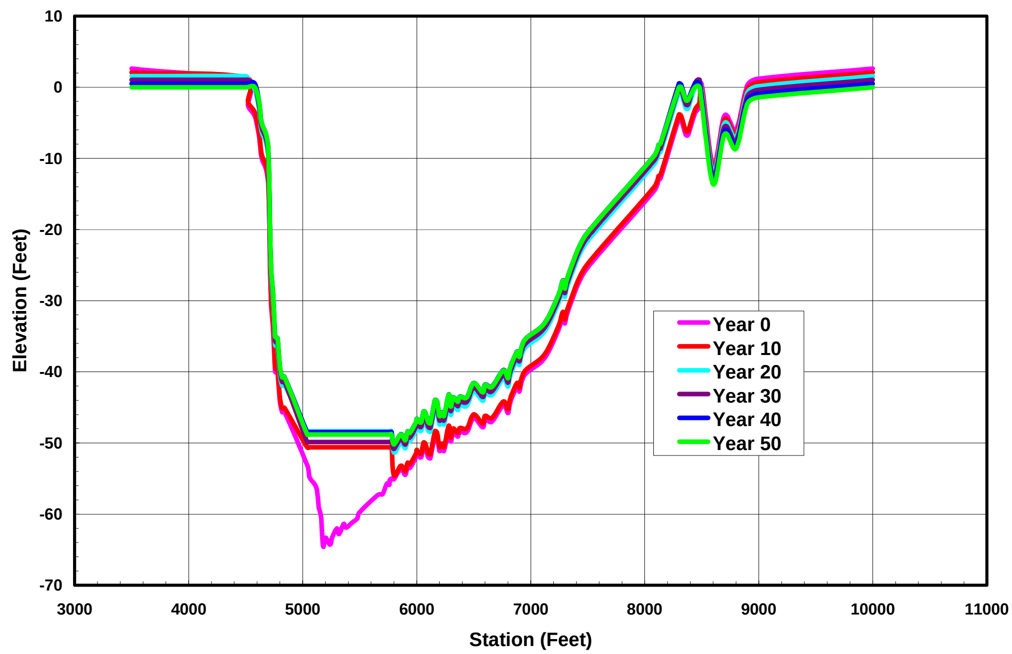


Figure 4.17. Channel Cross Section At River Mile 3.83 In 10 Year Intervals. West Bay Diversion Open, No Dredging Allowed in PAA

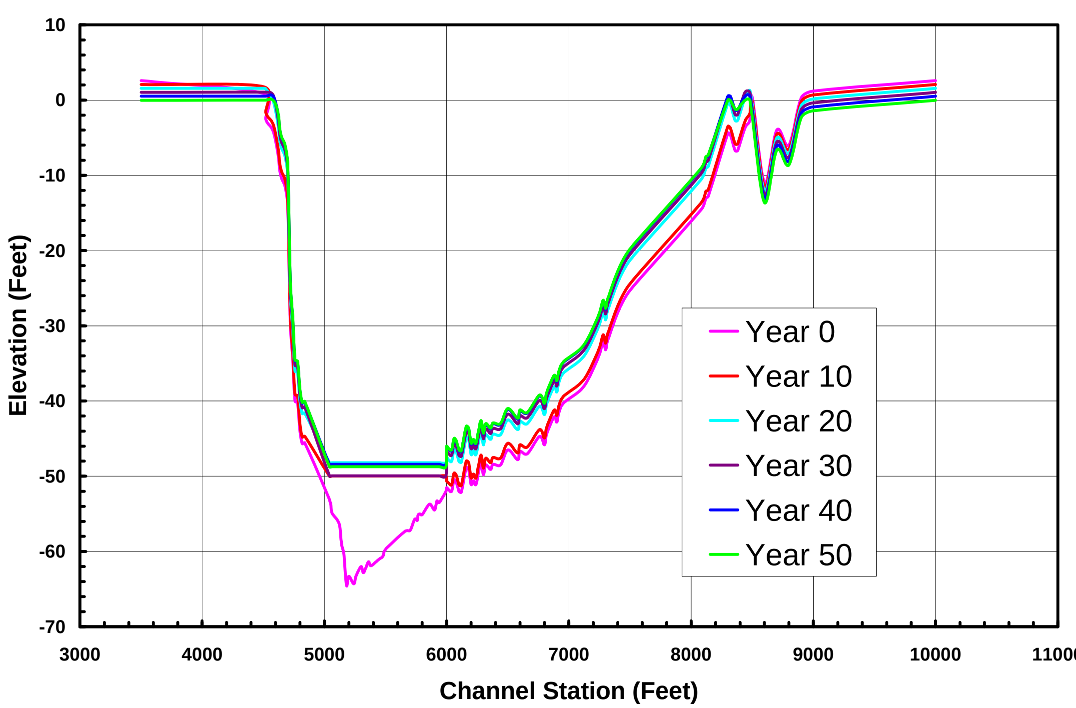


Figure 4.18. Channel Cross Section At River Mile 3.83 In 10 Year Intervals. West Bay Diversion Open, Dredging Allowed in PAA

The response of both dredging templates to the West Bay Diversion in the Venice to Head of Passes reach is summarized in Figure 4.19 by 10 year intervals. Changes in the first decade and to a lesser extent in the second decade include the influence of relatively rapid adjustments in cross-section shape that may not be representative of long-term channel responses. For the current condition (left-hand, blue bars) where both the navigation channel and the anchorage area are being dredged, the model indicates that the West Bay Diversion produces a 25% to 30% increase in dredging. This interpretation must be tempered by remembering that the model is dredging the anchorage area every year rather than on a 3-year cycle.

For the alternatives where only the navigation channel is dredged (right-hand, red bars), the model indicates a larger percentage increase in dredging in response to the West Bay Diversion. However, this percentage increase is being computed from a significantly lower base value and the absolute increase in dredging is slightly smaller than the absolute increase computed for the other dredging template.

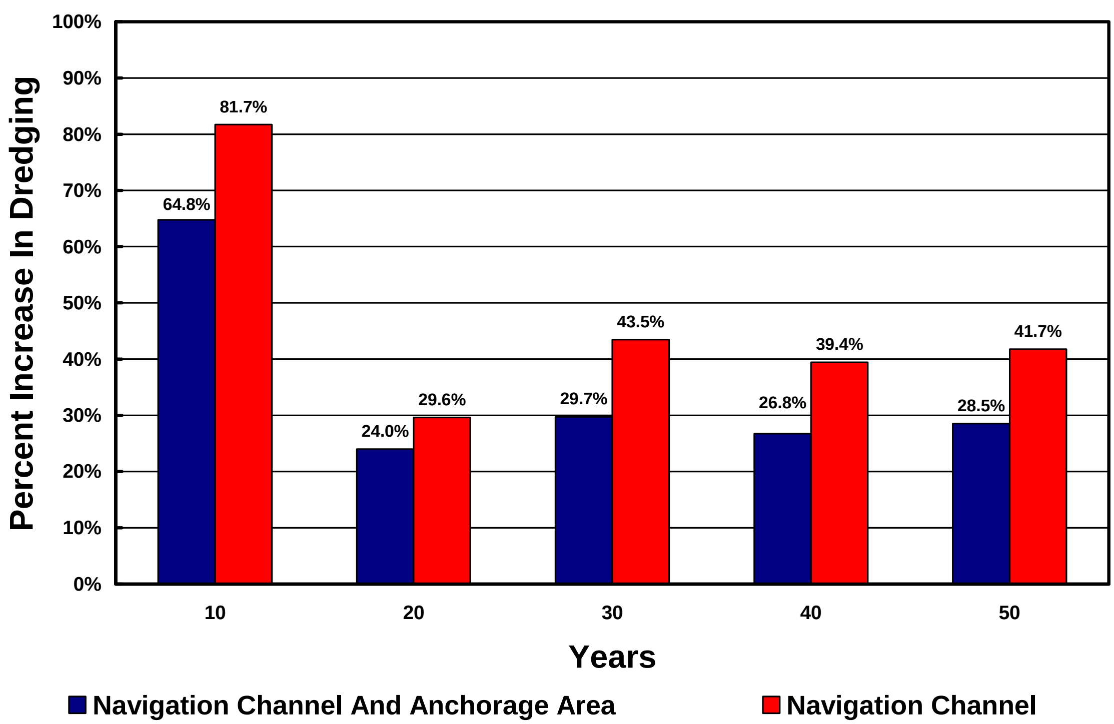


Figure 4.19. Percent Increase In Dredging Due To Opening West Bay Diversion

An alternate view of the same data is presented in Figure 4.20. In this chart, the dredging volumes are presented as the percentage of dredging above Head of Passes that can be attributed to the West Bay Diversion. For the current condition (left-hand, blue bars) where both the navigation channel and the anchorage area are being dredged, the increase in dredging generated by West Bay Diversion constitutes 20 to 25% of the model's estimate of total dredging under current conditions. If only the navigation channel were being dredged (a hypothetical condition shown by the right-hand, red bars), the increase in dredging generated by West Bay Diversion would constitute as much as 30% of total dredging.

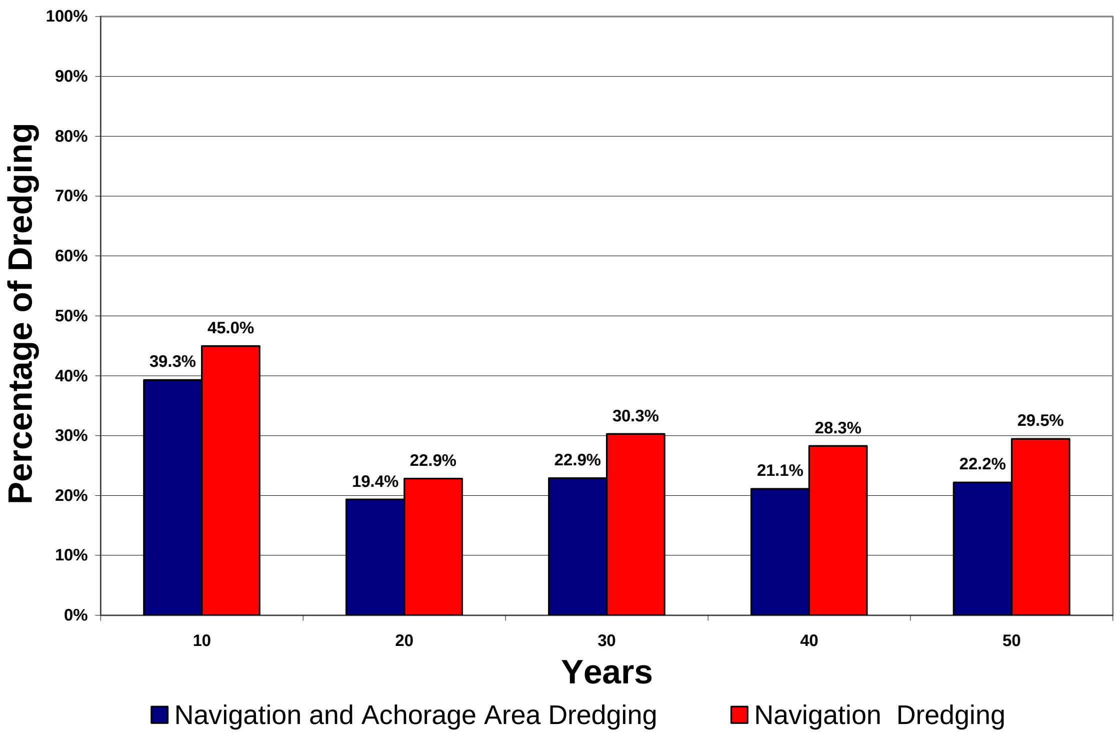


Figure 4.20. Percentage of Current Dredging Due to Opening West Bay Diversion

Sensitivity Analyses

Simulations conducted as modifications were being made to the original model obtained from MVK have provided some insight into the sensitivity of the various inputs which are discussed here in order of decreasing sensitivity.

Modification of the dredging template dimensions and the moveable bed width produced the most significant changes in computed dredging rates. The dredged channel, particularly in its lower reaches, is an efficient sediment trap and increasing the width of the trap produces nearly equal increases in the volume of dredging. Allowing uniform deposition and erosion across the entire bottom width in combination with dredging over a 50 year simulation completely fills the channel outside the dredged template, an unrealistic result. Restricting the moveable bed to the dredging template, permits no significant change in cross-section shape during the simulation, also an unrealistic result where all of the sediment in the cross-section will be dredged during the simulation. A third option that fills the dredge cut before allowing uniform deposition over the entire moveable bed produced reasonable changes in cross-section shape and was selected for use in this study. This option produced some unanticipated changes in the behavior of the model upstream of the study that need further exploration. These changes produced a relatively small increase in the total sediment load at the Venice discharge range that was deemed acceptable for this application of the model.

Previous 1D model studies have focused on the sediment diversion ratio by grain size as a key input determining the potential for deposition downstream of a diversion. As a check on consistency of the model's estimate of West Bay Diversion impacts, a constant sediment diversion ratio of 1.0 was used to specify the sediment diversion at West Bay. As expected, the increase in sediment diversion reduced downstream deposition and computed dredging quantities. This preliminary result was an approximately 2 percentage point decrease in the fraction of the computed dredging attributable to West Bay Diversion (as compared to the last three decades shown in figure 4.20) for the simulation of current conditions.

The bird's foot delta experiences relatively high subsidence rates which have the potential to deepen the river channel or offset some portion of sediment deposition occurring in the channel. Model results to date indicate that computed dredging quantities were significantly reduced with a conservative estimate of regional subsidence. Therefore, the sensitivity of the model to reasonable variations should be investigated.

Replacement of the monthly average stage at the downstream boundary condition with daily stages did not significantly affect computed long-term values of deposition. Sea level rise would be expected to increase deposition. Additional sensitivity testing should be conducted to evaluate the impacts of potential increases in the rate of sea level rise beyond the relatively modest estimate applied to date.

The addition of cross-sections to the model produced some minor redistribution of sediment deposits within the model. In some reaches, e.g. Plaquemines Bend (RM 18-23), the additional resolution shifted the net long-term bed change from erosion to deposition or vice-versa.

As a part of the 12 month effort, various sensitivity analyses are recommended. In the 1-D model, sensitivity analyses include varying specified input parameters to determine what impact changes in those parameters have on model results. Sensitivity analyses conducted in previous Mississippi River 1-D modeling has focused on the sediment concentration in the outflows at diversions / distributaries. Since the sediment concentration diversion ratios for the West Bay Diversion were derived from the 2-dimensional ADH model and since measured data indicates that at some of the modeled diversions some of the ratios might be greater than 1, sensitivity analyses are recommended.

For the West Bay Diversion evaluation, a sensitivity analysis should be conducted for the impact of using different sediment transport functions. Transport rates and scour / deposition locations and volumes can vary with different functions. The MVK model utilized the Toffaleti / Meyer-Peter Muller function. The ERDC model used the Toffaleti function. The Madden – Laursen function should also be used and the results compared to those from the Toffaleti function. Both functions were developed for large rivers. The Toffaleti function has been used successfully in previous Mississippi River studies and other large, sand bed streams. The Madden - Laursen function treats silt as bed load which may be important in the downstream most reaches of the Lower Mississippi River.

Model input includes an upstream hydrograph as a boundary condition. For the ERDC model, a typical hydrograph extending from 1 January 1984 through 31 December 2008 was duplicated for the 50 year simulation runs. A hydrograph with more frequent or higher frequency flood events or a drier hydrograph could have significant impacts on computed sediment transport loads and deposition / erosion rates. Both a wetter and drier hydrograph should be run in order to bracket possible results.

For the ERDC model, the size of the West Bay Diversion was held constant throughout the 50 year simulations. The current diverted flow rate of 7% of the Mississippi River flow was used. Potential future development of the West Bay

Diversion would increase the diverted flow rate well above 7% which would impact the sediment load and aggradation rates through the reach. A sensitivity analysis should be run to determine the impact of projected future development.

Conclusions

The West Bay Diversion can not be analyzed in isolation. It is a part of a complex interacting system of diversions which influence the morphology of the Mississippi River and Passes. An understanding of the response of the system to changes at any one diversion requires an understanding of the response of the system to each and every significant diversion.

Approximately 40-50% of the total flow and sediment passing the Venice discharge range at river mile 12.5 is diverted from the river upstream of Head of Passes at river mile 0. This reach is aggradational with deposition increasing in the downstream direction and concentrated below Cubits Gap. Deposition and subsequent maintenance dredging in this reach constitute a relatively small fraction of the difference in total sediment load entering and exiting this reach (Figure 4.12).

The 1D model performs well in reproduction of deposition and dredging locations but underestimates the best available estimates of dredging quantities in Southwest Pass. Average computed annual dredging rates during the 50-year model simulation, including the reach above Head of Passes, agree reasonably well with reported dredging rates over the last decade; however, these rates are considerably lower than the long-term average annual dredging rate.

From Cubits Gap downstream to Head of Passes, the navigation channel functions as an efficient sediment trap. Actions, such as dredging, that increase the width of the sediment trap increase the volumetric rate of deposition within this reach.

Although the West Bay Diversion diverts only 7% (as modeled) of the total flow, the computed impact on dredging is disproportionably large. The 1D model consistently indicates that the West Bay Diversion accounts for a 20-25% of the dredging required in the reach above Head of Passes including the Pilottown Anchorage Area. If only the navigation channel is maintained, the West Bay Diversion accounts for an even larger portion of the required dredging.

Sedimentation processes in Southwest Pass, particularly those describing the behavior of cohesive sediments, are strongly influenced by tides and salinity intrusion. While these processes may be simulated to a limited extent by adjustment of model coefficients affecting cohesive sedimentation, a 3D or laterally averaged hydrodynamic/salinity/sedimentation model may be required to resolve the processes producing this deposition.

5 Multi-Dimensional Modeling Analysis

Multi-Dimensional Modeling Approach

In general, sediment diversions are multi-dimensional phenomena. Horizontal and vertical variations in both velocities and sediment concentrations can have a significant impact on the performance of the diversion. In addition, erosion and deposition patterns in the main stem also tend to be spatially variable.

Observations of velocities and suspended sediment profiles conducted by ERDC for this study confirm the spatial variability of the velocity and suspended sediment concentration for the West Bay Diversion. In addition, the need to identify the impacts of the West Bay Diversion on a specific footprint within the main channel (the Anchorage Area dredging footprint) implies the need for a tool that can isolate the impacts on this footprint in isolation from the general impact on the entire reach.

For this study, 2 separate multi-dimensional modeling tools were used to analyze the impact of the West Bay Diversion on the dredging requirements in the Anchorage Area and adjacent channel. Each tool is equipped with unique capabilities that are needed to fully analyze the diversion impacts

The CH3D model is a 3-dimensional, multiple-grain sized, noncohesive sediment transport model. The 3D capability makes the model ideal for analyzing the impacts of multi dimensional. In addition, the CH3D model has been sued for several studies in the lower Mississippi River, including earlier studies of West Bay. Hence, it is a proven technology.

The AdH (Adaptive Hydraulics) model, linked to the SEDLIB sediment model, is a 2-dimensional, depth-averaged model. This model contributes several capabilites to the analysis, including:

- Quasi 3-D flow and transport formulations, which use analytical and semi-empirical methods of approximate the 3-Dimensional character fo the flow and sediment transport phenomena.
- The unstructured model mesh permits very high resolution in areas of interest, and high fidelity resolution of shoreline geometry.
- The ability to extend the boundaries sufficiently far from the project area so as not to prescribe the answer will ensure that the results are not biased by judgments concerning boundary conditions.

- Some improvements in the sand sediment model are available in the AdH model that are not in the CH3D model, including the ability to effectively armor the bed without having to pack a lot of thin bed layers into the model, and also including the influence of gravity on both the critical shear stress and the bedload magnitude and direction.

The use of both the AdH and CH3D models yields the most complete assessment of the multi-dimensional character of the West Bay Diversion and any associates in channel depositional impacts.

- The CH3D model can be used to assess the 3-dimensional character of the flow and transport at the diversion, and to what degree this capability is required to asses the impacts of the diversion on the downstream deposition.
- The AdH model can be used to provide more accurate boundary conditions to the Ch3D model (since the AdH boundary will extend far beyond the study area).
- Comparison of the results from both models will provide quantitative and qualitative insights into the need for 3D modeling at diversions, by demonstrating what a 2D model (with quasi-3D capability) can and cannot provide.
- Both models can provide insight into the dominant processes governing sediment deposition in the Anchorage area.

Adaptive Hydraulics Modeling

Model Description

AdH is a finite element model that is capable of simulating three-dimensional Navier Stokes equations, two and three-dimensional shallow water equations, and groundwater equations. It can be used in a serial or multiprocessor mode on personal computers, UNIX, Silicon Graphics, and CRAY operating systems. The uniqueness of AdH is its ability to dynamically refine the domain mesh in areas where more resolution is needed at certain times due to changes in the flow conditions. AdH can simulate the transport of conservative constituents, such as dye clouds, as well as sediment transport that is coupled to bed and hydrodynamic changes. The ability of AdH to allow the domain to wet and dry within the marsh areas as the tide changes is good for the shallow marsh environment. This tool is being developed at CHL and has been used to model sediment transport in sections of the Mississippi River, tidal conditions in southern California, and vessel traffic in the Houston Ship Channel.

More details about AdH and its computational philosophy and equations can be found in Appendix D or at https://adh.usace.army.mil.

SEDLIB is a sediment transport library developed at ERDC. The fundamental architecture of the sediment transport algorithms in SEDLIB are taken from the Ch3D model. It is capable of solving problems consisting of multiple grain sizes, cohesive and cohesionless sediment types, and multiple layers. The cohesive capabilities are currently developmental, and have not been fully validated. It calculates erosion and deposition processes simultaneously, and simulates such bed processes as armoring, consolidation, and discrete depositional strata evolution.

The SEDLIB library system is designed to link to any appropriate hydrodynamic code. The hydrodynamic code must be capable of performing advection diffusion calculations for a constituent. SEDLIB interacts with the parent code by providing sources and sinks to the advection diffusion solver in the parent code. The solver is then used to calculate both bedload and suspended load transport, for each grain class. The sources and sinks are passed to the parent code via a fractional step modification of the time derivative term.

Mesh Development

The mesh was developed using the Surface-water Modeling System (SMS), a graphical user interface developed by ERDC for increasing the modeling productivity for a variety of Corps numerical models, including AdH (see Appendix A). The entire model domain is shown in Figures 5.1 and 5.2 and an inset of the model showing the study area is shown in Figure 5.3. The upstream boundary is at approximately river mile 42.3 of the Mississippi River and the downstream water surface boundary extends approximately 55 miles beyond the end of Southwest Pass into the Gulf of Mexico.

The bathymetry for the mesh was taken from three sources: the SL-15 bathymetry for the ADCIRC model of the Gulf of Mexico, USACE Condition Surveys for the Mississippi River, and multi-beam bathymetry data gathered by ERDC. The multi-beam bathymetry data was gathered as part of the present study and included bathymetry for the Mississippi River from two miles upstream of the West Bay Diversion to two miles downstream of the West Bay Diversion. Multi-beam data was also gathered in the diversion and in several other passes including Grand Pass, Baptiste Collette, and Cubits Gap.

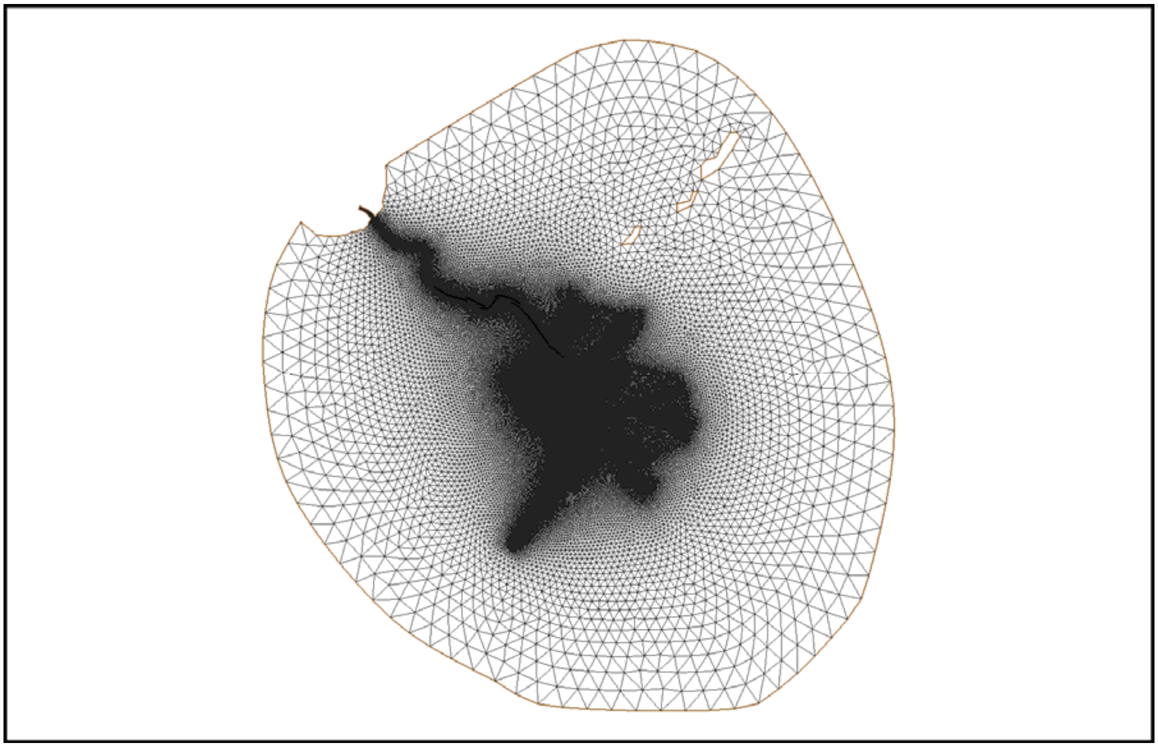


Figure 5.1. Model Domain

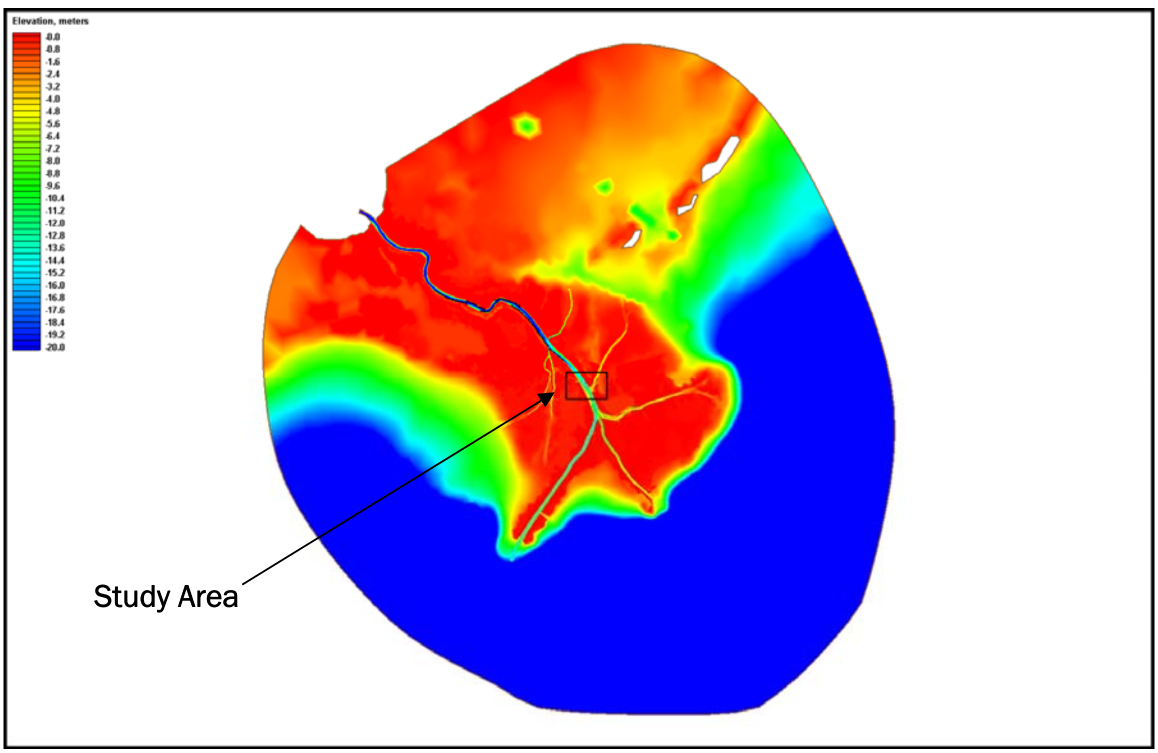


Figure 5.2. Model Domain with Contours

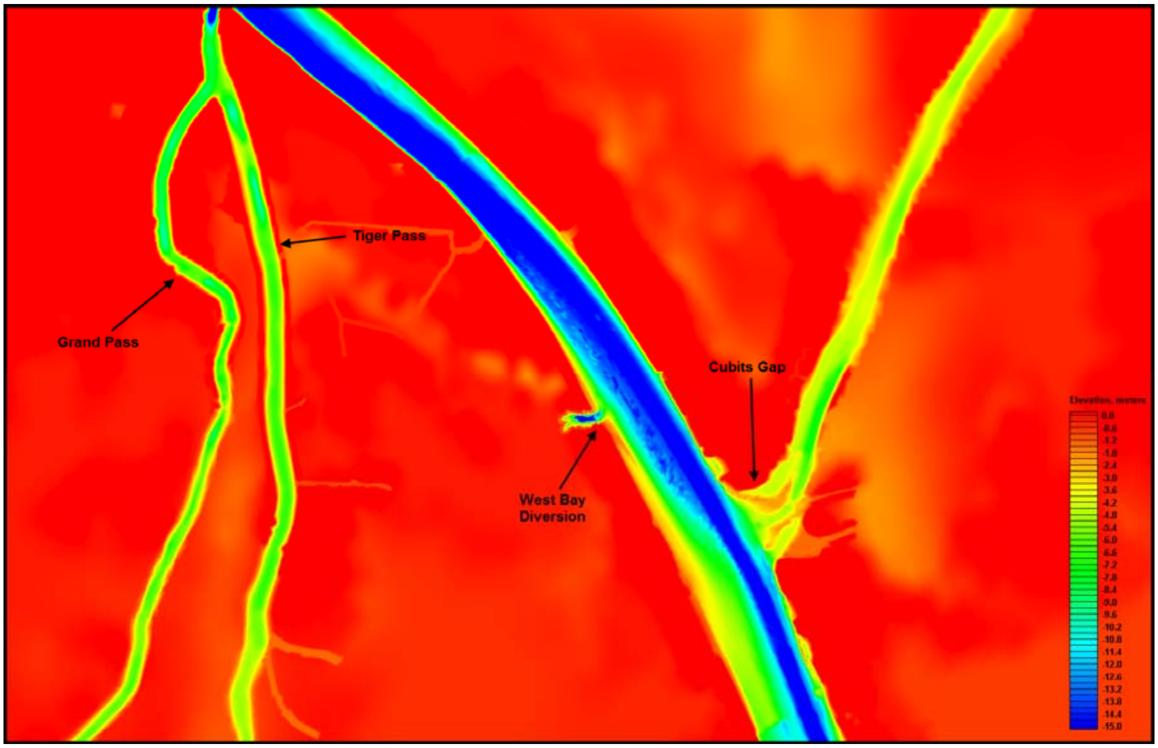


Figure 5.3. Inset Showing Study Area

Boundary Condition Development

For the AdH model, the 2009 hydrograph was simulated. The simulation ran from February though August.

The upstream boundary was specified using an inflow boundary based upon discharge measurements made at the USGS gage site at Tarbert Landing. The inflows were adjusted such that they matched the inflows recorded by the ERDC data collection team at River Mile 12.1. The Tarbert Landing inflows and the adjusted applied boundary inflows are given in Figure 5.4.

The downstream water surface boundary at the Gulf of Mexico was taken from the NOAA observation station at Southwest Pass. The data were adjusted such that the water surface elevation is referenced to NAVD88. The water surface elevation boundary is given in Figure 5.5.

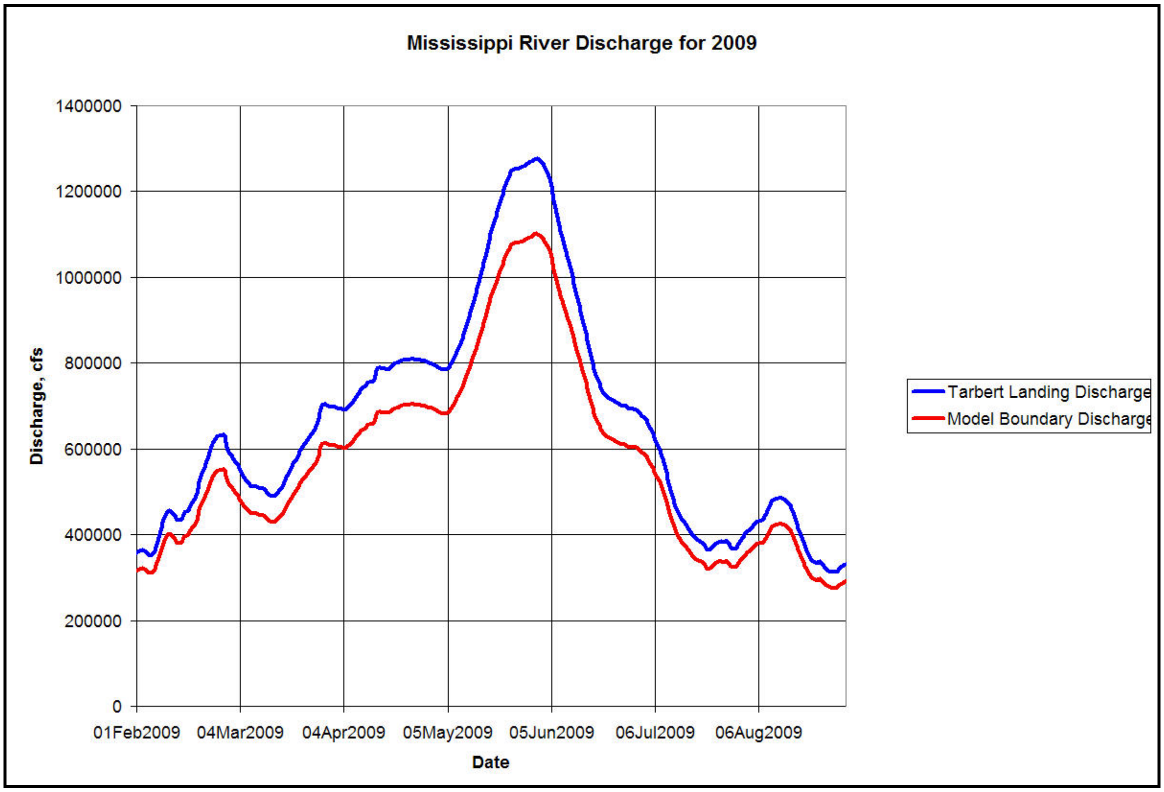


Figure 5.4. Mississippi River Discharge at Tarbert Landing and at the AdH Model Boundary for 2009.

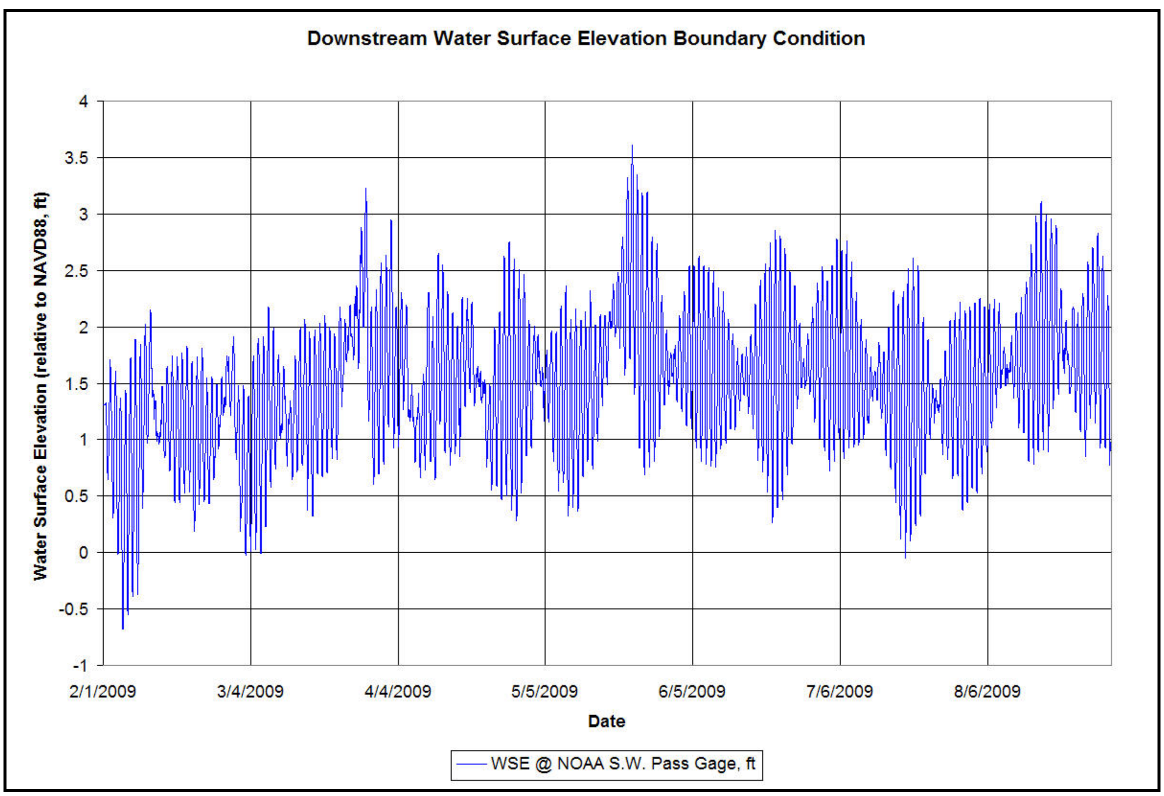


Figure 5.5. Downstream Water Surface Elevation Boundary for 2009.

The sediment grain classes implemented into the model was chosen based on information gleaned from the ERDC data collection effort and the 1D modeling effort. Analysis of the bed samples collected in the field data collection effort show a wide range of sediment classes, ranging from clay to medium sand. Little sediment coarser than the medium sand size was found in the samples: hence, this was chosen as the coarsest class to be simulated.

In the Pilottown Anchorage area, most of the sediment collected consisted of fine and very fine sand. Hence, as assumption was made that the transport mode primarily associated with deposition in the anchorage area was the noncohesive sand transport mode. So the smallest grain class to be simulated was chosen as very fine sand.

This resulted in 3 grain classes that were simulated in the model runs: Very Fine Sand, Fine Sand, and Medium sand.

Note that the assumption of noncohesive behavior is not necessarily valid in all cases, and cohesive properties can and apparently do affect the transport of sand in this reach. A study by Allison and Nittrouer (2004) indicates that the sand supply in the river is limited, and the river bottom can be scoured free of sand at high flows. However, below Venice, the geomorphological analysis conducted for this study indicates a long term trend of aggradation: therefore, the sand should be in plentiful supply here. Galler and Allison (2008) have noted that, during low flows, significant mud deposit is trapped in the channel thalweg by the presence of a persistent salt wedge. These muds likely mix with the sand deposit, and create a paved layer that is more resistant to erosion than sand alone. Hence, this cohesive behavior can limit the supply of sandy sediment available for transport.

For the purposes of this effort, it was assumed that this cohesive layer acts as a nonerodable armor layer. However, this assumption is a simplification of the real character of the bed, and indicates that the available sediment supply is a significant source of uncertainty in the simulations.

Initially, the inflowing boundary condition was given by the 1-D HEC model runs. However, this proved somewhat problematic, since small differences in the sediment supply and the sediment demand associated with the sediment model can result in large values of erosion and/or deposition at the model boundary. Therefore, it was decide to allow the model to calculate the inflowing boundary condition, based on the assumption that the model is in a state of sediment equilibrium at the boundary (i.e. the cross-section at the boundary is not eroding or aggrading).

To initialize the sediment bed, an initial bed sediment thickness of 3.2 feet was introduced into the model. The 2009 hydrograph was run though the model once to initialize the bed. This resulted in the scouring of much of the bed material, except in some deeper locations upstream, and in the depositional areas downstream of Venice. This eroded bed was used as the initial bed for the verification run and the production runs.

Model Verification

Hydrodynamic verification

Figures 5.6 and 5.7 show the comparison of the observed and computed discharges through each of the diversions in the study reach. These comparisons show that the model represents the observed distribution of flow to an acceptable degree of accuracy.

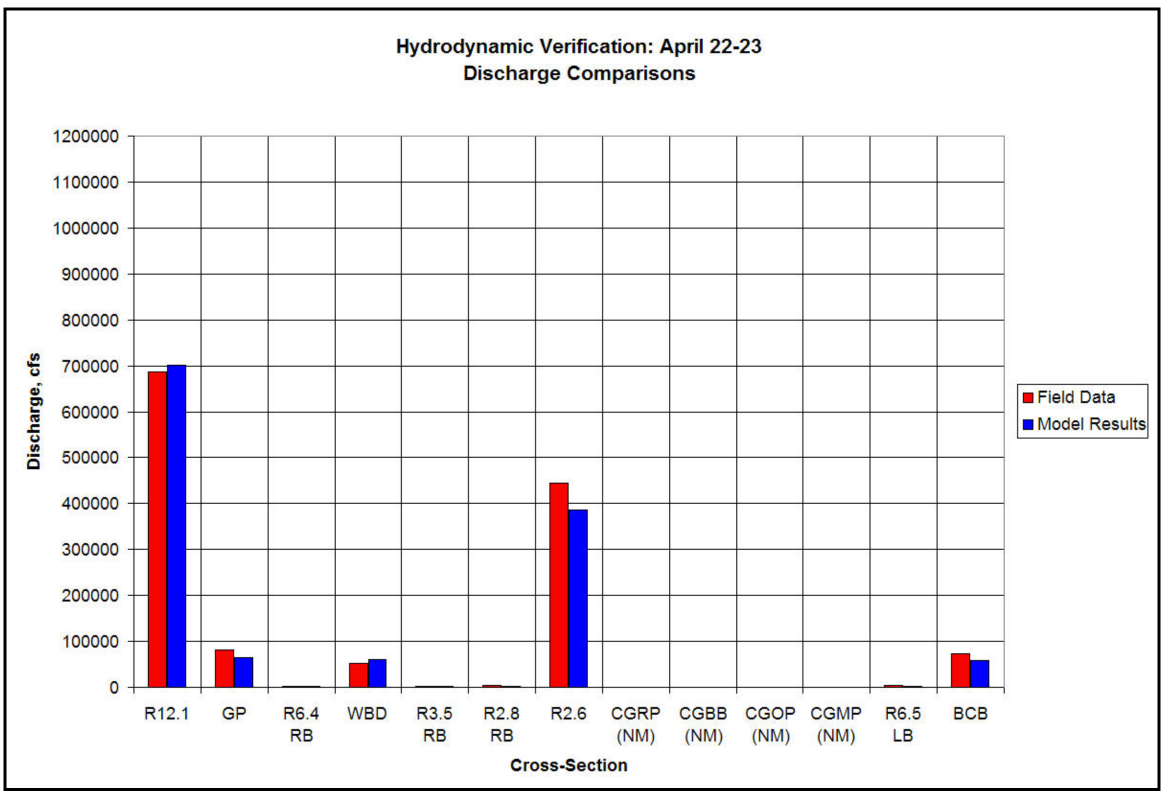


Figure 5.6. Hydrodynamic verification for April 22-23.

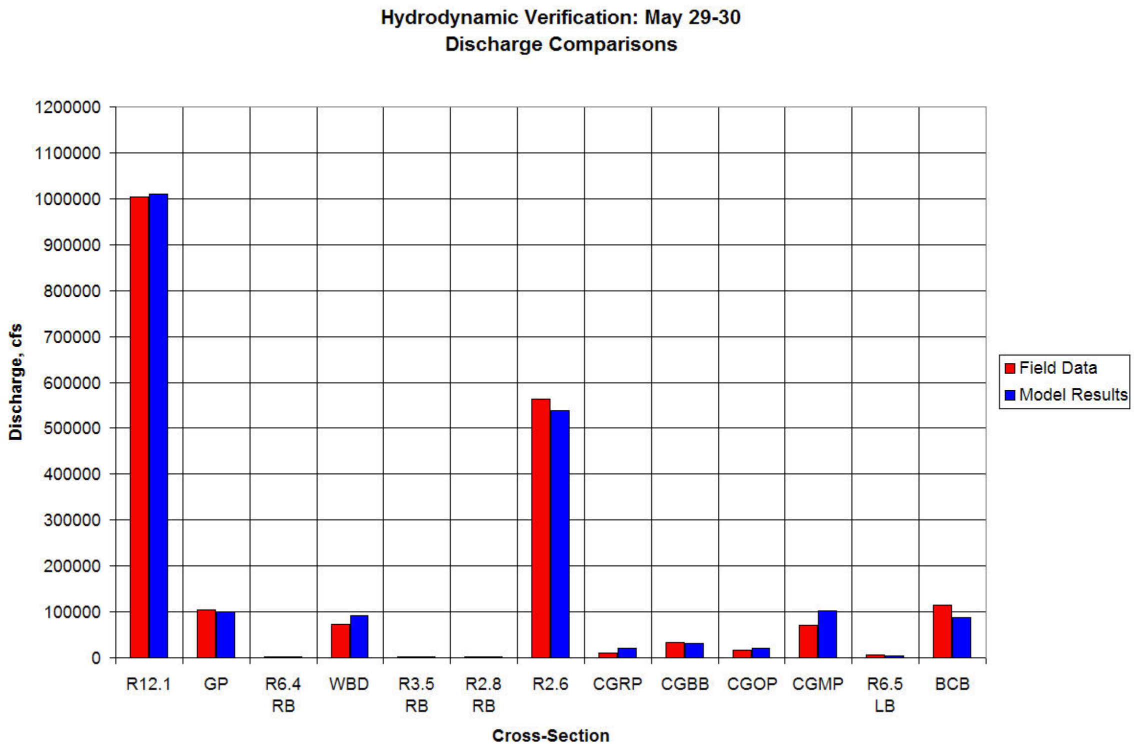


Figure 5.7. Hydrodynamic verification for May 29-30.

The flow distribution is primarily governed by the shape and bathymetry of the cuts themselves. Under high and median flow conditions, the stage in the river is significantly higher than the stage on the downstream side of each of the cuts. Hence, the flow through the cuts is essentially a local loss problem, with the magnitude of the flow governed by the geometry of the cuts themselves. Tidal signals and bed friction losses are of less significance. A significant wind set-up could have some influence, but this was not examined for this study.

The Manning's n value for the main stem was chosen to approximate the roughness height of the bedforms. It was set equal to 0.028. AdH is equipped with a friction algorithm that automatically adjusts the friction for variations in water depth.

Although the Adh model is a depth averaged model, it is equipped with several semi-analytical features designed to mimic 3-dimesional behavior. One of these is the implementation of streamwise vorticity transport (Bernard, 1992). This is an adjustment to the momentum of the flow is designed to simulate the helical flow resulting from the differential radial acceleration of the flow velocity over the vertical velocity profile. This differential acceleration is the mechanism whereby rivers develop meanders; hence, this mechanism is sometimes called the "bendway" effect.

The vorticity transport allows AdH to approximate the 3-dimesional character of the flow through the West Bay diversion. Figures 5.8 and 5.9 show the observed and computed surface velocities in the cut on April 22-23. Figures 5.10 and 5.11 show the observed and computed bottom velocities at the same location.

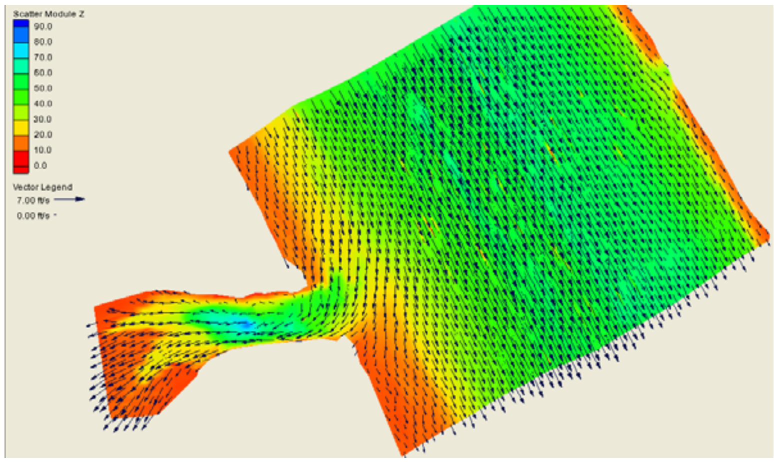


Figure 5.8. Observed surface velocities at West Bay Diversion on April 22-23.

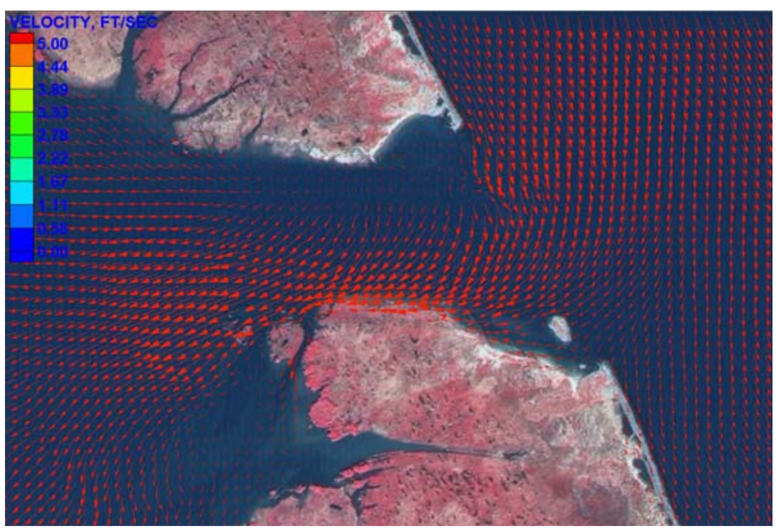


Figure 5.9. Computed surface velocities at West Bay Diversion on April 22-23.

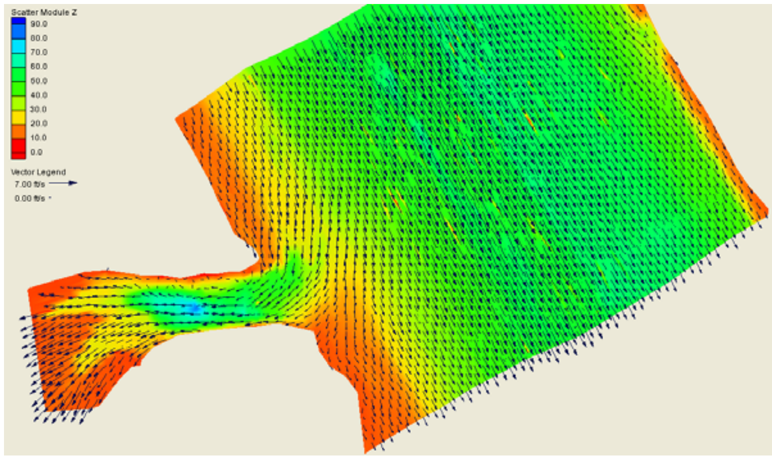


Figure 5.10. Observed bottom velocities at West Bay Diversion on April 22-23.

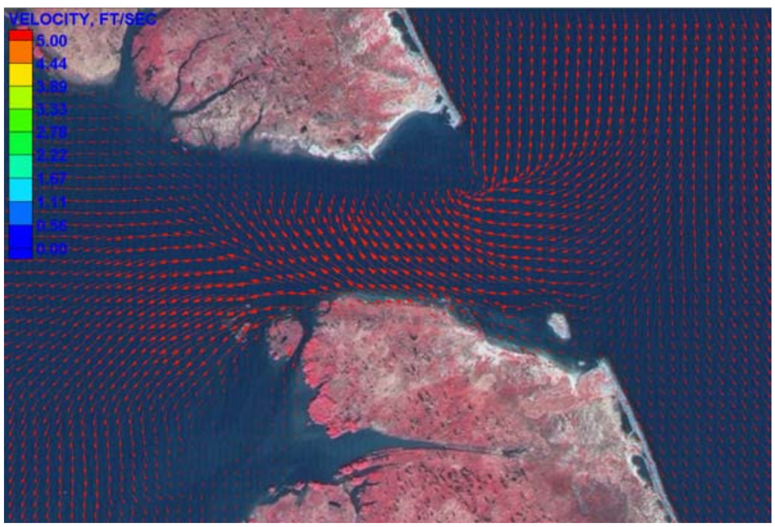


Figure 5.11. Computed bottom velocities at West Bay Diversion on April 22-23.

Suspended sediment verification

Figure 5.12 shows the observation locations for the suspended sediment samples in the vicinity of West Bay Diversion. Figures 5.13 – 5.15 show observed and computed values of total suspended sand concentration for the May 5-6 observation period (medium flow). Figures 5.16 – 5.20 show the same comparisons for the May 29-30 observation period (high flow). Note that these sand "profiles" result from a semi-analytic expression within AdH that produces a nonequilibrium sediment profile on the form of the Rouse equation (Brown, 2008). This quasi-3-D profile is used within the code for all sediment calculations.

Figure 5.12. Suspended sediment verification at RM 5.2 for May 5-6.

The medium flow concentrations compare reasonably well. The cross-channel variation in concentration is reproduced, although it is not as pronounced as the observed variation.

The high flow concentrations do not compare well. The model consistently over-predicts the suspended sand concentrations. This may be due to the inability to accurately initialize the bed. The available sand in 2009 is residual from 2008. Since 2008 was a very high flow year, it is likely that most of the available sand in the bed was mobilized and transport out of the reaches upstream of the West Bay Diversion. Hence, the lower concentrations observed in the field data may be due to a supply limitation associated with this scoured condition. The model bed is generally in a scoured condition, but there are some upstream sediment deposits that are only fully mobilized at high flow.

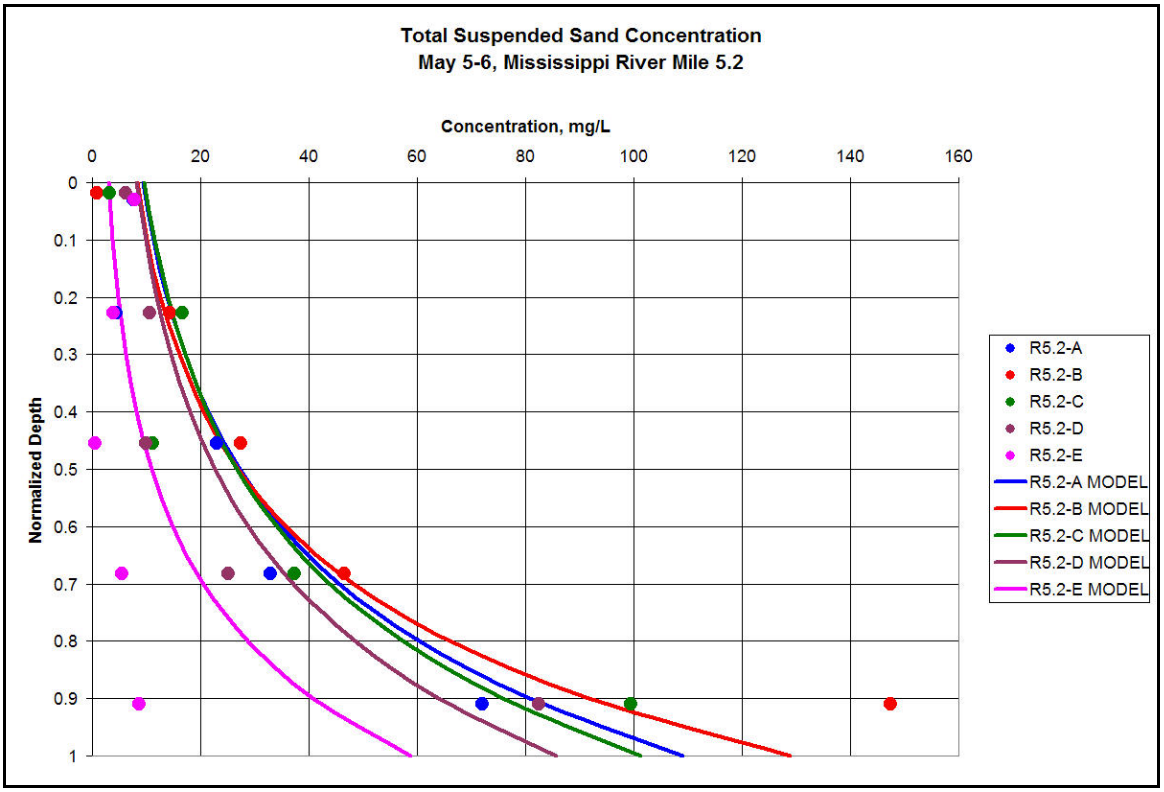


Figure 5.13. Suspended sediment verification at RM 5.2 for May 5-6.

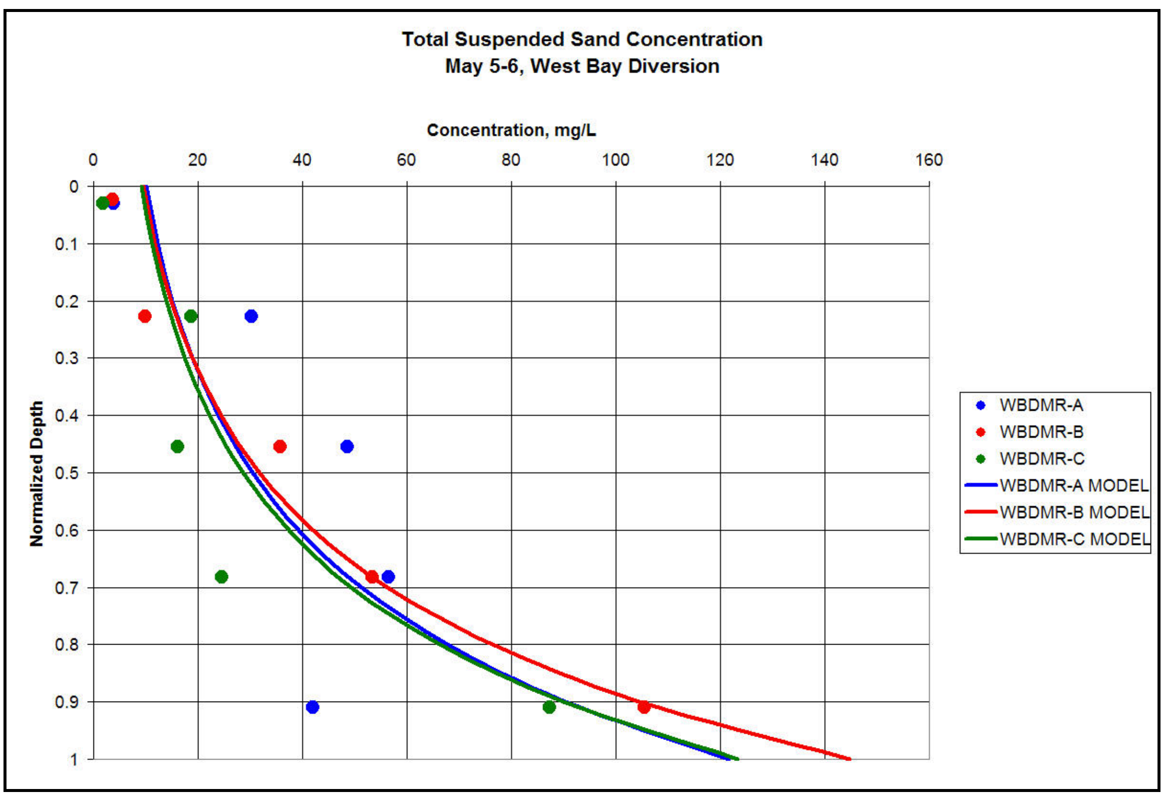


Figure 5.14. Suspended sediment verification at WBD for May 5-6.

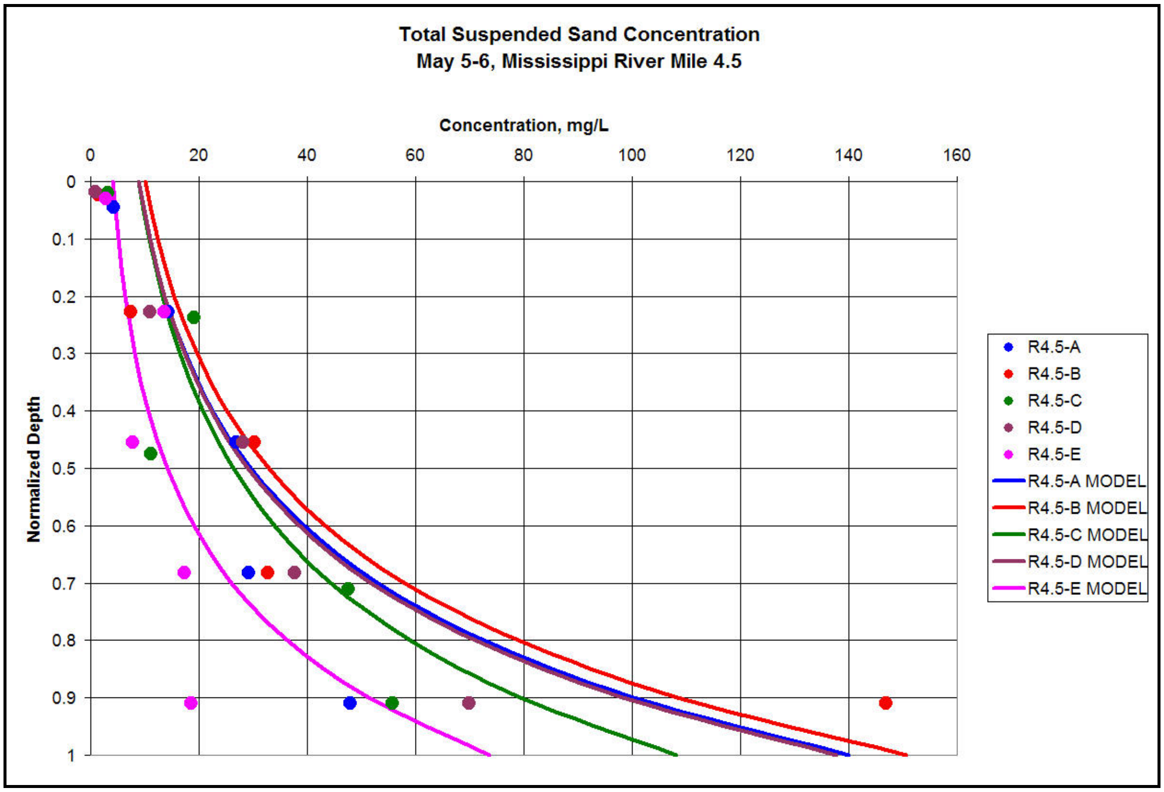


Figure 5.15. Suspended sediment verification for May 5-6.

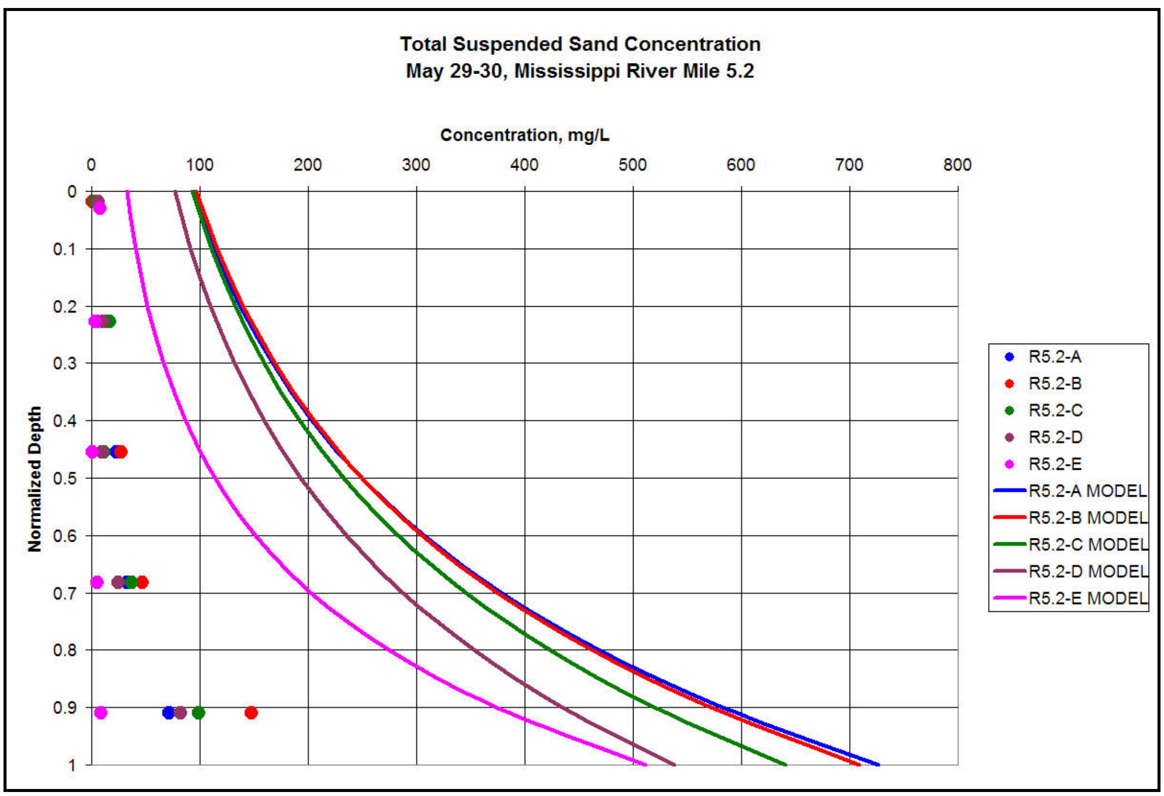


Figure 5.16. Suspended sediment verification at RM 5.2 for May 29-30.

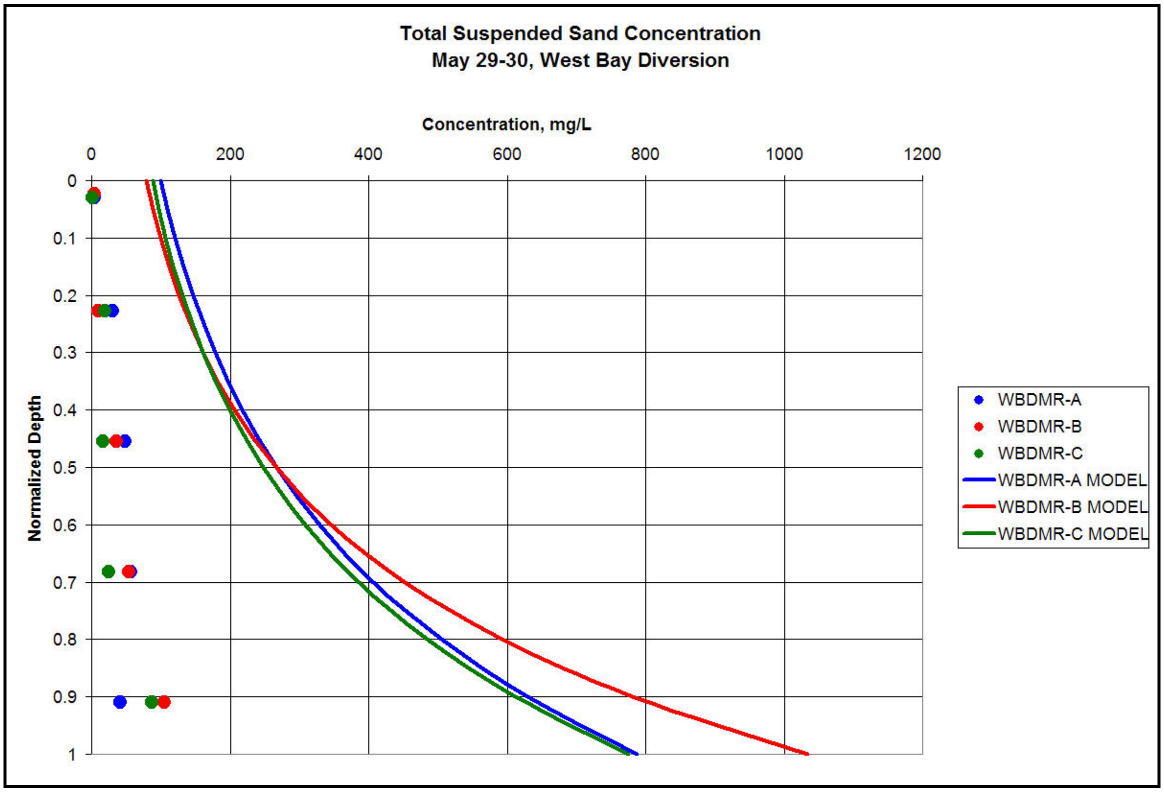


Figure 5.17. Suspended sediment verification at WBD for May 29-30.

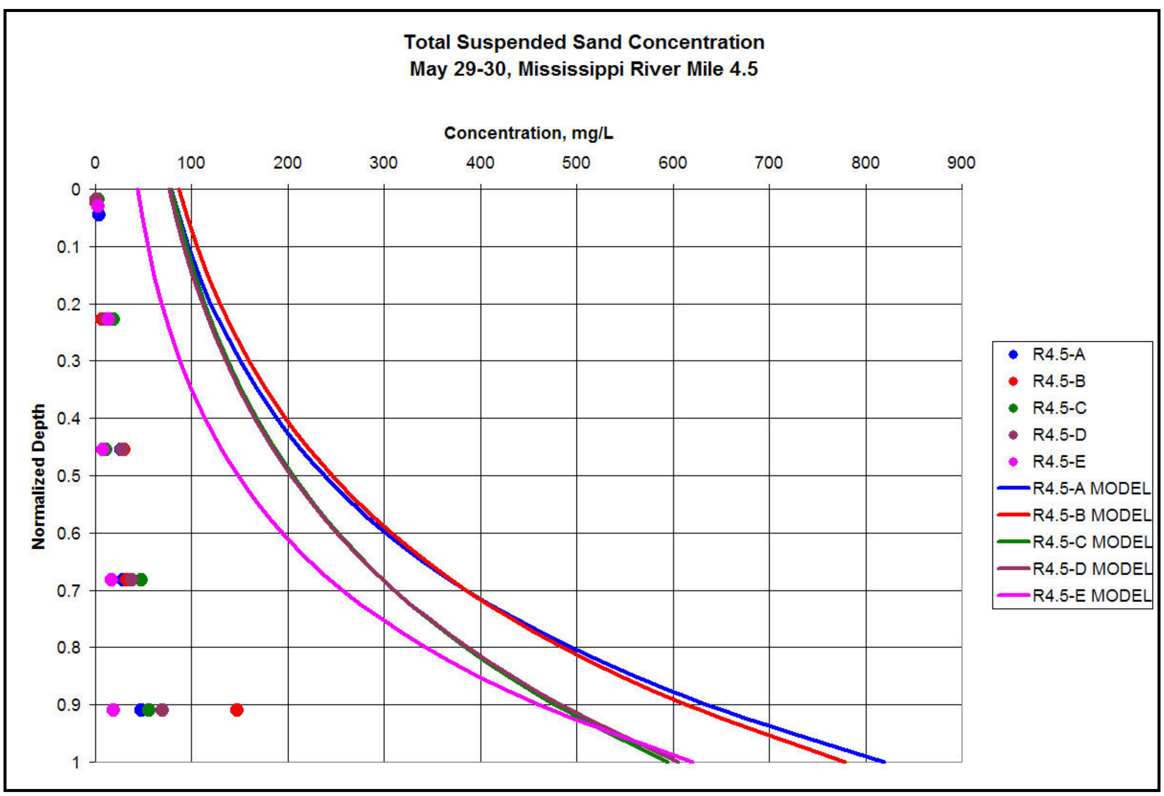


Figure 5.18. Suspended sediment verification at RM 4.5 for May 29-30.

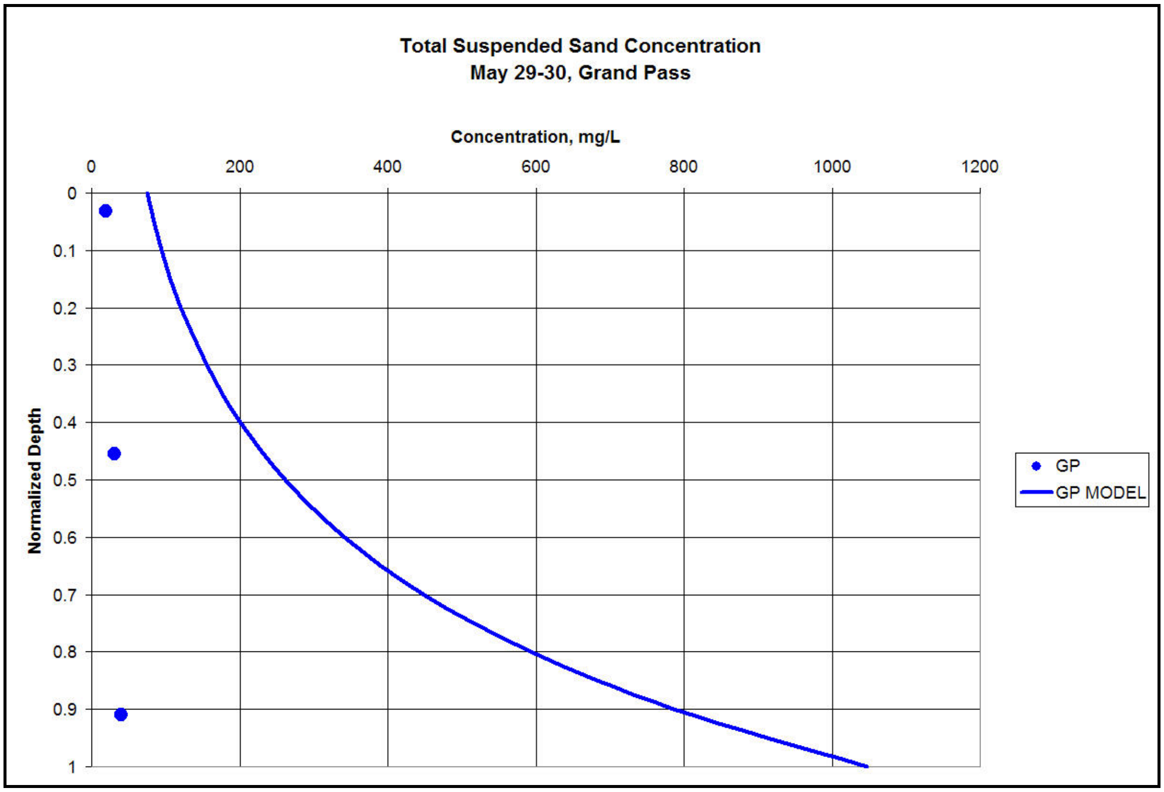


Figure 5.19. Suspended sediment verification at GP for May 29-30.

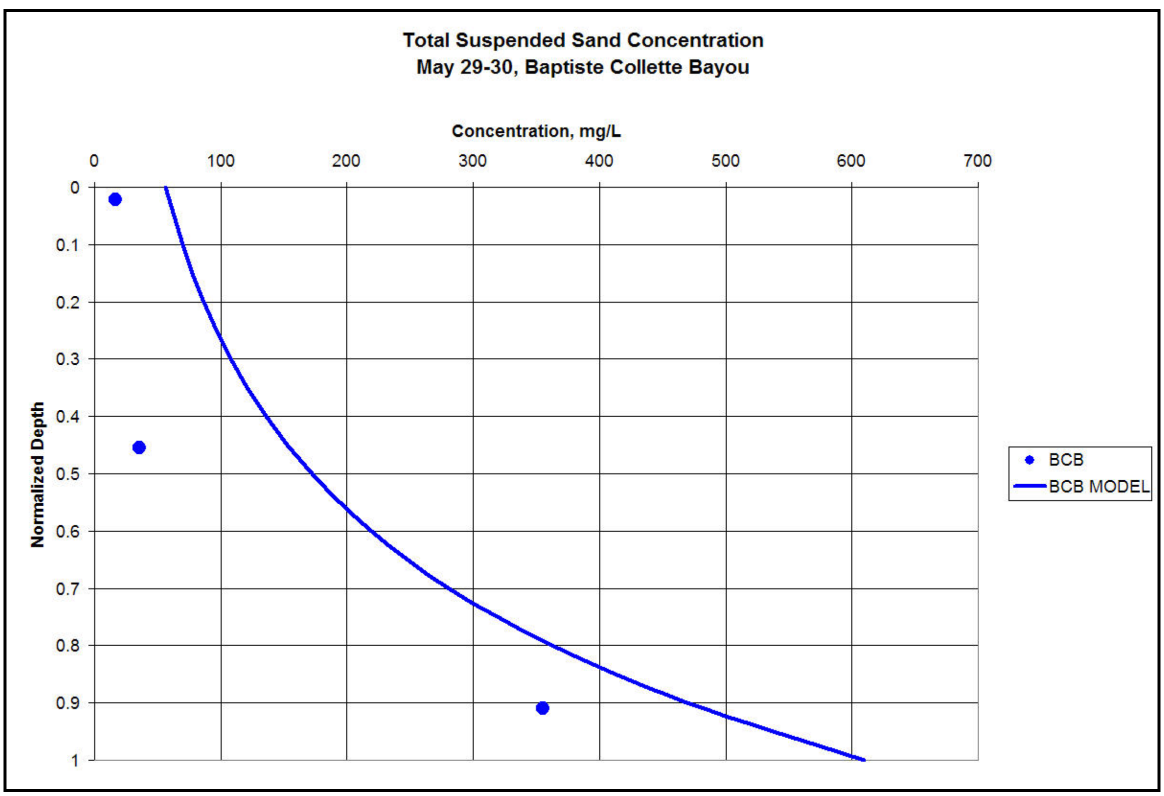


Figure 5.20. Suspended sediment verification at BCB for May 29-30.

Figures 5.21 and 5.22 show the calculated and observed bed elevation changes between March and August of 2009. The observed changes are taken from a difference plot of New Orleans District condition surveys. Note that both the model and the observed data indicate scouring along the leading edge of the point bar in the Anchorage area. This lends credibility to the assumption of an eroded bed due to the large flow year in 2008. The deposition patterns observed in the field are in general agreement with those observed in the model, except that the field data indicates some significant deposition upstream of the West Bay Diversion that is not replicated in the model.

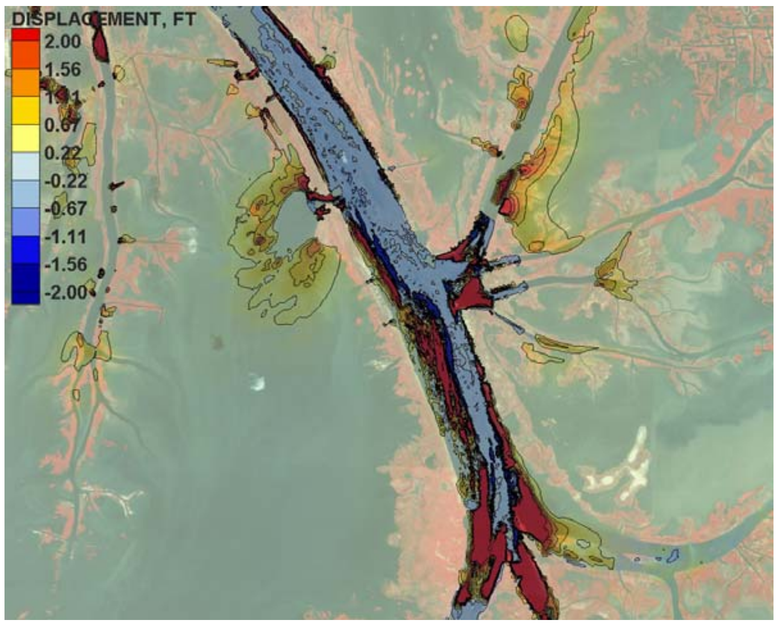


Figure 5.21. Computed sediment bed change, March to August, 2009.

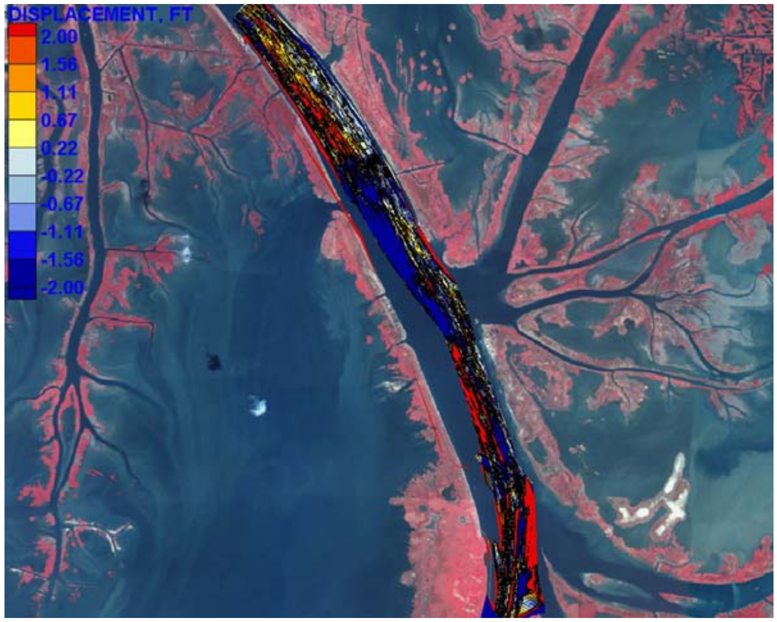


Figure 5.22. Observed sediment bed change, March to August, 2009.

Results

The model was simulated with 2 different bed sediment conditions. The base case run was run with the same bed conditions used for the verification run: hence, it represents the 2009 river conditions. The slug test run was run with a surplus of sediment in the bed upstream of the study area. Hence, it represents a condition similar to the apparent 2008 conditions, where several antecedent years of moderate flow conditions left significant sand deposits in the channel upstream of the study area.

Both runs were run with and without the west bay diversion in place. The resulting sediment deposition was measured in each run to determine the impacts of the west bay diversion.

Figures 5.23 and 5.24 show the cumulative bed change over the hydrograph for the base case run both with and without the west bay diversion. Figure 5.25 is a difference plot, depicting the bed change with the west bay diversion minus the bed change without the west bay diversion. Figures 5.26 -5.28 depict the same information for the slug test runs.

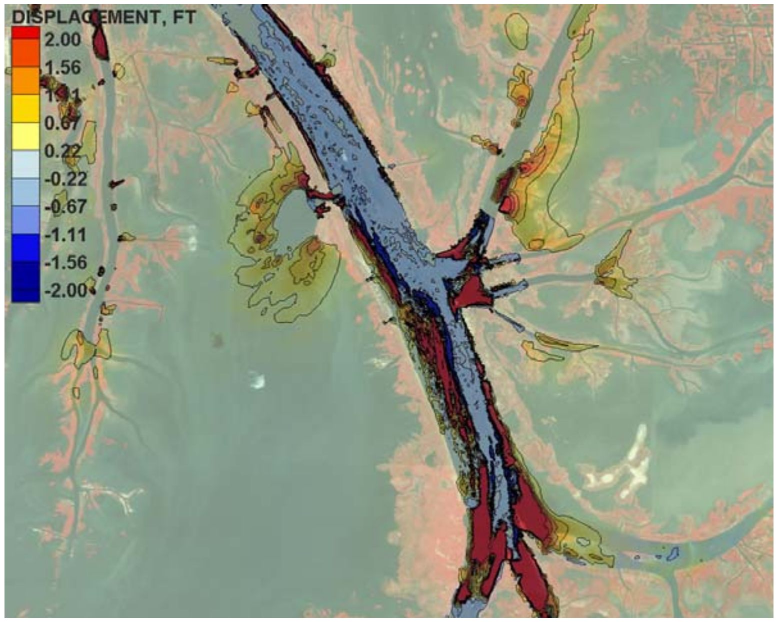


Figure 5.23. Cumulative bed change with West Bay Diversion, base case run.

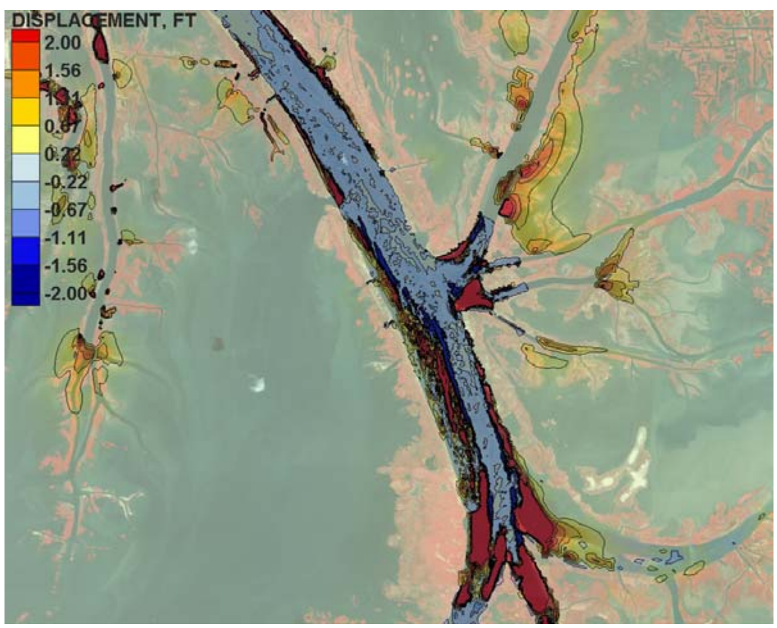


Figure 5.24. Cumulative bed change without West Bay Diversion, base case run.

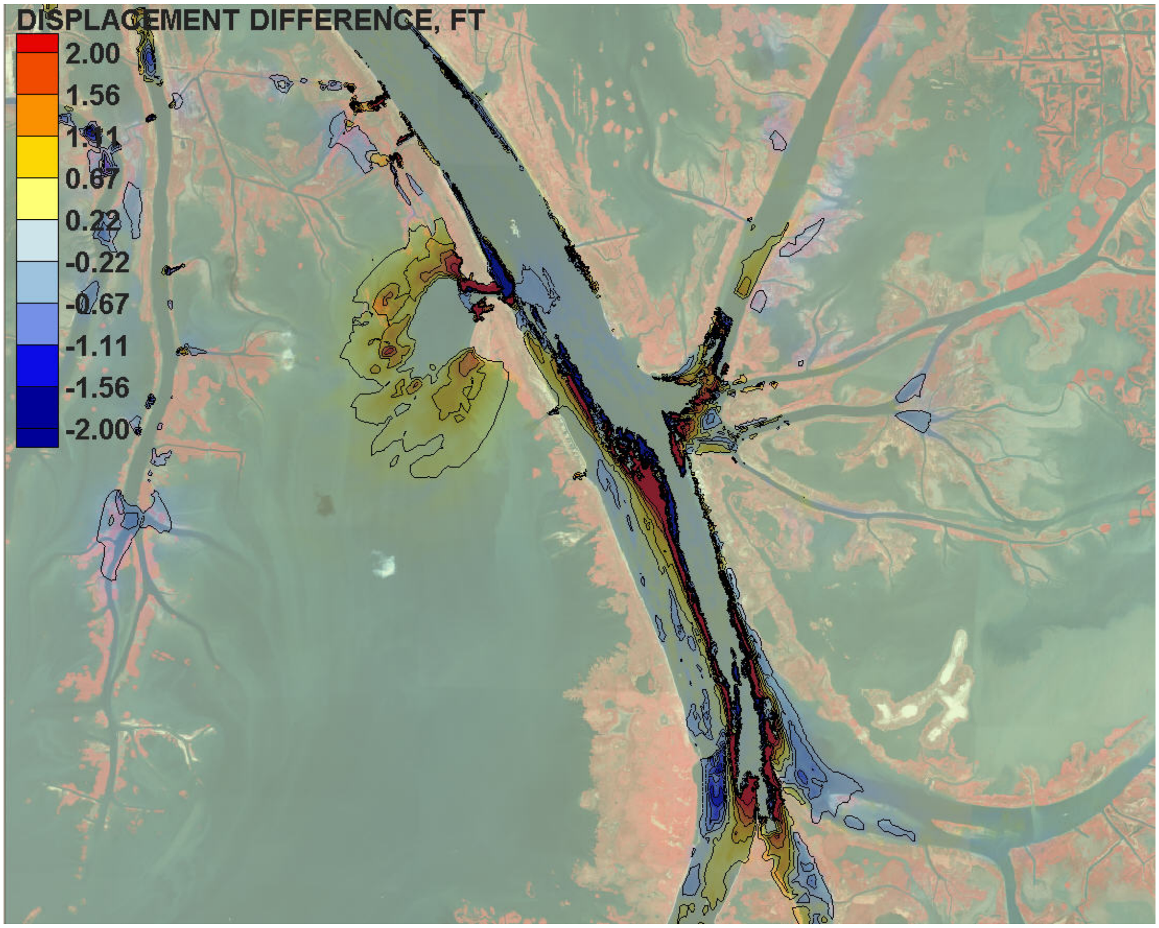


Figure 5.25. Cumulative bed change difference, base case run.

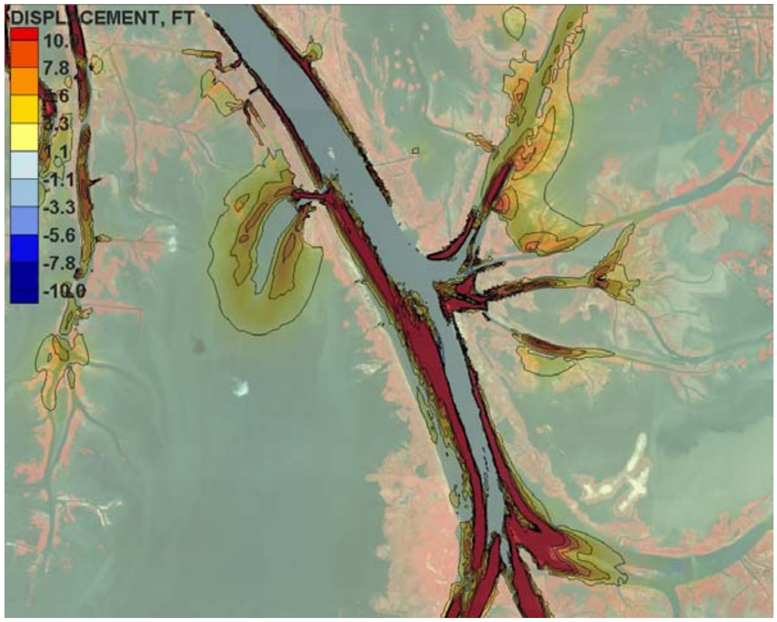


Figure 5.26. Cumulative bed change with West Bay Diversion, slug test run.

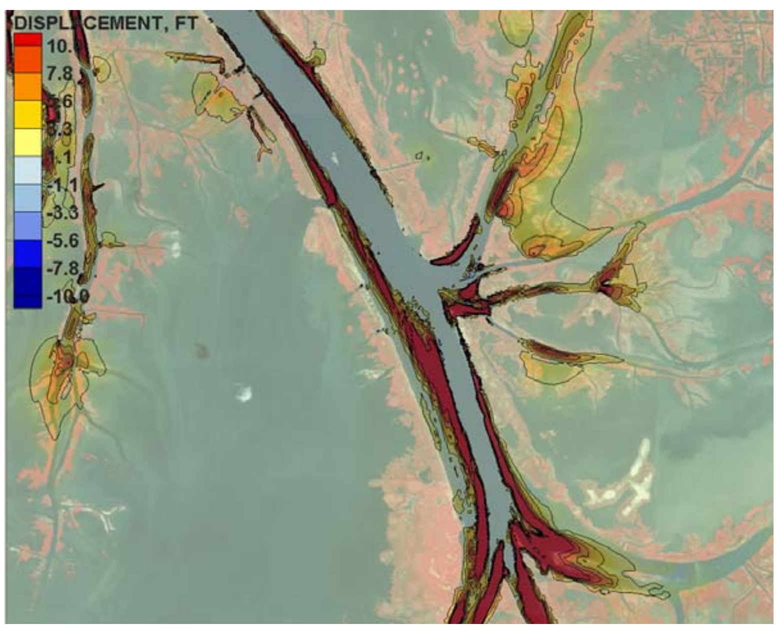


Figure 5.27. Cumulative bed change without West Bay Diversion, slug test run.

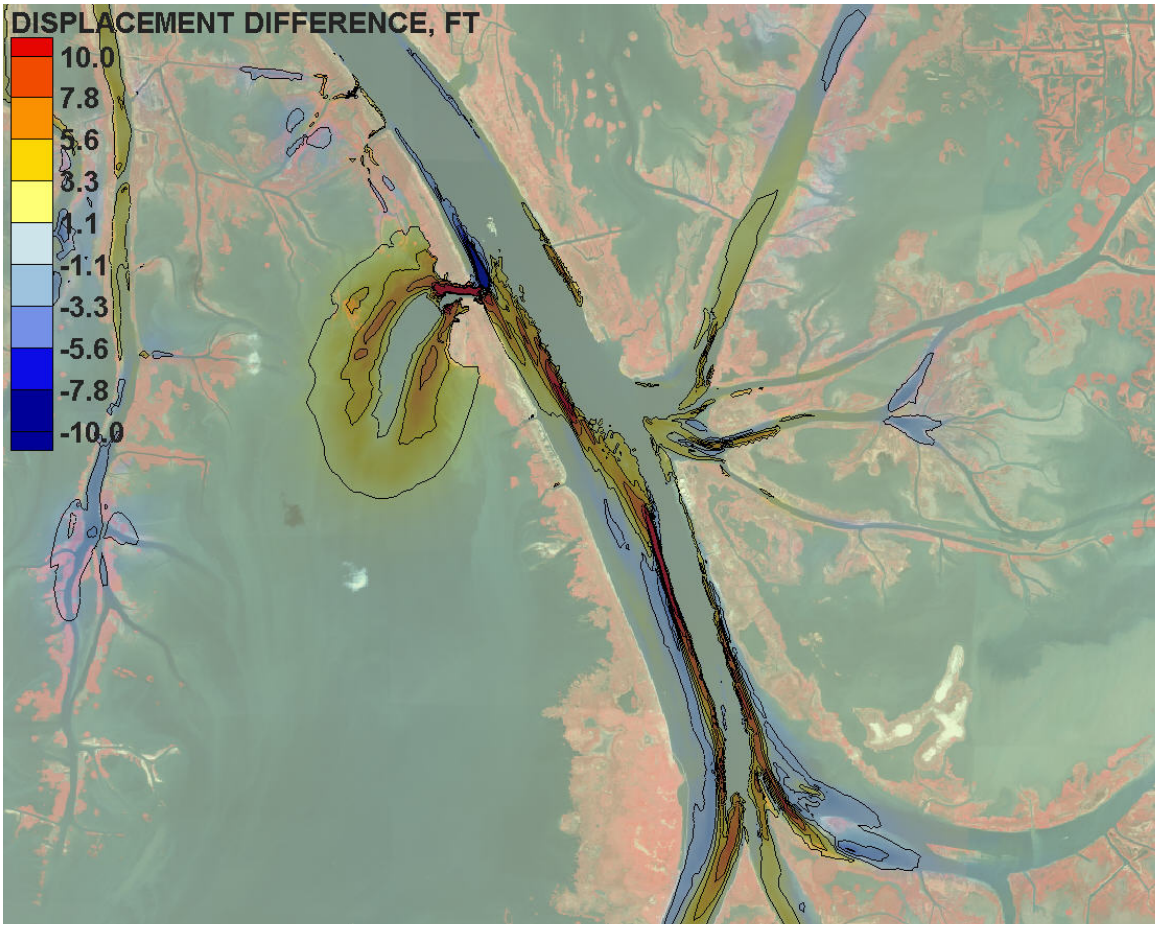


Figure 5.28. Cumulative bed change difference, base case run.

These results show deposition patterns consistent with the observed deposition in the study area subsequent to high flow years. The deposition is focused along the Anchorage area shoal, at the channel expansion near Cubit's Gap, and in the distributaries at head of passes. The addition of the west bay diversion is shown to shift the deposition closer to the center of the navigation channel. This indicates that the presence of the west bay diversion served to effectively contract the cross-section of the channel, resulting in additional dredging requirements. This contraction occurs along both sides of the channel. These general results persist for both the base case (sediment starved condition) and the slug test (sediment rich condition).

A quantitative analysis of the volume of deposition in both the anchorage area and the adjacent channel is given in Figures 5.29 though 5.35. Figure 5.29 depicts the footprints of both the anchorage area and the adjacent channel. The anchorage area footprint is west of the adjacent channel footprint.

Figure 5.29. The anchorage area and adjacent channel quantitative analysis footprints.

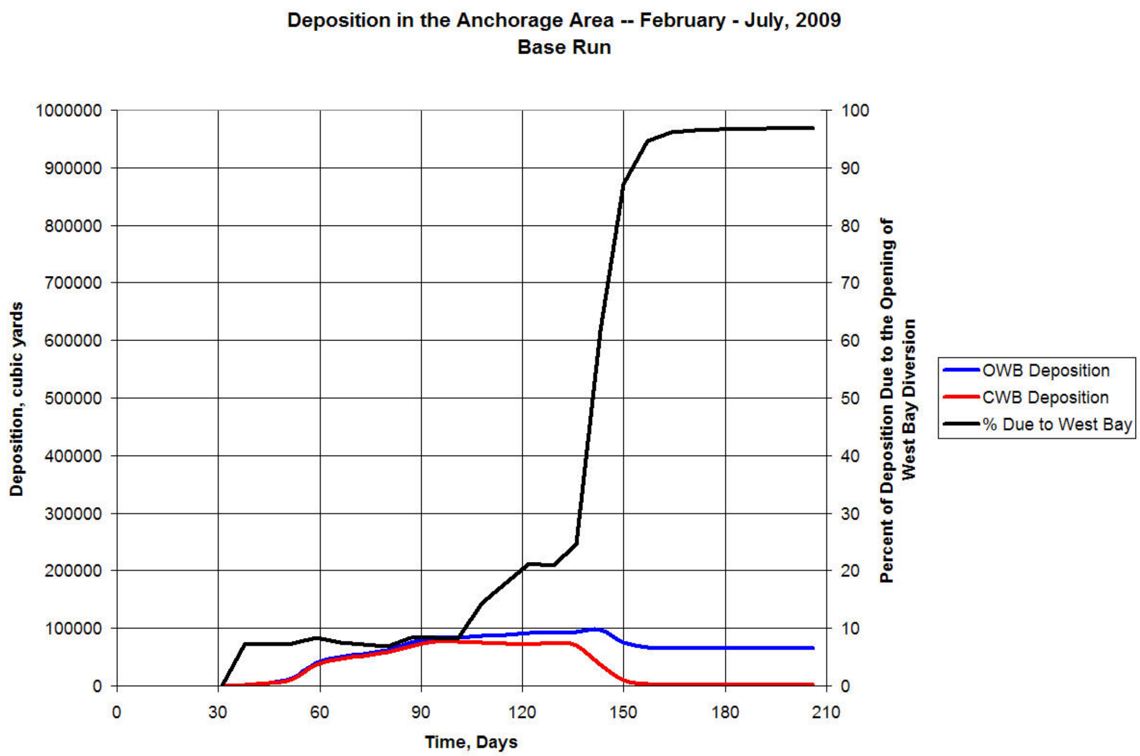


Figure 5.30. Deposition quantities for the anchorage area, base run.

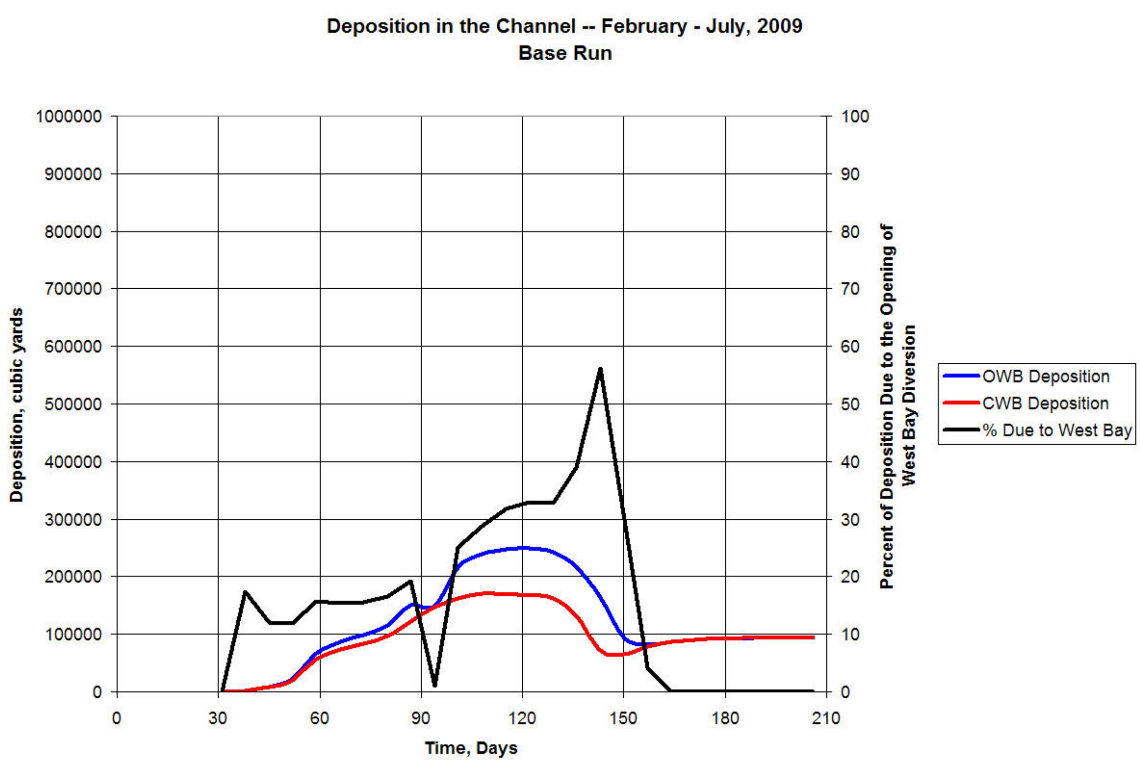


Figure 5.31. Deposition quantities for the adjacent channel, base run.

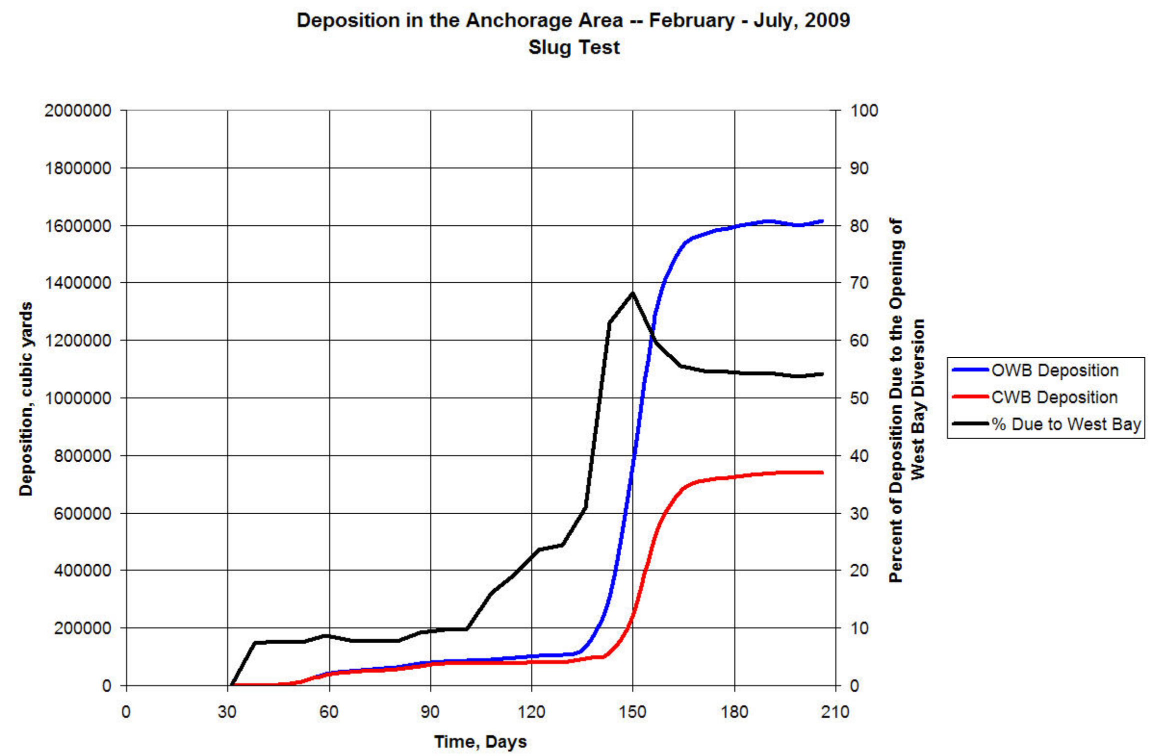


Figure 5.32. Deposition quantities for the anchorage area, slug test.

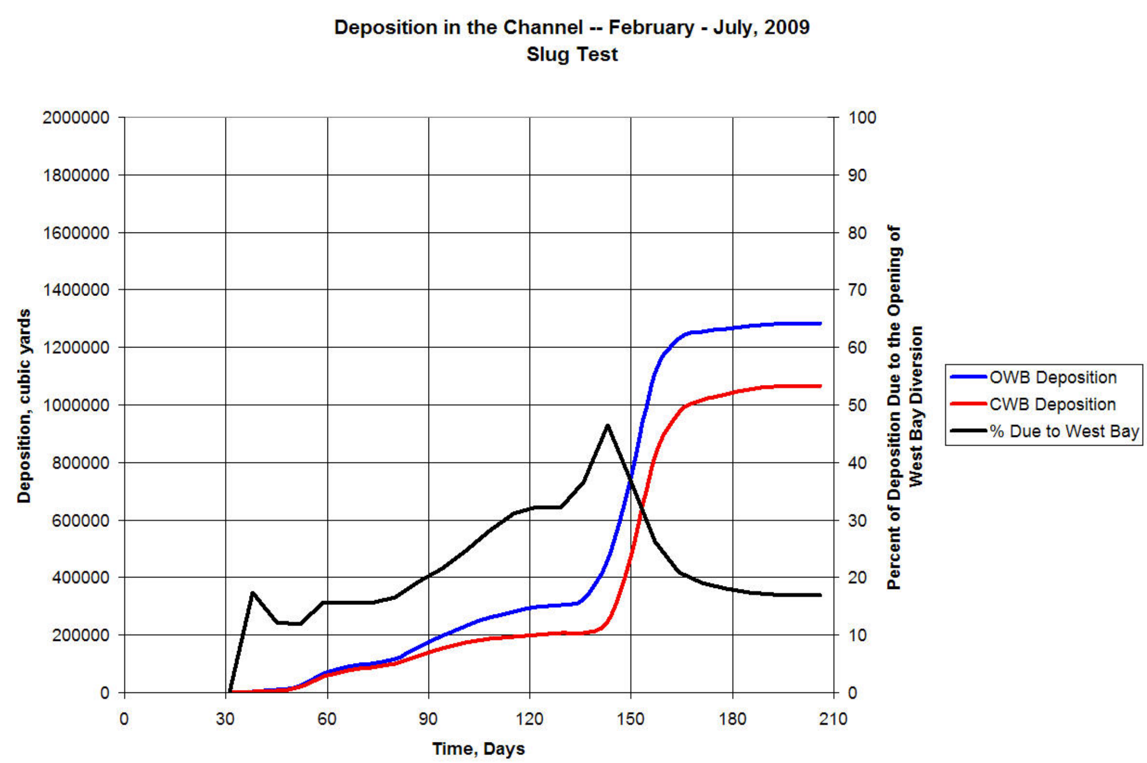


Figure 5.33. Deposition quantities for the adjacent channel, slug test.

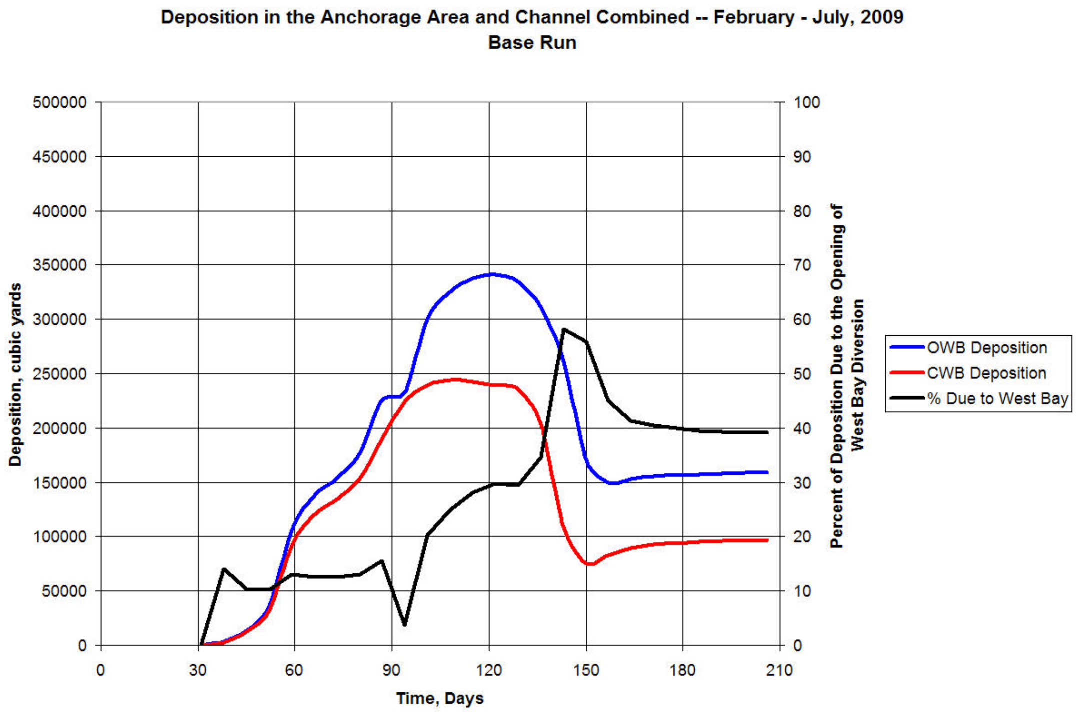


Figure 5.34. Deposition quantities for the combined anchorage area and adjencent channel, base run.

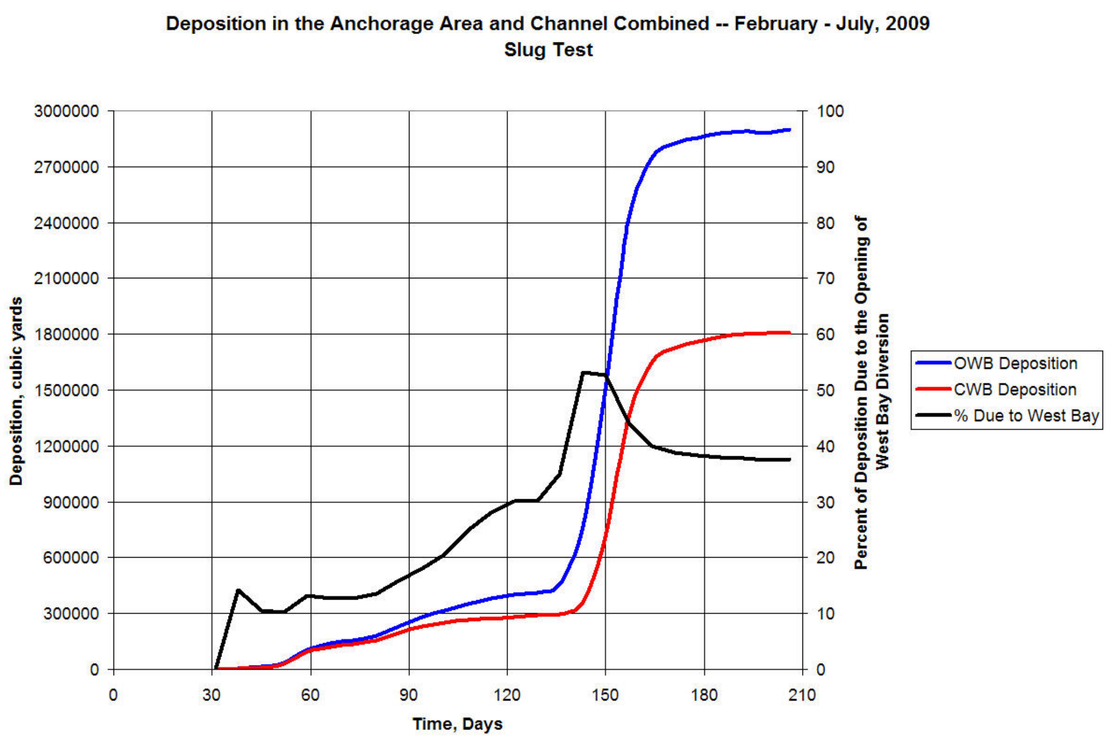


Figure 5.35. Deposition quantities for the combined anchorage area and adjencent channel, slug test.

The percent of deposition due to the West Bay diversion varies widely between nearly 100% in the base case run, to around 50% in the slug test run. Similarly, the percent of deposition in the adjacent channel varies between 0% in the base case run, to near 20% in the slug test run. However, the impact of west bay diversion on the combined anchorage area and adjacent channel footprint is consistent between the 2 runs (about 40%).

These results indicate that west bay has a relatively consistent impact on the total quantity of addition deposition, but that the spatial distribution of those impacts varies as a function of the specific depositional conditions of each particular year.

Figures 5.36 – 5.40 show the net deposition for a control volume extending from River Mile 5.2 to head of passes. The control volume is pictured in Figure 5.36. This analysis reinforces the consistency of the total percent change in deposition resulting from west bay diversion (about 20% for this control volume).

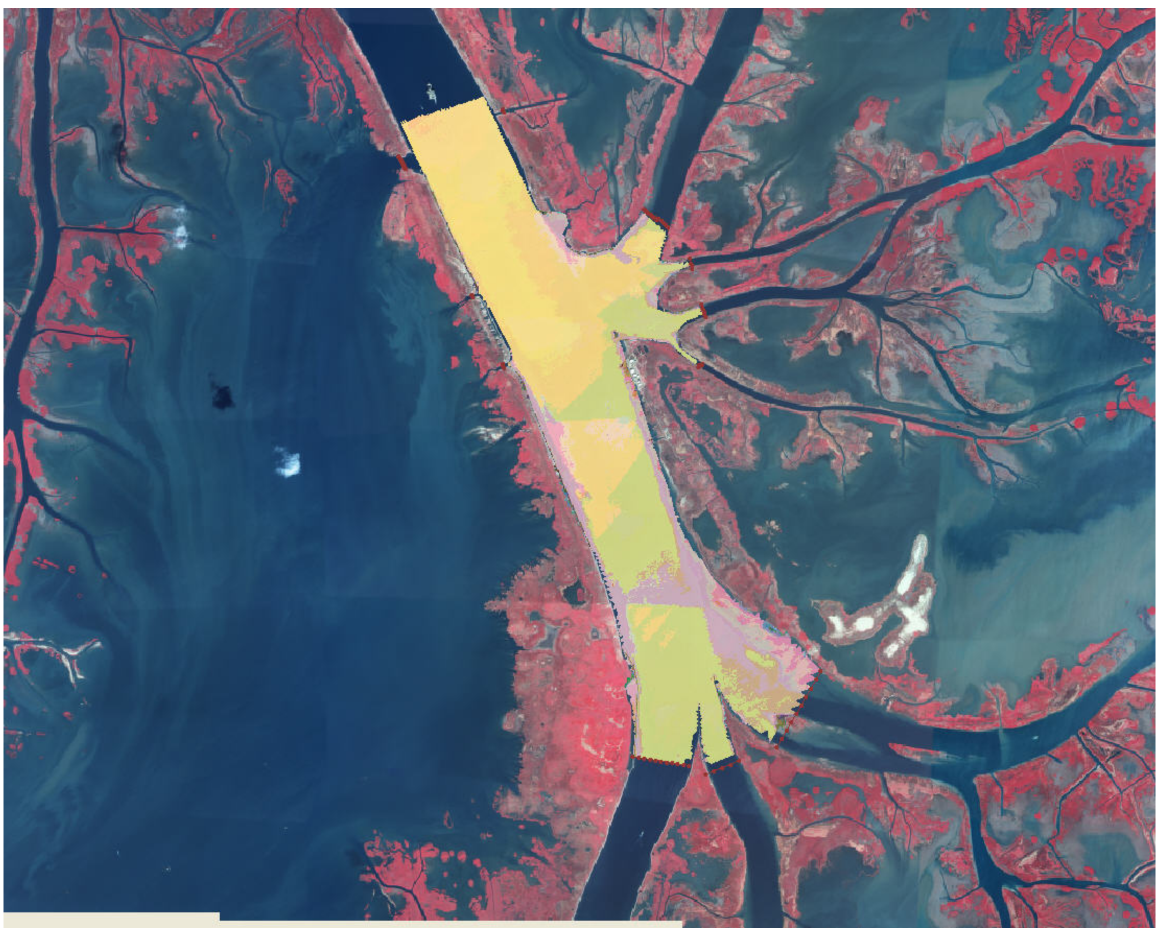


Figure 5.36. Control volume for net deposition analysis.

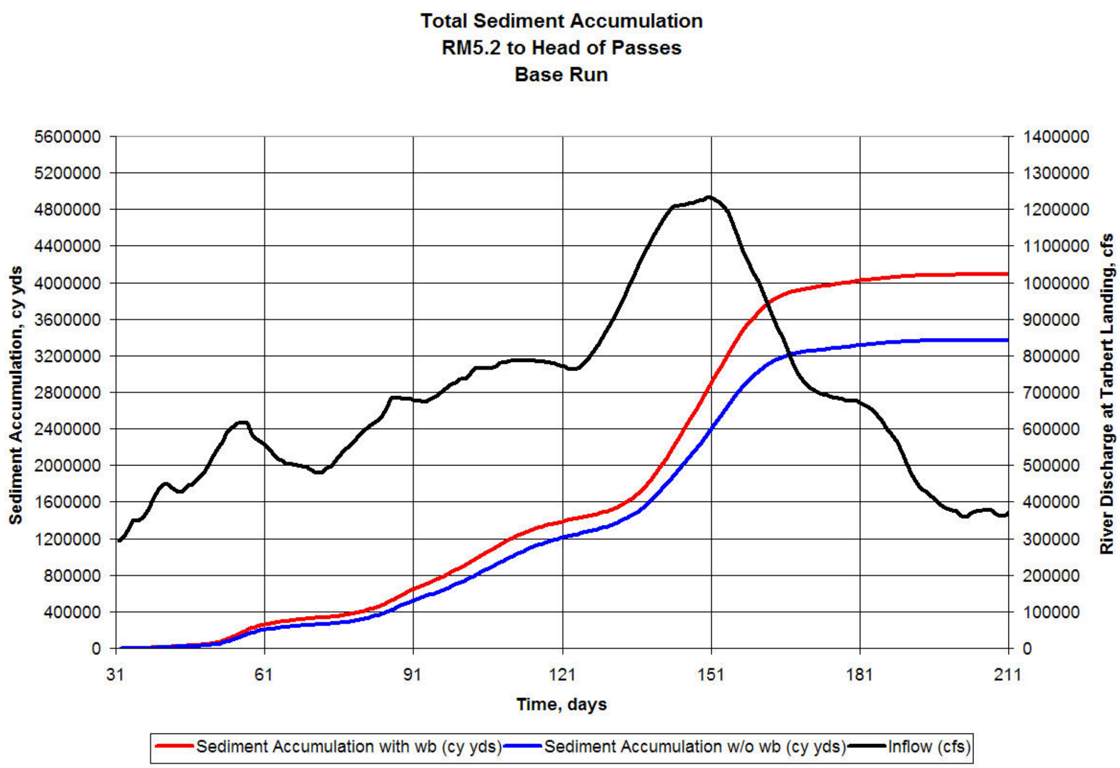


Figure 5.37. Net deposition within between RM 5.2 and Head of Passes, base run.

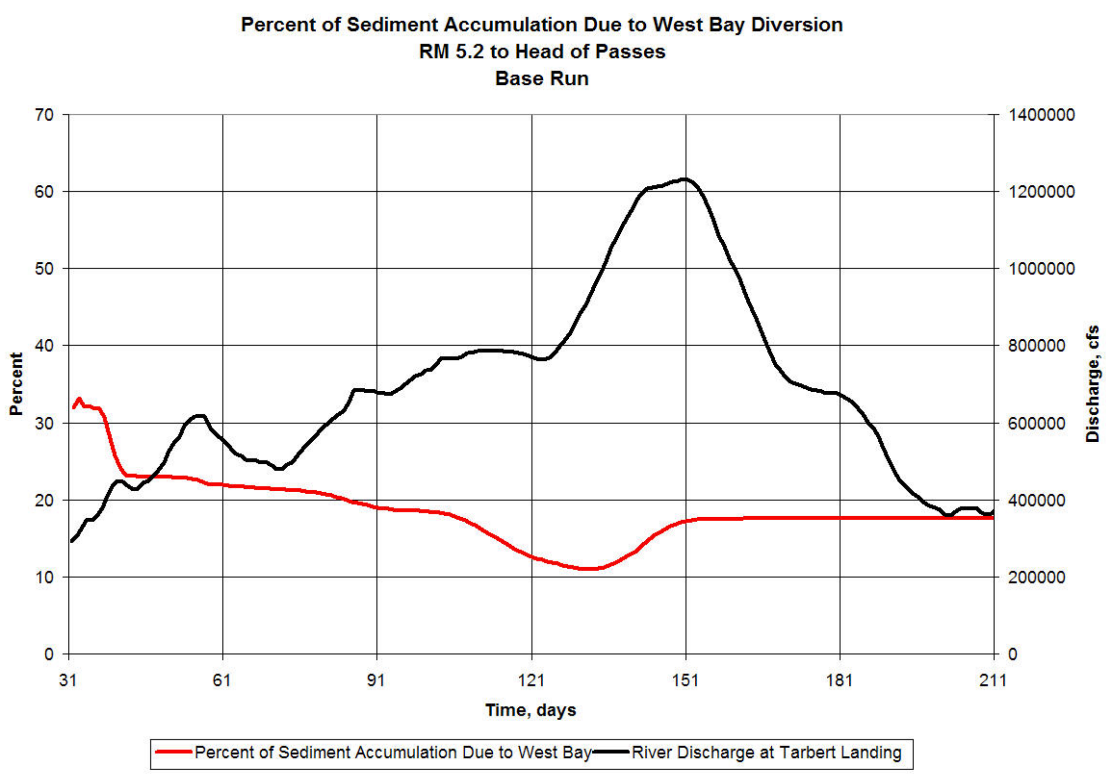


Figure 5.38. Percent increase in net deposition due to west bay diversion between RM 5.2 and Head of Passes, base run.

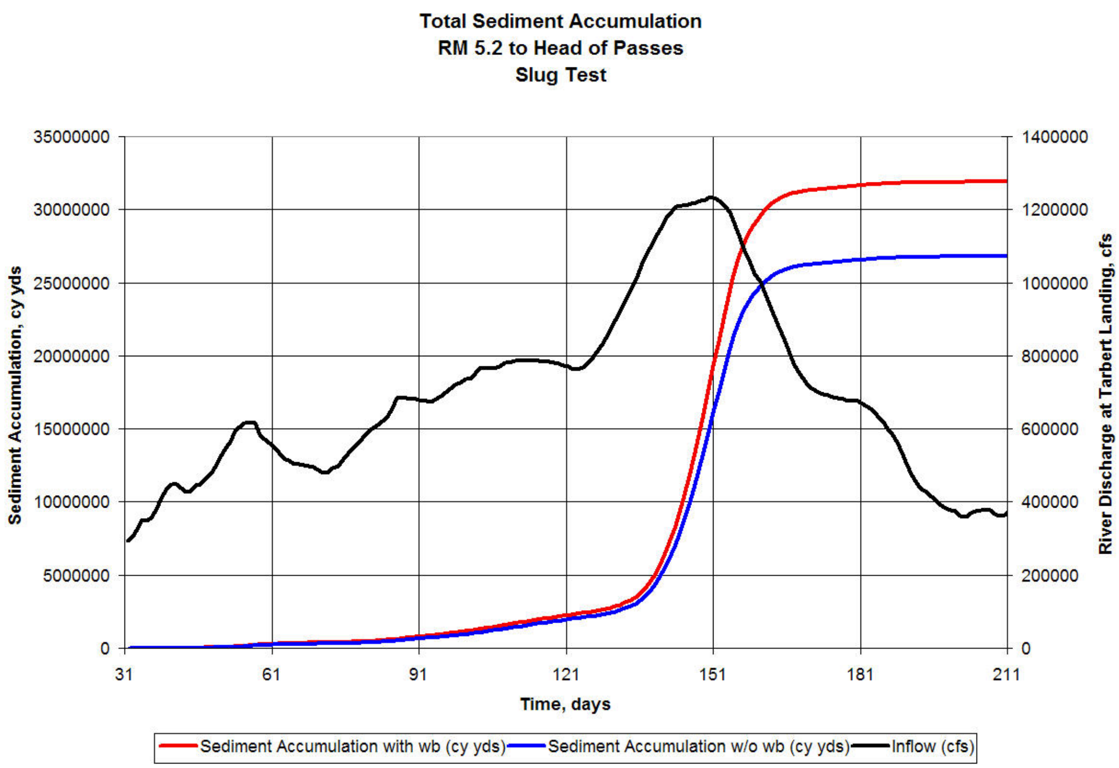


Figure 5.39. Net deposition within between RM 5.2 and Head of Passes, slug test.

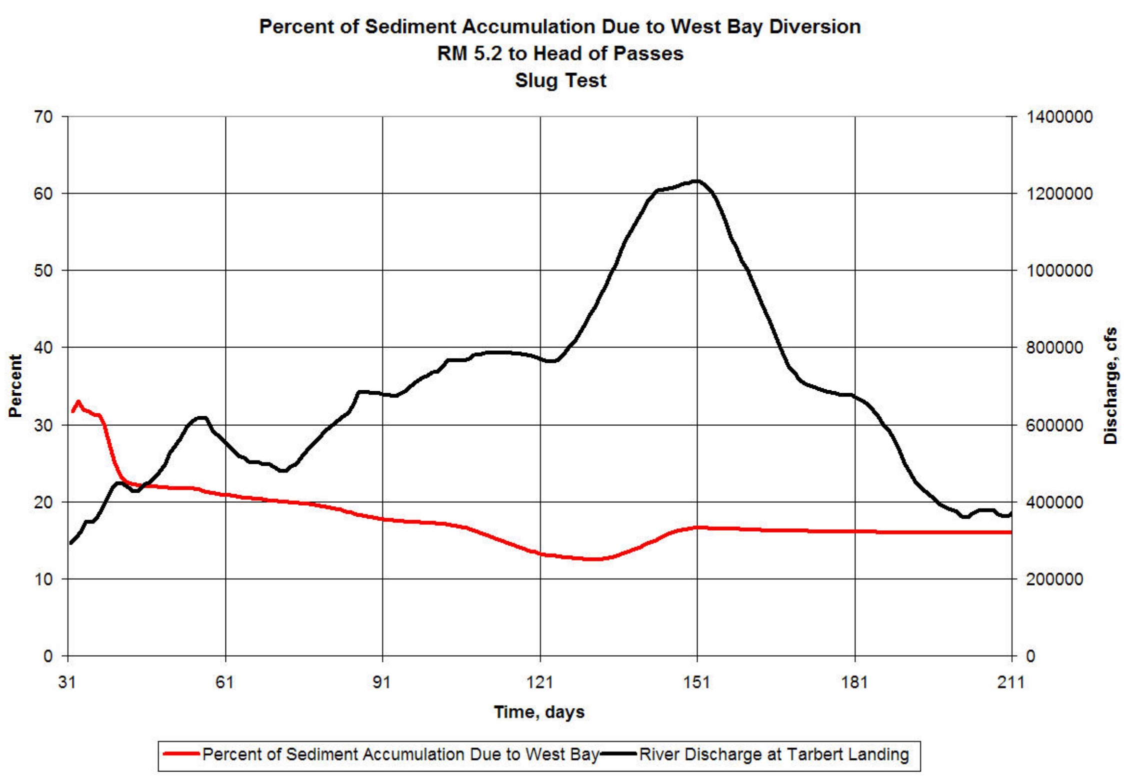


Figure 5.40. Percent increase in net deposition due to west bay diversion between RM 5.2 and Head of Passes, slug test.

CH3D-SED

Model Description

CH3D stands for Curvilinear Hydrodynamics in 3 Dimensions. CH3D-SED is a three-dimensional, finite-difference model suitable for simulating hydrodynamics and noncohesive sediment transport. The hydrodynamics in CH3D are based on work described in Sheng (1986), Johnson et al (1991), Chapman (1993), Chapman (1994), and Chapman et al. (1996). The governing sediment equations are based on a sediment modeling approach introduced by Spasojevic and Holly (1990). The original sediment modeling approach, developed for two dimensional shallow water situations, was extended by Spasojevic and Holly (1993) to fit the three-dimensional, non-orthogonal, curvilinear framework of the CH3D code. The sediment modeling approach includes bed-level changes (deposition and/or erosion), bedload transport, suspended-sediment transport, and interaction between the two. The approach allows for representing a sediment mixture in a natural watercourse through an unlimited number of size classes.

More details about CH3D-SED and its computational philosophy and equations can be found in Appendix D.

Mesh Development

The West Bay Diversion model domain has an upper inflow boundary located approximately at River Mile 7.5 (above Venice, LA) and extended to the south to approximately 3 miles below in head of passes into Southwest Pass, South Pass, and Pass A Loutre. The CH3D-SED computational grid was generated with dimensions 61x322 to accommodate high grid resolution at the West Bay Diversion. Figure 5.41 shows the CH3D-SED grid and figure 5.42 shows the bathymetric contours of the mesh.

Grid resolution across the river is approximately 30 by 30 meters with the highest grid resolution located at the diversion with approximately 7 by 7 meters. Figure 5.43 shows grid resolution at the West Bay Diversion.

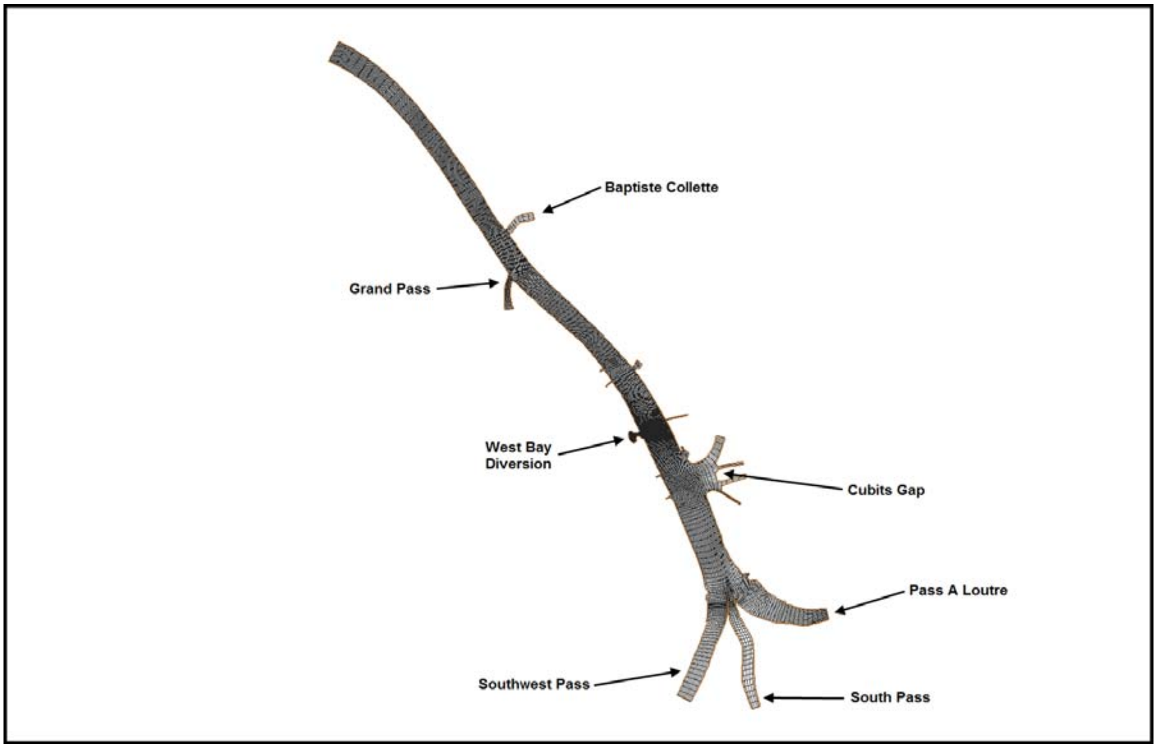


Figure 5.41. CH3D-SED Model Domain.

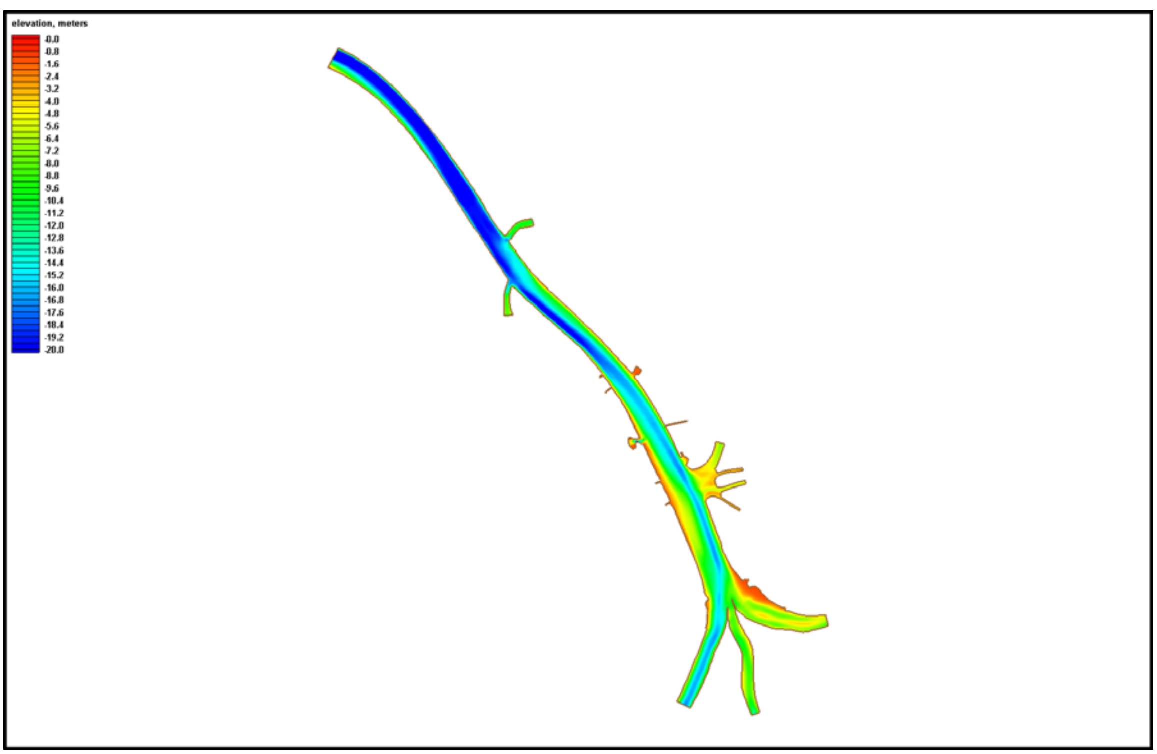


Figure 5.42. CH3D-SED Contours.

Figure 5.43. Grid Resolution at West Bay Diversion.

Boundary Condition Development

The model had an inflow boundary at the upstream end of the Mississippi River and outflow boundaries including Grand Pass, Baptiste Collette, West Bay Diversion, and Cubits Gap. The values used for these boundaries were taken from discharge measurements made by ERDC during the high flow event in May 29-30, 2009.

The water surface elevation boundaries at Southwest Pass, South Pass, and Pass A Loutre were developed using water surface elevation values from similarly located points in the AdH model.

CH3D-SED Verification

Sediment verification was obtained by comparing sediment concentrations from ERDC field data to those of the model for a 12 day simulation. Comparisons were made at river mile 5.2, just upstream of the West Bay Diversion (WBD), in the mouth of the WBD, and at river mile 4.5, just downstream of the WBD. The results of these comparisons are seen in figures 5.44 thru 5.46. The ERDC field data is represented by the individual points and the CH3D-SED model results by the correspondingly colored curves. Based upon the results in the figures 5.44 thru 5.46, the model produced a favorable verification of suspended sediment.

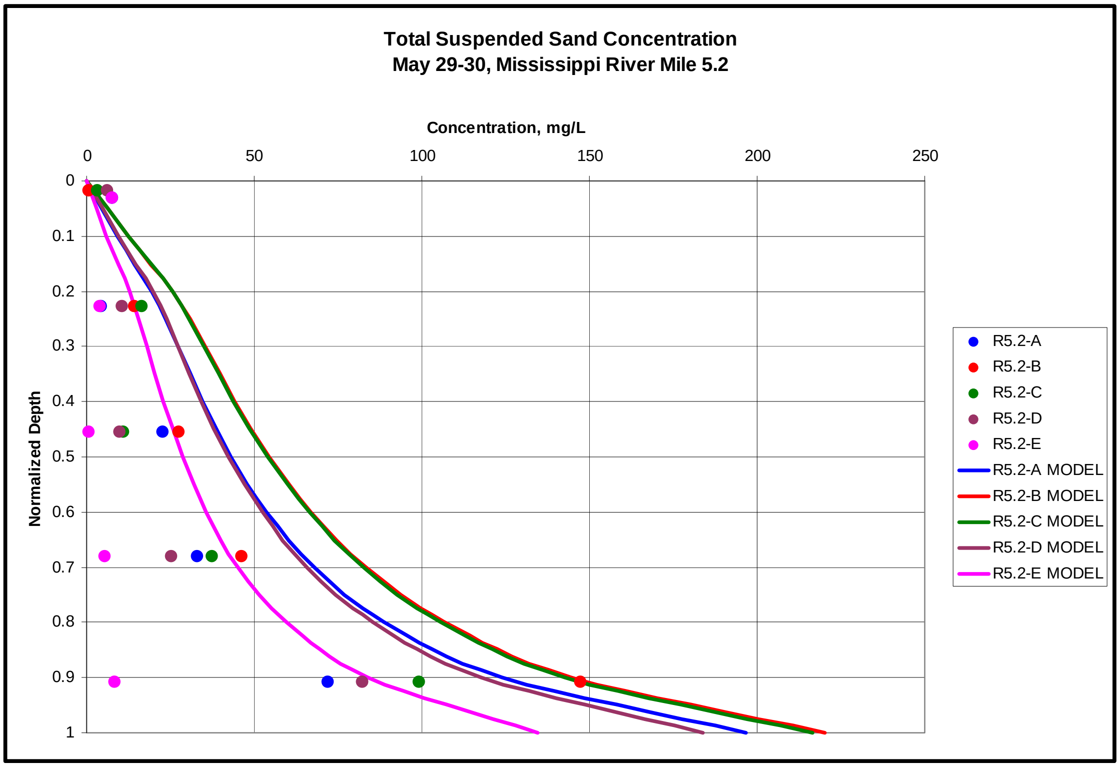


Figure 5.44. Sediment Concentration Comparison to Field Data, River mile 5.2.

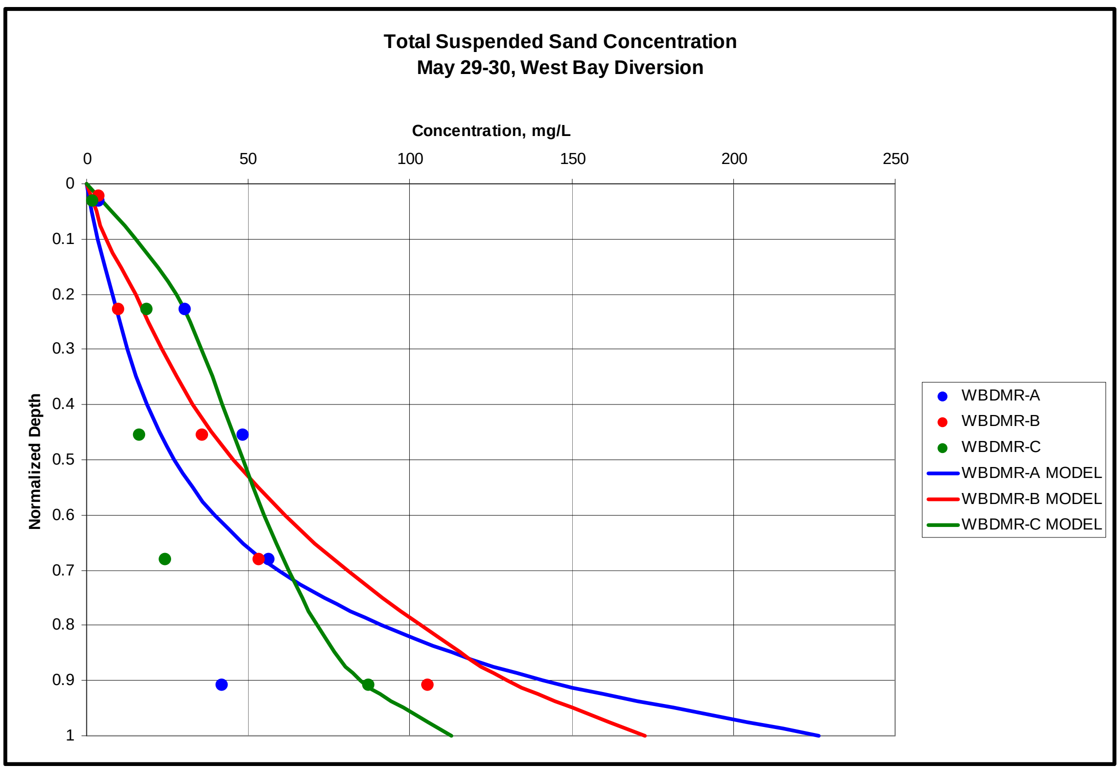


Figure 5.45. Sediment Concentration Comparison to Field Data, in Mouth of West Bay Diversion.

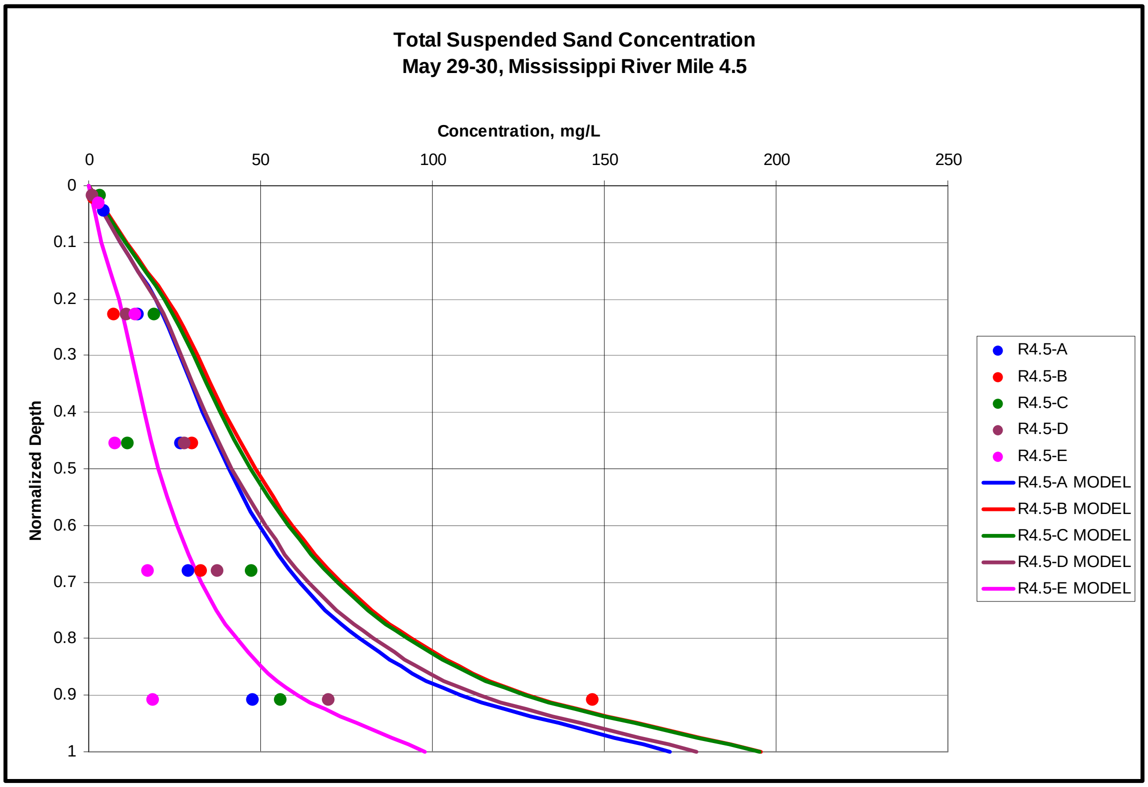


Figure 5.46. Sediment Concentration Comparison to Field Data, River mile 4.5.

CH3D Results

The velocity vectors at the surface and the bottom within the West Bay Diversion (WBD) are shown in figures 5.47 and 5.48. The flow patterns are representative of what was observed in the field. The eddy on the north side of the diversion shows favorable agreement with the pattern in the velocity data collected by ERDC. The strength of the eddy exceeds that observed in the ERDC field data collection effort, but these data were collected at a much lower flow than what was simulated, so this discrepancy is not unexpected.

The shoaling patterns are illustrated for the existing condition with the West Bay Diversion (Figure 5.49) and without the West Bay Diversion (Figure 5.51). These patterns are for the high flow condition used in the verification. A comparable AdH figure measured over similar flow conditions is included as well(Figure 5.50). This figure shows that the general pattern of deposition is reflected in both models.

Two major differences exist between the with and without West Bay simulations. The first difference is the increase in erosion on the right descending bank immediately upstream of the diversion. The second difference is the increase in shoaling from a point in the river at the diversion to just downstream of the diversion. This area of increased shoaling encompasses the anchorage area and the access to the anchorage area for this section of the river (Figure 5.52). These patterns appear to agree with results produced by AdH simulations (Figure 5.50).

As shoaling in the Pilottown Anchorage Area (PAA) and the adjacent access area are of primary importance in this study, the increase in shoaling/erosion in this area due to the construction of the WBD was examined. As the figures 5.49 thru 5-51 illustrated, the construction of the WBD did increase shoaling in the PAA. To determine the magnitude of the shoaling increase, the bed change for the two scenarios, with and without the WBD, was calculated for each day of the 12 day simulation. These bed changes were differenced from one another and divided by the bed change for the with WBD scenario to show the fraction of shoaling due to WBD. The results of this analysis are shown in figures 5.53 thru 5.55. During the spin-up period, percent increases in shoaling vary somewhat. After the spin-up period, the percent increase in shoaling due to the WBD settles at approximately 22% for PAA only, approximately 11% for the navigation channel only, and approximately 18% for PAA and the navigation channel combined.

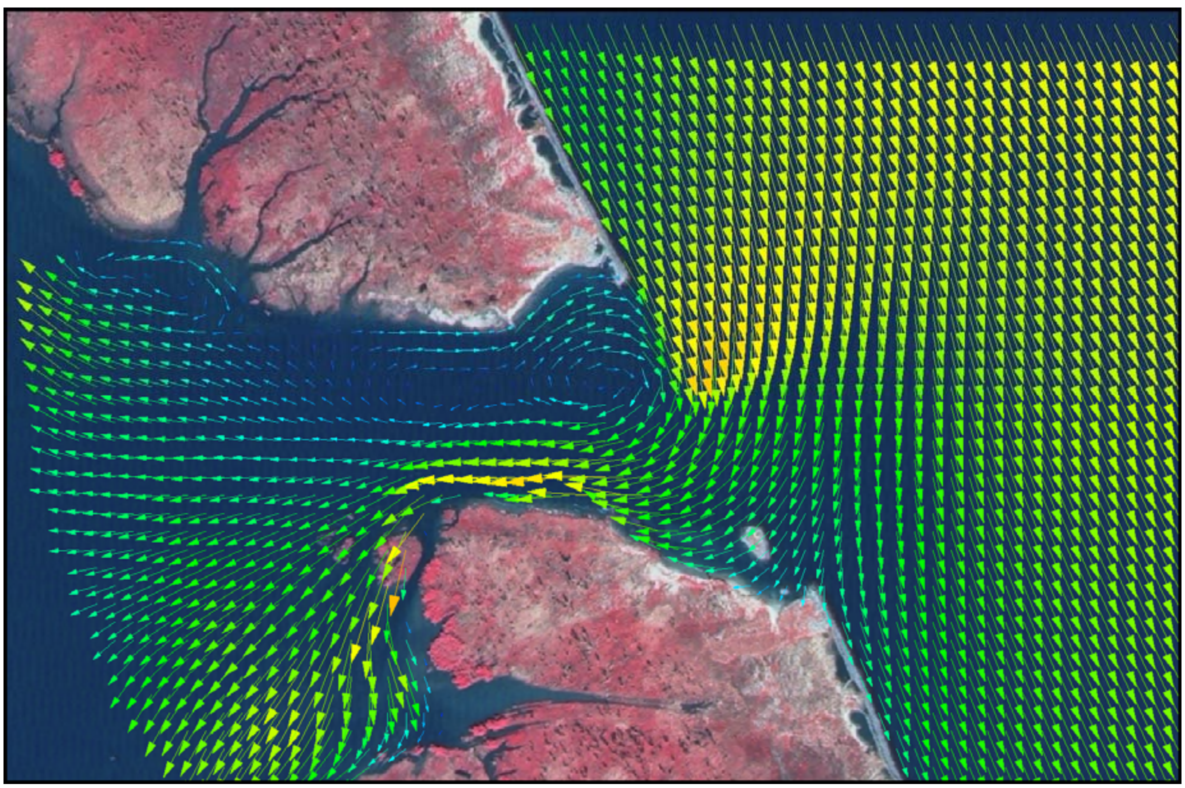


Figure 5.47. Surface Velocity Vectors.

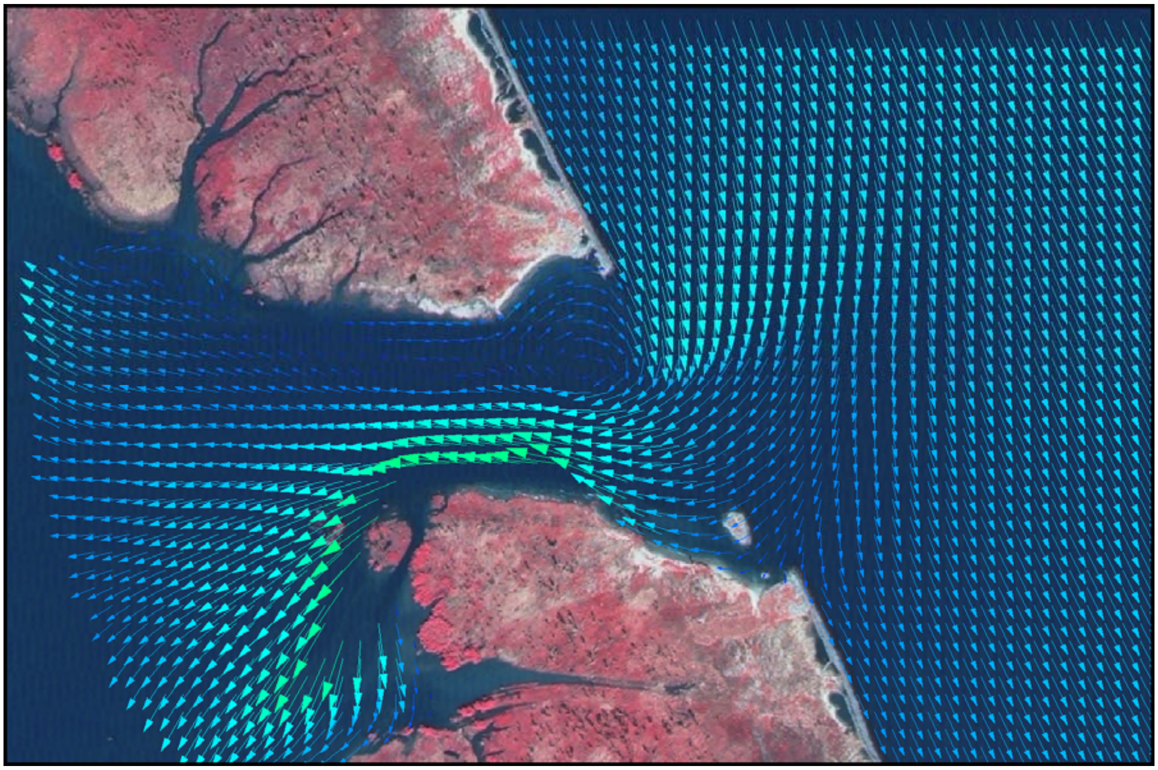


Figure 5.38. Bottom Velocity Vectors.

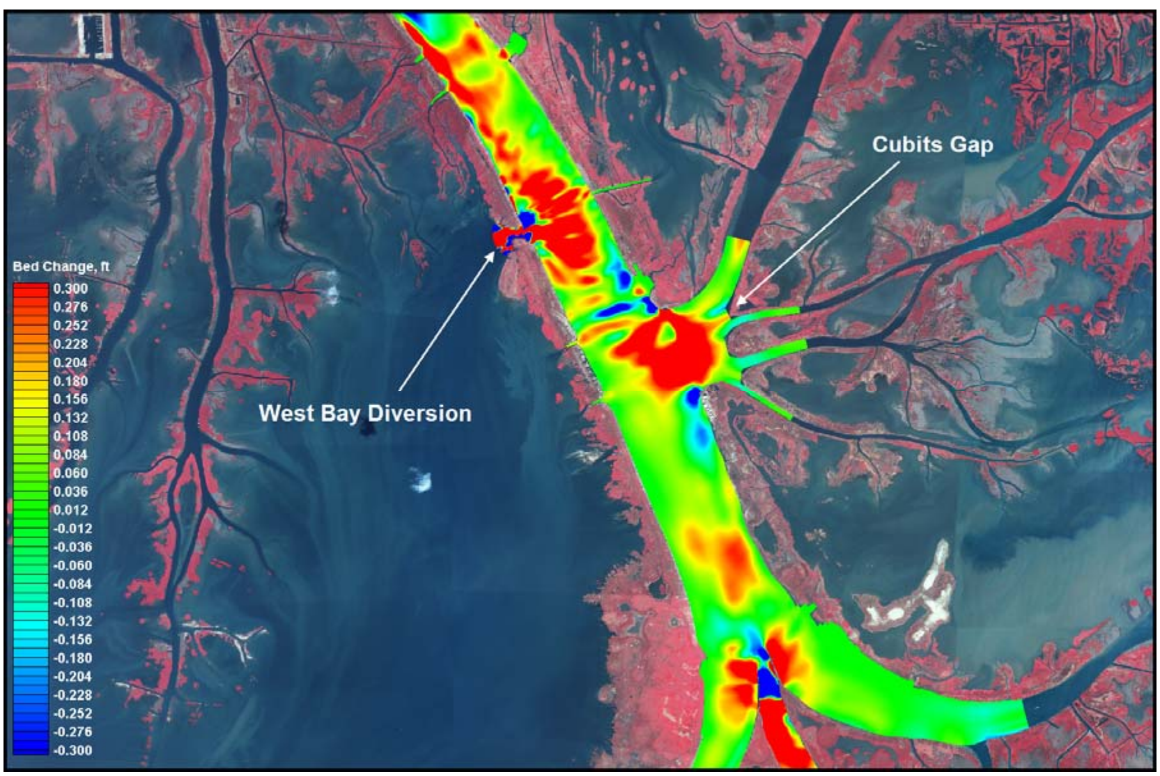


Figure 5.49. Bed Change over 12 Days – With West Bay Diversion.

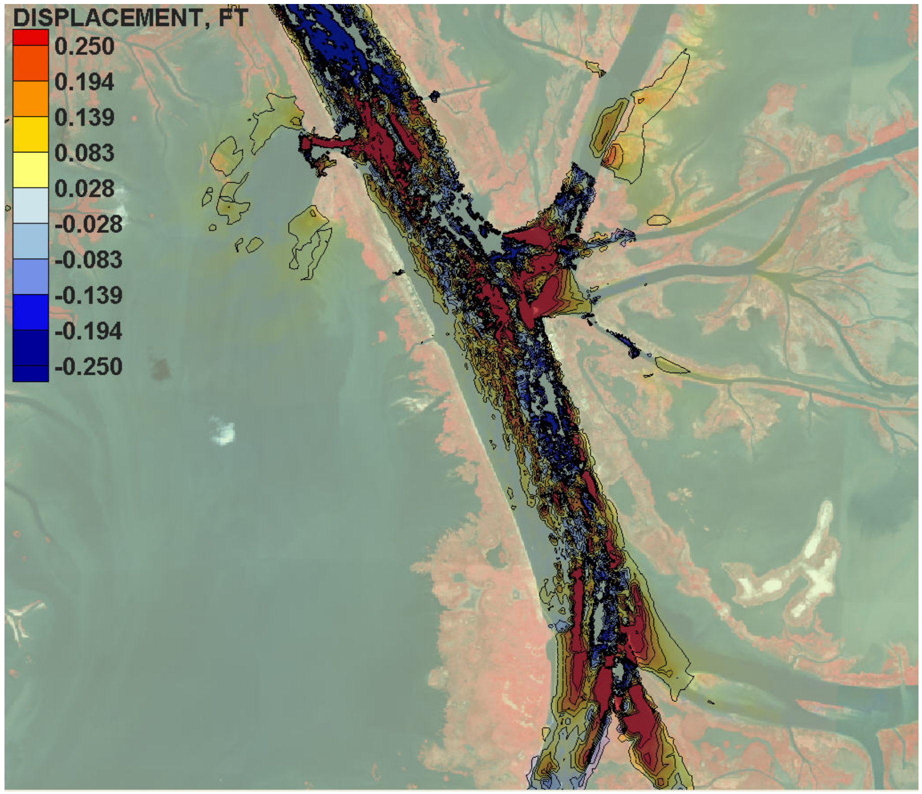


Figure 5.50. Bed Change in AdH mode – With West Bay Diversion.

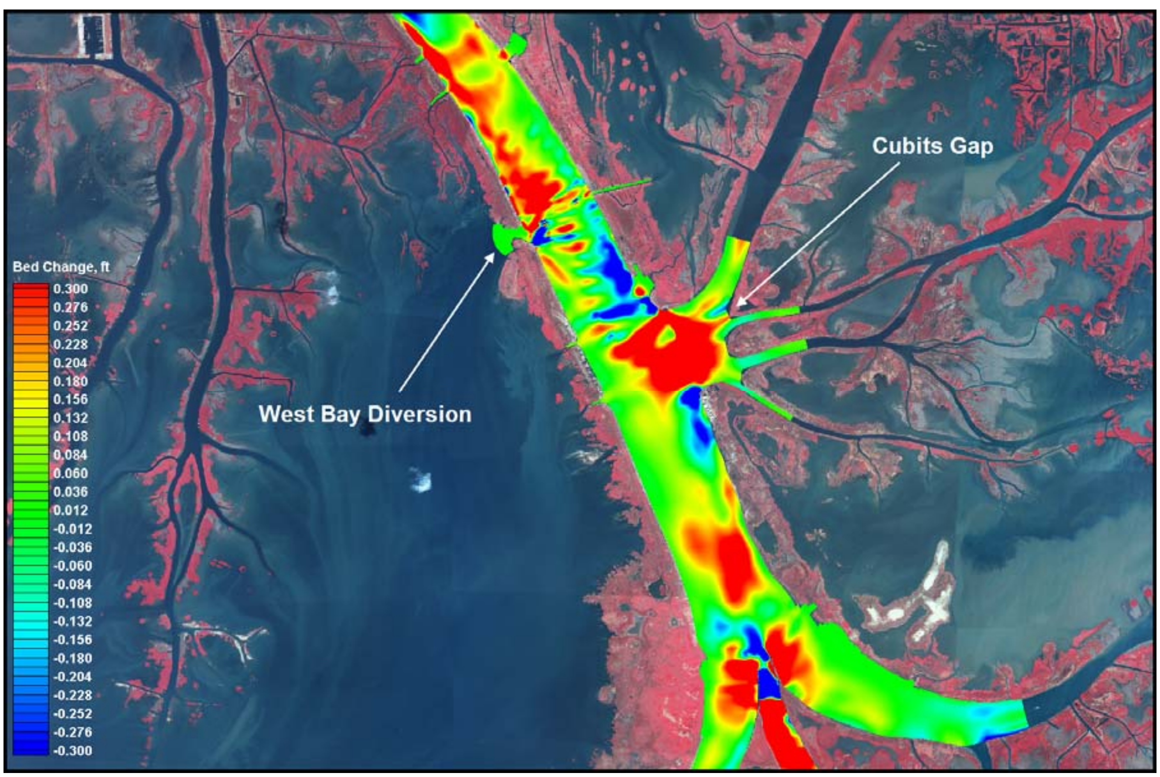


Figure 5.51. Bed Change over 12 days – Without West Bay Diversion.

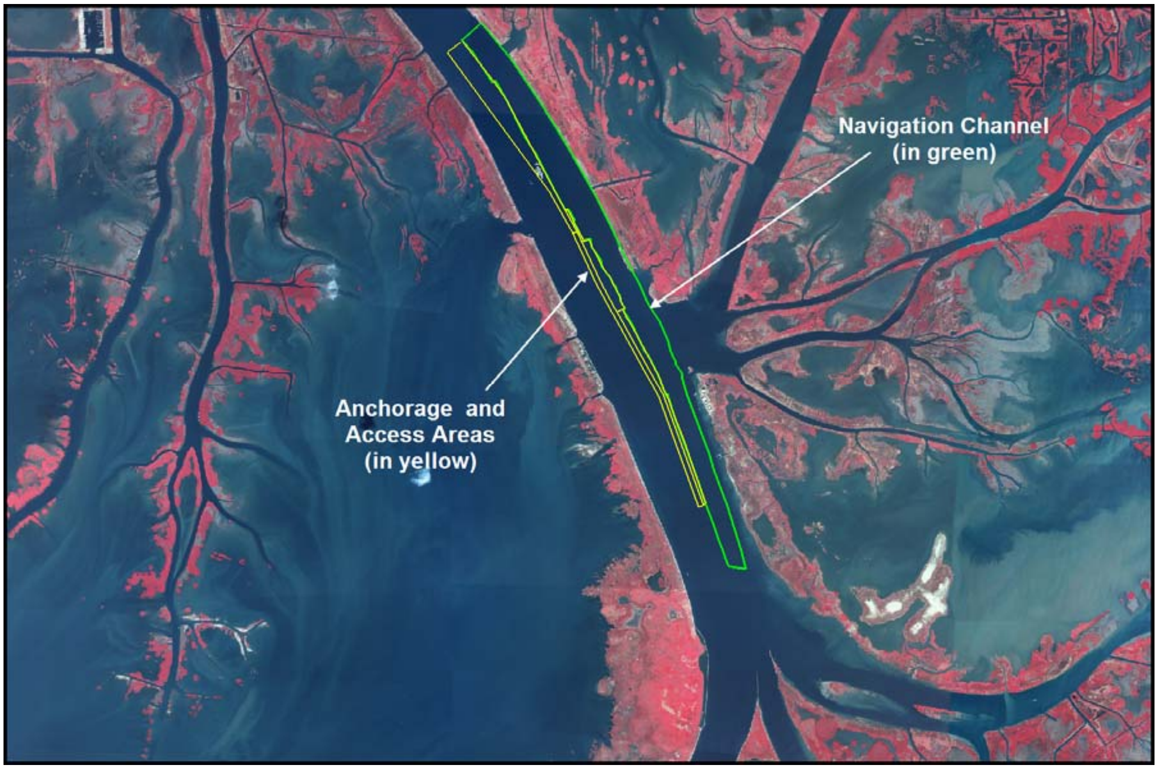


Figure 5-52. Pilottown Anchorage Area and Access Area bounds.

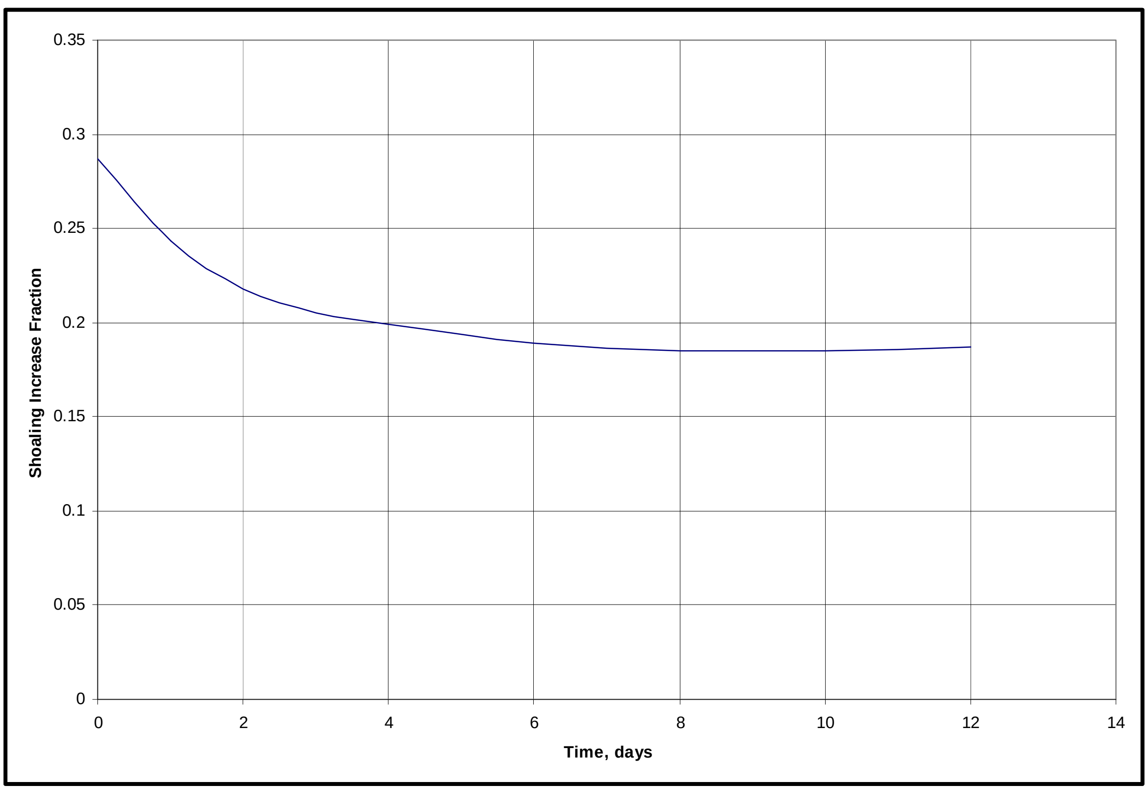


Figure 5.53. Shoaling Increase in the PAA Due to West Bay Diversion – 12 Day Period.

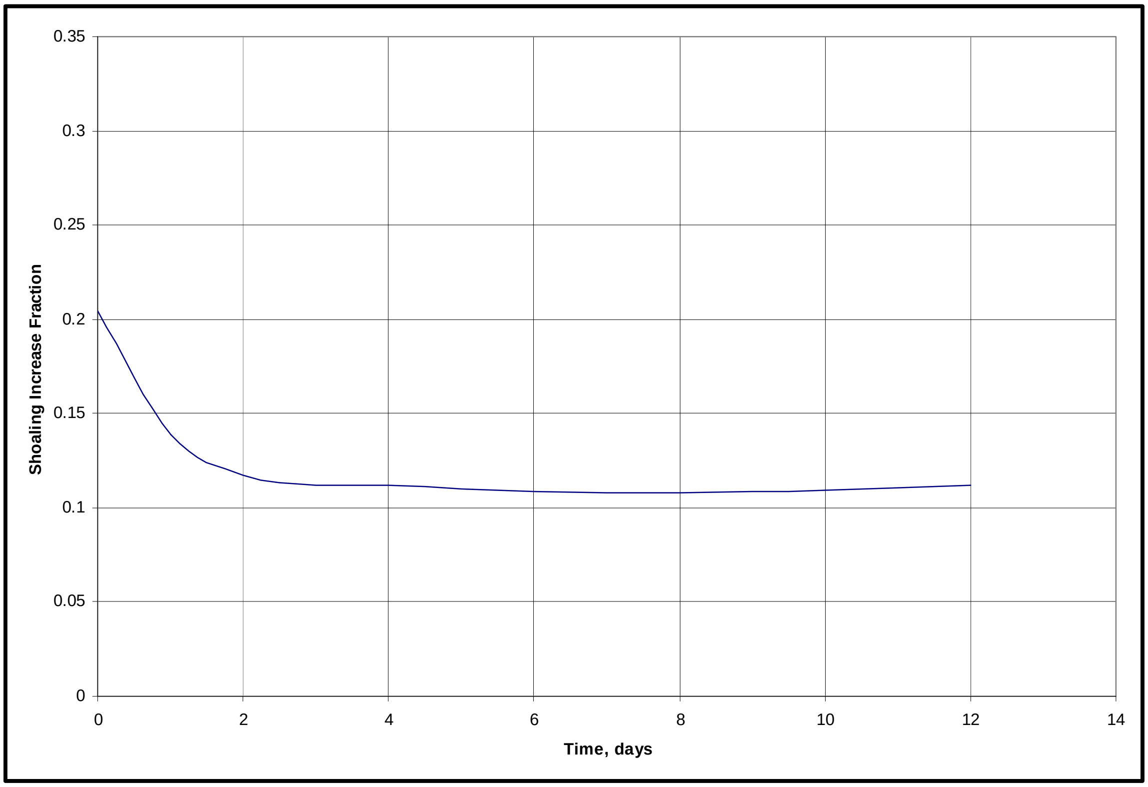


Figure 5.54. Shoaling Increase in the Nav Channel Due to West Bay Diversion – 12 Day Period.

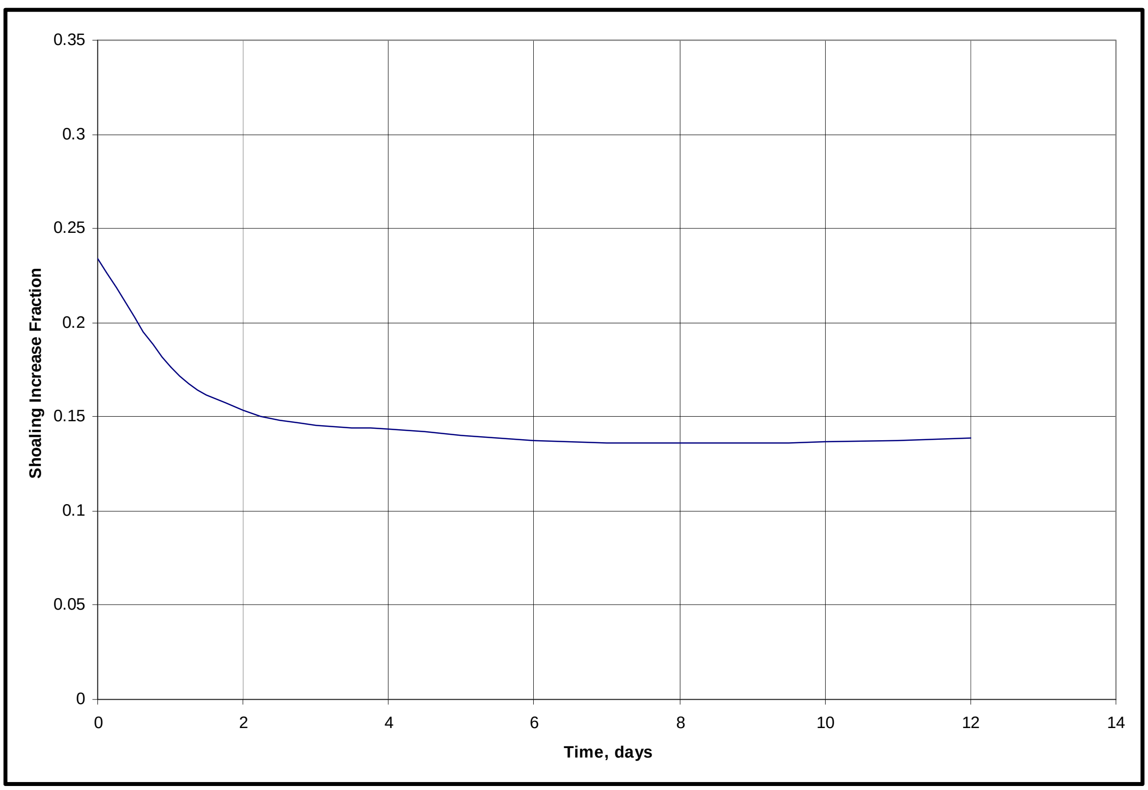


Figure 5.55. Combined Shoaling Increase in the Nav Channel and PAA Due to West Bay Diversion – 12 Day Period.

Conclusions

The modeling results indicate that the addition of West Bay Diversion has a relatively consistent impact on the total quantity of additional deposition (as a fraction of the total deposition), but that the spatial distribution of those impacts varies as a function of the specific depositional conditions of each particular year.

The addition of the diversion is shown to shift the deposition closer to the center of the navigation channel, effectively contracting the cross-section of the navigation channel. This contraction results in additional dredging requirements. This contraction occurs along both sides of the navigation channel.

For the AdH river hydrograph simulations, the net amount of sand storage attributable to the West Bay Diversion for a control volume extending from RM 5.2 to head of passes is consistently between 10 and 20%. However, the spatial distribution of this additional sediment storage can very from year-to year, depending on the specific flow and sediment regimes associated with the annual river hydrograph. The impact of west bay diversion on deposition in the combined anchorage area and adjacent navigation channel footprint is consistently about 40% at the end of the hydrograph. However, the distribution between the anchorage area footprint and the adjacent navigation channel footprint varies as a function of the available upstream sediment supply.

For the base case (a sediment starved condition), West Bay Diversion has almost no impact of the adjacent navigation channel deposition, but is responsible for almost 100% of the anchorage area dredging. For the slug test case (sediment rich condition) about 18% of the deposition in the adjacent navigation channel and about 55% of the deposition in the anchorage area is attributable to the diversion. Note that the sediment rich condition deposits a much greater volume of sediment than the sediment starved condition, so the percentages associated with the sediment rich condition represent a much larger fraction of the total deposition.

The Ch3D steady high flow simulations show consistency with the Adh simulations, in terms of general deposition patterns and quantities. This agreement between two separate physics-based multi-dimensional models gives good confidence that the modeling efforts are yielding reliable predictions of prototype behavior.

The percent of deposition due to West Bay for the Ch3D simulations is lower than that given for the Adh simulations: 22% for the anchorage area footprint, 11% for the navigation channel footprint, and 18% for the combined footprint. It is important to note that the Ch3D simulations were conducted for steady flow conditions, so there is no impact of the rate of change of the hydrograph on the deposition patterns. This shows that the shape of the hydrograph, as well as the available sediment supply, can be an important factor in determining deposition quantities.

6 Discussion and Conclusions

Overview

Each of the methods of analysis employed in this study have yielded insight into the central question this study is designed to address: i.e. what (if any) are the impacts of the West Bay Diversion on dredging requirements in the Pilottown Anchorage Area and the adjacent channel. The following chapter gives an overview of the pertinent information obtained from each of the study methods. This is followed by a discussion of how these results have been integrated into a coherent set of conclusions.

Conclusions Obtained from Each Method of Analysis

Geomorphic Assessment

Results from the various analyses conducted as part of the geomorphic assessment were integrated in order to formulate conclusions that best describe and explain the cause and effect of the overall morphological trends observed in the study area. The integration process takes the results from a given analysis and interprets the results in relation to the results of all analyses. In doing so, definitive trends can be established and areas of conflicting results can be identified.

The geometric data analyses indicate that in general there has been little change to a slight lowering of the river channel bed upstream of Venice. Results from cross section comparisons and reach average channel bed displacement and elevation comparisons agree reasonably and verify this trend. It should be noted that the geometric analyses for this reach of the river are based solely on comprehensive surveys collected approximately every decade. Observed changes in channel dimension for this reach can reasonably be correlated with revetment construction.

A distinct change in the trend of channel dimension occurs in the vicinity of Venice. Several things occur at this location. First, the main distribution of flow for the lower Mississippi River begins at Baptiste Collette and Grand Pass. The combined distribution of flow as a percentage of Mississippi River discharge for these two outlets has increased from approximately 5 percent to 16 to 20 percent over the study period.

Second, an alternating point bar channel pattern is observed. A point bar is located on the left descending bank immediately downstream of Grand Pass. The thalweg channel continues along the right descending bank until approximately the upstream limit of the anchorage area, where a crossing occurs. The thalweg channel shifts toward the left bank as it crosses through the upstream portion of the anchorage area, and is located closely along the left bank at Cubits Gap. A corresponding point bar begins along the right descending bank in the upper portion of the anchorage area, and extends throughout the anchorage area to near Head of Passes.

Third, a trend in reduced river channel depths is observed. Beginning at Venice and continuing to Cubits Gap, a general reduction in channel thalweg depths by as much as 20 feet has occurred over the study period. This trend is identified at individual cross sections and over reach average areas. There is a degree of variability in the data, particularly associated with the occurrence of large floods; however, the overall trend is one of general depth reduction. The effect of regular maintenance dredging is evident beginning at Cubits Gap and proceeding downstream to Head of Passes and throughout Southwest Pass. Due to the continual modification of the channel from maintenance dredging in this area, no definitive trends can be determined other than changes in depth that transpired as a result of the navigation channel deepening project.

The point bar that is located on the right descending bank within the anchorage area limits is very extensive, and the development of the bar has had a major impact on conditions within the anchorage area. From a qualitative assessment of cross section survey data, the point bar has been actively developing over the study period. Survey data indicates that there has been a degree of fluctuation in the vertical extent of the point bar. Some cross sections show that conditions in the anchorage area were actually higher in 1997 that they were at the time of diversion construction. Also, survey data gives evidence that the 1973 flood caused significant erosion of the point bar in the upper portion of the anchorage area. The development of the point bar downstream of Cubits Gap is potentially associated with the narrower, deeper navigation channel. The combination of the deep, narrow channel and the well developed point in this area produce a channel shape that is typically observed in sharp river bends. Reach average channel bed displacement determined from the comprehensive surveys indicates that the lower portion of the point bar within the anchorage area has increased in elevation 3 times as much as the upper portion of the anchorage area.

The development of the point bar in relation to the construction of West Bay diversion is difficult to accurately quantify. Analysis of average channel bed elevations along a 500 foot section landward (westward) of the Pilottown anchorage area line for cross sections within the anchorage area indicates an increase in post-construction deposition rates for locations at the diversion and downstream to Cubits Gap. For locations downstream of Cubits Gap, no significant change in the rate of deposition relative to diversion construction is observed. Reach average channel bed elevations indicate a similar trend, with an increase in post-construction elevations observed for the reaches in the vicinity of the diversion and downstream to Cubits Gap, but little change in rates for reaches downstream of Cubits Gap.

Indication of the development of the point bar can be seen in the analysis of channel pattern. The channel pattern analysis for the comprehensive surveys indicates that channel width was becoming narrower in the vicinity of Cubits Gap before the navigation channel deepening project. Since the deepening of the navigation project, the channel width and location downstream of Cubits Gap has been very consistent. Above Cubits Gap (outside of the dredging influences), channel width based on the comprehensive surveys has decreased, with the right side of the channel narrowing toward the left descending bank. This indicates that the point bar on the right descending bank is developing and encroaching to the east. In addition, it appears that the narrowing has increased in the years after diversion construction. Channel widths measured at the cross section locations in the vicinity of the diversion indicate a reduction in channel width of 750 to 1000 feet, with a large percentage of that occurring in the post-construction time period. Width data for cross sections downstream of Cubits Gap do not indicate a change in trend due to diversion construction.

The channel pattern analysis also indicates that the channel width at the -45 foot contour for the river reach immediately above Venice accounts for approximately 80 percent or more of the total top bank width. In the vicinity of the point bar on the left descending bank downstream of Venice, the channel width at the -45 foot contour is approximately 50 percent of the top bank width. Downstream of Cubits Gap the channel width at the -45 foot contour is only 25 to 30 percent of the top bank width, although the channel width is primarily determined by dredging at this location. This channel width pattern is obviously related to the alternating point bar sequence downstream of Venice. The beginning of Mississippi River flow distribution at Venice is believed to be the primary contributor to the development of this pattern.

Distribution of Mississippi River flow through some of the outlets located in the lower river and delta has changed over time. The combined percentage of river flow distributed by Baptiste Collette and Grand Pass has increased from approximately 5 percent to 16 to 20 percent, with the time frame of the increase corresponding to the enlargement of those outlets in the late 1970s. Flow distribution at Pass a Loutre has significantly decreased by as much as 20 to 25 percent beginning in the mid 1970s. The primary cause of this reduction at Pass a Loutre is unclear, but may be associated with the aforementioned changes at Baptiste Collette and Grand Pass, as well as the deepening of the navigation project in Southwest Pass. Flow distribution percentage for West Bay diversion has increased fairly uniformly since construction, from approximately 2 percent to 7 to 8 percent of river flow. The distribution percentage at Cubits Gap has decreased correspondingly, as has possibly the distribution percentage at Southwest Pass. In consideration of the geometric changes in depth and width that occur with the beginning of flow distribution near Venice, it appears that flow distribution through the outlets may be the primary physical agent for the observed morphological change in the study area. Given this, it is reasonable to assume that the construction of West Bay diversion, or any other diversion, will influence the trends of deposition in the anchorage area.

Major floods result in noticeable change to the channel perimeter, and changes are often without a discernable pattern. The flood of 1973 produced significant erosion in the point bar within the upper portion of the anchorage area. Patterns of scour and deposition are often observed for the same cross section. In the case of tropical storms, the effects seem to be more general. Sediment deposition observed during Hurricane Katrina appeared more uniform over the river channel, and deposit depths tended to increase with increasing proximity to the gulf. The track of the storm relative to the river delta most likely affects deposition trends.

1-D HEC-6T Modeling

The HEC-6T modeling effort has yielded several important insights to the long-term trends of morphological change in the study area. The West Bay Diversion can not be analyzed in isolation. It is a part of a complex interacting system of diversions which influence the morphology of the Mississippi River and Passes. An understanding of the response of the system to changes at any one diversion requires an understanding of the response of the system to each and every significant diversion. Even relatively small diversions can be important, because the cumulative effect of minor diversions may be significant.

Approximately 40-50% of the total flow and sediment passing just upstream of the Venice discharge range is taken from the river above head of passes through diversions. As a consequence, each reach downstream of Venice is aggradational with deposition increasing in the downstream direction and concentrated below Cubits Gap. From Cubits Gap downstream, the navigation channel functions as an efficient sediment trap. Any increase in the width of the trap produces nearly equal increases in the volume of dredging.

The 1D model performs well in reproduction of deposition and dredging locations but underestimates the best available estimates of deposition rates, particularly in Southwest Pass. The model results indicate that although the West Bay Diversion diverts only 7% (as modeled) of the total flow, the impact on dredging is disproportionably large. The model consistently indicates that the West Bay Diversion accounts for a 20-25% increase in dredging required in the Pilottown Anchorage. A similar increase in dredging occurs in the adjacent navigation channel.

Simulations were also conducted to estimate the impacts of dredging in the navigation channel if the anchorage area is not maintained. If only the navigation channel is maintained, the West Bay Diversion accounts for an even larger increase in required dredging.

The model results indicate that subsidence, and to a lesser extent (at current rates), sea level rise, have a potentially significant influence on system behavior. Better estimates of subsidence and its effects on the system are needed to understand this contribution fully.

2-D Adh and 3-D CH3D modeling

The modeling results indicate that the addition of West Bay Diversion has a relatively consistent impact on the total quantity of additional deposition (as a fraction of the total deposition), but that the spatial distribution of those impacts varies as a function of the specific depositional conditions of each particular year.

For the AdH river hydrograph simulations, the net amount of sand storage attributable to the West Bay Diversion for a control volume extending from RM 5.2 to head of passes is consistently between 10 and 20%. However, the spatial distribution of this additional sediment storage can very from year-to year, depending on the specific flow and sediment regimes associated with the annual river hydrograph. The impact of west bay diversion on deposition in the combined anchorage area and adjacent channel footprint is consistently about 40% at the end of the hydrograph. However, the distribution between the anchorage area footprint and the adjacent channel footprint varies as a function of the available upstream sediment supply.

For the base case (a sediment starved condition), west bay diversion has almost no impact of the adjacent channel deposition, but is responsible for almost 100% of the anchorage area dredging. For the slug test case (sediment rich condition) about 18% of the deposition in the adjacent channel and about 55% of the deposition in the Anchorage area is attributable to the diversion. Note that the sediment rich condition deposits a much greater volume of sediment than the sediment starved condition, so the percentages associated with the sediment rich condition represent a much larger fraction of the total deposition.

The Ch3D steady high flow simulations show consistency with the Adh simulations, in terms of general deposition patterns and quantities. This agreement between two separate physics-based multi-dimensional models gives good confidence that the modeling efforts are yielding reliable predictions of prototype behavior.

The percent of deposition due to West Bay for the Ch3D simulations is lower than that given for the Adh simulations: 22% for the anchorage area footprint, 11% for the navigation channel footprint, and 18% for the combined footprint. It is important to note that the Ch3D simulations were conducted for steady flow conditions, so there is no impact of the rate of change of the hydrograph on the deposition patterns. This shows that the shape of the hydrograph, as well as the available sediment supply, can be an important factor in determining deposition quantities.

Synthesis of Results and General Conclusions

Beginning at Venice, the morphology in the river transitions from a wide, relatively stable channel to an alternating point bar configuration. The time of initiation of the development of this point bar sequence corresponds to the deepening Grand Pass and Baptiste Collette. The subsequent growth and current shape of the channel thalweg appear to be primarily correlated with the existence and expansion of these diversions and of Cubit's Gap, and also the changes to the dredged channel dimensions near Cubit's Gap.

In consideration of the geometric changes in depth and width that occur with the beginning of flow distribution near Venice, it appears that flow distribution through the outlets may be the primary physical agent for the observed morphological change in the study area. Given this, it is reasonable to assume that the construction of West Bay diversion, or any other diversion, will influence the trends of deposition in the anchorage area.

The HEC-6T model indicates at approximately 46% of the total sediment load is either diverted or deposited between just upstream of Baptiste Collette Bayou and Head of Passes. This agrees well with the field data collection estimate that approximately 50% of the measured suspended sediment load is diverted or deposited within that reach.

The HEC-6T model also indicates that the reach from about mile 7 downstream to the West Bay Diversion, the reach from West Bay Diversion to Cubits Gap, and the reach from Cubits Gap to Head of Passes are all aggradational, with or without the West Bay Diversion open. This agrees well with the geomorphic assessment that indicates these reaches were aggradational before the West Bay Diversion was opened and continues to be aggradational after West Bay Diversion was opened.

The multi-dimensional modeling has shown that the addition of West Bay diversion results in a shift the deposition closer to the center of the navigation channel, effectively contracting the cross-section of the navigation channel. This contraction results in additional dredging requirements. This contraction occurs along both sides of the navigation channel. This result is consistent with observations of the morphological response since the construction of West Bay Diversion.

The multi-dimensional modeling has also shown that during flood events, some scouring of the face of the point bar can occur. This observation is also consistent with the morphohologal analysis.

The multi-dimensional model indicates that this scouring is only evident when the sediment bed upstream of the study area is relatively sediment starved. This implies that the morphological changes in the study area strongly dependent on both the current year’s hydrographs, and the antecedent conditions of the river from previous years.

The HEC-6T model consistently indicates that the West Bay Diversion accounts for a 20-25% increase in dredging required in the combined footprint of the Pilottown Anchorage and the adjacent navigation channel. The 1-D results represent 50 years of simulation time.

The Ch3D modeling indicates that 18% of the deposition in the combined Pilottown Anchorage and adjacent channel footprint is attributable to the West Bay Diversion. The Ch3d simulation represents 12 days of steady, high flow simulation time.

The Adh 2-D modeling results indicate that 40% of the deposition in the combined Pilottown Anchorage and adjacent channel footprint is attributable to the West Bay Diversion. The Adh results represent a single 6-month hydrograph, with 2 different sediment loading conditions: a sediment starved bed, and a sediment rich bed.

The differences in the result may be indicative of real inter-annual variations in the distribution of sediment in the river. The long-term 1-D modeling results tend to average out such variations, since the percentage results are averaged at the decadal scale. However, the results may also be a consequence of the different modeling assumptions and uncertainties inherent in different methods of analysis.

Therefore, we have selected a range of 20-40% for the likely percentage of deposition in the combined combined Pilottown Anchorage and adjacent channel footprint due to the West Bay Diversion. We intend to further refine the sources and estimates of this uncertainty a product of additional ongoing work

The 2-D Adh modeling indicates that the distribution of impacts between the Pilottown Anchorage Area and the adjacent channel varies as a function of the available upstream sediment supply. For the base case (a sediment starved condition), West Bay diversion has almost no impact of the adjacent channel deposition, but is responsible for almost 100% of the anchorage area dredging. For the slug test case (sediment rich condition) about 18% of the deposition in the adjacent channel and about 55% of the deposition in the Anchorage area is attributable to the diversion. Note that the sediment rich condition deposits a much greater volume of sediment than the sediment starved condition, so the percentages associated with the sediment rich condition represent a much larger fraction of the total deposition.

The Ch3d modeling results indicate that 11% of the deposition in the adjacent channel 22% of the deposition in the Anchorage area is attributable to the diversion.

Taking these results together with the results from the HEC 6T model for the composite section, we estimated the bounds of reasonable uncertainty for the percentage of deposition in each of the footprints that can be attributed to the West Bay Diversion: 15-55% for the Anchorage area, and 10-30% for the adjacent channel. Again, we intend to further refine the sources and estimates of this uncertainty as a product of additional ongoing work.

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