HURRICANE ISAAC WITH AND WITHOUT 2012 100-YEAR HSDRRS EVALUATION

FINAL REPORT

FEBRUARY 2013

US Army Corps of Engineers®

EXECUTIVE SUMMARY

SIGNIFICANT FINDINGS

- According to the Saffir-Simpson Hurricane Wind Scale, Isaac was a minimal Category 1 hurricane; however, the storm produced 45 hours of tropical force winds from the south and south east on a track west of New Orleans, LA. This wind and track, combined with slow forward motion, large maximum wind radius, and intense rainfall produced high storm surges and water levels. The resulting inundation in communities outside the greater New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) demonstrates that every hurricane is unique and that the Saffir-Simpson Scale should not be used as the sole predictor of inundation risk.

- High water marks show that there were only a few places that the old system would have been overtopped during Hurricane Isaac; thus the old system would have displaced about the same amount of water as the new system and the HSDRSS could not have significantly influenced inundation at communities external to the system.

- The Hurricane Isaac surge modeling produced water level differences between the with and without 2012 100-year HSDRRS conditions that were consistent with and support the previous modeling used in the design and environmental assessment of the HSDRRS.

- The Hurricane Isaac model simulations showed that any changes of water level due to the 2012 100-year HSDRRS system are 0.4 feet or less at communities outside the system. Changes in water level of this magnitude are less than model precision.

- Potential changes in water level from previous modeling were communicated to the general public in Individual Environmental Reports as well as public meetings regarding the HSDRRS held between 2007 and 2012.

- These increased water levels due to the 100-year HSDRRS do not explain the many feet of flooding that several communities outside of the system experienced during Hurricane Isaac. This flooding was caused by intense and long duration storm surge due to the long duration of tropical force winds, which, in some cases were aggravated by extreme local rainfall.

Introduction

On 29 August 2012, Hurricane Isaac made landfall along and impacted the Louisiana and Mississippi coastline. Impacts to the coastal Louisiana area, including New Orleans and surrounding communities, were considerable. The 2012 greater New Orleans area 100-year Hurricane and Storm Damage Risk Reduction System (100-year HSDRRS) performed to expectations in preventing the Hurricane Isaac storm surge from inundating the areas within the system. However, substantial flooding did occur in areas without federal levee systems, including, but not limited to Slidell, Mandeville, Madisonville, LaPlace, Braithwaite, Lafitte and others.

During the design of the 100-year HSDRRS, multiple sensitivity analyses were conducted to describe the potential effects of the system on storm surge elevations outside of the system. These modeling efforts predicted that the 100-year HSDRRS would increase the estimated peak water levels generally less than 0.2 feet in communities outside the HSDRRS. However, in response to the substantial flooding outside of the HSDRRS, concerns were raised regarding the effects of the 100-year HSDRRS during Hurricane Isaac on areas outside the system. Local and state officials requested an analysis to assess the effect of the 100-year HSDRRS on certain areas outside the system as a result of Hurricane Isaac.

The analyses contained in this assessment were conducted by a team consisting of personnel from the U.S. Army Corps of Engineers' New Orleans District, Mississippi Valley Division, and Engineering Research and Development Center, and the National Oceanic and Atmospheric Administration's National Weather Service. Data were compiled from the Corps of Engineers New Orleans District, the National Oceanic and Atmospheric Administration's National Hurricane Center, National Weather Service River Forecast Center in Slidell, LA, National Data Buoy Center, and National Ocean Service, the United States Geological Survey, and the State of Louisiana.

Assessment Purpose

This assessment was developed and conducted to answer one primary question:

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system inundated by Hurricane Isaac?

Assessment Overview

To examine the question on the impact of HSDRRS, this assessment focused on:

1. Defining Hurricane Isaac's meteorological statistics and surge propagation, and how they contributed to inundation outside the 100-year HSDRRS;

2. Previous Corps of Engineers analyses regarding effects from the 100-year HSDRRS;

3. Identifying the differences in surge conditions between the "With" and "Without" 2012 100-year HSDRRS conditions specifically for Isaac.

The data, methodologies and analyses supporting the assessment findings are organized by chapter. Refer to specific chapters for detailed discussions. Chapter summaries are provided below:

Chapter 1: Introduction - This chapter provides the purpose, scope and limitations of the assessment. A summary of assessment limitations are provided below, after these chapter summaries.

Chapter 2: Summary of 100-Year HSDRRS Conditions - This chapter provides a description of the "With" and "Without" 2012 100-year HSDRRS conditions and the comparative analysis between the two conditions. The footprint of the two conditions is, with the exception of some project features, essentially along the same alignment, although the HSDRRS project is higher in elevation and has a wider levee footprint. However, high water marks from Hurricane Isaac generally indicate that the storm would not have overtopped the pre- 2012 HSDRRS system, except in a few areas identified, and did not overtop the 2012 100-year HSDRRS system.

Chapter 3: Hurricane Isaac Event Overview - This chapter provides a detailed synopsis of the meteorological characteristics of Hurricane Isaac, including analysis of winds, wind directions, surge levels, storm track and duration and wave data. According to the Saffir-Simpson Hurricane Wind Scale, Isaac was a minimal Category 1 hurricane, reaching maximum sustained wind speeds of approximately 80 miles per hour immediately before landfall. However, the storm's ability to move water into the low-lying areas of coastal Louisiana and Mississippi was much greater than this wind speed suggests. The long duration of tropical force winds, the storm track and slow forward motion, the storm size, the high tide conditions and significant rainfall occurring at the same time as the maximum storm surge, resulted in large amounts of water being pushed into the coastal areas of the northern Gulf. In many cases, water levels exceeded those from more intense storms such as Hurricanes Katrina and Gustav.

Chapter 4: Comparison of System Characteristics and Performance - This chapter summarizes the performance of the 2012 100-year HSDRRS during Hurricane Isaac based on gage data, high water marks, and photographs taken during the damage assessment site visits. Based on analysis of the collected data, there is no indication of wave overtopping or surge overflow along the 2012 100-year HSDRRS, including the Mississippi River Levees between river mile 80 and 130. High water marks show that there were only a few places that the old system would have been overtopped during Hurricane Isaac; thus the old system would have displaced about the same amount of water as the new system and the HSDRSS could not have significantly influenced inundation at communities external to the system.

Chapter 5: Prior Evaluations of HSDRRS Performance - This chapter provides a synopsis of analyses on the potential impact of the HSDRRS on areas outside the system that were conducted during the development and design of the HSDRRS and communicated to the public through Individual Environmental Reports and public meetings The model generally predicted increases in estimated peak water levels of less than 0.2 feet at communities outside the HSDRRS, although it produced about 0.9 feet of increase in the vicinity of the Caernarvon Floodwall near Braithwaite.

Chapters 6: Hurricane Isaac Model Simulations - This chapter documents model simulations of Hurricane Isaac with and without the 2012 100-year HSDRRS in place. A preliminary assessment of the model made through comparison of measured data to model predictions indicates the model does reasonably well in simulating Hurricane Isaac across southeast Louisiana and Mississippi. The greatest differences were in Breton Sound. The model over predicts water levels at the upper end of Caernarvon marsh near Braithwaite by as much as approximately 3 feet. In general, model results indicate that water levels are relatively higher in Breton Sound and lower in Lake Pontchartrain with the HSDRRS in place. The differences between the with and without 2012 100-year HSDRRS condition are generally 0.2 feet or less across southeast Louisiana and Mississippi. An overview of the differences produced by the model are provided in Figure i.1. A positive difference indicates that water levels are higher with the 2012 100-year HSDRRS in place, negative values indicate lower predicted water levels with the 2012 100-year HSDRRS in place. The dark blue regions represent flooding within polders that was prevented by the HSDRRS. The largest difference outside of polders shown in the figure is an increase in water level of approximately 0.8 feet in the immediate vicinity of the Western Closure Complex in an uninhabitated area. Increases in water level outside the immediate vicinity of the West Closure Complex diminish to 0.4 feet near the communities of Crown Point, 0.2 feet at Jean Lafitte and less than 0.1 feet in the majority of the Barataria basin.

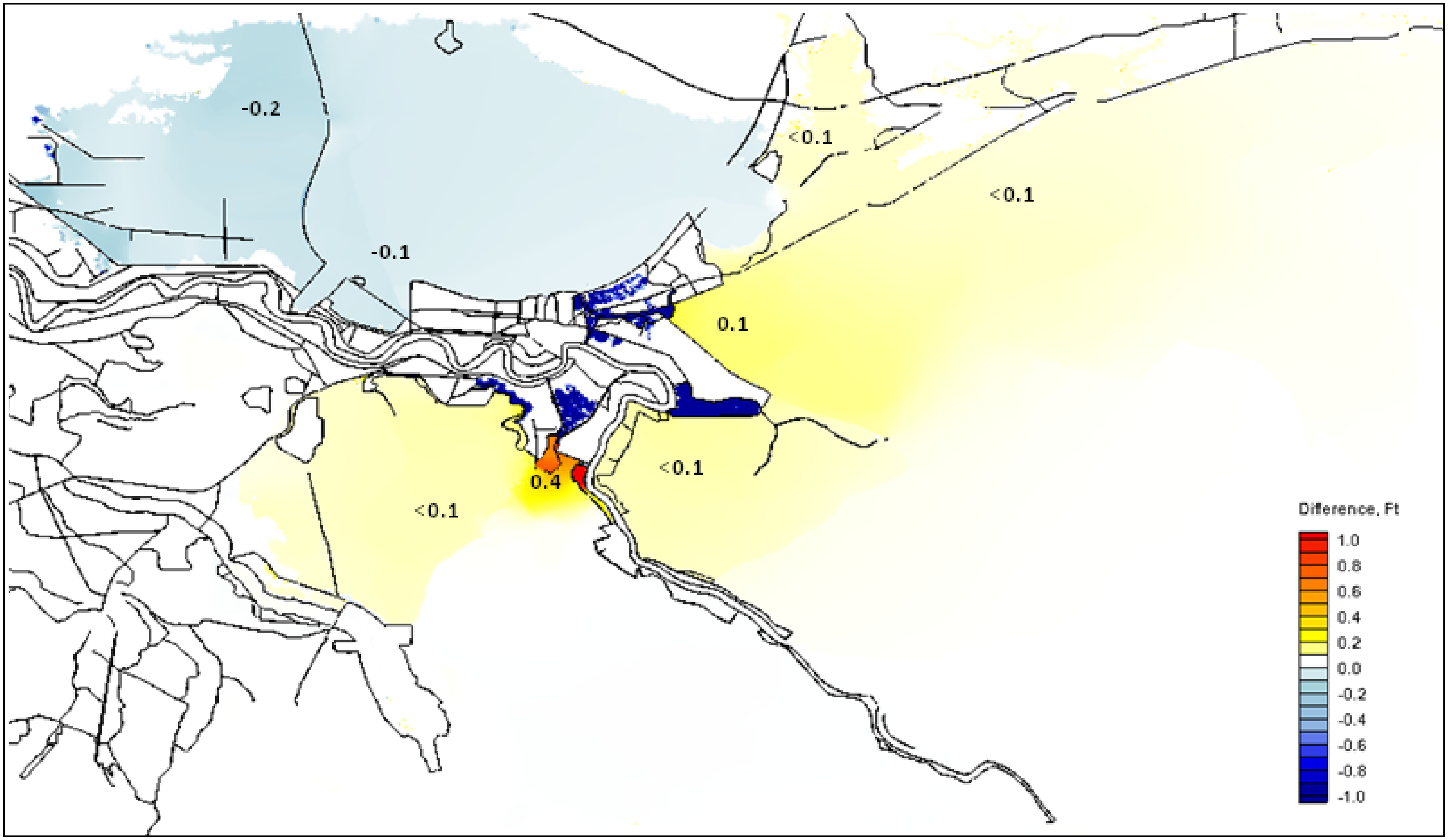

Figure i.1. Results of ADCIRC model simulation showing difference in maximum water level for Hurricane Isaac between with and without 2012 100-Year HSDRRS

Chapter 7: Detailed Evaluations - This chapter provides a summary of the hydrodynamic model results for certain areas outside the 2012 100-year HSDRRS adversely impacted by Hurricane Isaac. Lake Pontchartrain Northshore & West Shore: Peak water levels would decrease by approximately 0.1 feet. Total rainfall was approximately 10 to 15 inches. Plaquemines Parish East Bank: Peak water level would increase by approximately 0.3 feet in the immediate vicinity of Caernarvon floodwall and 0.1 or less throughout the area. Total rainfall was approximately 11 inches. High water marks indicated peak stage of approximately 13.8 feet. West Closure Complex (WCC) & Eastern Tie-In: Peak water level would increase by approximately 0.8 feet in the immediate vicinity of WCC; 0.4 feet near Crown Point; 0.2 feet at Jean Lafitte and 0.1 or less in the majority of Barataria basin. Total rainfall was approximately 10 to 11 inches. High water marks indicated peak stage of approximately 5.0 feet. near WCC. Mississippi Gulf Coast: Peak water level would increase by less than 0.1 feet in the Mississippi Gulf Coast area. Total rainfall was approximately 10 inches (Gulfport) to 22 inches (Pascagoula). Gage indicated peak stage of approximately 9 feet in the Bay St. Louis area. It should be noted that these areas were selected as representative areas to assess the impact of the 2012 100-year HSDRRS; it is not an exhaustive investigation of all areas that were subject to inundation.

Chapter 8: Summary of Findings – This chapter summarizes the findings of the assessment.

Assessment Limitations

The analyses and findings contained in this assessment utilized only available data. Specific data limitations were:

- All gage data are considered provisional, subject to revision.

- High water marks were collected only in accessible locations where right of entry was not required.

- Data related to hurricane characteristics, such as track, wind speed, radius to maximum winds, central pressure, and other parameters were compiled from available data.

- Available hurricane surge models were utilized. The model grids were updated (including local levees in the existing models) using 2012 Light Detection and Ranging (LIDAR) information and as-built survey information to describe the 2012 100-year HSDRRS. The grids have not been updated to include new local features such as Mardi Gras Pass.

- Rainfall modeling was limited:

    - St. John the Baptist Parish: Where existing models were available, these models were used to perform an initial assessment of the direct rainfall impacts.
    - Western Closure Complex: Previous rainfall model results were considered.
    - Remaining Areas: A qualitative assessment was performed using rainfall and gage data.

- This assessment does not include analyses on economic damages or potential solutions to the flooding.

Conclusion

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system flooded by Hurricane Isaac?

Most of the HSDRRS system was built on the same alignment as the old hurricane protection system. In all but three areas, the high water marks were below the elevation of the old system. In general, model results indicate that water levels were relatively higher in Breton Sound and lower in Lake Pontchartrain with the HSDRRS in place. The Hurricane Isaac model simulations showed that any changes of water level due to the 2012 100-year HSDRRS system are 0.4 feet or less at communities outside the system. Changes in water level of this magnitude are less than model precision. These findings are consistent with previous modeling of HSDRRS impacts during design and construction of the project and previously communicated to the public.

Hurricane Isaac With & Without 2012 100-Year Hurricane Storm Damage Risk Reduction System Evaluation

TABLE OF CONTENTS

TABLE OF CONTENTS I

FIGURES IV

TABLES VII

LIST OF PLATES VIII

APPENDICES (VOLUME II) IX

LIST OF ACRONYMS X

1.0 INTRODUCTION 1-1

1.1 PURPOSE AND SCOPE 1-1
1.2 LIMITS OF INVESTIGATION 1-4

2.0 SUMMARY OF 100-YEAR HSDRRS CONDITIONS 2-1

2.1 CHAPTER SUMMARY 2-1
2.2 WITHOUT 2012 100-YEAR HSDRRS CONDITION 2-1
2.3 2012 100-YEAR HSDRRS CONDITION 2-3

3.0 HURRICANE ISAAC EVENT OVERVIEW 3-1

3.1 CHAPTER SUMMARY 3-1
3.1.1 Forward motion and track of the storm 3-1
3.1.2 Rainfall 3-1
3.1.3 Winds 3-2
3.1.4 Water Level Heights 3-3
3.1.5 Comparison of Isaac to other Events 3-4
3.2 HURRICANE ISAAC DATA 3-4
3.2.1 Storm Chronology 3-4
3.2.1.1 Synoptic History 3-7
3.2.2 Meteorological Data 3-8
3.2.2.1 Storm Total Rainfall Summary 3-8
3.2.2.2 Wind Summary 3-14
3.2.2.3 Wave Buoy Data 3-18
3.2.2.4 Water Level Data 3-20
3.2.2.5 River Gages 3-24
3.3 COMPARISON OF HURRICANE ISAAC WITH PRIOR TROPICAL EVENTS 3-27
3.3.1 Hurricane Interaction with the Coast of Southeastern Louisiana 3-27
3.3.2 Storm Comparisons (Katrina, Gustav, & Isaac) 3-28
3.3.2.1 Storm Tracks 3-28
3.3.2.2 Surface Winds Nearing Landfall 3-30
3.3.2.3 Comparison of Storm Surge 3-38
3.3.2.4 Comparison of Rainfall (Additional Data for TS Allison) 3-45
3.4 COMPARISON OF ISAAC WITH MODELED SYNTHETIC STORMS 3-48

4.0 COMPARISON OF SYSTEM CHARACTERISTICS AND PERFORMANCE 4-1

4.1 CHAPTER SUMMARY 4-1
4.2 HURRICANE ISAAC AND POST STORM DATA 4-2

4.3 PERFORMANCE OF THE HSDRRS WITH AND WITHOUT 2012 100-YEAR ELEVATIONS AND FEATURES 4-7
4.4 CONCLUSIONS 4-26

5.0 PRIOR EVALUATIONS OF EXPECTED 100-YEAR HURRICANE STORM DAMAGE RISK REDUCTION SYSTEM (HSDRRS) PERFORMANCE 5-1

5.1 CHAPTER SUMMARY 5-1
5.2 LACPR STUDY (2007-2009) 5-3
5.3 IHNC STORM SURGE BARRIER MODELING STUDY (2011) 5-9
5.4 CAERNARVON FLOODWALL EVALUATION (2010) 5-13
5.5 WESTERN CLOSURE COMPLEX EVALUATION (2009-2012) 5-14
5.5.1 Storm Surge Analysis 5-15
5.5.2 Pump Impact Assessment 5-17
5.6 LIST OF PRIOR REPORTS AND REFERENCES 5-21

6.0 HURRICANE ISAAC MODEL SIMULATIONS 6-1

6.1 CHAPTER SUMMARY 6-1
6.2 MODEL INPUT AND SIMULATIONS 6-2
6.2.1 Introduction 6-2
6.2.2 Overview of Modeling System 6-3
6.2.3 Storm Surge Modeling 6-12
6.2.4 2012 / 100-year HSDRRS 6-15
6.2.5 Without 2012 100-Year HSDRRS 6-18
6.3 PRELIMINARY HURRICANE ISAAC STORM SURGE MODEL ASSESSMENT 6-18
6.4 RESULTS 6-25
6.4.1 Sensitivity Analysis 6-29
6.4.1.1 General Overview 6-29
6.4.1.2 Areas of Orleans and St Bernard Parishes Immediately Outside the HSDRRS 6-29
6.4.1.3 Mississippi Coast 6-30

7.0 DETAILED EVALUATIONS 7-1

7.1 EAST BANK PLAQUEMINES PARISH 7-1
7.1.1 ADCIRC Model Results 7-1
7.1.1 Rainfall and Runoff Analysis 7-1
7.1.2 Summary of Effects 7-5
7.2 ST TAMMANY & TANGIPAHOA PARISHES 7-6
7.2.1 ADCIRC Model Results 7-6
7.2.2 Rainfall and Runoff Analysis 7-7
7.2.3 Summary of Effects 7-13
7.3 WEST SHORE LAKE PONTCHARTRAIN 7-14
7.3.1 ADCIRC Model Results 7-16
7.3.2 Rainfall and Runoff Analysis 7-16
7.3.3 Rainfall runoff amounts in the watershed 7-19
7.3.3.1 St. John Parish 7-19
7.3.3.2 St. James and Ascension Parishes 7-25
7.3.3.3 Lake Maurepas 7-29
7.3.4 Summary of Effects 7-38
7.3.4.1 Surge Peak Timing and Duration 7-38
7.4 LOWER JEFFERSON & PLAQUEMINE PARISHES 7-40
7.4.1 Hydrodynamic Model Results 7-40
7.4.2 Rainfall and Runoff Analysis 7-41
7.4.3 Summary of Effects 7-45

8.0 SUMMARY OF FINDINGS 8-1

8.1 INTRODUCTION 8-1

8.2 EVALUATION BACKGROUND 8-2
8.3 EVALUATION OF COLLECTED DATA AND QUALITATIVE ASSESSMENT OF SYSTEM 8-2
8.4 NUMERICAL MODELING OF HURRICANE ISAAC 8-3
8.4.1 General 8-3
8.4.2 Detailed Evaluations 8-4
8.4.2.1 Eastbank Plaquemines Parish 8-4
8.4.2.2 Lake Pontchartrain Northshore and West Shore 8-5
8.4.2.3 West Closure Complex / Eastern Tie-In Area 8-6
8.4.2.4 Areas of Orleans and St Bernard Parishes Immediately Outside the HSDRRS 8-6
8.4.2.5 Mississippi Coast 8-6

FIGURES

Figure 1.1 Vicinity Map of study area including southeast Louisiana and the Mississippi Gulf Coast.................... 1-2
Figure 1.2 Southeastern Louisiana study area 1-3
Figure 1.3 Map showing the extents of the ADCIRC computational domain and the area of coverage for the wind and pressure fields 1-7
Figure 1.4 Map showing the ADCIRC computational domain along with H*Wind domains of coverage for several dates corresponding to Hurricane Isaac. 1-8

Figure 2.1 Major features of the 2012 100-Year HSDRRS 2-5
Figure 2.2 IHNC Surge Barrier and Seabrook Complex 2-7
Figure 2.3 Interim Closure Structures Orleans Parish Outfall Canals 2-8
Figure 2.4 Caernarvon Floodwall and Gate 2-9
Figure 2.5 Westbank and Vicinity Eastern Tie-In 2-10
Figure 2.6 West Closure Complex and Estelle Water Control Structure 2-12
Figure 2.7 Harvey Sector Gate 2-12
Figure 2.8 Bayou Segnette Complex 2-13
Figure 2.9 Westbank and Vicinity Western Tie-In 2-14
Figure 2.10 Construction Closures and Interim Structures 2-15

Figure 3.1 Gulf of Mexico track for Hurricane Isaac 27 August through 30 August 3-6
Figure 3.2 Total Rainfall for Hurricane Isaac event 3-11
Figure 3.3 Stage vs. 6-Hour Rainfall on Bayou Manchac at Little Prairie, LA 3-12
Figure 3.4 Stage vs. 6-Hour Rainfall on the Tchfuncte River at Madisonville, LA. 3-13
Figure 3.5 Stage vs. 6-Hour Rainfall on the Pearl River at Bogalusa, LA. 3-13
Figure 3.6 Stage vs. 6-Hour Rainfall on the Tangipahoa River at Osyka, LA. 3-14
Figure 3.7 Wind measurements at Mississippi Sound at Grand Pass 3-16
Figure 3.8 Wind measurements on Lake Pontchartrain at Slidell, LA. 3-16
Figure 3.9 Wind measurement near the Tchefuncte River at Madisonville, LA. 3-17
Figure 3.10 Wind measurement near the Amite River River at Maurepas, LA. 3-18
Figure 3.11 Wave heights from wave buoy 42001 3-19
Figure 3.12 Wave heights from wave buoy 42012 3-20
Figure 3.13 Observed tide vs. predicted tide at Waveland Yacht Club 3-21
Figure 3.14 Observed tide vs. predicted tide on Lake Pontchartrain's south shore at New Canal Station............ 3-21
Figure 3.15 Observed vs. predicted tide at Shell Beach 3-22
Figure 3.16 Observed vs. predicted tide at Grand Isle, LA. 3-23
Figure 3.17 Observed vs. predicted tide on the East Bank Bayou LaBranche at Norco, LA. 3-23
Figure 3.18 Stage, Mississippi River at West Bay 3-24
Figure 3.19 Stage, Mississippi River at Carrollton 3-25
Figure 3.20 Stage, Mississippi River at Donaldsonville 3-25
Figure 3.21 Stage, Mississippi River at Baton Rouge 3-26
Figure 3.22 Stage, Mississippi River at Red River Landing 3-26
Figure 3.23 Tracks of Hurricanes Katrina (2005), Gustav (2008) and Isaac (2012) 3-28
Figure 3.24 Hurricane Isaac 1-min sustained surface wind field at 1730 LST 28 August 2012............ 3-32
Figure 3.25 Hurricane Gustav 1-min sustained surface wind field at 0830 LST 1 September 2008..... 3-34
Figure 3.26 Hurricane Katrina 1-min sustained surface wind field at 0400 LST 29 August 2005........ 3-37
Figure 3.27 Map of the estimated maximum storm surge during Hurricane Isaac 3-40
Figure 3.28 Map of the estimated maximum storm surge during Hurricane Gustav 3-41
Figure 3.29 Map of the estimated maximum storm surge during Hurricane Katrina 3-42
Figure 3.30 Measured water level at Waveland, MS, during Hurricane Isaac 3-44
Figure 3.31 Measured water level at Waveland, MS, during Hurricane Gustav 3-45
Figure 3.32 Total precipitation, in inches, during Hurricane Isaac (2012) 3-46
Figure 3.33 Total precipitation, in inches, during Hurricane Gustav (2008) 3-46

Figure 3.34 Total precipitation, in inches, during Hurricane Katrina (2005) 3-47
Figure 3.35 Total precipitation, in inches, during Tropical Storm Allison (2001) 3-47
Figure 3.36 Synthetic storm tracks used for the southeast Louisiana storm suite 3-48
Figure 3.37 Tracks for Hurricanes Katrina, Gustav, and Isaac...... 3-50

Figure 4.1 Status of major HSDRRS structures on 29 August 4-3
Figure 4.2 Forecast model outputs indicating possible timeline for HSDRRS structure closure 4-3
Figure 4.3 Status of HSDRRS major structures on 1 September...... 4-4
Figure 4.4 Forecast model outputs indicating possible timeline for HSDRRS structure re-opening...... 4-5
Figure 4.5 Damage assessment team data from the Caernarvon area 4-8
Figure 4.6 Damage assessment team data from the Highway 46 to IHNC area 4-9
Figure 4.7 Damage assessment team data from the Highway 46 to IHNC area 4-10
Figure 4.8 Damage assessment team data from the IHNC Surge Barrier...... 4-12
Figure 4.9 Damage assessment team data from the New Orleans Back Levee Reach 4-13
Figure 4.10 Damage assessment team data from the Southpoint to GIWW Reach...... 4-14
Figure 4.11 Damage assessment team data from the New Orleans East Lakefront Reach...... 4-15
Figure 4.12 Damage assessment team data from the New Orleans Metro Reach...... 4-16
Figure 4.13 Damage assessment team data from the Jefferson Lakefront Reach...... 4-17
Figure 4.14 Damage assessment team data from the St. Charles Parish Reach...... 4-18
Figure 4.15 Damage assessment team data from the Western Tie-In area 4-19
Figure 4.16 Damage assessment team data from the Westwego to Harvey Reach...... 4-21
Figure 4.17 Damage assessment team data from the Eastern Tie-In area...... 4-22
Figure 4.18 Recorded high water marks on the west bank Mississippi River Levee near Buras...... 4-24
Figure 4.19 Recorded high water marks on the east bank Mississippi River Levee near Caernarvon 4-25
Figure 4.20 Damage assessment team photos and data west bank Mississippi River Levee river mile 80-85...... 4-26
Figure 4.21 Locations of likely surge overflow and inundation for the pre-100-year HSDRRS...... 4-28

Figure 5.1 100-year water level, 2007 & 2010 - Lake Pontchartrain area 5-5
Figure 5.2 100-year water level, 2007 & 2010 - IHNC/GIWW, West Bank, St. Bernard, and Plaquemines...... 5-6
Figure 5.3 100-year water level, 2007 & 2010 - Mississippi Coast...... 5-8
Figure 5.4 100-year water level, 2007 & 2010 - in the vicinity of the IHNC closure 5-10
Figure 5.5 Save point set for Hurricanes Ike and Gustav sensitivity analysis 5-12
Figure 5.6 Caernarvon Floodwall Alignment 5-14
Figure 5.7 Location of WCC evaluation save points analyzed...... 5-16
Figure 5.8 Location of pump analysis save points 5-19

Figure 6.1 Flow chart for the spiral one version of ERDC's CSTORM-MS 6-4
Figure 6.2 Model domains for simulation 6-5
Figure 6.3a Comparison of measured and modeled wind speed and direction at Station 42003...... 6-7
Figure 6.3b Comparison of measured and modeled wind speed and direction at Station 42036 6-8
Figure 6.3c Comparison of measured and modeled wind speed and direction at Station 42040 6-9
Figure 6.4a Comparison of measured and modeled significant wave height, and direction at Station 42003...... 6-10
Figure 6.4b Comparison of measured and modeled significant wave height, and direction at Station 42036...... 6-11
Figure 6.4c Comparison of measured and modeled significant wave height, and direction at Station 42012...... 6-11
Figure 6.5 STWAVE model domains...... 6-14
Figure 6.6a Features added and modified in 2010 grid to create 2012 HSDRSS Condition 6-16
Figure 6.6b Topography/bathymetry and sub-grid features in the 2012 HSDRRS condition ADCIRC grid...... 6-17
Figure 6.7 Elevations of levees, road systems and structures in the 2012 HSDRRS condition ADCIRC grid 6-17
Figure 6.8 Elevations of levees, road systems and structures in the Without HSDRRS condition ADCIRC grid 6-18
Figure 6.9a Modeled versus measured water level, wind, & pressure in Barataria Bay at Lake Salvador...... 6-19
Figure 6.9b Modeled versus measured water level, wind, & pressure in Breton Sound 6-20
Figure 6.9c Modeled versus measured water level, wind, & pressure in Lake Pontchartrain at Causeway 6-21
Figure 6.9d Modeled versus measured water level, wind, & pressure at Pass Manchac. 6-22
Figure 6.9e Modeled versus measured water level, wind, & pressure on north shore of Lake Pontchartrain 6-23
Figure 6.9f Modeled versus measured water level, wind, & pressure on Mississippi coast at Bay St. Louis 6-24

Figure 6.10 Difference between provisional measured and modeled high water marks for Hurricane Isaac 6-25
Figure 6.11 Envelope of max water level for Hurricane Isaac for the Without HSDRRS condition..................... 6-27
Figure 6.12 Envelope of max water level for Hurricane Isaac for the 2012 HSDRRS condition.......................... 6-28
Figure 6.13 Difference in max water level (With and Without 2012 100-year HSDRRS).................................. 6-31
Figure 6.14 Difference in max water level on the Mississippi coast (With and Without 2012 HSDRRS)............ 6-32

Figure 7.1.1 Difference in max water level, East bank of Plaquemines Parish (With and WIthout HSDRRS) 7-2
Figure 7.1.2 Map of gages and precipitation output points in East Bank Plaquemines Parish 7-3
Figure 7.1.3 Hourly precipitation data at synthetic R1 gage during Hurricane Isaac 7-4
Figure 7.1.4 Stage observations at the Scarsdale gage during Hurricane Isaac 7-5
Figure 7.2.1 Difference in max water level, St.Tammany and Tangipahoa Par. (With and Without HSDRRS) 7-6
Figure 7.2.2 Hourly incremental precipitation data on the north shore of Lake Pontchartrain................................ 7-7
Figure 7.2.3 Louisiana and Mississippi Rainfall Totals for Hurricane Isaac 7-8
Figure 7.2.4 Lake Pontchartrain and Northshore River Stage Hydrographs 7-9
Figure 7.2.5 Tangipahoa River and Tchefuncte River Flows 7-10
Figure 7.2.6 Tangipahoa River and Tchefuncte River Discharge Volumes 7-10
Figure 7.2.7 Cross section of Lake Catherine Land Bridge 7-11
Figure 7.2.8 Color-shaded LiDAR relief map of the New Orleans East Land Bridge 7-12
Figure 7.3.1 West Shore Lake Pontchartrain Area 7-15
Figure 7.3.2 Difference in max water level, West Shore Lake Pontchartrain (With and Without HSDRRS) 7-16
Figure 7.3.3 Hourly incremental precipitation for Hurricane Isaac at New Orleans International Airport 7-18
Figure 7.3.4 Rainfall Time pattern for Hurricane Isaac (shifted)... 7-18
Figure 7.3.5 Rainfall runoff hydrograph produced by hydrologic model for St. John the Baptist Parish 7-21
Figure 7.3.6 Combined Rainfall – Surge Inundation Map St John the Baptist Parish 7-24
Figure 7.3.7 Ascension Parish Rainfall Hyetograph.. 7-26
Figure 7.3.8 Measured gage data at Bayou Francois near Gonzales, LA 7-27
Figure 7.3.9 Measured gage data at Black Bayou near Prairieville, LA.. 7-28
Figure 7.3.10 Measured gage data at Muddy Creek near Oak Grove, LA... 7-29
Figure 7.3.11 Aerial image of Marvin J. Braud Pump Station in Ascension Parish 7-30
Figure 7.3.12 Manchac Pass and North Pass Topography... 7-31
Figure 7.3.13 Typical Cross Section of Pass Manchac 7-32
Figure 7.3.14 Stage hydrograph for Pass Manchac 7-33
Figure 7.3.15 Amite River Flow Hydrograph 7-35
Figure 7.3.16 Tickfaw and Natalbany River Flow Hydrographs... 7-36
Figure 7.3.17 Progression of Surge Plots 7-39
Figure 7.4.1 Difference in max water level, Lower Jefferson & Plaquemine Par. (With and Without HSDRRS) 7-38
Figure 7.4.2 Map of USGS/USACE gages and precipitation output points in Barataria Basin............................. 7-42
Figure 7.4.3 Barataria Basin Precipitation data at synthetic gages 7-43
Figure 7.4.4 Stage observations at gages near the WCC 7-44
Figure 7.4.5 Discharge observations at the WCC.. 7-44

TABLES

Table 2.1 Surveys used to determine without 2012 100-year HSDRRS elevations 2-2
Table 2.2 Surveys used to determine 2012 100-year HSDRRS elevations 2-3

Table 3.1 Hurricane Isaac Preliminary Best Track Information 3-4
Table 3.2 Hurricane Isaac Mean Aerial Precipitation.. 3-9
Table 3.3 Wind Data from NWS Slidell Post Tropical Cyclone Report for Hurricane Isaac 3-15
Table 3.4 Central Pressure, Size Scaling Radius, Forward Speeds used to define the JPM-OS storm suite 3-49

Table 4.1 Peak stages recorded at Corps gages during Hurricane Isaac 4-23

Table 5.1 100-year return period water level for selected points LACPR 5-4
Table 5.2 100-year return period water level for selected points IHNC Barrier... 5-11
Table 5.3 Peak surge results for Hurricane Ike... 5-12
Table 5.4 Peak surge results for Hurricane Gustav... 5-13
Table 5.5 Coordinates for WCC save points 5-16
Table 5.6 Maximum surge values at save locations for the 2010 and WCC conditions....................................... 5-17
Table 5.7 Results for With and Without-WCC, 1% Pump Discharge Hydrograph.. 5-18
Table 5.8 Historic Strom Peak surge results with and without WCC 5-20

Table 7.1 Comparison of Stages at Select Gages for Isaac, Gustav, Katrina & Juan 7-12
Table 7.2 Rainfall Totals in the Upper Pontchartrain Basin 7-19
Table 7.3 Total Rainfall Volume entering Lake Maurepas 7-34
Table 7.4 Peak Water Elevations of Past Tropical Events.. 7-37
Table 7.5 Barataria Basin Gage IDs 7-39

LIST OF PLATES

Plate 1 With and Without 2012 100-year HSDRRS Levee Elevations Map ... A-1
Plate 2a Maximum Gage Still Water Elevations – Lake Pontcartrian Basin ... A-2
Plate 2b Maximum Gage Still Water Elevations – Plaquemines Parish ... A-3
Plate 2c Maximum Gage Still Water Elevations – Mississippi Coast ... A-4
Plate 3a Maximum High Water Mark Still Water Elevations – USACE ... A-5
Plate 3b Maximum High Water Mark Still Water Elevations – USGS ... A-6
Plate 3c Maximum High Water Mark Still Water Elevations – Lower Jefferson & Plaquemines Parishes. A-7
Plate 3d Maximum High Water Mark Still Water Elevations – Mississippi Coast ... A-8

APPENDICES (VOLUME II)

APPENDIX A - PLATES

APPENDIX B - ADDITIONAL ADCIRC NUMERICAL MODEL VERIFICATION DATA

APPENDIX C - RAINFALL ANALYSIS OF LAKE PONTCHARTRAIN WESTSHORE

APPENDIX D - COMMENT RESPONSES

LIST OF ACRONYMS

ADCIRC	Advanced Circulation Model
CRMS	Coastal Reference Monitoring System
FEMA	Federal Emergency Management Agency
GIWW	Gulf Intracoastal Water Way
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HSDRRS	Hurricane & Storm Damage Risk Reduction System
IER	Interim Environmental Report
IHNC	Inner Harbor Navigation Canal, Inner Harbor Navigation Canal Surge Barrier
IPET	Interagency Performance Evaluation Team
JPM-OS	Joint Probability Method – Optimal Sampling
LACPR	Louisiana Coastal Restoration and Protection study
LPV	Lake Pontchartrain & Vicinity Hurricane & Storm Damage Risk Reduction Project
LST	Local Standard Time
MRGO	Mississippi River Gulf Outlet
MRL	Mississippi River Levee
NAVD	North American Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
QPE	Quantitative Precipitation Estimate
SELA	South East Louisiana Flood Control Project
STWAVE	Steady State Spectral Wave Model
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UTC	Coordinated Universal Time (Greenwich Mean Time, GMT)
WAM	Wave Prediction Model
WBV	West Bank & Vicinity Hurricane & Storm Damage Risk Reduction Project
WCC	Western Closure Complex

1.0 INTRODUCTION

Purpose and Scope

Hurricane Isaac's impacts to the coastal Louisiana and Mississippi area were considerable. The greater New Orleans area 100-year Hurricane & Storm Damage Risk Reduction System performed to expectations in preventing the Hurricane Isaac storm surge from inundating the areas within its system. However, substantial flooding did occur in areas without federal levee systems, including, but not limited to Slidell, Mandeville, Madisonville, LaPlace, Braithwaite, and Lafitte and others. As this was the first major test of the 100-year HSDRRS, some have raised concerns regarding the effects of the 100-year HSDRRS during Hurricane Isaac on areas outside the system. Local and state officials have requested an analysis to assess the role of the 100-year HSDRRS during Hurricane Isaac on the areas outside the system. Figures 1.1 and 1.2 provide maps of the study area to help orient the reader to the communities and major geographic features referenced in this report.

This assessment was developed and conducted to answer one primary question:

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system flooded by Hurricane Isaac?

To answer this question, the following were examined:

- Hurricane Isaac's meteorological statistics and surge propagation, and how they contributed to flooding outside the 100-year HSDRRS

- Previous Corps of Engineers analyses regarding effects from the 100-year HSDRRS

- What, if any, differences in surge conditions are identifiable between the with and without 100-year HSDRRS (2012 conditions) specifically for Isaac?

Most of the new 100-year HSDRRS was built on the same alignment as the old system. During the design of the 100-year HSDRRS, extensive modeling and analysis was performed during the design phase of the system to determine what effect, if any, the system would have on other areas. Public meetings were held across the area at which the modeling and analyses were discussed. Environmental documentation included discussions on effects of the 100-year HSDRRS on adjacent areas.

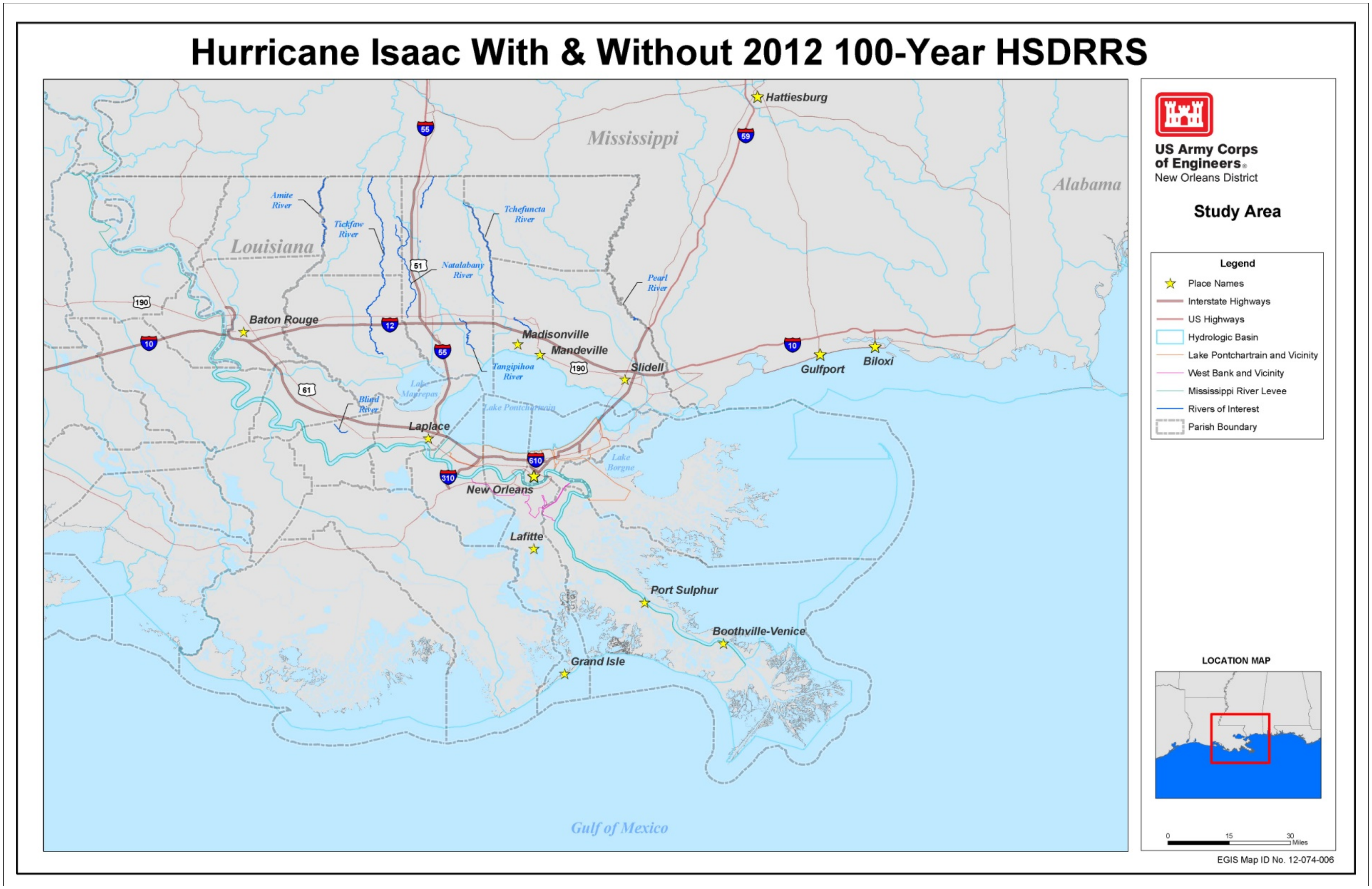

Figure 1.1 Vicinity Map of study area including southeast Louisiana and the Mississippi Gulf Coast.

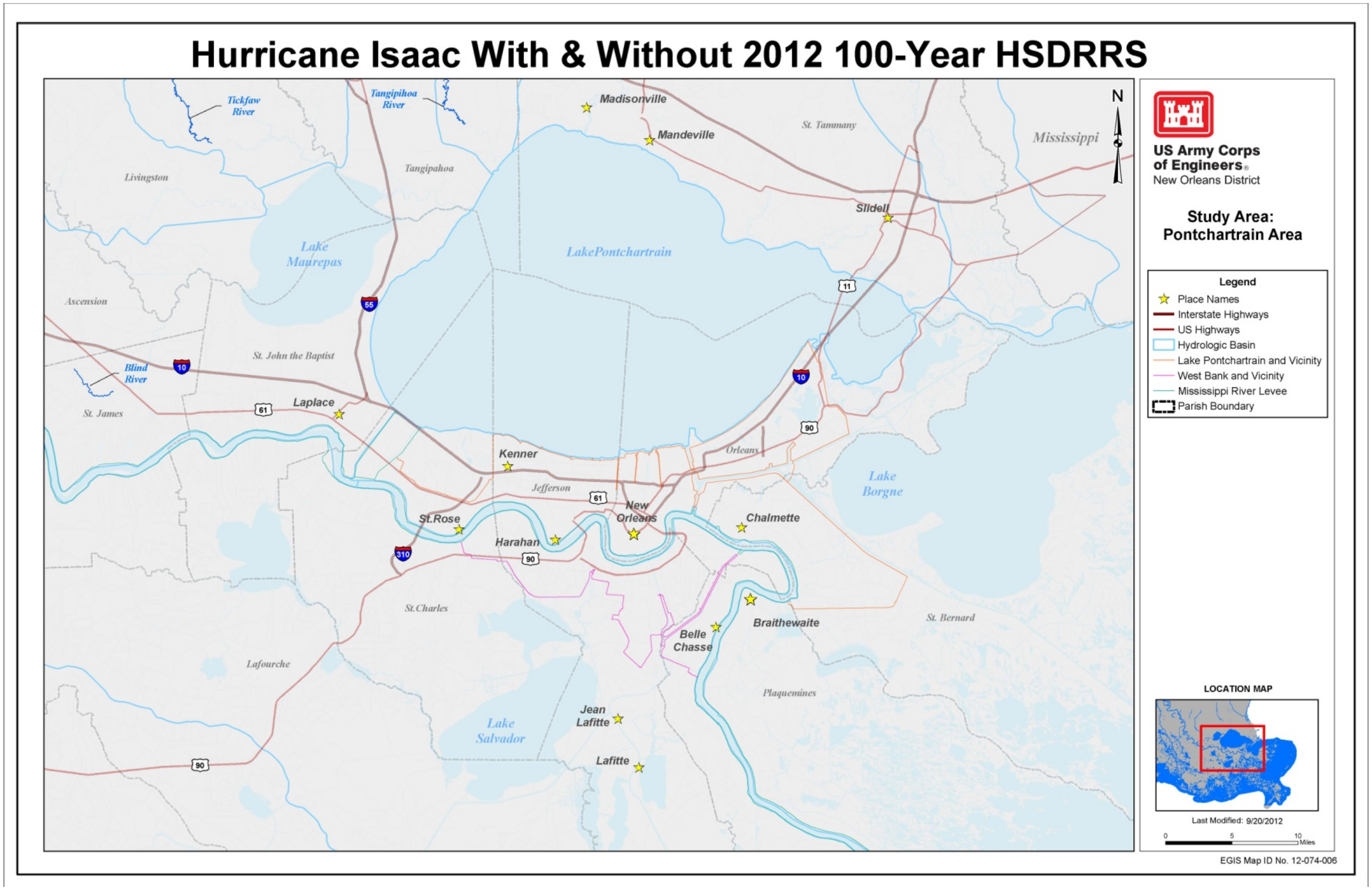

Figure 1.2 Southeastern Louisiana study area including major geographic features and communities referenced in report

This effort integrates the aforementioned work with an assessment of available storm data and modeling of Hurricane Isaac for two conditions: without the 100-year HSDRRS and with the 2012 100-year HSDRRS features. The scope consists of several parts:

- Compilation and analysis of available Hurricane Isaac storm information, meteorological, stage, and high water mark data
- Comparison of with and without 2012 100-year HSDRRS characteristics and performance
- Qualitative analysis and review of previous modeling and analyses
- ADCIRC Isaac model simulations for with and without-HSDRRS conditions.
- Evaluation of specific areas outside the 100-year HSDRRS where flooding occurred. It should be noted that these areas were selected as representative areas to assess the impact of the 100-year HSDRRS; it is not an exhaustive investigation of all areas that were subject to inundation.

The work has been conducted by a team consisting of personnel from the Corps of Engineers' New Orleans District, Mississippi Valley Division, and Engineering Research and Development Center, and the National Oceanic and Atmospheric Administration's National Weather Service. Data were compiled from the Corps of Engineers New Orleans District, the National Oceanic and Atmospheric Administration's National Hurricane Center, National Weather Service River Forecast Center in Slidell, LA, National Data Buoy Center, and National Ocean Service, the United States Geological Survey, and the State of Louisiana. The Water Institute of the Gulf and the Southeast Louisiana Flood Protection Authority – East (SLFPA-East) has performed an over the shoulder review of the data, modeling, and analyses, and provided comments which are provided in Appendix D.

This report presents the findings of these analyses. Quality control and agency technical review have been conducted on the findings. Independent external peer review has been scheduled; the results of the review will be appended to this document upon completion.

Limits of Investigation

In the interest of providing a timely assessment, there are several limitations regarding the data used and the analysis performed.

- All gage data are considered provisional, subject to revision.

- High water marks were collected only in accessible locations where right of entry was not required.

- Data related to hurricane characteristics, such as track, wind speed, radius to maximum winds, central pressure, and other parameters were compiled from available data.

- Available hurricane surge models were utilized. The model grids were updated (including local levees in the existing models) using 2012 Light Detection and Ranging (LiDAR) information and as-built survey information to describe the 2012 100-year HSDRRS. The grids have not been updated to include new local features.

- Rainfall-runoff analysis and modeling was limited:

    - St. John the Baptist Parish: Where existing models were available, these models were used to perform an initial assessment of the direct rainfall impacts.
    - Western Closure Complex: Previous rainfall model results were considered.
    - Remaining Areas: A qualitative assessment was performed using rainfall and gage data.

- This assessment does not include analyses on economic damages or potential solutions to the flooding.

Data related to hurricane characteristics, such as track, wind speed, radius to maximum winds, central pressure, and other parameters have been compiled from available data. The referred data sources are the same as those listed in, for example, Cardone and Cox 2009 and include gridded and image fields of marine surface wind composites from the Hurricane Research Division (HWind). For a hindcast of a storm, winds are typically constructed by an expert meteorologist through a careful and time consuming process of assimilating best available data collected during the storm into the calculation of the wind and pressure fields, see Cardone and Cox 2009, Cox et al. 1998 and Powell et al, 2010 for detailed descriptions of this process including a discussion of the tropical planetary boundary layer model (PBL). In summarizing this process, the hindcast approach used to produce the model inputs as applied in this study consists of four basic steps and follows from the description of the PBL hindcast section in Cardone and Cox 2009.

First, all relevant meteorological data is assembled from in-situ sources, reconnaissance aircraft and meteorological satellites. Second, the storm parameters required to initialize a tropical planetary boundary (PBL) model are determined using all available data. The PBL output is then compared to available in situ data, iterated if required, then blended within a basin-wide synoptic wind and pressure field. Finally, the wind and pressure fields are adopted on a working grid to be applied by the wave and surge models.
The National Hurricane Center has not completed an analysis of the storm data collected during Hurricane Isaac, nor have they completed a tropical cyclone report. The National Hurricane Center usually prepares these reports after hurricane season; a report on Hurricane Isaac is expected to be available in early 2013.

The wind product used in the simulations was constructed in accordance with the procedures outlined in Cardone and Cox 2009. Figure 1 shows the relationship between the ADCIRC computational domain and the PBL domain. Wind and pressure fields were provide in a rectangular domain that completely encompasses the Gulf of Mexico. The domain is between longitudes -98.0 degrees west to -80.0 degrees west and between latitudes 18.0 degrees north and 32.0 degrees north. The winds and pressures are specified on a regular grid within this domain with grid cells spaced 0.05 degrees apart. The surge model ADCIRC linearly interpolates the regular gridded data unto its unstructured computational nodes. Any ADCIRC node that lies outside the PBL domain has a wind velocity of zero meters per second and a pressure value set to a standard background value of 1013.0 MB (milibars). The wind and pressure values were specified every 15 minutes beginning on August 24, 2012 at 1200 hrs UTC and going through August 31, 2012 1800 hours UTC. The beginning time was just prior to the center of Hurricane Isaac entering the Gulf of Mexico and continuing more than two days after making landfall.

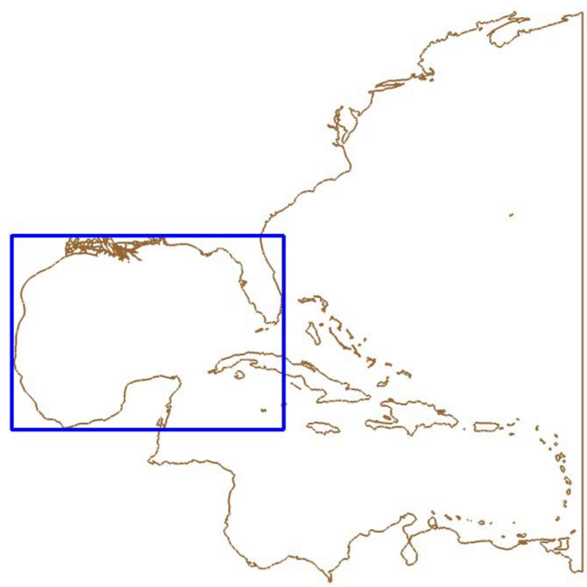

Figure 2.3. Map showing the extents of the ADCIRC computational domain and the area of coverage for the wind and pressure fields.

As part of the testing of available wind/pressure products for use with the surge and wave models, the HWinds products as available from the Hurricane Research Division were evaluated. However, without properly blending these HWinds into a larger background meteorological field, a process described in Cardone and Cox 2009 and Powell et al 2010 among others, the raw HWinds products are typically not suitable for driving accurate surge responses. For Hurricane Isaac, driving ADCIRC with the HWinds gridded data consistently produced lower than observed surges (at times more than 1 foot lower) at most of the NOAA buoys in the area of interest. The HWinds products are available beginning August 21, 2012 at 1930 hours UTC and ending August 29, 2012 at 1930 hours UTC. The frequency of the data varies between 6 hour intervals at the onset of the data and transitions to 3 hour intervals at 0130 hours UTC on August 26, 2012. The Marine gridded HWinds data is on a moving grid that is centered on the center of the storm. Thus as the storm moves so does the area over which the winds are available. Figure 2 shows a map of the ADCIRC computational domain in relation to several of the moving grid domains used in the HWinds product as the storm moves. Just like in the PBL model case, ADCIRC linearly interpolates the regular gridded data onto its unstructured computational nodes. Any ADCIRC node that is outside of a gridded box has the wind values set to zero meters per second and a constant background pressure of 1013 MB. As can be seen from the red outlined box in Figure 2, the area of interest for this study does not begin to experience wind and pressure effects from the storm until August 27, 2012 at 1930 hours UTC. Furthermore, at no time does the entire Gulf experience computationally the full effects of the entire storm forcing due to the limited domain sizes of the HWinds gridded data, thus limiting the impacts of surge buildup from the entire Gulf due to the generally northwesterly background winds. Another issue is that the HWinds data ends less than a day after landfall even though the storm had virtually stalled in the area and continued to contribute to higher than normal water levels in the area of interest to this study beyond August 31, 2012.

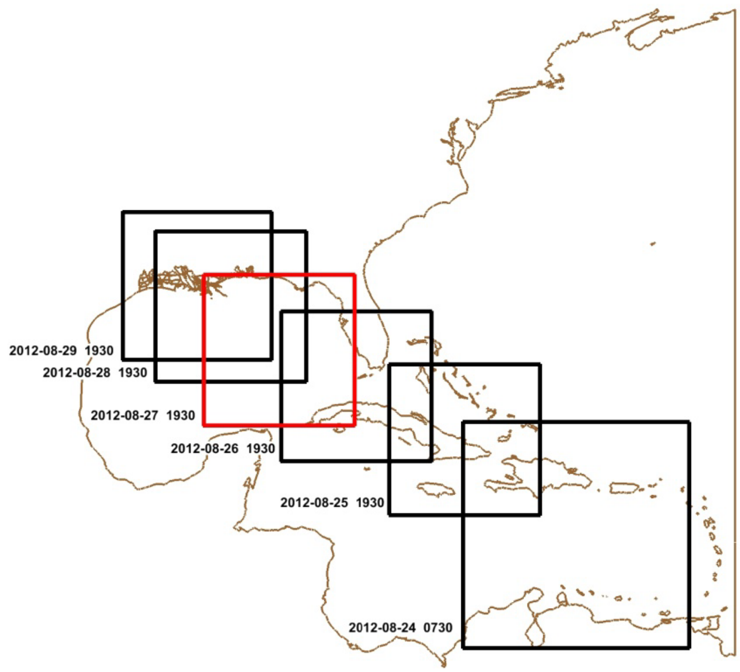

Figure 1.4. Map showing the ADCIRC computational domain along with H*Wind domains of coverage for several dates corresponding to Hurricane Isaac.

This assessment considers the 2012 100-year HSDRRS as it existed at the time of Hurricane Isaac. Although 100-year level of risk reduction has been achieved, the HSDRRS is not complete. Any incomplete features were not incorporated into the assessment.

Because the purpose of the Hurricane Isaac modeling investigation was to assess possible differences in surge related to the 100-year HSDRRS, and resulting specifically from Hurricane Isaac, the "without HSDRRS" condition applied only to features of the 2012 100-year HSDRR System. Other landscape features represented in the model were identical for the with and without 2012 100-year HSDRRS simulations.

Available hurricane surge models have been utilized. The model grids have been updated using 2012 LiDAR information and as-built survey information to describe the 2012 100-year HSDRRS. Local levees, such as the

Braithwaite levee that are in existing models, have been updated based on 2012 LiDAR information. The grids have not been updated to include new local features.

Rainfall modeling has been limited; for St. John the Baptist Parish, where existing models were available, these models were used to perform a preliminary assessment of the direct rainfall impacts. For the West Closure Complex, previous rainfall model results were considered. For the remaining areas a qualitative assessment was performed using rainfall and gage data.

This assessment is limited to answering the questions listed in the scope section. This assessment does not address economic damages or potential solutions to the flooding.

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Powell, M.D., S. Murillo, P. Dodge, E. Uhlhorn, J. Gamache, V. Cardone, A. Cox, S. Otero, N. Carrasco, B. Annane, R. St. Fleur, 2010, Reconstruction of Hurricane Katrina's wind fields for storm surge and wave hindcasting. Ocean Engineering, 37(1), 26-36.

2.0 SUMMARY OF 100-YEAR HSDRRS CONDITIONS

Chapter Summary

This chapter describes with and without 2012 100-year HSDRRS condition. While the without 100-year HSDRRS condition captures the system as it existed prior to construction of the 100-year HSDRRS, the 2012 100-year HSDRRS condition includes increased levee and floodwall heights around the system as well as additional features IHNC Surge Barrier, Seabrook Gate Complex, Outfall Canal interim closure structures, Caernarvon floodwall and gate, Eastern Tie-In, Harvey-Algiers system with the West Closure Complex, Bayou Segnette Complex, and Western Tie-In. The Harvey Sector Gate which was completed after Hurricane Katrina, is considered part of the without 100-year HSDRRS conditions.

The majority of the 2012 100-year HSDRRS levees, floodwalls, and structures were constructed generally following the existing alignment of the Lake Pontchartrain & Vicinity (LPV) and West Bank & Vicinity (WBV) features that comprise the without 2012 100-year HSDRRS condition.

New features that have been added and features at locations where the existing alignment has been modified are discussed in detail. Additional discussions are included regarding the features of the 100-year HSDRRS under construction that were not complete at the time Hurricane Isaac made landfall and for which temporary risk reduction measures were put in place.

Without 2012 100-year HSDRRS Condition

The without 2012 100-year HSDRRS condition is comprised of LPV and WBV levees, floodwalls, and structures that were in place prior to the construction of the 100-year HSDRRS. The height of the levees and floodwalls are shown on Plate 1.

Several survey datasets were utilized to develop the without 2012 100-year HSDRRS condition and are listed in Table 2.1. Surveys were taken between 2004 and 2012.

Table 2.1 – Surveys used to determine without 2012 100-year HSDRRS elevations

Survey Job Title
Mississippi River Levee Profiles (WEST PONTCHARTRAIN LEVEE DISTRICT)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (PLAQUEMINES) (ARCADIS)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (ST BERNARD) (ARCADIS)
New Orleans District National Levee Foot Print Data Base Surveys (WEST PLAQUEMINES)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (EAST JEFFERSON) (HTNB)
2006 LEVEE/FLOODWALL ASSESSMENT HPS(NEW ORLEANS EAST)(HTNB)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (WEST OF ALGIERS) (C&C Technologies)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (ST CHARLES) (BFM)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (NEW ORLEANS) (ARCADIS)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (WESTWEGO) (C&;C Technologies)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (EAST OF ALGIERS) (C&C Technologies)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (CATAOUATCHE) (C&C Technologies)
HSDRRS Line of Protection Survey (MRL)
New Orleans District National Levee Foot Print Data Base Surveys (BELLE CHASSE)
New Orleans District National Levee Foot Print Data Base Surveys (MRL ST JUDE TO VENICE)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (PLAQUEMINES) (ARCADIS)
Precision Airborne LiDAR Surveys of the MRL and Battures (WEST PLAQUEMINES)
Mississippi River Levee Profiles

NOTE: HPS = Hurricane Protection System

2012 100-year HSDRRS Condition

The 2012 100-year HSDRRS condition consists of the HSDRRS features that were in place at the time of Hurricane Isaac. Several survey datasets were utilized to develop the 2012 100-year HSDRRS condition and are listed in Table 2.2. Surveys were taken between 2006 and 2012.

An overview of the system features is shown in Figure 2.1, and described in detail below.

The height of the levees and floodwalls for the system is shown on Plate 1. The majority of the 2012 100-year HSDRRS levees, floodwalls, and structures have been constructed generally following the existing alignment of the LPV and WBV features that comprise the without 2012 100-year HSDRRS condition. The following is a list of new features that have been added and features at locations where the existing alignment has been modified.

Table 2.2 - Surveys used to determine 2012 100-year HSDRRS elevations

Survey Job Title
HSDRRS Line of Protection Survey (LP-01)
New Orleans District National Levee Foot Print Data Base Surveys
HSDRRS Line of Protection Survey (MRL)
New Orleans District National Levee Foot Print Data Base Surveys (NEW ORLEANS EAST)
HSDRRS Line of Protection Survey (LP-02)
IHNC EAST AND CHALMETTE LOOP - RIVER LOCK TO BAYOU BIENVENUE
HSDRRS Line of Protection Survey (LP-03)
Chalmette Loop HSP Levee Profiles
MISSISSIPPI RIVER LEVEES, LEVEE ENLARGEMENT STA 414 TO 570
New Orleans District National Levee Foot Print Data Base Surveys (ST CHARLES)
NEW ORLEANS LAKEFRONT FLOOD PROTECTION PROFILE
New Orleans District National Levee Foot Print Data Base Surveys (ST BERNARD)
Chalmette Loop HSP Levee Profiles
New Orleans District National Levee Foot Print Data Base Surveys (BELLE CHASSE)
2006 LEVEE/FLOODWALL ASSESSMENT HPS (NEW ORLEANS) (ARCADIS)
NEW ORLEANS LAKEFRONT LPV 101-104
NCC, LPV-03d.2, St. Charles Parish, AP Runway Levee Ph II

IHNC EAST AND CHALMETTE LOOP - RIVER LOCK TO BAYOU BIENVENUE
HSDRRS LiDAR Data Review
Post-Katrina JALBTCX 2005 LiDAR
LPV Citrus Back Levee
ELMWOOD CANAL PUMP STATION #3
Jefferson Parish Lakefront Survey
LSER surveys for flood walls. (VARIOUS LOCATIONS)
LPV Citrus Back Levee
HSDRRS LiDAR Data Review
New Orleans District National Levee Foot Print Data Base Surveys
Jefferson Parish Lakefront NCC Survey - Additional Work at Bonnabel Blvd.
PUMPING STATION #2
HSDRRS LiDAR Data Review
STRUCTURE SURVEYS IN SUPPORT OF FLOOD FIGHT 2011
17TH STREET CANAL CLOSURE
Tie-In wall elevations
New Orleans District National Levee Foot Print Data Base Surveys
IHNC West River Lock to Seabrook

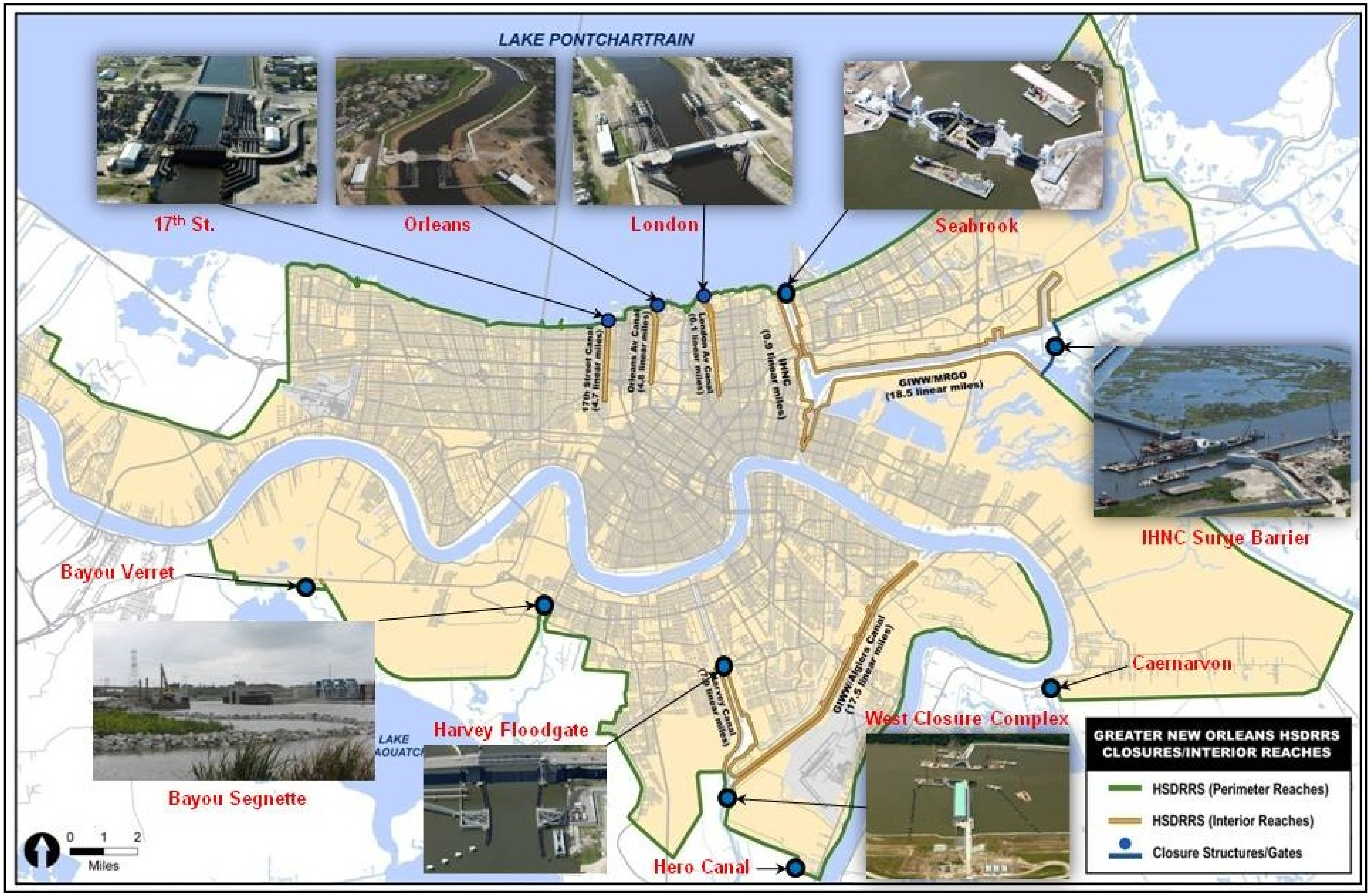


Figure 2.1. Major features of the 2012 100-year HSDRRS

IHNC System –The IHNC (Inner Harbor Navigation Channel) System is located in Orleans and St. Bernard Parishes in the state of Louisiana and contains several structures.

> IHNC Surge Barrier - (HSDRRS Project Number IHNC-02) The IHNC Surge Barrier, a 10,000-foot long barrier, is located near the confluence of the Gulf Intracoastal Waterway (GIWW) and the Mississippi River Gulf Outlet (MRGO). The barrier consists of a bypass barge gate and a flood control sector gate at the GIWW, a vertical lift gate at Bayou Bienvenue, a braced concrete barrier wall across the MRGO and the Golden Triangle Marsh, and floodwalls on the north and south ends that tie into the risk reduction system in Orleans Parish and St. Bernard Parish, respectively. The surge barrier is also referred to as the Lake Borgne Surge Barrier.
>
> Seabrook Gate Complex – (HSDRRS Project Number IHNC-01) The Seabrook Gate Complex is located at the confluence of the IHNC and Lake Pontchartrain in Orleans Parish. This complex consists of a sector gate and two lift gates.

At the time of Hurricane Isaac, all IHNC structures were in place (Figure 2.2).

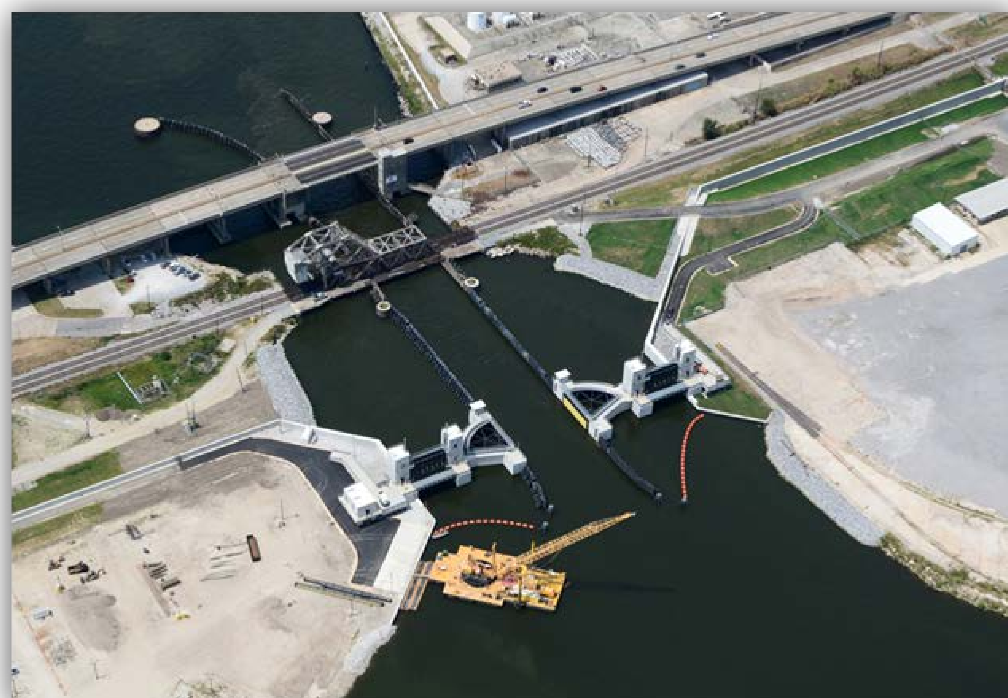


Figure 2.2. IHNC Surge Barrier (top) and Seabrook Complex (bottom) in Orleans and St. Bernard Parishes.

The Outfall Canal Interim Closure Structures – Three interim closure structures (Figure 2.3) have been constructed on the London Avenue, 17th St, and Orleans Avenue Outfall canals near their confluence with Lake Pontchartrain in Orleans Parish. These structures restrict the entrance of Lake Pontchartrain storm surge into the outfall canals while allowing the water evacuated from the city via local pump stations to enter the lake. The structures consist of a series of panel gates and pumps. The rated pump capacity at the structures is: London Avenue 5,196 cubic feet per second (cfs); 17th St 9,794 cfs, and Orleans Avenue 2,200 cfs. Although these temporary structures provide the 100-year level of risk reduction to the three outfall canals, these structures will be replaced by permanent features of the HSDRRS (HSDRRS Project Number PCCP-01).

Figure 2.3. Interim Closure Structures. These temporary features provide the 100-year level of risk reduction at the mouths of the three outfall canals in Orleans Parish.

Caernarvon Floodwall and Gate – (HSDRRS Project Number LPV-149) A new floodwall has been constructed in the vicinity of the Caernarvon freshwater diversion structure, in St. Bernard and Plaquemines Parishes, with a sector gate, a road gate at Highway 39, a railroad gate, and drainage features to evacuate rainfall runoff from the area across the existing levee into St. Bernard Parish (Figure 2.4). This new alignment ties into the Mississippi River Levee just downriver from the Caernarvon Canal.

Figure 2.4. Aerial view of the Caernarvon Floodwall and Gate in St. Bernard and Plaquemines Parishes.

Eastern Tie-In – (HSDRRS Project Number WBV-09) The Eastern Tie-In, located on the west bank of the Mississippi River (Westbank) in Plaquemines Parish, has been constructed with the overall alignment shown in yellow and orange in Figure 2.5 below. In addition to levees and floodwalls, the project includes a navigable stop log gate on Hero Canal (WBV-09b), a swing gate for the Highway 23 closure (WBV-09c), and another swing gate for the adjacent railroad. Interior drainage from the WBV-09a and WBV-09c project components is routed to the WBV-09a pump station and gravity drain. The existing drainage to Hero Canal is handled by another pump station at the WBV-09b site. Since at the time of Hurricane Isaac, the swing gate for the Highway 23 closure was not installed, a temporary closure was placed at that location.

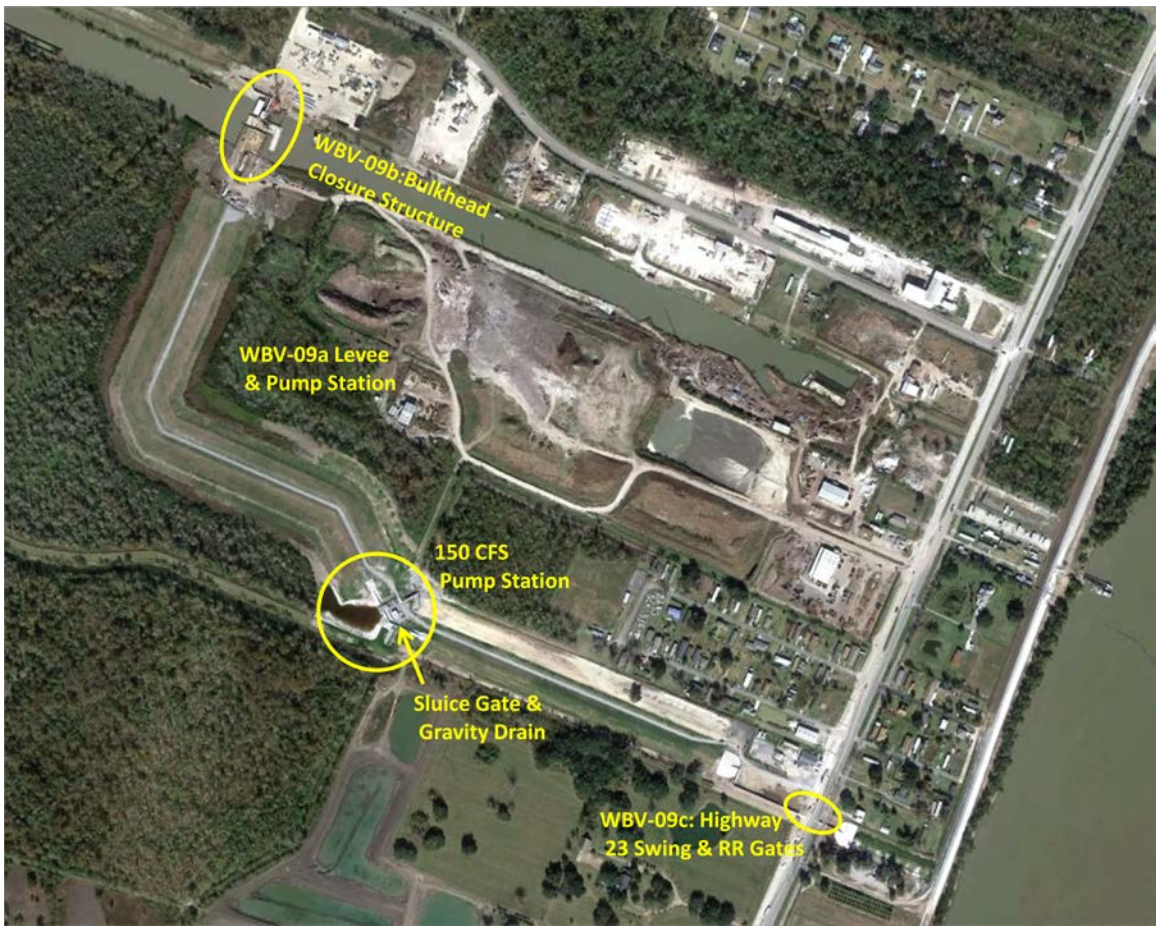


Figure 2.5. Aerial view of the Eastern Tie-In projects on the Westbank in Plaquemines Parish.

Harvey-Algiers System – The Harvey-Algiers System is located on the Westbank in Orleans, Jefferson, and Plaquemines Parishes and contains several structures added to the HSDRRS.

> West Closure Complex. (HSDRRS Project Number WBV-90) The West Closure Complex (WCC) in Jefferson and Plaquemines Parishes (Figure 2.6) includes a sector gate and five gravity sluice gates that convey the flow in the GIWW when opened, and block storm surge when closed. The WCC also includes a 19,140 cfs pump station to pass the flow when the gates are closed.
>
> The Estelle Water Control Structure on the Westbank in Jefferson Parish includes a pair of 8-foot by 8-foot sluice gates through the WCC floodwall that control the discharge from the Old Estelle Pump Station, allowing the flow to pass into the GIWW when opened, and blocking the flow (and storm surge) when closed.
>
> The Harvey Canal Sector Gate (or Harvey floodgate, HSDRRS Project Number WBV-14) on the Westbank in Jefferson Parish (Figure 2.7) is a feature that was completed after Hurricane Katrina. The gate separates the southern end of the Harvey Canal from the northern end. For this analysis, it is assumed this gate is part of the pre-HSDRRS condition.

At the time of Isaac, all of the Harvey-Algiers System features were in place.

Figure 2.6. Aerial view of the West Closure Complex and Estelle Water Control Structure in Plaquemines and Jefferson Parishes.

Figure 2.7 Aerial view of the Harvey Sector Gate on the Westbank in Jefferson Parish.

Bayou Segnette Complex – (HSDRRS Project Number WBV-16) A new sector gate and pump station have been constructed in the Bayou Segnette area, on the Westbank in Jefferson Parish (Figure 2.8). The complex is operated to prevent high water stages from entering the Westwego area, to drain landside floodwaters, and to allow water traffic to proceed along Company Canal.

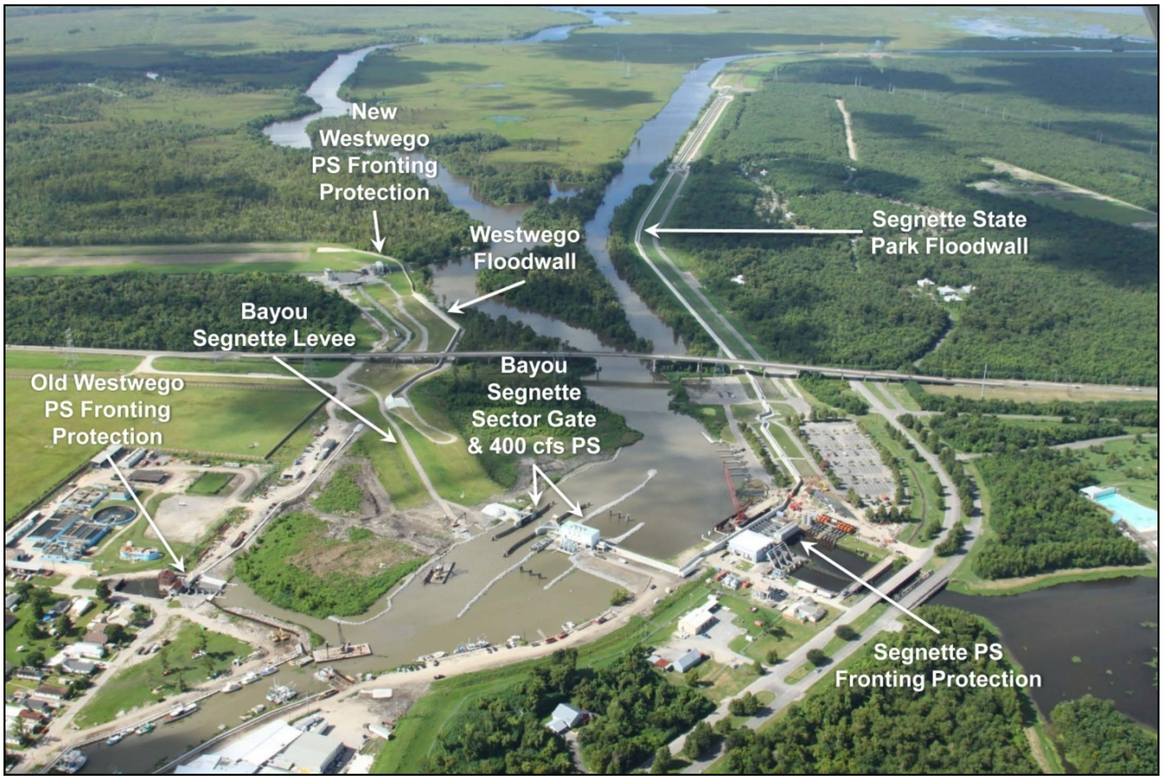


Figure 2.8. Aerial view of the Bayou Segnette Complex on the Westbank in Jefferson Parish.

Western Tie-In – (HSDRRS Project Number WBV-70-75) The Western Tie-In has been constructed with the overall alignment shown in Figure 2.9. In addition to levees and floodwalls, the project includes a gate at Highway 90 and a closure structure across the Bayou Verret Canal consisting of a 56- foot sector gate and a sluice gate structure with five 5-foot by 5-foot gates. At the time of Hurricane Isaac, the Highway 90 closure was not complete; Hesco baskets were placed across Highway 90 in advance of the storm event.

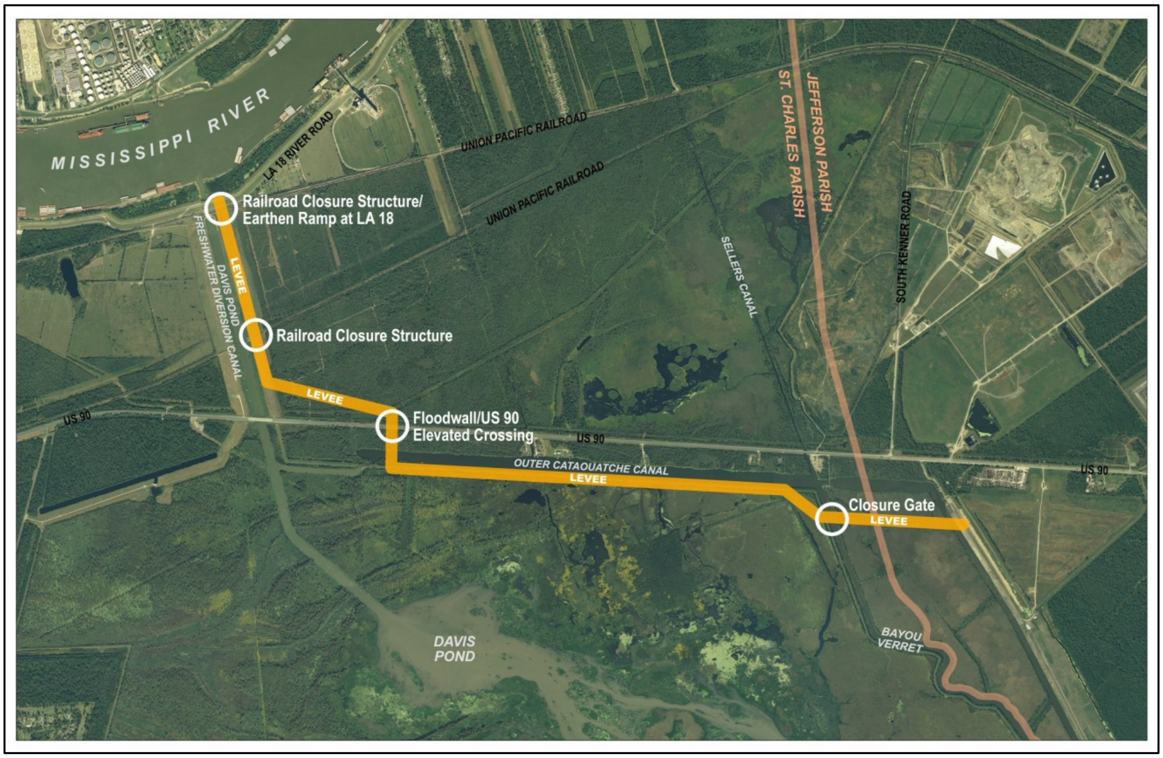
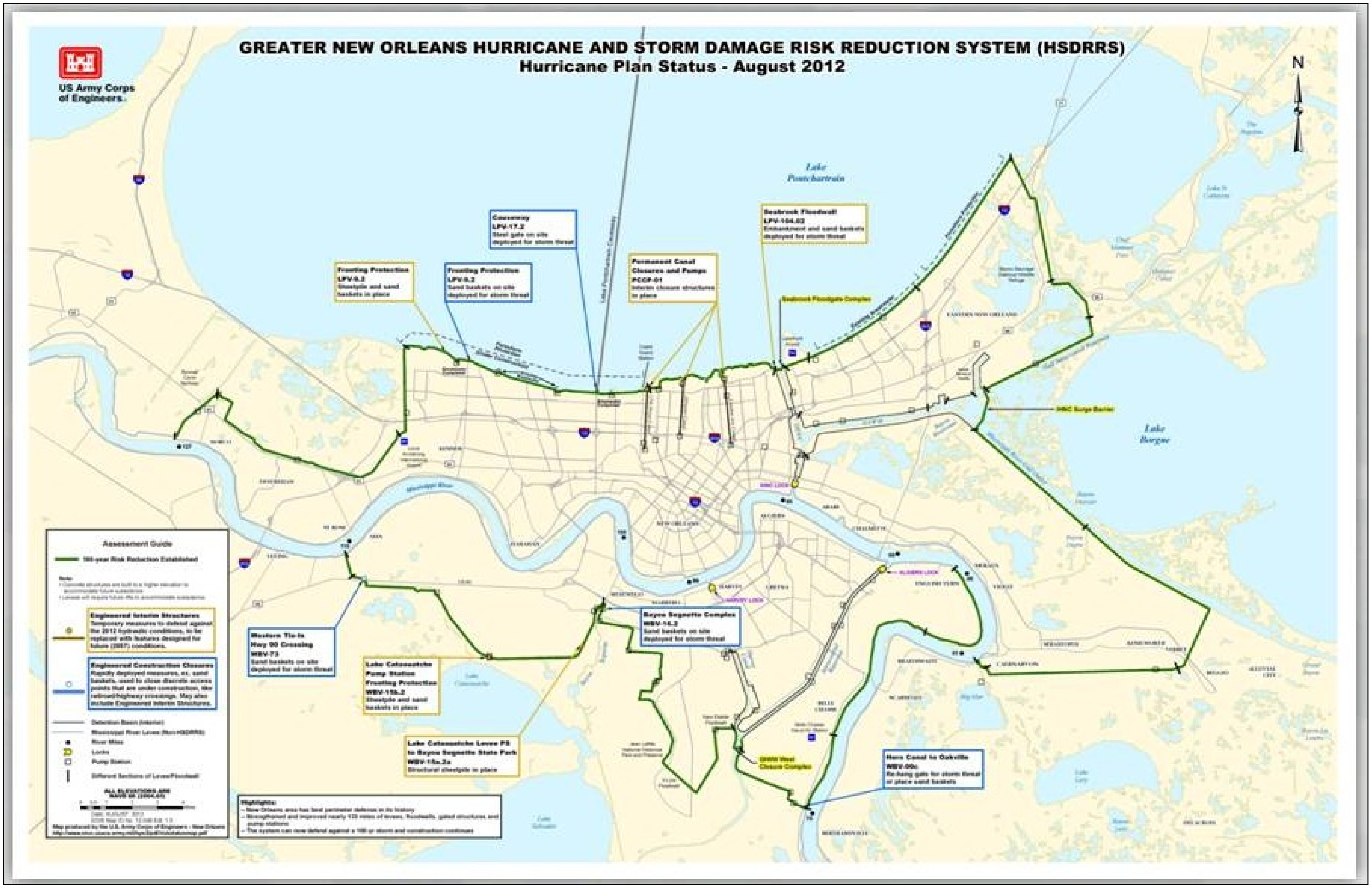


Figure 2.9. Aerial view of the Western Tie-In project features on the Westbank in St. Charles and Jefferson Parishes

Construction Closures and Interim Structures. At the time of Hurricane Isaac, construction was not complete on all of the 100-year HSDRRS features. Construction closures and interim structures were present in several locations, as shown on Figure 2.10.



. **Figure 2.10 HSDRRS Construction Closures and Interim Structures in place during Hurricane Isaac.**

3.0 HURRICANE ISAAC EVENT OVERVIEW

Chapter Summary

According to the Saffir-Simpson Hurricane Wind Scale, Hurricane Isaac was a minimal Category 1 hurricane, reaching maximum sustained wind speeds of approximately 80 miles per hour immediately before landfall. The extended duration of tropical force winds, the storm track and slow forward motion, the storm size, the high tide conditions and significant rainfall occurring at the same time as the maximum storm surge, resulted in large amounts of water being pushed into the coastal areas of the northern Gulf. In many cases, water levels exceeded those from more intense storms such as Hurricanes Katrina and Gustav.

3.1.1 Forward motion and track of the storm

Section 3.2.1 and 3.2.2 in this chapter highlight the storm chronology and synoptic history of Hurricane Isaac. The forward motion of Isaac was very slow. From the time Isaac entered the Gulf, winds from the south and east began filling coastal bays and inlets. The center of Isaac spent approximately 15 hours just off of the mouth of the Mississippi River, where eastern and southeastern winds pushed water into Barataria Basin, Breton Sound, the Pontchartrain Basin and Bay St. Louis areas. The storm then traveled slowly northward. For enclosed lakes and bays such as Lake Pontchartrain, the forward speed has an influence on the storm surge and timing of peak surge around the periphery of the lake. Like Hurricane Gustav, Hurricane Isaac approached Louisiana from the southeast, increasing the flow of surge waters into the coastal bays and inlets.

3.1.2 Rainfall

Section 3.2.3.1 provides details on the rainfall which occurred during Hurricane Isaac. The bulk of the storm total rainfall occurred between 0700 LST (1200 UTC) on 29 August and 1300 LST (1800 UTC) on 30 August. Storm total rainfall amounts of 8-12 inches were the norm across southeastern Louisiana and southern Mississippi. Many areas reported higher amounts with the highest measured total reported at Pascagoula, Mississippi of 22.20”. Rainfall caused most rivers across the area to swell to above flood stage with new stage records set in southern Mississippi on the Wolf River at Landon and Gulfport, Mississippi and on East Hobolochitto Creek near Caesar, Mississippi. Over 10 inches of rainfall occurred at the Percy Quinn State Park with the bulk of the rain falling between 1300 LST (1800 UTC) 29 August and 0700 LST (1200 UTC) 30 August resulting in flooding along the Tangipahoa River. In southern Mississippi/Louisiana, 10-15 inches of rain that fell over the southern Pearl River and Bogue Chitto drove the rivers above major flood stage. Rainfall amounts of 8-15 inches occurred in the Lake Maurepas Basin adding to flooding that occurred from storm surge. The CoCoRaHS site at Reserve, Louisiana in St John the Baptist Parish recorded 14.84 inches. These rainfall amounts were greater than recent hurricanes, but comparable to Tropical Storm Allison in 2001.

3.1.3 Winds

As further detailed in Section 3.2.3.2, sustained tropical storm force winds were experienced over southeastern Louisiana and southern Mississippi for as long as 45 hours from midday on 28 August through midday 30 August. One station (Buras, LA) reported a sustained wind of Category 1 hurricane force. Peak gusts exceeding hurricane force were experienced at numerous locations across the area as well. The highest peak gust, 86 mph, was measured at Buras, Louisiana and with Boothville, Louisiana recorded a gust of 84 mph. Generally easterly winds were experienced over southeastern Louisiana and southern Mississippi from 26 August to the morning of 29 August. Winds then shifted so that they came from a southeastern to southern from 29 August through 31 August. Winds drove water toward the eastern shores of southeastern Louisiana and into Lake Pontchartrain causing elevated tide levels prior to Hurricane Isaac making landfall. After Isaac moved inland, winds shifted to the south, moving water from the north into the coastal areas. The southerly wind shift in the Mississippi Sound coincided with the timing of the peak surges along the western Mississippi coast. Because Isaac moved so slowly, the water surface gradient between Lake Borgne and Lake Pontchartrain caused the persistent filling action in Lakes Pontchartrain and Maurepas for several days before arrival of the main core winds of the hurricane.

Maximum winds were in the northeast quadrant of the storm, with strongest winds in the northeast and southeast quadrants. Isaac did not have a well-defined band of maximum winds wrapped around the eye. The observed maximum wind speed was a distance of 38 miles northeast of the eye. This ratio of radius to maximum winds is considered to be a relatively large value. In terms of hurricane intensity near landfall, Isaac had a central pressure of 975 mb and maximum observed wind speed of 75 mph, a magnitude at the lower limit of a Category 1 hurricane (74 mph) in terms of the Saffir-Simpson Hurricane Wind scale. These winds generated offshore waves generally in the range of 5-15 feet. However, the National Data Buoy Center's Station 42012 located at 30°03'55"N 87°33'19"W offshore from Orange Beach, Alabama on the east side of the storm track reported a peak wave height of 19.02 feet at approximately 1700 LST (2200 UTC) on 28 August.

3.1.4 Water Level Heights

Section 3.2.3.4 shows that tide levels were already high in coastal Louisiana due to a period of easterly winds prior to Hurricane Isaac entering the Gulf of Mexico, with Lake Pontchartrain almost 1 foot above predicted tide levels. Water levels began to rise from Hurricane Isaac around midnight on 28 August and continued to rise until late on 29 August.

Characteristics of the surface winds and the storm tracks help explain differences in storm surge throughout the Louisiana and Mississippi coastal areas. There is extensive documentation of high water marks and surge elevations elsewhere in this report, however, generally, surge elevations ranged from 5-7 feet on the West Bank near Ama, Louisiana to 12-14 feet in the Caernarvon area and in the vicinity of the new IHNC Barrier. Data from USGS sensors indicate that peak water levels at Braithwaite reached 13.5 to 13.7 feet, NAVD88 during Isaac, while preliminary high water marks collected by the USGS after Isaac indicated 5.1 and 4.9 feet at Lafitte, Louisiana.

The filling of Lakes Pontchartrain and Maurepas is controlled by the water level in Lake Borgne and western Mississippi Sound. As long as the water level in the sound exceeds the water level in the lakes, filling of the lakes occurs. Water level data from the NOAA gage at Bay Waveland Yacht Club in Mississippi was evaluated during both Hurricanes Isaac and Gustav. The water level in western Mississippi Sound remained high for a much longer period of time during Isaac than during Gustav. This is primarily due to the much slower forward speed of Isaac compared to Gustav. The peak water level reached about 9.5 feet NAVD88 during Isaac; however, the water level exceeded 6 feet NAVD88 for about 24 hours, and exceeded 4 feet NAVD88 for about 48 hours. During Gustav, the peak water level reached 10.5 feet NAVD88; however, it only exceeded 6 feet NAVD88 for about 12 hours and 4 feet NAVD88 for 24 hours. This difference led to an increase in the filling of the lakes for Isaac compared to Gustav.

In addition to the wind-driven storm surge, heavy rainfall was a contributing factor to peak water levels throughout southeastern Louisiana and southern Mississippi. Some gages initially rose as a result of storm surge, then received a second rise due to rainfall

Graphs of river gage data presented in Section 3.2.3.5 show that storm surge from Hurricane Isaac propagated up the Mississippi River as far at the Red River Landing gage at river mile 302.5.

3.1.5 Comparison of Isaac to other Events

Due to its storm track, slow forward motion, large size and the location of maximum winds, Hurricane Isaac resulted in higher levels of storm surge and higher rainfalls in many locations in coastal Louisiana and Mississippi than other recent storms. Section 3.3 of this chapter provides detailed information on the storm tracks, the effects of wind on the storm surge, and rainfall patterns for Hurricanes Isaac, Katrina and Gustav. The wind conditions that acted to move water into places like Barataria basin during Hurricane Isaac were very different than those experienced in other storms, such as Hurricane Katrina. Section 3.4 compares Isaac to a suite of synthetic storms that was defined for simulation in the various risk reduction studies conducted by USACE in coastal Louisiana and Mississippi following Hurricane Katrina. The combination of Hurricane Isaac's intensifying as it approached the coast, halting of forward motion and drifting near landfall, extremely large size, and slow forward speed made it unlike any storm in the synthetic storm suite.

Hurricane Isaac Data

3.1.6 Storm Chronology

Hurricane conditions were experienced over southeastern Louisiana and southern Mississippi from midday 28 August through midday 30 August. The eastern shores of southeastern Louisiana experienced tropical storm force winds for nearly 2 days due to the slow movement of Isaac (Table 3.1). Rainfall amounts of 8-12 inches were the norm over the region with some areas recording storm totals exceeding 20 inches.

Table 3.1 Hurricane Isaac Preliminary Best Track Information based on NHC advisories where LST is Local Time in New Orleans. TD=Tropical Depression, TS=Tropical Storm, HU=Hurricane.

Date/Time (UTC)(2012)	Date/Time (LST)(2012)	North Latitude	West Longitude	Maximum Sustained wind speed (mph)	Central Pressure (mb)	Stage
21 Aug 0900	21 Aug 0400	15.2	51.2	35	1007	TD
21 Aug 1200	21 Aug 0700	15.2	52.0	35	1007	TD
21 Aug 1500	21 Aug 1000	15.1	52.3	35	1008	TD
21 Aug 1800	21 Aug 1300	15.3	53.2	35	1005	TD
21 Aug 2100	21 Aug 1600	15.4	53.9	40	1006	TS
22 Aug 0000	21 Aug 1900	15.4	54.8	40	1006	TS
22 Aug 0300	21 Aug 2200	15.6	55.6	40	1006	TS
22 Aug 0600	22 Aug 0100	15.5	56.5	45	1003	TS
22 Aug 0900	22 Aug 0400	15.5	57.3	45	1003	TS
22 Aug 1200	22 Aug 0700	15.9	58.5	45	1006	TS

22 Aug 1500	22 Aug 1000	15.9	59.3	45	1006	TS
22 Aug 1800	22 Aug 1300	15.9	60.4	45	1004	TS
22 Aug 2100	22 Aug 1600	16.0	61.2	45	1004	TS
23 Aug 0000	22 Aug 1900	15.8	62.2	45	1004	TS
23 Aug 0300	22 Aug 2200	15.8	63.0	45	1003	TS
23 Aug 0600	23 Aug 0100	15.3	63.5	40	1004	TS
23 Aug 0900	23 Aug 0400	15.3	64.0	40	1004	TS
23 Aug 1200	23 Aug 0700	15.4	64.8	40	1003	TS
23 Aug 1500	23 Aug 1000	15.6	65.4	40	1003	TS
23 Aug 1800	23 Aug 1300	15.9	66.4	40	1004	TS
23 Aug 2100	23 Aug 1600	16.0	67.1	40	1003	TS
24 Aug 0000	23 Aug 1900	16.5	68.0	45	1002	TS
24 Aug 0300	23 Aug 2200	16.7	68.7	45	1001	TS
24 Aug 0600	24 Aug 0100	16.2	69.6	45	1000	TS
24 Aug 0900	24 Aug 0400	16.1	70.0	45	1000	TS
24 Aug 1200	24 Aug 0700	15.9	70.4	60	1000	TS
24 Aug 1500	24 Aug 1000	16.3	70.8	60	1000	TS
24 Aug 1800	24 Aug 1300	16.7	71.3	65	995	TS
24 Aug 2100	24 Aug 1600	17.2	71.9	65	994	TS
25 Aug 0000	24 Aug 1900	17.3	72.0	65	992	TS
25 Aug 0300	24 Aug 2200	17.7	72.5	70	990	TS
25 Aug 0600	25 Aug 0100	18.1	72.7	65	991	TS
25 Aug 0900	25 Aug 0400	19.0	73.3	60	992	TS
25 Aug 1200	25 Aug 0700	19.7	73.7	60	998	TS
25 Aug 1500	25 Aug 1000	20.1	74.6	60	998	TS
25 Aug 1800	25 Aug 1300	20.8	75.3	60	997	TS
25 Aug 2100	25 Aug 1600	21.3	76.0	60	997	TS
26 Aug 0000	25 Aug 1900	21.7	76.7	60	997	TS
26 Aug 0300	25 Aug 2200	22.1	77.2	60	997	TS
26 Aug 0600	26 Aug 0100	22.8	78.2	60	995	TS
26 Aug 0900	26 Aug 0400	23.1	79.0	65	995	TS
26 Aug 1200	26 Aug 0700	23.5	80.0	65	995	TS
26 Aug 1500	26 Aug 1000	23.9	80.8	65	995	TS
26 Aug 1800	26 Aug 1300	23.9	81.5	60	992	TS
26 Aug 2100	26 Aug 1600	24.2	82.3	60	992	TS
27 Aug 0000	26 Aug 1900	24.0	82.5	65	992	TS
27 Aug 0300	26 Aug 2200	24.2	82.9	65	993	TS
27 Aug 0600	27 Aug 0100	24.9	83.7	60	990	TS
27 Aug 0900	27 Aug 0400	25.2	84.2	65	990	TS
27 Aug 1200	27 Aug 0700	25.8	84.8	65	987	TS
27 Aug 1500	27 Aug 1000	26.1	85.3	65	988	TS
27 Aug 1800	27 Aug 1300	26.1	85.9	70	984	TS
27 Aug 2100	27 Aug 1600	26.4	86.2	70	981	TS
28 Aug 0000	27 Aug 1900	26.7	86.5	70	981	TS
28 Aug 0300	27 Aug 2200	27.1	87.0	70	979	TS
28 Aug 0600	28 Aug 0100	27.4	87.7	70	978	TS
28 Aug 0900	28 Aug 0400	27.5	88.1	70	977	TS
28 Aug 1200	28 Aug 0700	27.8	88.2	70	976	TS
28 Aug 1500	28 Aug 1000	28.1	88.5	70	976	TS

28 Aug 1620	28 Aug 1120	28.1	88.6	75	975	HU
28 Aug 1800	28 Aug 1300	28.5	88.9	75	975	HU
28 Aug 2100	28 Aug 1600	28.7	89.2	80	975	HU
29 Aug 0000	28 Aug 1900	28.9	89.5	80	968	HU
29 Aug 0300	28 Aug 2200	29.0	89.7	80	968	HU
29 Aug 0600	29 Aug 0100	29.0	90.1	80	968	HU
29 Aug 0900	29 Aug 0400	29.2	90.5	80	969	HU
29 Aug 1200	29 Aug 0700	29.4	90.5	80	970	HU
29 Aug 1500	29 Aug 1000	29.6	90.7	75	972	HU
29 Aug 1800	29 Aug 1300	29.8	90.8	70	974	TS
29 Aug 2100	29 Aug 1600	30.0	91.1	70	975	TS
30 Aug 0000	29 Aug 1900	30.1	91.1	60	980	TS
30 Aug 0300	29 Aug 2200	30.3	91.2	60	980	TS
30 Aug 0600	30 Aug 0100	30.6	91.5	55	982	TS
30 Aug 0900	30 Aug 0400	30.9	91.6	45	983	TS
30 Aug 1200	30 Aug 0700	31.3	92.0	45	985	TS
30 Aug 1500	30 Aug 1000	31.7	92.1	40	987	TS
30 Aug 1800	30 Aug 1300	32.2	92.4	40	992	TS
30 Aug 2100	30 Aug 1600	32.7	92.6	35	995	TD
31 Aug 0300	30 Aug 2200	33.5	93.0	30	998	TD
31 Aug 0900	31 Aug 0400	34.7	93.9	25	999	TD
31 Aug 1500	31 Aug 1000	35.6	94.1	25	1003	TD
31 Aug 2100	31 Aug 1600	37.3	93.8	25	1004	TD
01 Sep 0300	31 Aug 2200	38.3	93.5	25	1005	TD
01 Sep 0900	1 Sep 0400	38.5	93.0	25	1004	TD

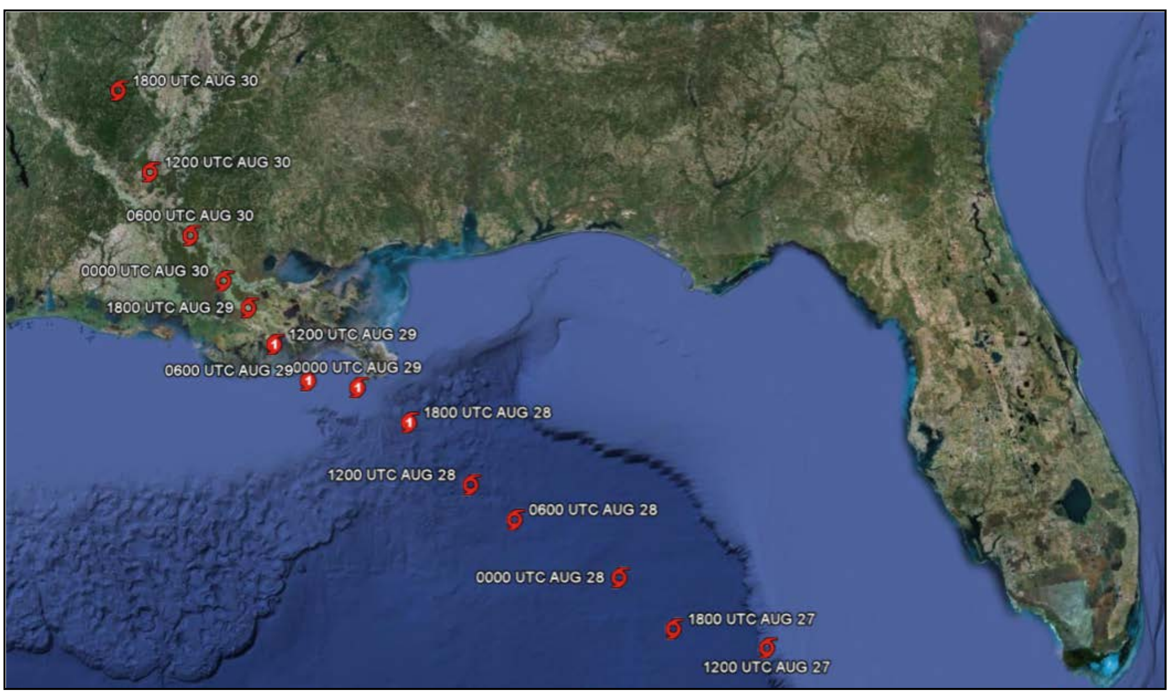


Figure 3.1 Gulf of Mexico track for Hurricane Isaac 27 August through 30 August.

3.1.6.1 Synoptic History

Hurricane Isaac began as Tropical Depression Nine which formed from a tropical wave on 21 August at 0400 LST (0900 UTC) approximately 715 miles east of the Leeward Islands of the eastern Caribbean. Air Force reconnaissance aircraft investigating the tropical depression that afternoon found that Tropical Depression Nine had intensified into Tropical Storm Isaac about 500 miles east of Guadeloupe. Shear and dry air inhibited intensification during the next several days with the system passing through the Leeward Islands (near Guadeloupe) as a minimal tropical storm the afternoon of 22 August. Isaac became a little better organized and strengthened to a strong tropical storm just prior to moving across southwestern Haiti during the early morning hours of 25 August. The center of Isaac avoided significant land interaction from the mountains of Hispaniola and eastern Cuba on 25 August emerging into the southwestern Atlantic during the evening. Tropical Storm Isaac continued to move west-northwest, passing just south of Key West, FL during the day of 26 August; reaching the Gulf of Mexico on the evening of 26 August.

While moving slowly west-northwest through the Gulf of Mexico on 27/28 August (Figure 3.5), Tropical Storm Isaac remained a poorly organized system with a very large wind field envelope. The central core of the tropical storm remained broad due to shear and did not begin to consolidate until hours prior to landfall. Isaac finally intensified into a Category 1 hurricane at 1120 LST (1620 UTC) on 28 August approximately 75 miles south-southeast of the mouth of the Mississippi River.

Hurricane Isaac made landfall at 1845 LST (2345 UTC) 28 August just to the west of the mouth of the Mississippi River. Steering currents at landfall were very weak and the center of Isaac actually drifted back over water for several hours later that evening with the center making a second landfall near Port Fourchon, LA around 0115 LST (0615 UTC) on Wednesday 29 August. Isaac moved very slowly northwestward during the day of 29 August, causing a prolonged period of strong east to east/southeast winds along the eastern shores of southeastern Louisiana, across the Lake Pontchartrain Basin, and along the Mississippi coast.

These persistent tropical storm force winds, very slow forward motion, and the broadness of the wind field in Isaac were main contributing factors in producing much higher than normal storm surge values than for a typical Category One hurricane. During the afternoon of 30 August, Tropical Storm Isaac had gained sufficient latitude (west of New Orleans/south of Baton Rouge) to become influenced by the Western Atlantic ridge and began to move quicker northwest across Louisiana, entering Arkansas around 1700 LST (2200 UTC) 30 August.

The center of Isaac moved northward during the next several days producing moderate to locally heavy rains across Arkansas, Missouri and Illinois. On 1 September, the remnants of Isaac were absorbed by a cold front with the system moving through the Ohio Valley producing moderate to locally heavy rains during its passage.

3.1.7 Meteorological Data

3.1.7.1 Storm Total Rainfall Summary

Storm total rainfall amounts of 8-12 inches were the norm across southeastern Louisiana and southern Mississippi. Many areas reported higher amounts with the highest measured total reported at Pascagoula, MS of 22.20 inches. Rainfall caused most rivers across the area to swell to above flood stage with new stage records set in southern Mississippi on the Wolf River at Landon and Gulfport and on East Hobolochitto Creek near Caesar. Over 10 inches of rainfall occurred at the Percy Quinn State Park with the bulk of the rain falling between 1300 LST (1800 UTC) 29 August and 0700 LST (1200 UTC) 30 August resulting in flooding along the Tangipahoa River. In southern Mississippi/Louisiana, 10-15 inches of rain over the southern Pearl River and Bogue Chitto drove the rivers above major flood stage. Rainfall amounts of 8-15 inches occurred in the Lake Maurepas Basin adding to flooding that occurred from storm surge. The CoCoRaHS rain gage site at Reserve, Louisiana in St John the Baptist Parish recorded 14.84 inches.

Table 3.2 is condensed from data provided by the National Weather Service (NWS) River Forecast Center in Slidell and shows measured rainfall data at locations along the river systems in southeastern Louisiana and southern Mississippi. From the data it is noted that the bulk of the storm total rainfall occurred between 0700 LST (1200 CTU) on 29 August and 1300 LST (1800 UTC) on 30 August. The Hydrometeorological Prediction Center in their document pertaining to storm total rainfall with respect to duration located at **http://www.hpc.ncep.noaa.gov/tropical/rain/tcduration.html** states that 75-80% of the average tropical cyclone rainfall occurs during a 30 hour period. The selected 30-hour period produced 81.1% of Isaac's storm total rainfall over southern Mississippi and southeastern Louisiana.

Table 3.2 Hurricane Isaac Mean Aerial Precipitation. This table provides total rainfall data in inches provided for river gages by NWS River Forecast Center in Slidell and rainfall totals for the period 0700 LST (1200 UTC) 29 August-1300 LST (1800 UTC) 30 August.

Location	Storm Total Rain 8/28-8/30	Rainfall 8/29 0700 LST 8/30-1300 LST
Amite River at Darlington	8.63	7.92
Amite River at Denham Springs	7.13	6.25
Amite River at Bayou Manchac	8.75	7.14
Amite River at Port Vincent	12.73	9.97
Comite River at Olive Branch	6.33	5.93
Comite River at Zachary	6.53	6.05
Tickfaw River at Liverpool	9.9	8.93
Tickfaw River at Montpelier	9.56	8.42
Tickfaw River at Holden	12	10.34
Tangipahoa River at Osyka	10.88	9.87
Tangipahoa River at Kentwood	10.71	9.52
Tangipahoa River at Amite	10.51	9.38
Tangipahoa River at Robert	10.79	9.43
Tchefuncte River at Folsom	10.36	9.24
Tchefuncte River at Covington	10.32	8.69
Bogue Falaya at Boston Street	10.32	8.41
Pearl River at Bogalusa	11.62	9.42
Bogue Chitto River at Tylertown	9.98	8.75
Bogue Chitto near Franklinton	11.07	9.75
Bogue Chitto near Bush	10.64	9.27
Pearl River at Pearl River	10.52	8.63
Landon	12.12	8.97
Wolf River at Gulfport	11.7	8.76
Wortham	12.92	8.91
Biloxi River at Lyman	12.59	8.74
Tchoutacabouffa River near D'Iberville	12.2	8
Mississippi River at Red River Landing	4.79	4.25
Mississippi River at Baton Rouge	5.03	4.71
West Hobolochitto Creek near McNeil	11.09	8.81
Hobolochitto Creek at Carriere	11.34	8.83

The heaviest rainfall occurred mostly over southern Mississippi which remained in a strong outer band of Isaac for nearly two days. Generally, rainfall totals decreased slowly as one moved from east to west with some exceptions such as the gage in New Orleans at Carrollton which recorded 20.66 inches. Figure 3.6 was derived from data contained in the Post Tropical Cyclone Report issued on 13 September by the NWS Slidell weather forecast office and from the National Weather Service storm total rainfall graphic.

Hurricane Isaac produced high rainfall totals throughout southeastern Louisiana and southern Mississippi due to the very slow movement after landfall and its angle of approach. Historically, Isaac was much wetter over a larger area than Katrina (2005), Gustav (2008), Juan (1985), Camille (1969), and Betsy (1965). Tropical Storm Allison (2001) produced slightly more rainfall than Isaac over especially the western portions of southeastern LA. Storm total rainfall of 8-12 inches with locally higher amounts to 20+ inches caused numerous rivers to exceed major flood stage and added to the flooding caused by storm surge.

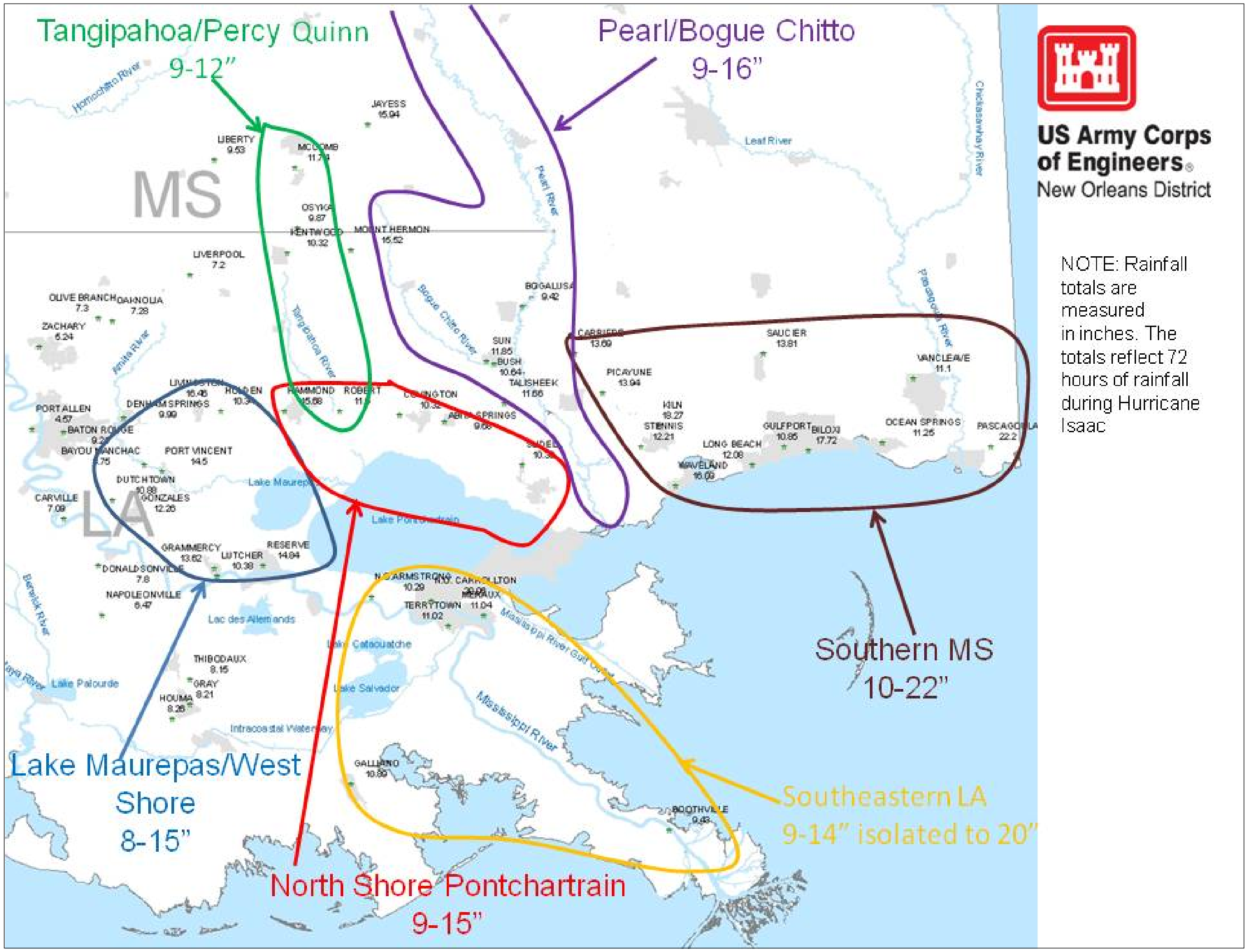


Figure 3.2 Total rainfall for Hurricane Isaac. Graphic was derived from NWS rainfall observational data. Areas are divided into sub-basins of maximum impacts in the region. The sub-basin delineation was derived for communication purposes.

Figures 3.3 and 3.4 show that Bayou Manchac in the Lake Maurepas area and the Tchefuncte River at Madisonville on the north shore of Lake Pontchartrain experienced a significant rise prior the heaviest rainfall occurring. Then these sites showed a secondary rise as a direct result of rainfall. The gages located on rivers displayed in Figures 3.3 and 3.4 show a response primarily due to rainfall over the river basin, although this water drained to the coastal areas as well.

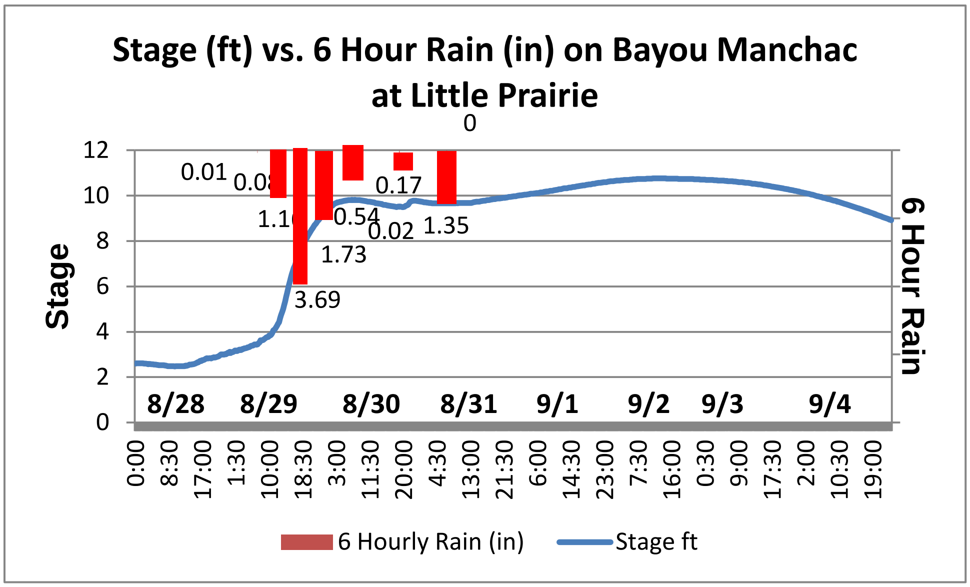


Figure 3.3 Stage vs. 6-Hour Rainfall on Bayou Manchac at Little Prairie, LA. This figure illustrates that at this location the storm surge was building prior to significant local rainfall. Stage datum: NAVD88.

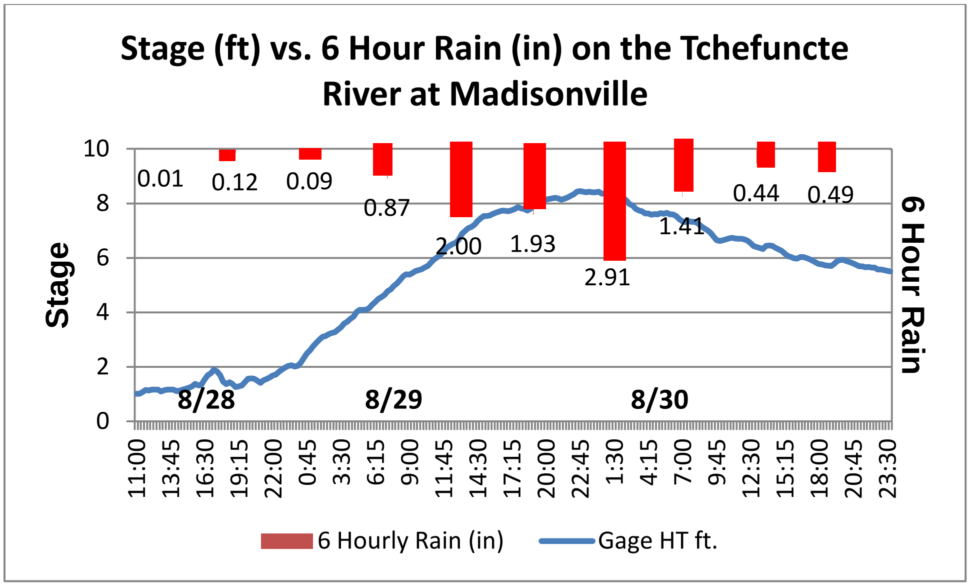


Figure 3.4 Stage vs. 6-Hour Rainfall on the Tchefuncte River at Madisonville, LA. This figure illustrates that at this location the storm surge was building prior to significant local rainfall. Gage height, no datum.

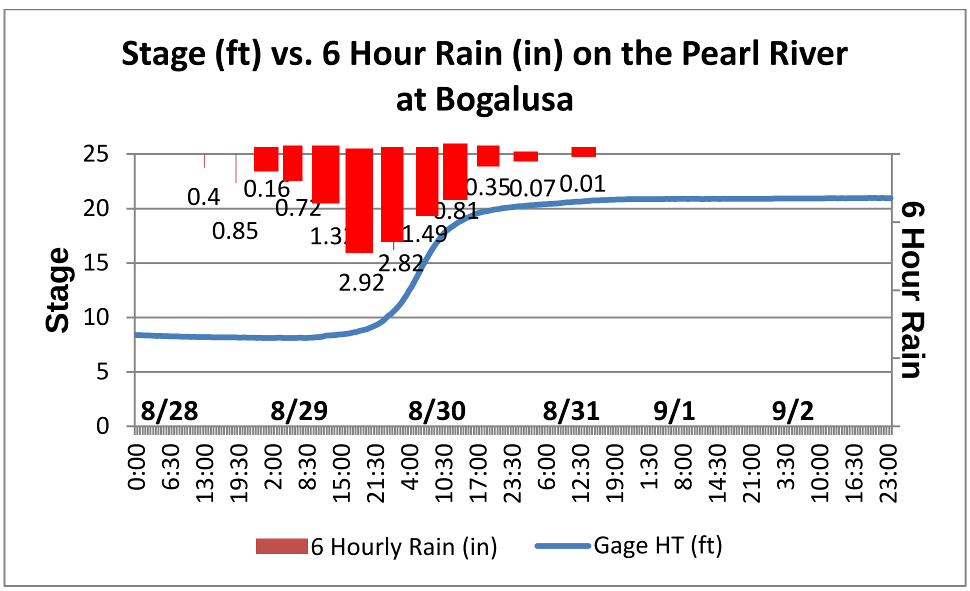


Figure 3.5 Stage vs. 6-Hour Rainfall on the Pearl River at Bogalusa, LA. This figure illustrates that at this location the water level increase was primarily due to significant local rainfall. Gage height, gage zero is 54.64 ft NAVD88.

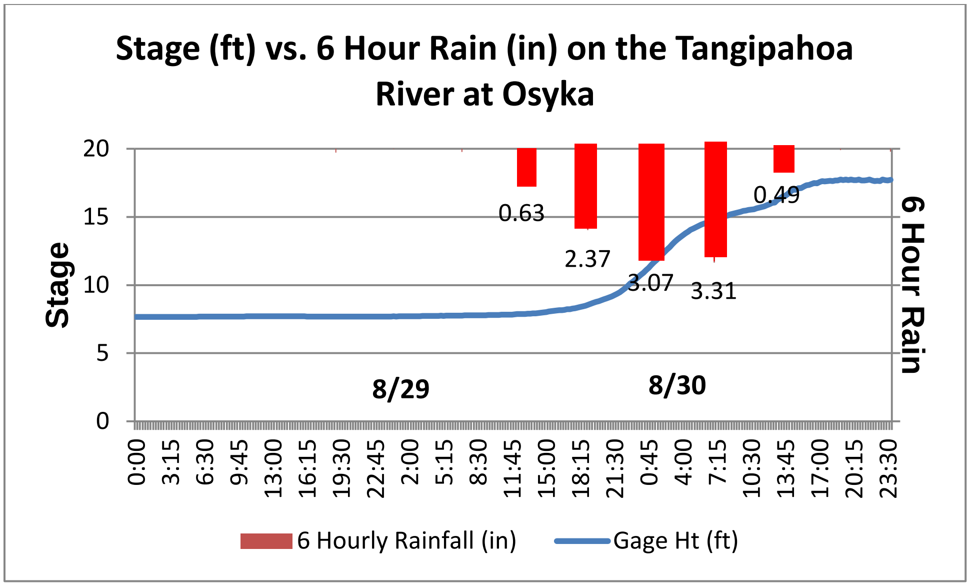


Figure 3.6 Stage vs. 6-Hour Rainfall on the Tangipahoa River at Osyka, LA. This figure illustrates that at this location the water level increase was primarily due to significant local rainfall. Gage height, no datum.

3.1.7.2 Wind Summary

Tropical storm force winds were experienced over southeastern Louisiana and southern Mississippi for as long as 45 hours from midday on 28 August through midday 30 August. One station (Buras, LA) reported a sustained wind of Category 1 hurricane force. Peak gusts exceeding hurricane force were experienced at numerous locations across the area as well. The highest peak gust, 86 mph, was measured at Buras, Louisiana; additionally Boothville, Louisiana recorded a gust of 84 mph. Table 3.3, compiled from the Post Tropical Cyclone Report issued by the NWS's Slidell office on 13 September, depicts the maximum sustained wind direction/speed at various locations in Louisiana and Mississippi. Peak gusts at the locations are included as well as anemometer heights. Data has been adjusted from the NWS report to convert knots to mph and UTC to LST.

Since Isaac was a very slow moving hurricane with a large wind field, the duration of tropical storm force winds was a key factor in producing higher than normal surges when compared to a typical Category 1 hurricane. On the Mississippi Sound at Grand Pass (Figure 3.7), tropical storm force winds were recorded from 0615 on 28 August through 0345 on 30 August, a total of 45 hours. It should be noted that winds of 10-30 mph generally from the east occurred from the morning of 26 August to the onset of tropical storm force winds. In fact, east to southeast winds blew from 26 August into the morning of 29 August before shifting to southerly from mid morning on the 29 August through 31 August. The extended duration of generally easterly winds caused increased levels of surge along the eastern facing shores of southeastern Louisiana and into Lake Pontchartrain. The southerly wind shift in the Mississippi Sound during the middle of the day on 29 August coincided with the timing of the peak surges along the western Mississippi coast (Figure 3.30).

Table 3.3 Wind Data from NWS Slidell Post Tropical Cyclone Report for Hurricane Isaac updated 13 September. Winds were adjusted to MPH and times to LST.

Station	Lat	Lon	Anem. Height (Meter)	Max Sustained Winds (Dir/MPH)	Date/ Time (LST)	Peak Gust (Dir/MPH)	Date/ Time (LST)	Rainfall (In.)
New Orleans Lakefront Airport	30.04	90.03	10	040/60	28/2228	070/76	28/2305	-
South Lafourche Airport	29.44	90.26	10	100/58	28/2355	100/77	28/2355	-
Boothville	29.33	89.40	10	100/54	28/2202	100/84	28/2159	9.43
Belle Chase NAS	29.82	90.03	10	080/53	29/0338	080/79	29/0338	-
New Orleans Armstrong Airport	29.98	90.25	10	030/53	28/2248	080/75	29/0507	10.29
Gulfport Airport	30.40	89.07	10	130/53	29/1219	130/70	29/1219	10.85
Houma-Terrebonne Airport	29.57	90.67	10	360/49	29/0255	360/66	29/0315	8.26
Baton Rouge Ryan Field	30.54	91.15	10	030/45	29/0653	030/58	29/0753	9.21
Slidell Airport	30.35	89.82	10	160/39	29/2206	090/58	29/0739	10.39
Pascagoula Airport	30.46	88.53	10	150/37	29/2130	110/52	29/2036	13.33
Hammond Airport	30.52	90.42	10	100/35	29/1715	100/54	29/1915	15.68
McComb Airport	31.18	90.47	10	160/29	30/1411	110/56	29/2329	11.74
Buras	29.36	89.56	2.25	045/75	28/1833	045/86	28/1832	-
Dulac	29.35	90.73	10	338/56	29/543	355/75	29/0305	-
Jefferson Parish	29.93	90.23	10	060/56	29/0425	047/70	29/0310	-
Mandeville	30.36	90.09	10	118/54	29/1556	112/66	29/1415	-
Lafitte	29.77	90.03	2.25	075/49	29/0258	075/66	29/0353	-
Franklinton	30.79	90.20	10	138/39	30/0015	138/53	30/0100	-
Bay St Louis	30.31	89.33	2.25	159/47	29/1046	159/58	29/1046	-

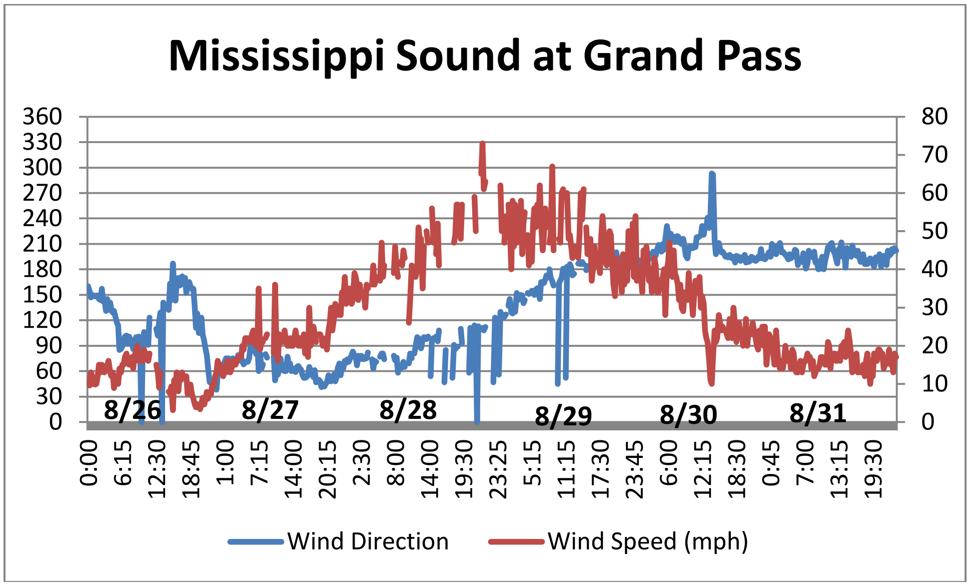


Figure 3.7 Wind measurements at Mississippi Sound at Grand Pass. Wind direction in degrees and wind speed in mph on the Mississippi Sound at Grand Pass from 26 August-31 August.

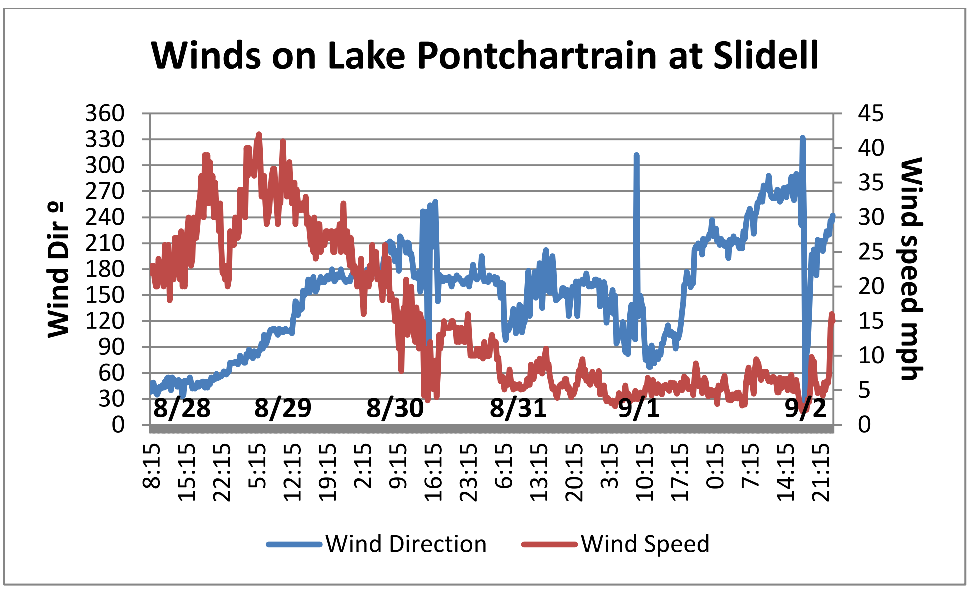


Figure 3.8 Wind measurements on Lake Pontchartrain at Slidell, LA. Wind direction in degrees and wind speed in mph from 28 August through 2 September.

Winds on Lake Pontchartrain at Slidell (Figure 3.8) were 20-35mph from the northeast on 28 August, 25-40mph from the east-northeast to east from 0000 29 August-0600 29 August, east to east-southeast at 30-45 mph from 0600-1200 on 29 August, 20-35 mph from the southeast to south from 1200 29 August through 0900 30 August, and south to southwest at 10-25 mph from 900 30 August to 0400 31 August. The wind shift to the southeast beginning at noon on 29 August coincided with the maximum increase in surge levels with the peak surge values occurring during the evening of 29 August.

Also along the northern shore of Lake Pontchartrain, Madisonville (Figure 3.9) recorded north to northwest winds of 10-20mph on 28 August, northeast winds from 0200-0900 on 29 August, east to east-southeast winds of 15-30 mph from 0900-2200 on 29 August, shifted to southeast at 10-30mph from 2200 on 29 August to 1300 on 30 August, and then south to southeast at 10mph or less from 1300 through 31 August. This area also received over 10 inches of rainfall during this same time period.

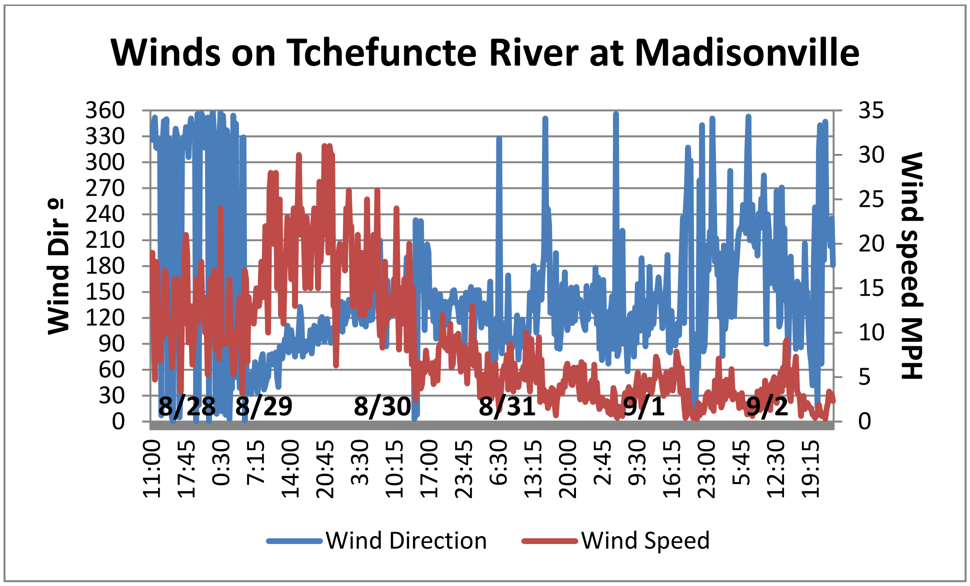


Figure 3.9 Wind measurement near the Tchefuncte River at Madisonville, LA. Wind direction in degrees and wind speed in mph from 28 August through 2 September.

In the Lake Maurepas Basin (Figure 3.10), variable winds of 5-10mph were experienced from 26-28 August. Winds increased to 10-30mph from the northeast to east from 2200 28 August through 0900 29 August, shifted to east to east northeast winds at 10-30mph from 0900 29 August to 1900 29 August, then southeast to south at 10-20mph from 1900 29 August to 1400 30 August. After midday 30 August winds decreased to 10mph or less generally from the south to southwest.

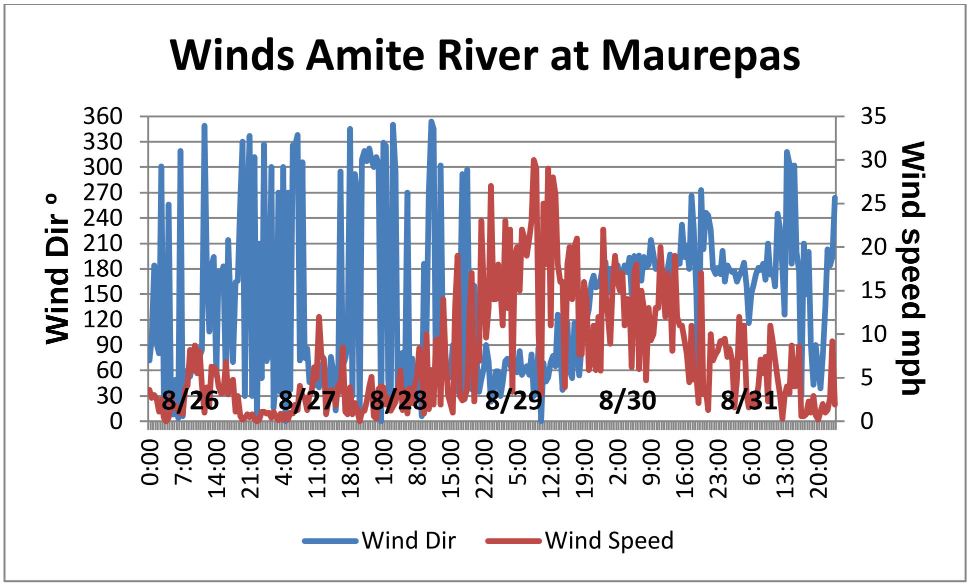


Figure 3.10 Wind measurements near the Amite River River at Maurepas, LA. Wind direction in degrees and wind speed in mph from 26 August through 31 August.

Damages resulting solely from Isaac's wind were comparable to what is expected from a Category 1 hurricane in the Saffir-Simpson Hurricane Winds Scale: structural damage to roofs, widespread tree damage, and downed power lines (http://www.srh.noaa.gov/data/LIX/PSHLIX). Over one million homes lost power in Louisiana and Mississippi as a result of the winds of Isaac. Winds were also a main contributing factor to the significant storm surge impacts throughout the region.

In conclusion, wind speeds exceeding tropical storm force were experienced over southeastern LA and southern MS from midday on 28 August through the end of 29 August with some locations along the eastern shores experiencing tropical storm force winds up to 45 hours. Generally easterly winds were experienced over southeastern LA and southern MS from 26 August to the morning of 29 August. Winds then shifted to southeasterly to southerly from 29 August through 31 August. Winds drove water toward the eastern shores of southeastern LA and into Lake Pontchartrain causing elevated tide levels prior to Hurricane Isaac making landfall. After Isaac moved inland, with the southerly shift in the winds, elevated water levels in Lake Pontchartrain moved toward the northern coasts.

3.1.7.3 Wave Buoy Data

Most of the buoys monitored by the National Data Buoy Center in the Gulf of Mexico did not report wave height observations during Hurricane Isaac either because they were not operational at the time of the storm or received damage during the storm. Of those buoys that did report wave heights, most of the wave heights were in the 5-15 foot range. However, Station 42001 located at 25°53'16"N 89°39'27"W did reach a peak wave height of 15.42 feet at approximately 1500 LST of 28 August (Figure 3.11) and Station 42012 located at 30°03'55"N 87°33'19"W offshore from Orange Beach, Alabama on the east side of the storm track reported a peak wave height of 19.02 feet at approximately 1700 LST on 28 August (Figure 3.12).

To put this in perspective, the observed significant wave heights were in the range of 25-30 feet for Hurricane Gustav and 30-35 feet for Hurricane Ike.

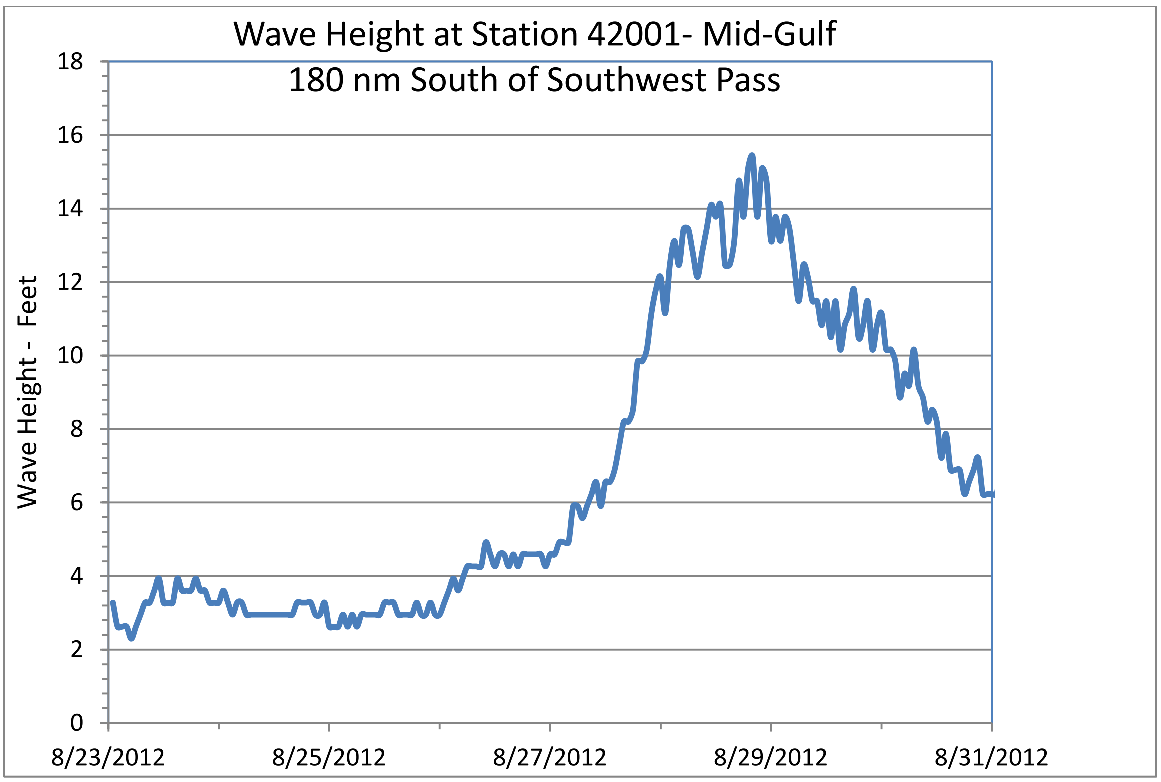


Figure 3.11 Wave heights from wave buoy 42001. Peak wave height was 15.42 feet at approximately 1500 LST on 28 August. (Data from NOAA National Data Buoy Center.)

In contrast, the National Data Buoy Center developed a report on the passage of Hurricane Katrina in 2005 which noted that Station 42040, located at 29°11'03"N 88°12'48"W approximately 64 nautical miles south of Dauphin Island Alabama, reported a significant wave height of 16.91 meters (55.5 feet) at 0600 LST (1100 UTC) on 29 August. At the time of the report, Hurricane Katrina was approximately 73 nautical miles to the west of 42040 with maximum sustained winds of 145 miles per hour (Public Advisory 26A issued by the National Hurricane Center). In addition to the 55-foot report, 42040 reported seas 12 feet or greater for 47 consecutive hours.

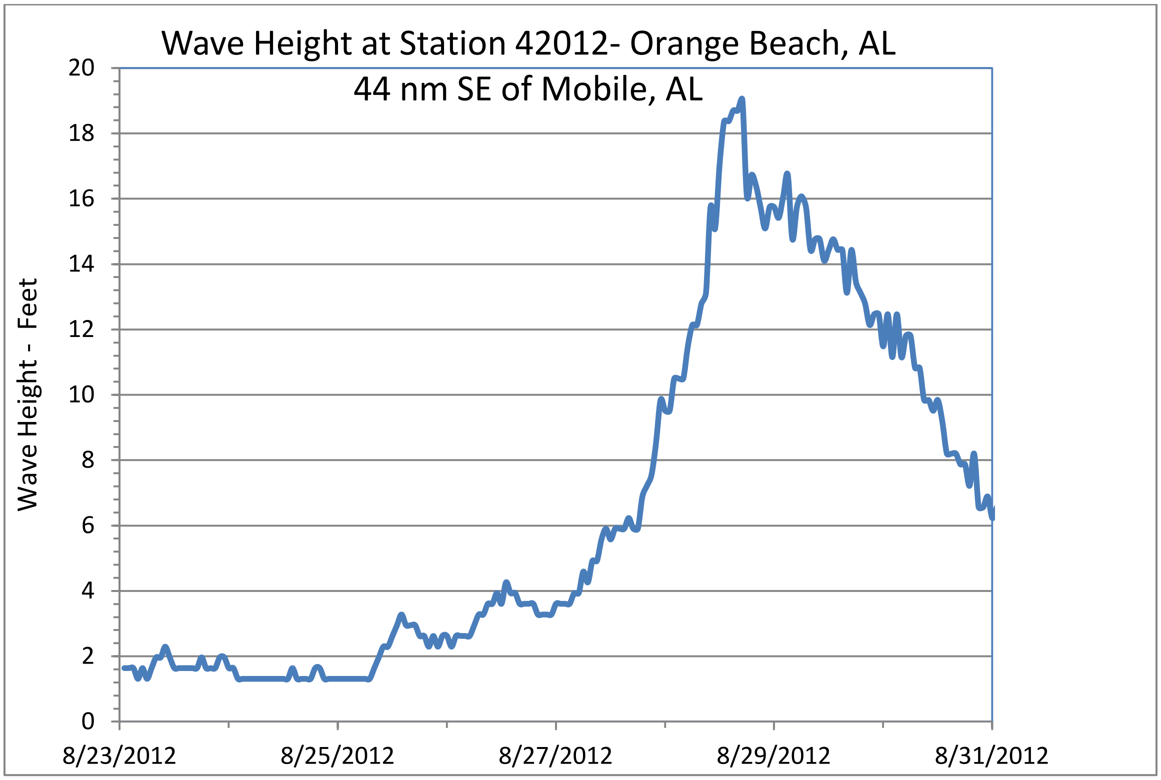


Figure 3.12 Wave heights from wave buoy 42012. Peak wave height was 19.02 feet at approximately 1700 LST on 28 August. (Data from NOAA National Data Buoy Center.)

3.1.7.4 Water Level Data

According to the NOAA National Ocean Service's tides on line website, http://www.tidesonline.nos.noaa.gov/geographic.html, tide levels along the Southeastern Louisiana and Mississippi coasts were running approximately 0.5 to 1 foot above predicted well in advance of Isaac reaching the Gulf of Mexico. Tides were elevated over the Gulf of Mexico primarily due to persistent easterly winds that began on 20 August which caused water to pile up along the eastern shores of southeastern Louisiana and flow into Lake Pontchartrain. This weather pattern periodically occurs during the year and causes tide levels to elevate above normally predicted levels. The tidal gage at Waveland Yacht Club, Mississippi (Fig. 3.13) was running approximately 0.5 to 1 foot above normal prior to Isaac entering the Gulf of Mexico.

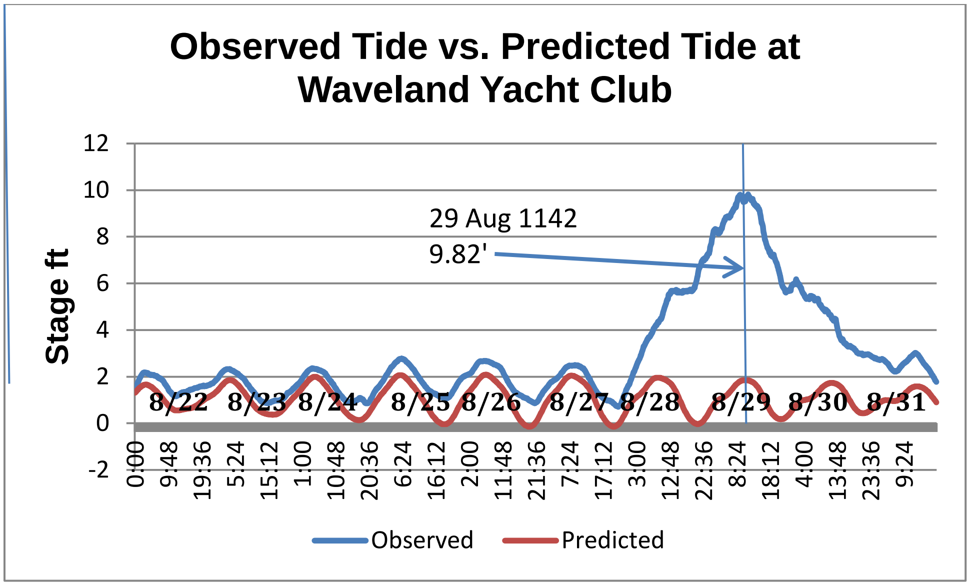


Figure 3.13 Observed tide vs. predicted tide at Waveland Yacht Club 22 August through 31 August. Stage datum: MLLW.

Along the southern shore of Lake Pontchartrain at New Canal Station, Louisiana (Fig. 3.14), observed tides were 0.5-0.75 feet above normal from 22 August through 24 August, 0.75-1.1 feet above normal from 25 August-27 August, and then steadily increased on 28/29 August to the peak of 6.53 feet early on 30 August.

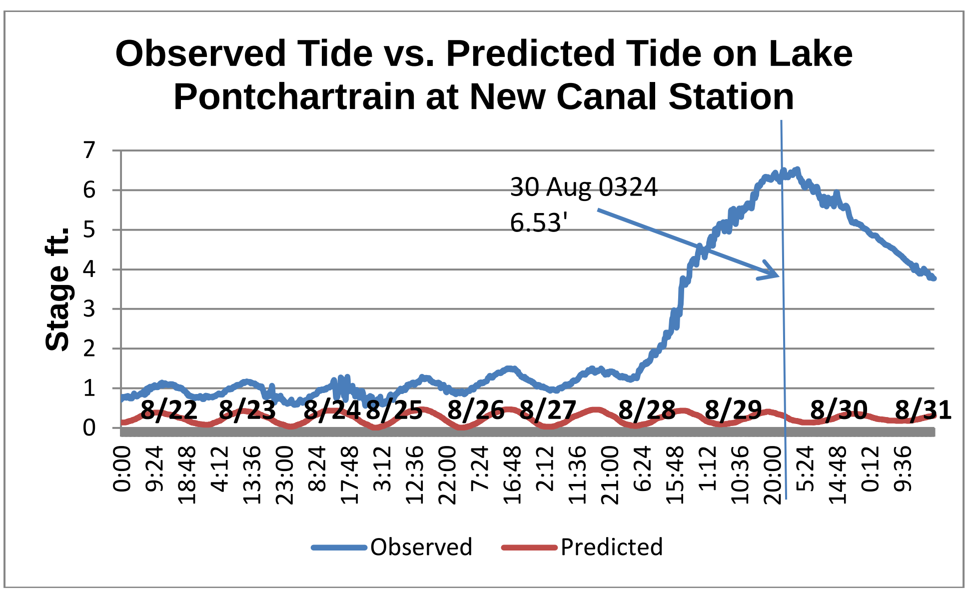


Figure 3.14 Observed tide vs. predicted tide on Lake Pontchartrain's south shore at New Canal Station 22 August-31 August. Stage datum: MLLW.

The eastern facing shores of southeastern Louisiana, Shell Beach, Louisiana (Fig. 3.15) experienced tides of 0.75-1.2 feet above normal 22 August-24 August, 0.75-1.25 feet above normal 25/26 August, and 1-2 feet above normal on 27 August. Tides steadily rose to a crest of 11.02 feet shortly after midnight on 29 August.

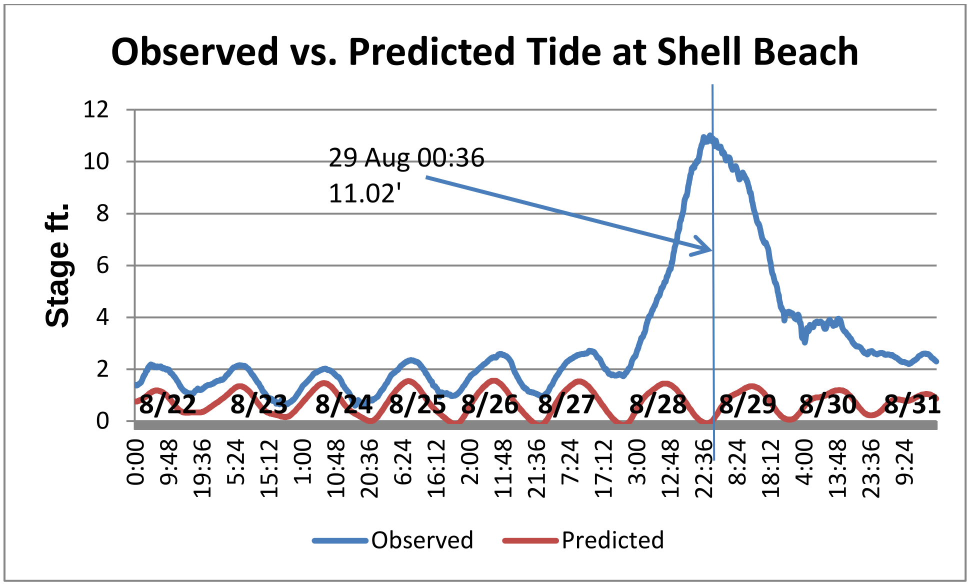


Figure 3.15 Observed vs. predicted tide at Shell Beach along the Eastern Shores of Southeastern LA 22 August through 31 August. Stage datum: MLLW.

Along the southern coast of Louisiana at Grand Isle (Fig 3.16), tides were only slightly elevated (0.5 feet or less) from 22 August-27 August. Tide levels began to increase early in the morning on 28 August reaching a peak of 5.64 feet mid morning 29 August.

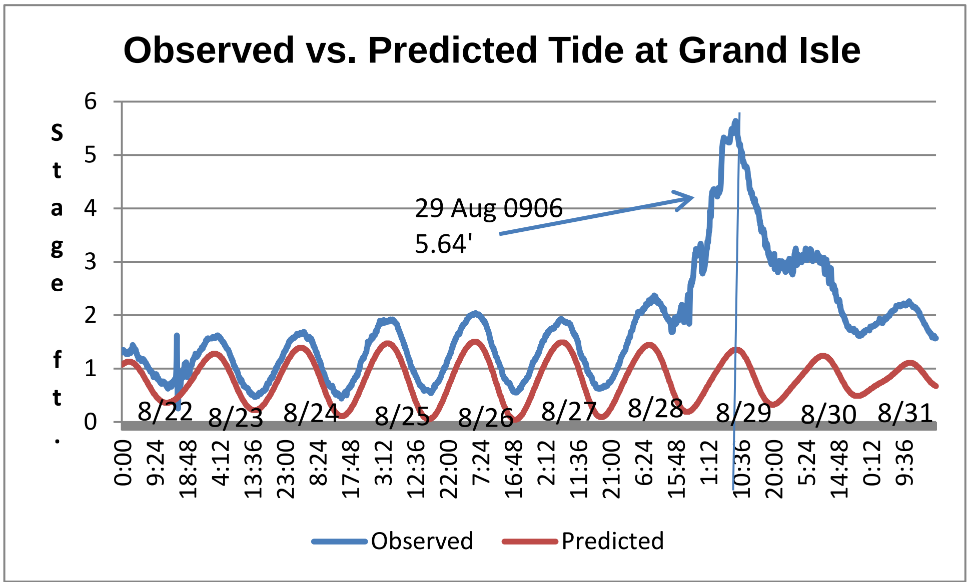


Figure 3.16 Observed vs. predicted tide at Grand Isle, Louisiana from 22 August through 31 August. Stage datum: MLLW.

Lastly, along the East Bank on Bayou LaBranche at Norco, tides were running 0.75-1.25 feet above normal 22 August through 25 August and 1-1.75 feet above normal on 26-27 August. Tides began to steadily rise on 28 August and had reached 6.67 feet on the morning of 29 August when the gage stopped functioning.

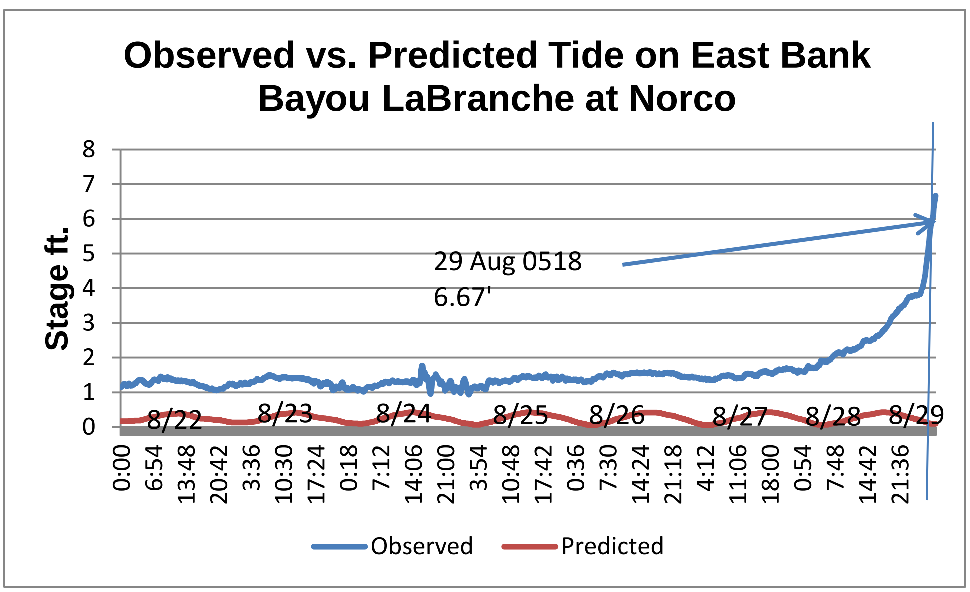


Figure 3.17 Observed vs. predicted tide on the East Bank Bayou LaBranche at Norco, Louisiana from 22 August through 29 August. Stage datum: MLLW.

3.1.7.5 River Gages

As Hurricane Isaac approached the Louisiana Coast its forward speed slowed significantly. This allowed the tropical storm force winds to remain constant out of the southeast for a much longer period of time than is typical for tropical events. This long term forcing on the Mississippi River caused water elevations to continue to rise for or as long as winds blew from this direction.

As seen in the graphs below, the propagation of the storm surge from Hurricane Isaac up the Mississippi River was seen as far as 300 river miles inland.

Figures 3.18 through 3.22 are presented from the downstream most site at West Bay to the farthest upstream at Red River Landing at RM 302.5. The peak passed West Bay just after 1800 hours on 28 August, then moved upstream to peak at 0000 hours on 29 August at the Carrollton gage, and finally moved to Red River Landing at 1000 later that day.

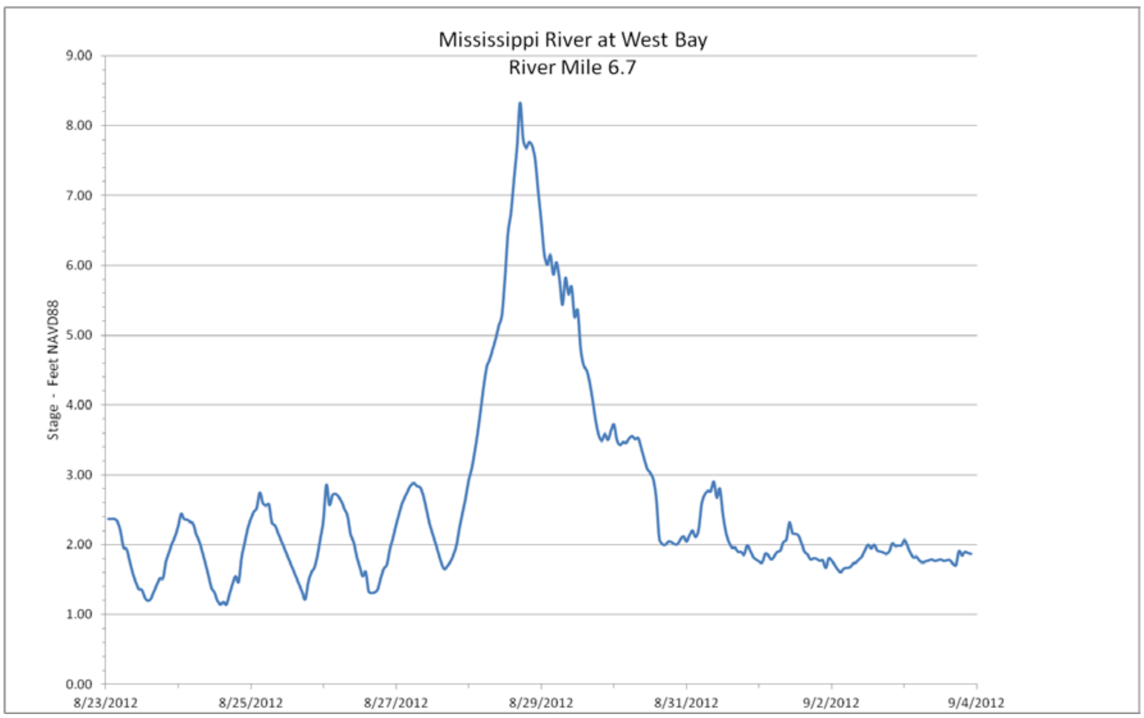


Figure 3.18 Mississippi River at West Bay (RM 8). Stages increased from 2 feet to 8 feet from the storm surge.

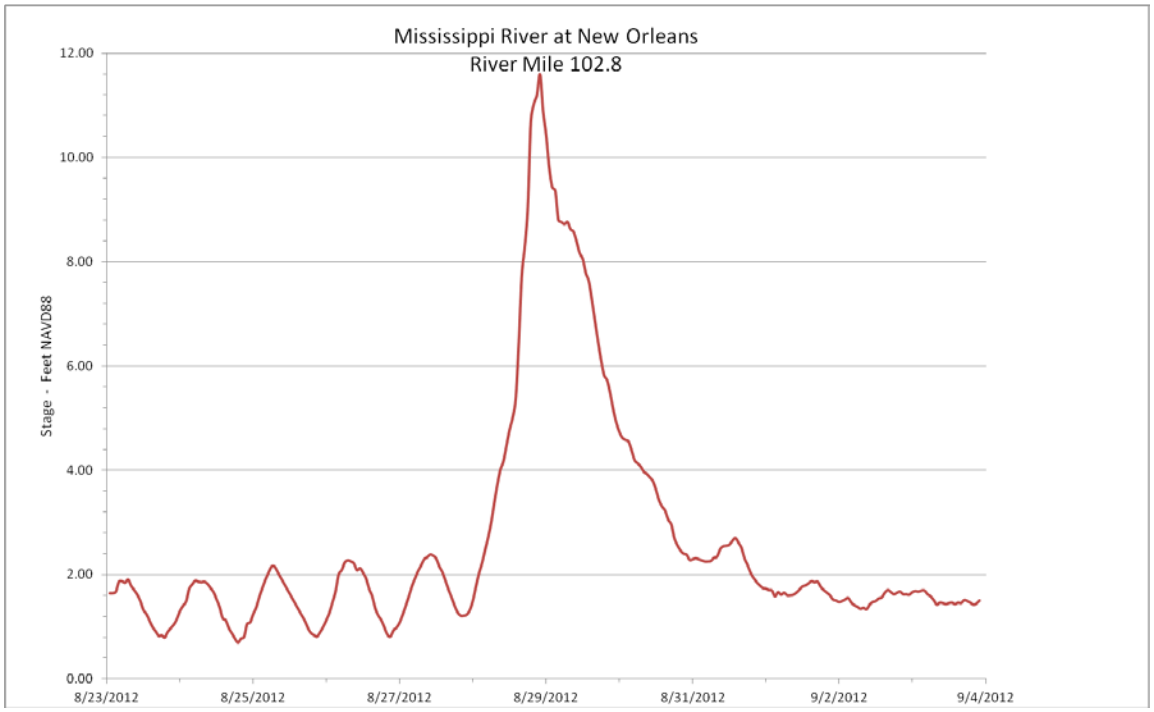


Figure 3.19 Mississippi River at Carrollton (RM 102.7). Stages increased from 2.5 feet to 12.5 feet from the storm surge.

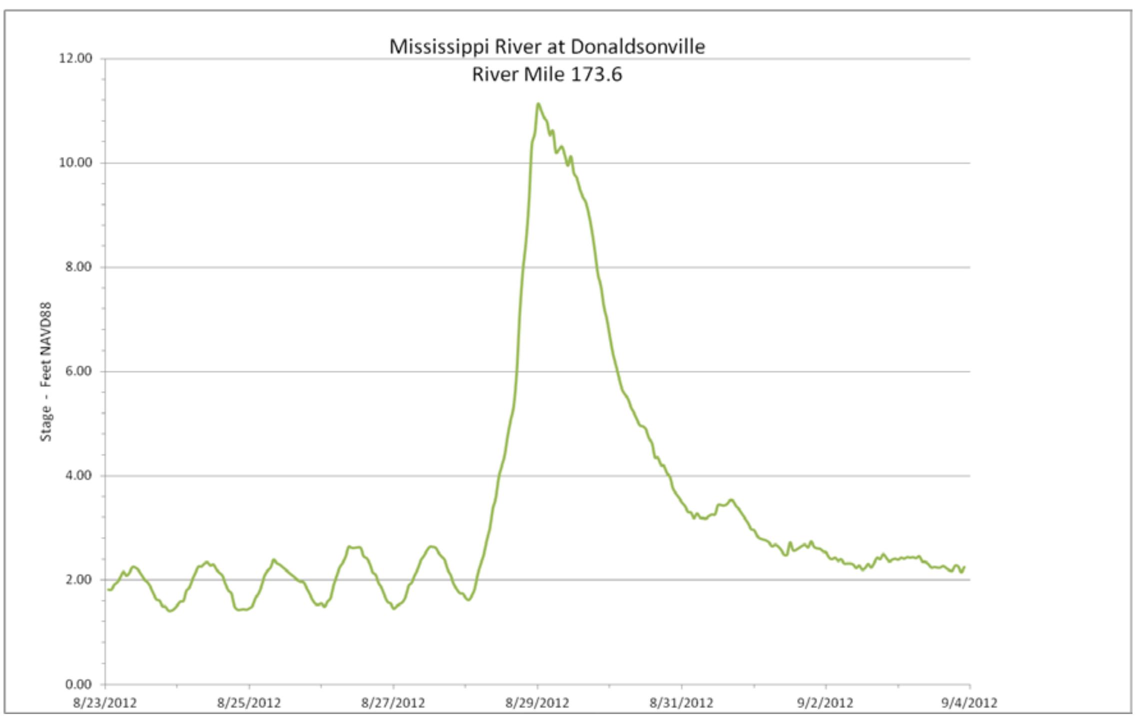


Figure 3.20 Mississippi River at Donalsonville (RM 175.7). Stages increased from 3 feet to 12 feet from the storm surge.

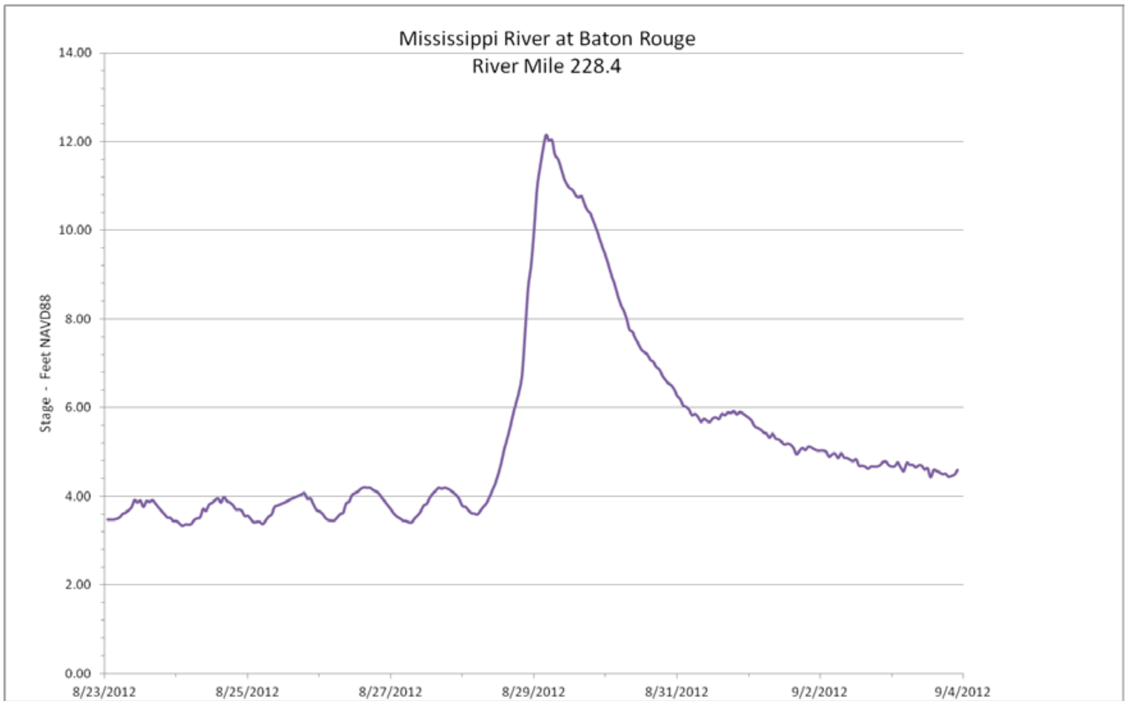


Figure 3.21 Mississippi River at Baton Rouge (RM 228.5). Stages increased from 4 feet to 12.5 feet from the storm surge.

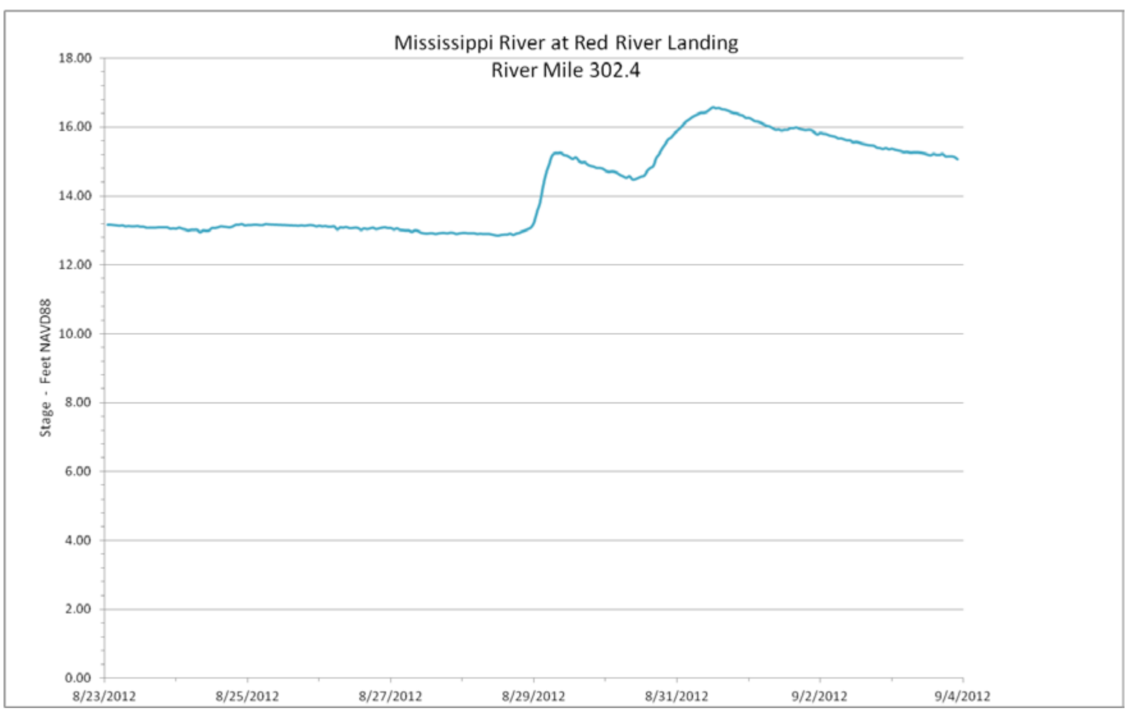


Figure 3.22 Mississippi River at Red River Landing (RM 302.5). Stages increased from 13.1 feet to 17 feet from the storm surge.

Comparison of Hurricane Isaac with Prior Tropical Events

3.1.8 Hurricane Interaction with the Coast of Southeastern Louisiana

The southeastern Louisiana landscape responds in a very complex way to an approaching hurricane. Storm wave and water level responses in this geographic region can be highly variable in space and time during an event due to complexity of the regional landscape and the varying characteristics of approaching hurricanes.

Coastal Louisiana is highly irregular, having large expanses of wetlands interspersed with very shallow open water areas with widely varying dimensions, and having extensive, irregularly-shaped and shallow open water bays to the east of New Orleans (Lake Borgne), to the southeast (Breton Sound) and to the south (Barataria Bay). Each of these water bodies is surrounded by large wetland systems. The large Breton Sound and Barataria basins are separated by an extensive Mississippi River delta, and a long levee system that follows the Mississippi River, comprised of both federal levees and locally-owned “back” levees.

Together the river delta and levee system strongly influence the movement of water along the coast during an approaching hurricane, and they limit the movement of water between these two wetland basins. The Mississippi River delta also acts as a barrier against the east to west movement of water along the Mississippi and Alabama coasts and continental shelves that is forced by winds from the east as hurricanes approach the northern Gulf of Mexico coast.

The footprint of the HSDRRS, which is comprised of levees, vertical walls, pump stations and gates, not only reduces the risk of flooding but also influences the movement of water, acting as a barrier against the winds which build storm surge. The relatively deep Mississippi River, and passes that lead to and from it, enable storm surge that builds on one side of the river levee system to propagate up the river.

The large shallow Lake Pontchartrain north of New Orleans is hydraulically connected to Lake Borgne and western Mississippi Sound via several narrow channels (the Rigolets and Chef Menteur passes). The smaller shallow Lake Maurepas, and the extensive wetlands that surround it, lies to the west of Lake Pontchartrain and is connected to it through a narrow channel. Lake Maurepas and the region between Maurepas and Pontchartrain are surrounded by extensive wetlands. All these features influence the pathways water can and does take as a hurricane moves through the area.

Hurricanes that directly impact this region of the coast can be quite different in terms of storm size, intensity and forward speed; even if they have similar tracks that pass close by. Their precipitation characteristics can be quite varied depending on moisture patterns within the storm, which vary with space and time during the event, and on the prevailing weather systems with which the advancing hurricane interacts. The complexity of the landscape and differences in hurricane characteristics (track, forward speed, intensity and size) can lead to marked differences in storm waves and water levels at any one location, at any one time, for each and every hurricane. In addition, natural and man-made changes in the landscape have affected the hydraulic response to storms.

It is worthwhile to examine Hurricane Isaac in the context of other hurricanes that have impacted southeastern Louisiana in recent years. Such an examination is useful because people remember hydraulic responses which they observed during historic storms, such as peak water level, rainfall, and depth and extent of flooding. It's those experiences upon which they form their opinions regarding the relative severity of different historic storms. It is informative to examine how different hurricanes produce different hydraulic responses, how those responses vary with location throughout the impacted region, and how they vary with time during any one particular storm.

A hurricane that produces an unusually high storm surge at one location might not produce very high surge at another location. One area might experience its peak surge early in the storm, and another area might experience its peak surge later during the storm, after the storm center has moved through. One area might experience high peak surge during one storm, and a much lower peak surge during another storm. Local precipitation during one hurricane can be dramatically different from that experienced during another. Isaac's interaction with the southeastern Louisiana coast was both similar to, in some ways, and different from Hurricanes Gustav in 2008 and Katrina in 2005, and some other notable storms. Some similarities and differences are discussed here.

3.1.9 Storm Comparisons (Katrina, Gustav, & Isaac)

3.1.9.1 Storm Tracks

Hurricanes Katrina and Gustav are recent storms that affected the northern Gulf Coast and had similar storm tracks, so there is much to be learned by comparing some of the characteristics of these storms and their impacts. Figure 3.23 shows the tracks for Hurricanes Katrina (2005), Gustav (2008) and Isaac (2012). The tracks show the position of the storm center every 6 hours; therefore the distance between positions separated by 6 hours reflects the hurricane's forward speed, i.e., the shorter the distance the slower the forward speed.

Hurricanes Gustav and Isaac both approached Louisiana from the southeast; whereas Hurricane Katrina approached from the south. The differences in approach direction resulted in differences in storm water level responses at certain locations, differences that are discussed later. The tracks of Gustav and Isaac were nearly parallel to each other. The location of landfall during Gustav was further west than the landfall point of the other two storms. Of the three hurricanes, Gustav's track was the farthest away from New Orleans; Katrina passed most closely to New Orleans.

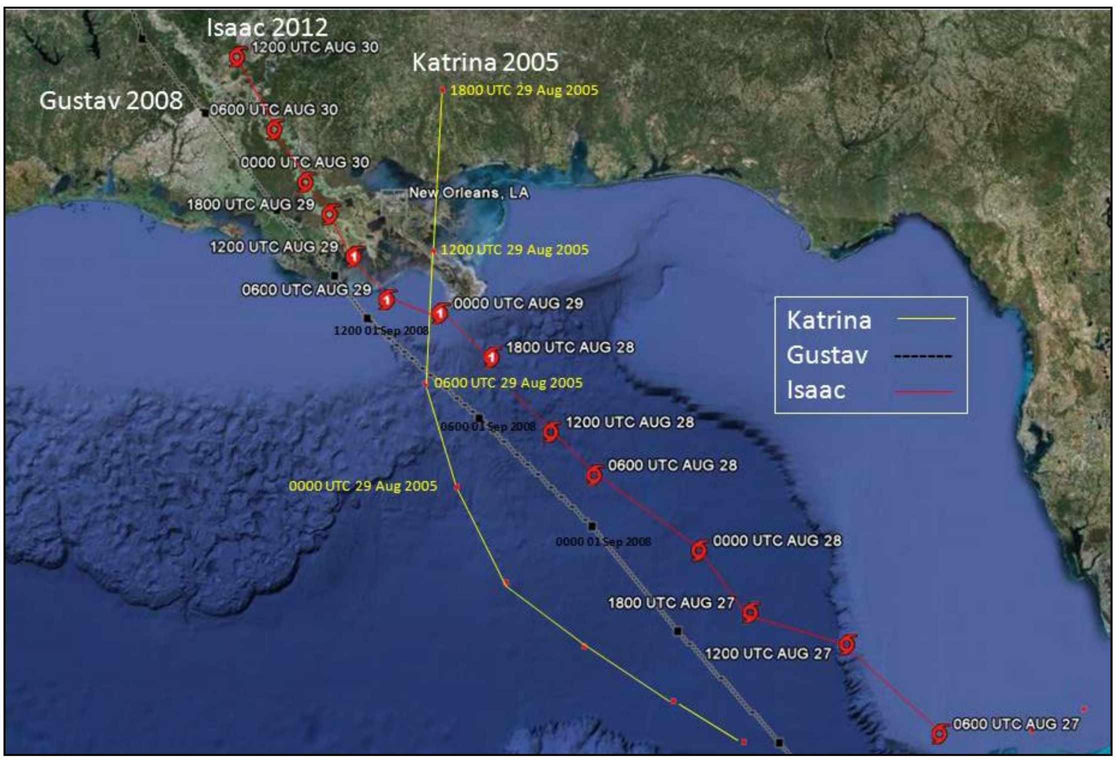


Figure 3.23 Tracks of Hurricanes Katrina (2005), Gustav (2008) and Isaac (2012).
Figure courtesy of the U.S. Army Engineer Research and Development Center.

Isaac had a lower forward speed, compared to the speeds of either Gustav or Katrina. Approximately 50 hours elapsed from the time Isaac was at the southernmost extent of the region shown in Figure 3.23 until the time it made landfall. For Hurricane Katrina, the elapsed time was much less, 35 hours. For Gustav, the elapsed time was even less, 28 hours. Of the three hurricanes, as the hurricane was approaching and crossing the continental shelf which is the primary region of storm surge generation, Gustav's forward speed was greatest among the three storms.

Forward speed generally has a lesser influence on the peak surge along the open coast. For enclosed lakes and bays such as Lake Pontchartrain, the forward speed has an influence on the storm surge height and timing of peak surge around the periphery of the lake. Slower moving storms have the potential for allowing greater surge penetration into wetlands, which can act to slow the rate of advance of the storm surge. Slower moving storms can enhance the filling action which occurs within Lakes Pontchartrain and Maurepas and is discussed later.

Following landfall, both Isaac and Gustav moved to the northwest. Isaac's forward speed was slower than Gustav's after landfall. Katrina moved quickly to the north after landfall, much more quickly than the other two storms. Of the three storms, Isaac lingered longer in southern Louisiana than the other two. The speed of Isaac after landfall was slightly slower compared to its speed prior to landfall. The speed of Gustav after landfall was slower that its speed prior to landfall. The speed of Katrina after landfall was much faster than its speed immediately prior to landfall.

3.1.9.2 Surface Winds Nearing Landfall

Figures 3.24 through 3.26 show the surface (10-m elevation), 1-min average wind fields for Hurricanes Isaac, Gustav and Katrina at a time when the storm was just offshore but nearing landfall. These figures were generated by the Atlantic Oceanographic and Meteorological Laboratory (AOML) Hurricane Research Division of NOAA, using an analysis technique called Hwind analysis, which is based on measurements made by satellite and reconnaissance aircraft. The figures represent the surface wind field at a snap-shot in time.

The time represented by the snap-shot is indicated in the figure caption. The color-shaded contours show the speed of the wind (in knots, kt). The same color scale is used in all three figures. White vectors indicate the direction the wind is blowing. The caption for each figure lists the maximum observed wind speed (in knots, kt), the radius to maximum winds (in nautical miles, nm), and the central pressure (in millibars, mb). The radius to maximum winds is the distance from the center of the storm to the position of the highest wind speed, and it is a measure of storm size. Central pressure is the atmospheric pressure at the center of the eye. Maximum wind speed and central pressure are both measures of storm intensity, and they are inversely correlated with one another. Generally, the lower the central pressure the greater the maximum wind speed.

In hurricanes, wind speed is near zero at the storm's center; it increases radially outward from there to a maximum value in the band of maximum winds that surrounds the storm center; then it decreases from there radially outward with increasing distance away from the storm center. The table in the upper left corner of each figure shows the distance in nm (nautical miles) to wind speeds of 34, 50, 64 kt (knots), for each of the central compass directions in each of the four quadrants, NE, SE, SW, NW. 34 kt is the wind speed threshold value for which a storm is considered a tropical storm and not a tropical depression. 64 kt is the threshold value for which a storm is considered a hurricane and not a tropical storm. These data also provide a measure of the storm's size as indicated by the far-field extent of tropical storm -and hurricane-force winds, as well as an indication of the asymmetry in the radial distribution of wind speed. Some hurricanes have a significant band of very high winds that wraps completely around the central eye of the storm; others have distinctly higher winds in one or two quadrants and a much less distinct band that is wrapped around the eye.

In all hurricanes in the northern hemisphere, air circulates in a counterclockwise rotation around the eye. So winds blow in a counterclockwise pattern around the storm center. White vectors in these figures indicate that wind pattern. In light of this counterclockwise circulation, as hurricanes approach the northern Gulf of Mexico, but are far offshore, prevailing winds along the coast blow from the east. These winds from the east push water from east to west along the Mississippi and Alabama coasts and continental shelves. This westward-moving water is blocked by the Mississippi River delta and it begins piling up to the east of the river delta, influencing all of southeastern Louisiana and Mississippi. This build-up of water against the Mississippi River delta also begins forcing the filling of Lakes Pontchartrain, Maurepas, and surrounding wetlands in the Lake Pontchartrain basin because water levels in western Mississippi Sound are higher than those in Lake Pontchartrain. This filling process can begin several days in advance of a hurricane arriving at the coast. Once the core of the storm arrives near the coast, winds begin to shift in direction and change in speed as the rotational wind field moves through the region, and these winds drive the generation of the storm surge.

Figure 3.24 shows a surface wind field snap-shot near landfall for Hurricane Isaac. Maximum winds were in the NE quadrant, with strongest winds in the NE and SE quadrants. Isaac did not have a well-defined band of maximum winds wrapped around the eye. The observed maximum wind speed was 65 kt at a distance of 33 nm NE of the eye. This radius to maximum winds is considered to be a relatively large value. In the NE quadrant, wind speeds exceeded 50 kt for a distance of 86 nm away from the storm center. In terms of hurricane intensity near landfall, Isaac had a central pressure of 975 mb and maximum observed wind speed of 65 kt, a magnitude at the lower limit of a Category 1 hurricane (64 kt) in terms of the Saffir-Simpson intensity scale.

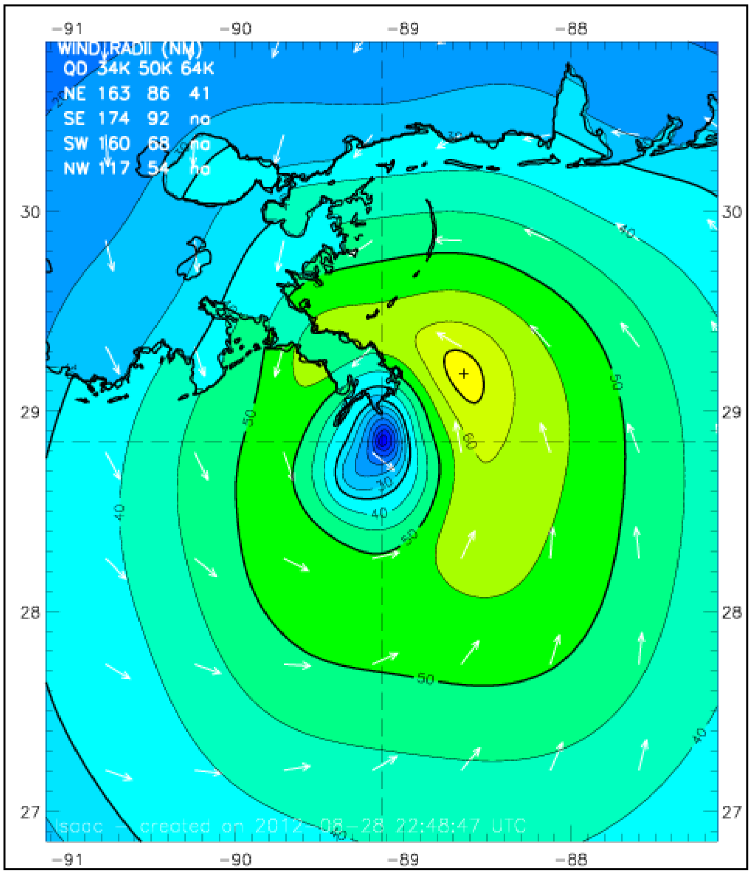


Figure 3.24 Hurricane Isaac 1-min sustained surface wind field at 1730 LST (2230 UTC) 28 August. Isolines in figure indicate the observed maximum wind speed in knots. Figure courtesy of NOAA AOML Hurricane Research Division.

Within the southern Breton Sound basin, since Isaac tracked west of and nearly parallel to the Mississippi River delta toward the northwest, the highest winds on the right hand side of the storm (looking in the direction of movement) were steadily directed from the northeast, then from the east, then from the southeast as the storm approached and made landfall. Winds from the northeast and east push water into the southern Breton Sound basin and build storm surge against the east-side back levees along the Mississippi River. Then as wind direction shifts with the approaching storm, winds from the southeast build storm surge against the back levees of the northern side of the basin including the Braithwaite community which is situated along the northwestern edge of the basin, west of the Caernarvon diversion structure. As the storm center moved through the region, winds shifted from the southeast to the south and then from the southwest directions because of the counterclockwise rotational wind pattern. This shift in winds pushed water to the north against the back levees of the Braithwaite community and the HSDRRS levees along the northern limit of the southern Breton Sound basin.

In Barataria Basin, near Lafitte, at this snap-shot in time, winds were from the northeast, acting to push water out of the wetland system. This prevailing wind direction continued as the storm approached. Near landfall, the storm made a slight jog to the west, and then continued in the northwest direction. Because Lafitte was on the right hand side of the storm, like the Braithwaite community, the track led to a shift to winds from the northeast to the east and then from the southeast, followed by winds shifting in direction from the south, then from the southwest as the storm center moved through. Once the storm center moved through the area, the Barataria basin was subjected to storm surge created by water being pushed toward the north that was associated with winds from the southeast, south and southwest directions.

In Lake Pontchartrain, at this snap-shot in time, winds were from the northeast, acting to push water to the southwest towards LaPlace. As the storm approached closer to LaPlace, winds shifted to blow from the east as the storm was situated south of LaPlace. At this point winds acted to push water toward the west. Wind direction continued to change as the storm center moved through the region, first from the southeast as the storm moved toward the northwest, then from the south and southwest after the storm center had passed to the west of LaPlace. This pattern of wind from the northeast and east acted to push water toward the southwest and west in Lakes Pontchartrain and Maurepas, building storm surge in the LaPlace area. Winds from the east also act to build storm surge in Lake Borgne which increases water levels in Lakes Pontchartrain and Maurepas through a filling action via the Chef Menteur and Rigolets passes that is driven by the water surface elevation difference between the water level in Lake Borgne and the water level in Lake Pontchartrain. Because Isaac moved so slowly, the water surface gradient between Lake Borgne and Lake Pontchartrain caused the persistent filling action in Lakes Pontchartrain and Maurepas for several days before arrival of the main core winds of the hurricane.

Figure 3.25 shows the surface wind field for Hurricane Gustav. The track of Gustav and its landfall position is further to the west than was the case for Isaac. At this particular time, maximum winds were in the NW quadrant, with strongest winds in both the NW and SE quadrants. Gustav had a much more defined band of strongest winds wrapped around the eye, compared to Isaac. The observed maximum wind speed was 81 kt at a distance of 26 nm NW of the eye. This radius to maximum winds is somewhat smaller than Isaac's value. In the NE quadrant, wind speeds exceeded 50 kt for a distance of 124 nm away from the storm center. Hurricane Gustav also was a large hurricane.

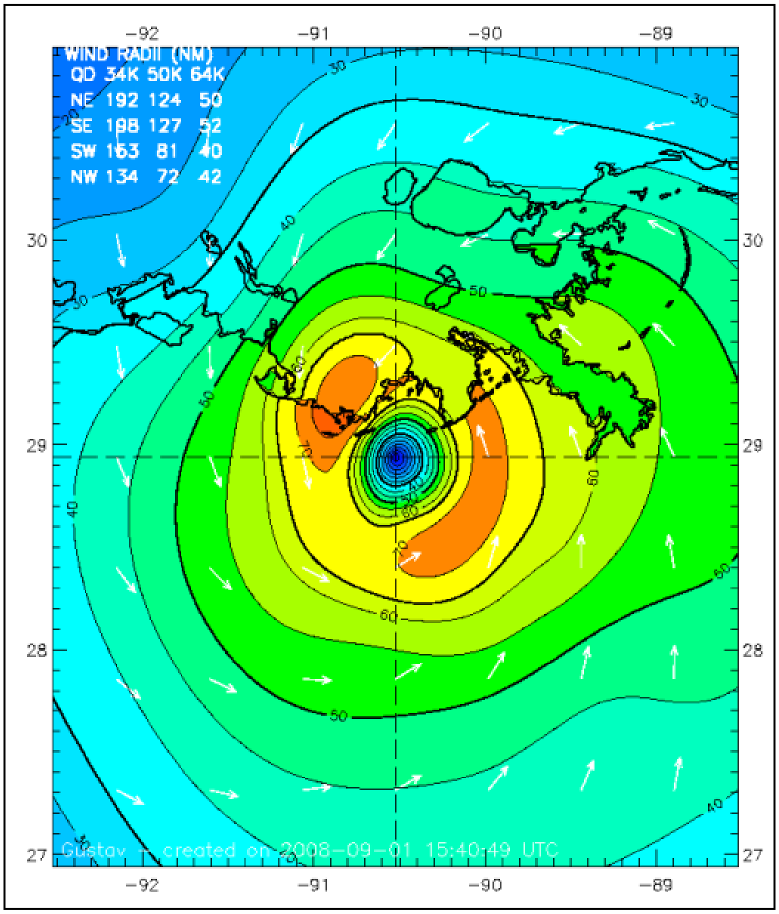


Figure 3.25 Hurricane Gustav 1-min sustained surface wind field at 0830 LST (1330 UTC) 1 September 2008. Isolines in figure indicate the observed maximum wind speed in knots. Figure courtesy of NOAA AOML Hurricane Research Division.

In terms of hurricane intensity near landfall, Gustav had a central pressure of 955 mb and with the maximum observed wind speed of 81 kt, right at the upper limit of a Category 1 hurricane on the Saffir-Simpson intensity scale. Gustav was more intense than Isaac near landfall.

Much like Isaac, Gustav tracked toward the northwest, nearly parallel to the Mississippi River delta. Like Isaac, as Gustav approached winds were steadily directed from the east then the southeast in the southern Breton Sound basin as the storm approached. Near landfall, at this snap-shot in time, winds in Breton Sound were from the southeast and south-southeast. Initially, winds from the southeast built storm surge against the east side back levees along the Mississippi River and against the back levees of the Braithwaite community. As the storm center moved to the northwest, winds shifted to directions from the southeast, then to directions from the south and then to directions from the southwest because of the counterclockwise rotational wind pattern. This shift in winds pushed water to the northwest and north against the back levees of the Braithwaite community and the HSDRRS levees along the northern limit of the southern Breton Sound basin.

One important difference between Isaac and Gustav was the wind speed in Breton Sound. Despite being a more intense storm, because Gustav was a bit smaller in terms of radius to maximum winds, and because it tracked further to the west, winds in southern Breton Sound were lower during Gustav (55-60 kt) then they were in Isaac (55-65 kt). When this track difference is coupled with increased duration of winds, and taking into consideration that the effects of wind on surge is non-linear, this suggests potential for higher storm surge in northwestern Breton Sound basin, near the Braithwaite community, during Isaac compared to Gustav.

In Barataria Basin, near Lafitte, at this time, strong winds were from the southeast, acting to push water northward into the wetland system. Because the track of Gustav was further to the west, the region of highest winds was situated over Barataria Basin, which was different from Isaac. This prevailing wind direction continued as the storm approached. Once the storm moved through the Lafitte area, the Barataria basin in general was subjected to storm surge created by water being blown toward the north by strong winds on the back side of the storm that were associated with winds from the southeast, south and southwest directions. The presence of higher winds from the southeast, south and southwest directions had a greater capacity to push water to the north into the Barataria basin and produce higher storm surge. However, Gustav had a much greater forward speed than Isaac. Since Isaac moved more slowly than Gustav, the winds on the back side of Isaac could work longer at pushing water to the northern Barataria basin compared to the relatively fast moving Gustav.

In Lake Pontchartrain, at this snap-shot, winds were from the east, as the storm center was then situated south of LaPlace. As the storm approached closer to LaPlace, winds in Lake Pontchartrain shifted to blow from the southeast as it moved toward the northwest, then from the south and southwest after the storm center had passed to the west of LaPlace. This pattern of wind from easterly directions acted to push water toward the southwest and west in Lake Pontchartrain and Maurepas, building storm surge in the LaPlace area. As was the case during Isaac, winds from the east and southeast also act to build storm surge in Lake Borgne which increases water levels in Lakes Pontchartrain and Maurepas through a filling action via the Chef Menteur and Rigolets passes.

Figure 3.26 shows the surface wind field for Hurricane Katrina. The track of Katrina was quite different from that taken by Isaac and Gustav. Whereas Isaac and Gustav tracked toward the northwest, Katrina tracked toward the north. Katrina also tracked closer to New Orleans than the other two storms. At this particular time, maximum winds were in the SE quadrant, with very strong winds wrapped around much of the storm center, except on the western side. The observed maximum wind speed was 99 kt at a distance of 30 nm SE of the eye, a wind speed much greater than Isaac and greater than Gustav.

Since wind stress is approximately related to wind speed raised to the second power for this magnitude of wind speed, the capacity for Katrina to push water and build storm surge was much greater than Gustav and far greater than Isaac. Katrina's radius to maximum winds of 30 nm was similar to the radius to maximum winds during Isaac, and slightly larger than conditions during Gustav. In the NE quadrant, wind speeds exceeded 50 kt for a distance of 144 nm away from the storm center. Hurricane Katrina was a large hurricane. In terms of hurricane intensity near landfall, Katrina had a central pressure of 917 mb and with the maximum observed wind speed of 99 kt, a Category 3 hurricane on the Saffir-Simpson intensity scale.

As Katrina approached, winds were steadily directed from the east in the southern Breton Sound basin. Near landfall, at this snap-shot in time, the Category 3 strength winds in Breton Sound were directed from the east building tremendous storm surge against the east side back levees along the Mississippi River, overwhelming back levees and building surge against the main Mississippi River levees. The track of Katrina was located to the east of the Braithwaite community, and the storm tracked from south to north.

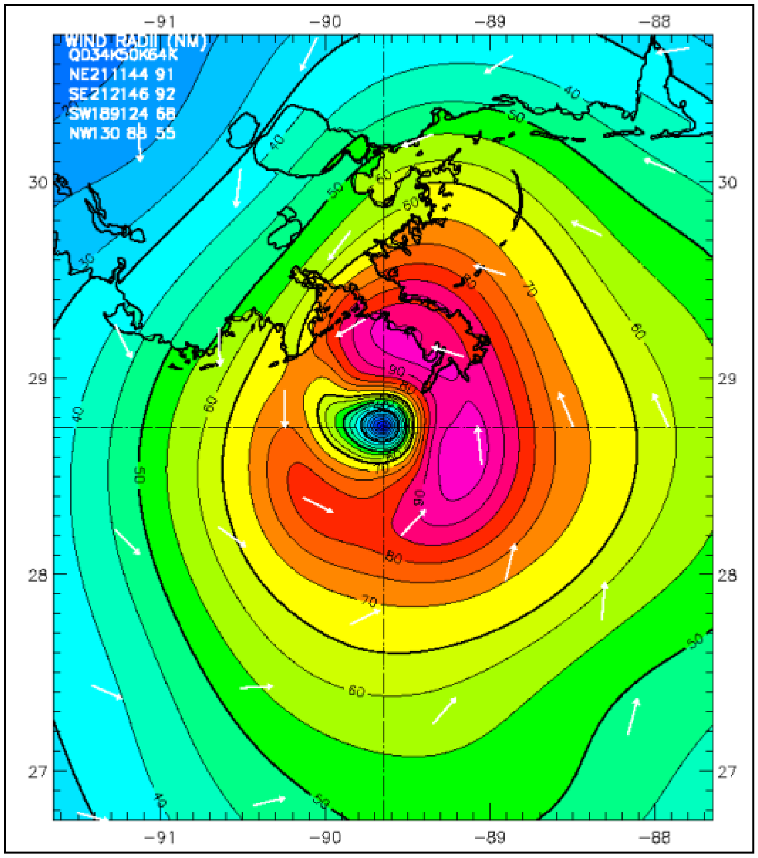


Figure 3.26 Hurricane Katrina 1-min sustained surface wind field at 0400 LST (0900 UTC) 29 August 2005. Isolines in figure indicate the observed maximum wind speed in knots. Figure courtesy of NOAA AOML Hurricane Research Division.

As the storm center quickly moved to the north, in the vicinity of Braithwaite winds quickly shifted to directions from the northeast, then the north, then the northwest, then the west, then the southwest because of the counterclockwise rotational wind pattern. Unlike Isaac and Gustav, winds were not directed from the southeast toward the Braithwaite community for very long. Once the eye of Katrina moved through southern Breton Sound basin, strong winds from westerly directions pushed water away from the east-side levees along the Mississippi River and away from the Braithwaite community.

In Barataria Basin, near Lafitte, at this time, strong winds were blowing from the northeast and east, acting to push water out of the basin and wetland system. Because of the much stronger winds associated with Katrina, the forces acting to push water out of the Barataria basin were greater than for the other two storms. As Katrina tracked northward, with its storm center positioned to the east of Barataria basin, winds shifted to directions from the north, enhancing the push of water out of the basin, although winds on the western side of Katrina were relatively weaker compared to those on the eastern side. This prevailing wind direction from the north continued as the storm moved through the region, and as winds shifted to a direction from the northwest as the storm moved through, they were still acting to push water out of the basin. It was only after Katrina had tracked well to the north that weaker winds from the southwest began to push water toward the north into Barataria basin. The wind conditions that acted to move water during Katrina in Barataria basin were much different than conditions experienced in the basin during Isaac and Gustav.

In Lake Pontchartrain, at the time of this snap-shot, winds were from the northeast, as the storm center was situated to the southeast of LaPlace, pushing water toward LaPlace. As the storm quickly approached closer to and east of New Orleans, winds in Lake Pontchartrain shifted to blow from the north and then from the northwest as Katrina tracked toward the north. This pattern of wind from northerly directions acted to push water first toward the southwestern shore of Lake Pontchartrain, then quickly shifted to push water against the southern shoreline, then quickly shifted to push water against the southeastern shoreline of the Lake. As the wind direction changed quickly with rapid movement of the storm center northward, water pushed toward regions in the down wind direction and away from regions on the upwind side of the lakes. The wind patterns that affected storm surge at LaPlace were quite different during Katrina than during the other two storms.

As was the case during Isaac and Gustav, winds from the east and southeast acted to build a high storm surge in Lake Borgne because wind speeds in Lake Borgne were much greater during Katrina than winds during Isaac or Gustav. During Katrina, storm surge in Lake Borgne was quite high, and surge increased water levels in Lakes Pontchartrain and Maurepas through a filling action via the Chef Menteur and Rigolets passes and in the region between the two passes as it was overwhelmed by the storm surge. The degree of filling within the lakes was limited by the rapid movement of Katrina to the north.

3.1.9.3 Comparison of Storm Surge

Figures 3.27, 3.28 and 3.29 provide estimates of the maximum storm surge that was generated during the three hurricanes. The maps were made from screen captures obtained through the Coastal Emergency Risk Assessments web site that is maintained by Louisiana State University and represent the "still" water level. The web site provides access to both hindcast and forecast results from an operational storm surge model for the northern Gulf of Mexico. Wave and storm surge models are run operationally using information provided by NOAA regarding the storm track, intensity, radial wind distribution and size to calculate the storm surge field at discrete times during the storm. Storm surge is computed at all points within the model domain. Then the storm surge maxima for each point in the domain are examined to compute the maximum experienced at each point, regardless of when during the storm the maximum occurred. Figures 3.27, 3.28 and 3.29 display the maximum storm surge field calculated in this way for the hindcast model simulation made for each of the three hurricanes. The vertical scale for the storm surge, shown in both feet and meters, is displayed in each figure. While there is certainly some uncertainty with modeling results, past experience and comparisons with measured water levels and high water marks from Katrina, Rita, Gustav, Ike and Isaac have shown this modeling system to be a reasonably reliable qualitative and quantitative tool for examining hurricane-induced storm surge in the Louisiana and Mississippi region.

Characteristics of the surface winds and storm tracks help explain differences in storm surge at Braithwaite, LaPlace and Lafitte during each of the three hurricanes. At Braithwaite, the estimated maximum surge during Gustav, 10 feet, (see Figure 3.28) was lower than the estimated surge during Isaac, 13 to 14 feet (see Figure 3.27). This is primarily due to the higher wind speeds in southern Barataria basin compared to slightly lower wind speeds experienced during Gustav, which acted to push water toward the northwest, directly toward Braithwaite during both storms. The larger peak surge values during Isaac were also probably caused by the slower moving Isaac, which enabled more effective penetration of the storm surge into the wetlands in the northwest end of the basin. During Gustav, peak storm surge levels reached right to the crests of the local back levees at Braithwaite; whereas maximum surge during Isaac was clearly higher and led to extensive flooding of the community. Data from USGS sensors indicate that peak water levels at Braithwaite reached 13 feet, NAVD88 during Isaac, which compares favorably with the predicted value of 13 feet, as discussed above.

During Katrina, estimated maximum surge levels outside the Braithwaite back levees were similar to or slightly less than those for Hurricane Isaac. Despite the fact that Katrina had much higher wind speeds, the winds were directed from the northeast and east along the Mississippi River levee system as the storm made landfall, not directed from the southeast for very long, and not long enough to generate the same magnitude of peak surge that was generated along the northeast facing Mississippi River levees further to the south. Also, Katrina moved through the basin relatively quickly compared to Isaac, reducing the time for which surge could advance toward the Braithwaite community before winds directed from the west on the back side of the storm began to push water away from this area.

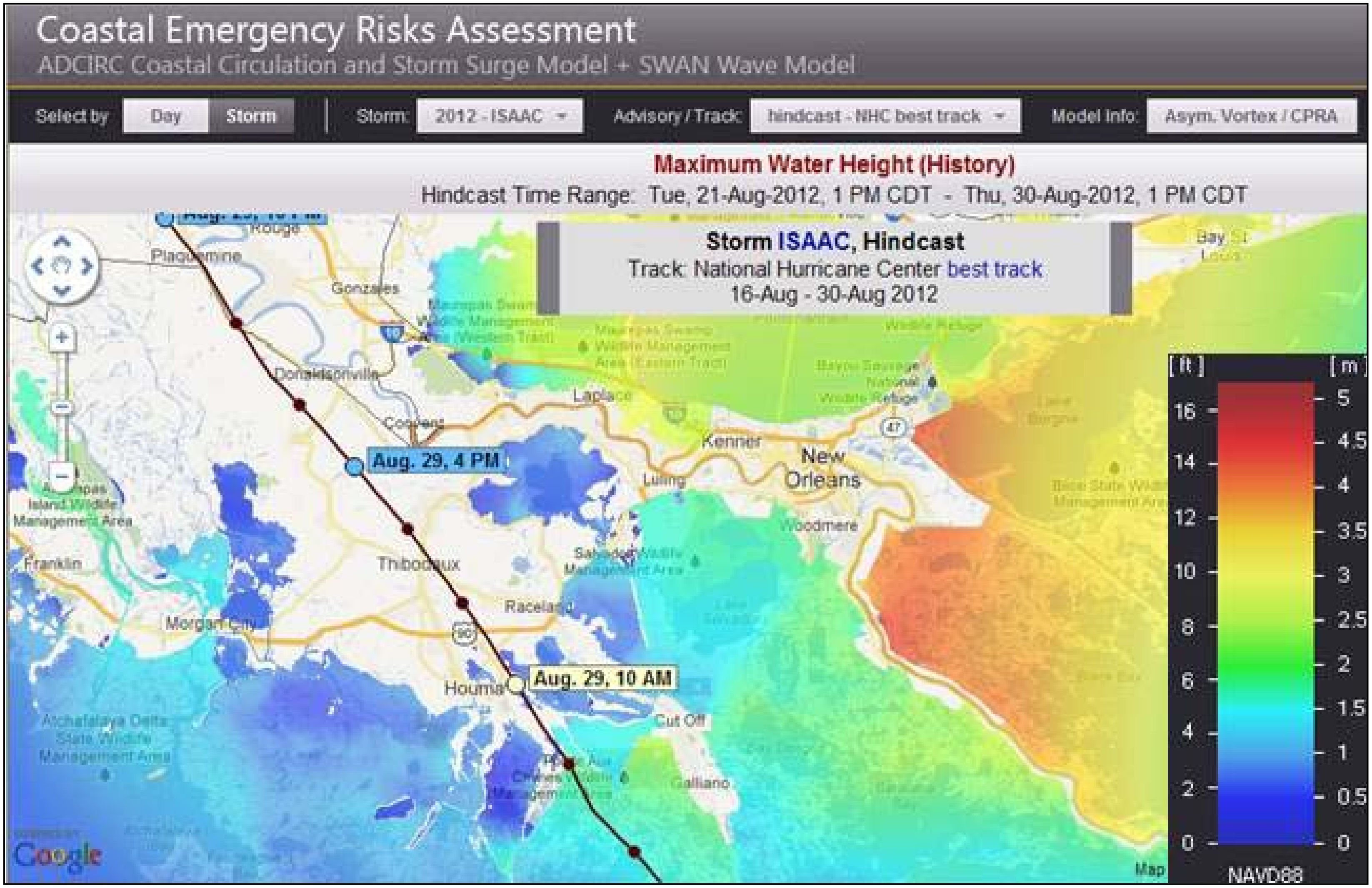


Figure 3.27 Map of the estimated maximum storm surge during Hurricane Isaac.

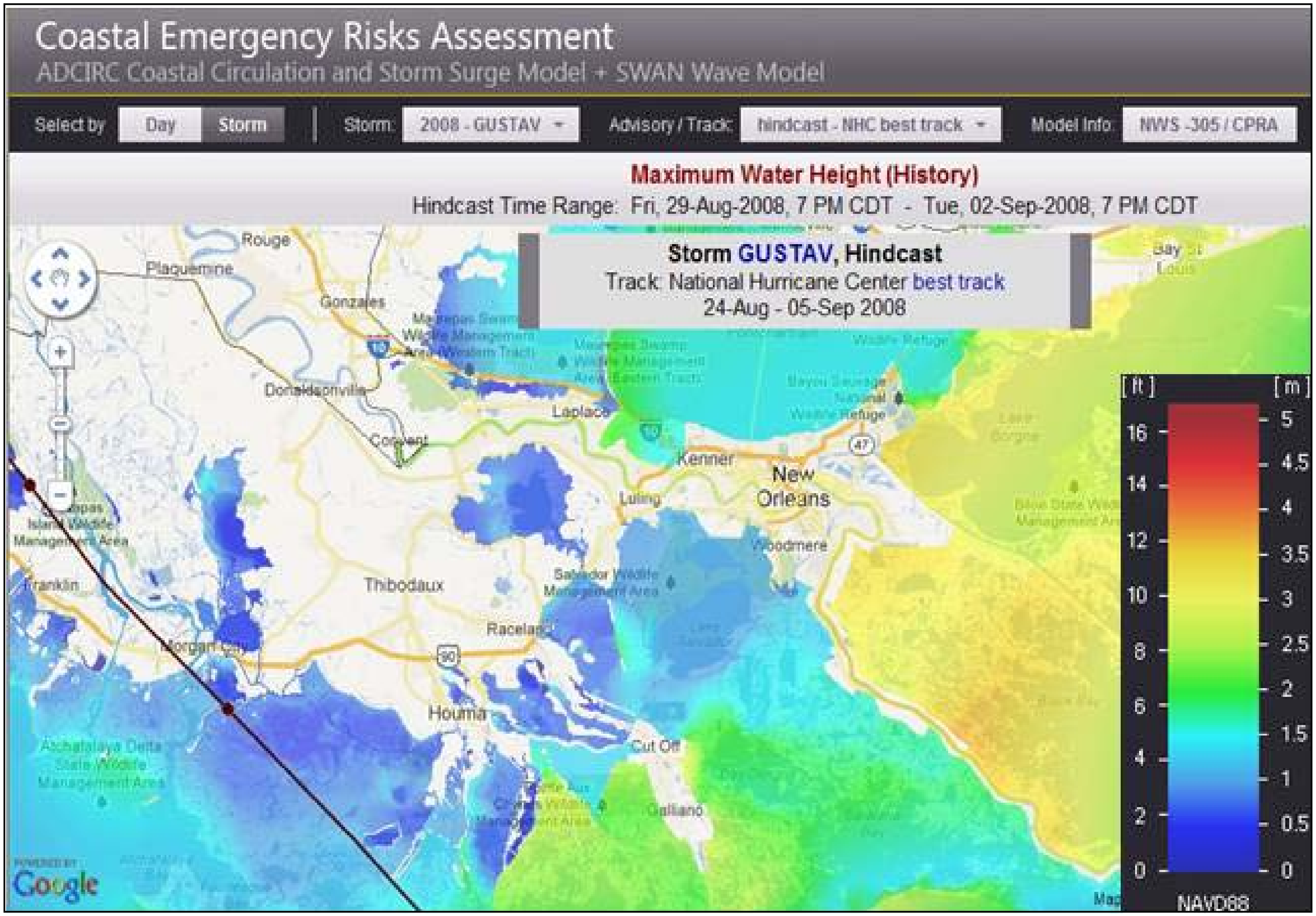


Figure 3.28 Map of the estimated maximum storm surge during Hurricane Gustav.

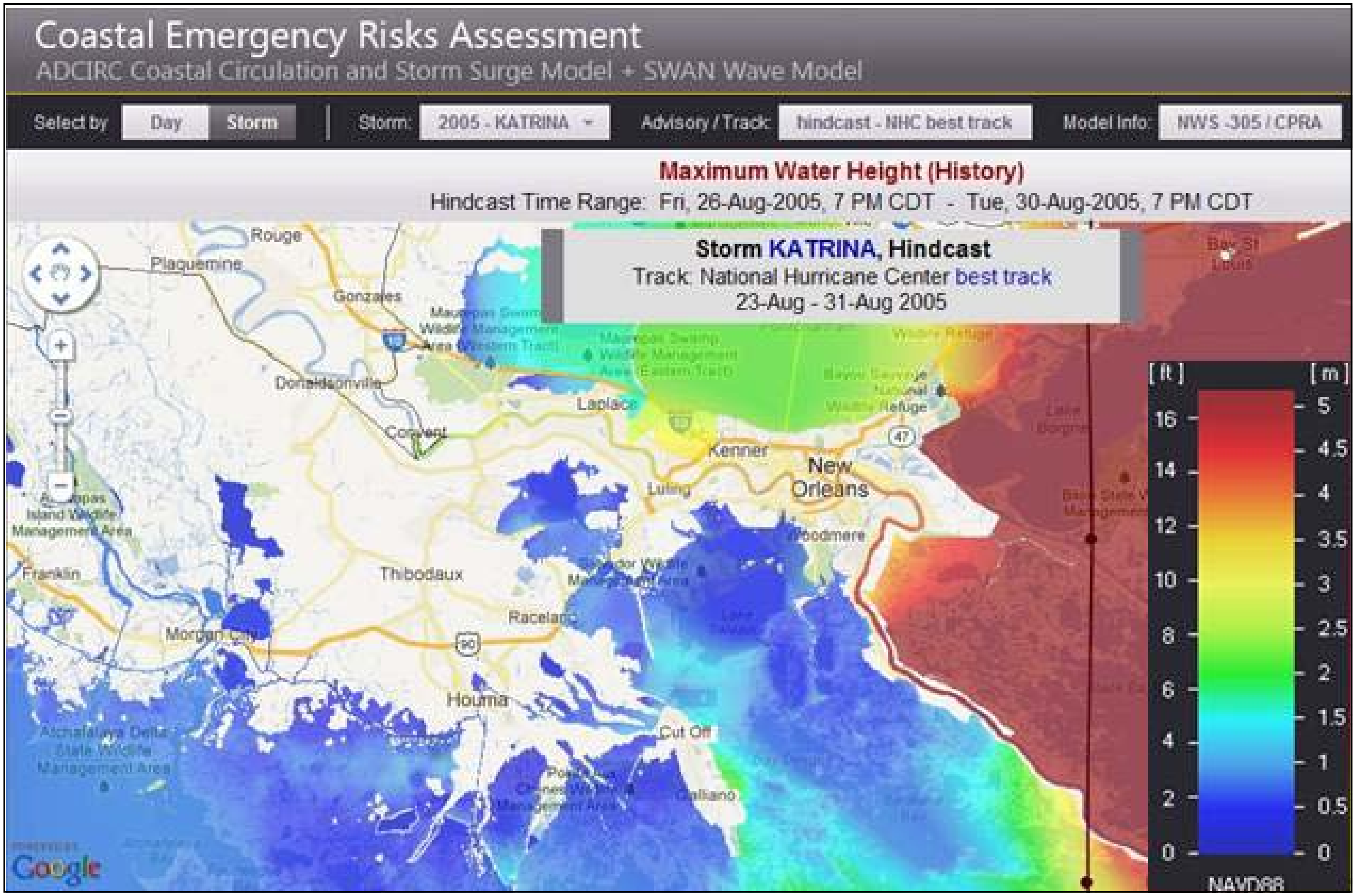


Figure 3.29 Map of the estimated maximum storm surge during Hurricane Katrina.

Of the three hurricanes, Katrina produced the least amount of storm surge in the Lafitte area. Isaac appears to have produced the greatest surge. The track of Katrina led to winds that acted to push water out of the basin prior to, during, and immediately after landfall, until the storm had moved well to the north of the basin, which it did relatively quickly. The direction of winds was not conducive to development of storm surge in this basin. The northwestward tracks of Isaac and Gustav were more effective than Katrina in pushing water into the Barataria basin. For both Gustav and Isaac, the peak surge in the Lafitte area is generated once the eye of the storm has moved through and winds on the back side of the storm are directed from the southeast, south and southwest, which act to push water to the north within the basin.

Examination of observed temporal variation in both atmospheric pressure and water level within the basin during Isaac show this to be the case. The more slowly moving Isaac and the closer proximity of its eye and peak winds to Lafitte, compared to Gustav, appears to have been more effective at pushing water into this area and into the wetlands in the northern reaches of the basin, all despite the higher surface wind speeds that occurred during Gustav compared to Isaac. Water levels observed in Lake Salvador, near but north of Lafitte, during both storms appear to confirm this; USGS gages indicate a peak of 4.6 feet NAVD88 in Lake Salvador during Isaac and a peak of 3.4 feet NAVD88 during Gustav. Observations from the USGS gage at Little Lake, south of Lafitte, show the same pattern, a peak of 5.5 feet (gage height, no datum) during Isaac and a peak of approximately 4 feet (gage height, no datum) during Gustav. Preliminary high water marks collected by the USGS after Isaac indicated 5.1 and 4.9 feet (NAVD88) at Lafitte.

The estimated magnitude of peak surge in western Lake Pontchartrain, in Lake Maurepas, and in the LaPlace area was greater during Hurricane Isaac than during Gustav. While the magnitude of peak surge estimated from the modeling for the LaPlace area during Isaac appears to be significantly higher that the observed peak water levels in Lakes Pontchartrain and Maurepas (approximately 6 feet NAVD), measured peak water levels along the south shore of Lake Pontchartrain indicate that peak water levels there were approximately 1.6 to 1.8 higher during Isaac than during Gustav. The USACE gage at West End shows a peak water level of 6.4 feet NAVD88 during Isaac and 4.3 feet NAVD 88 during Gustav. The NOAA gage at New Canal Station shows a peak water level of 6.53 feet MLLW or 6.1 feet MSL for Isaac and 5.19 feet MLLW or 4.95 feet MSL for Gustav. A CRMS gage site in St John the Baptist Parish indicated a peak water level of 5.8 feet NAVD88 during Isaac, and a CRMS gage site west of Lake Maurepas indicated a peak water level of 6.2 feet NAVD88 during Isaac, both values similar to the peak measured along the south shore of Lake Pontchartrain.

These data and the model results suggest that peak water levels in the LaPlace area were also greater during Isaac than during Gustav. Peak winds measured at New Canal Station were about 50 kt for both Isaac and Gustav from the northeast. However, because of the slower movement of Isaac compared to Gustav, winds in Lake Pontchartrain remained above 40 kt for 8 to 10 hours during Isaac; whereas they remained above 40 kt for only 2 to 3 hours during Gustav. This difference in winds, in addition to more filling of Lake Pontchartrain, led to the greater storm surges experienced at LaPlace during Isaac compared to those experienced during Gustav.

Filling of Lakes Pontchartrain and Maurepas is controlled by the water level in Lake Borgne and western Mississippi Sound. As long as the water level in the sound exceeds the water level in the lakes, filling of the lakes occurs. Figures 3.30 and 3.31 show measured water level data from the NOAA gage at Bay Waveland Yacht Club in Mississippi, during Isaac and Gustav, respectively. The two figures show that the water level in western Mississippi Sound remained high for a much longer period of time during Isaac than during Gustav. This is primarily due to the much slower forward speed of Isaac compared to Gustav. The peak water level reached about 9.5 feet NAVD88 during Isaac (Figure 3.30); however, the water level exceeded 6 feet NAVD88 for about 24 hours, and exceeded 4 feet NAVD88 for about 48 hours. During Gustav, the peak water level reached 10.6 feet NAVD88; however, it only exceeded 6 feet NAVD88 for about 12 hours and 4 feet NAVD88 for 24 hours. This difference lead to an increase in filling of the lakes for Isaac compared to Gustav.

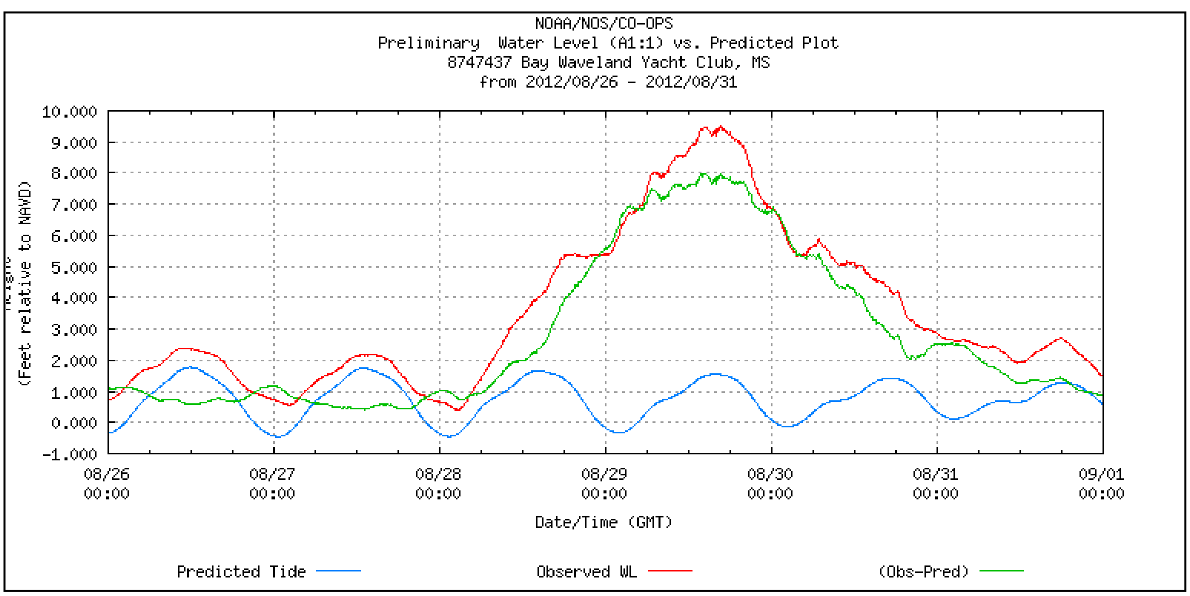


Figure 3.30 Measured water level at Waveland, MS, during Hurricane Isaac.
Figure courtesy of NOAA/NOS/CO-OPS. Datum: NAVD

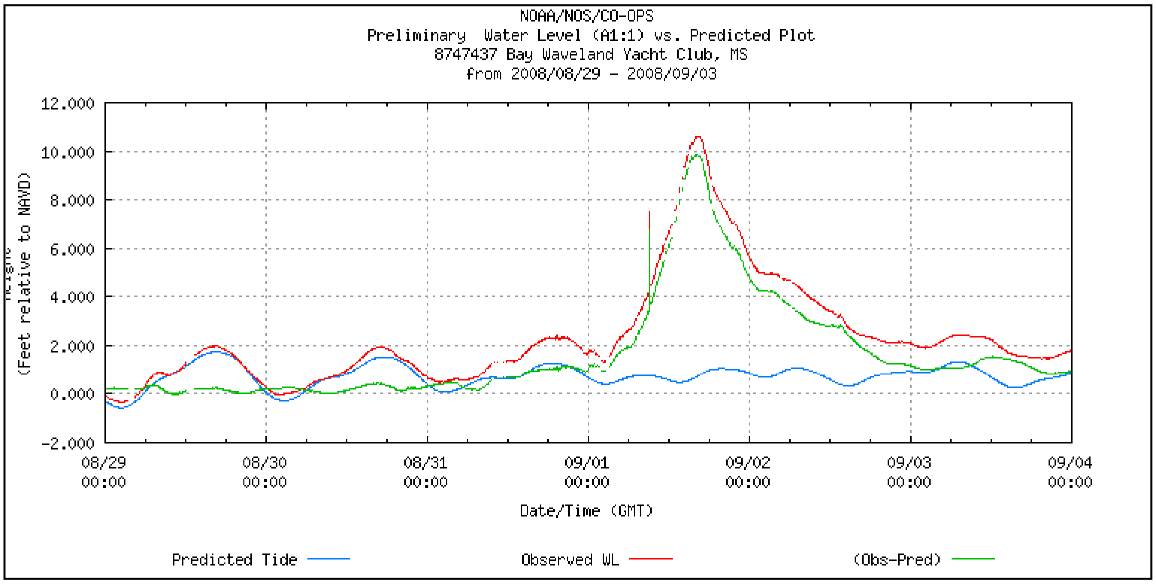


Figure 3.31 Measured water level at Waveland, MS, during Hurricane Gustav.
Figure courtesy of NOAA/NOS/CO-OPS. Datum: NAVD

3.1.9.4 Comparison of Rainfall (Additional Data for TS Allison)

Figures 3.32 and 3.33 show the maximum rainfall amounts for Hurricanes Isaac, Gustav, Katrina and Tropical Storm Allison (2001). For Hurricane Isaac, there was extensive precipitation throughout southeastern Louisiana, with rainfall amounts of 10 to 15 inches throughout much of the New Orleans area and with a local maximum recorded at Carrollton of 20.7 in. For Hurricane Gustav, precipitation throughout southeastern Louisiana was 5 inches or less, except in the Barataria basin where amounts reached 10 inches. In southeastern Louisiana, rainfall amounts during Gustav were less than amounts experienced during Isaac. During Katrina, rainfall in the vicinity of Lake Pontchartrain reached 10+ inches, but little rain fell elsewhere in southeastern Louisiana. During Tropical Storm Allison, total rainfall amounts were 10 in to 20 inches throughout southeastern Louisiana. The contribution of rainfall from Isaac to local inundation is described for several geographic areas in Chapter 7 of this report.

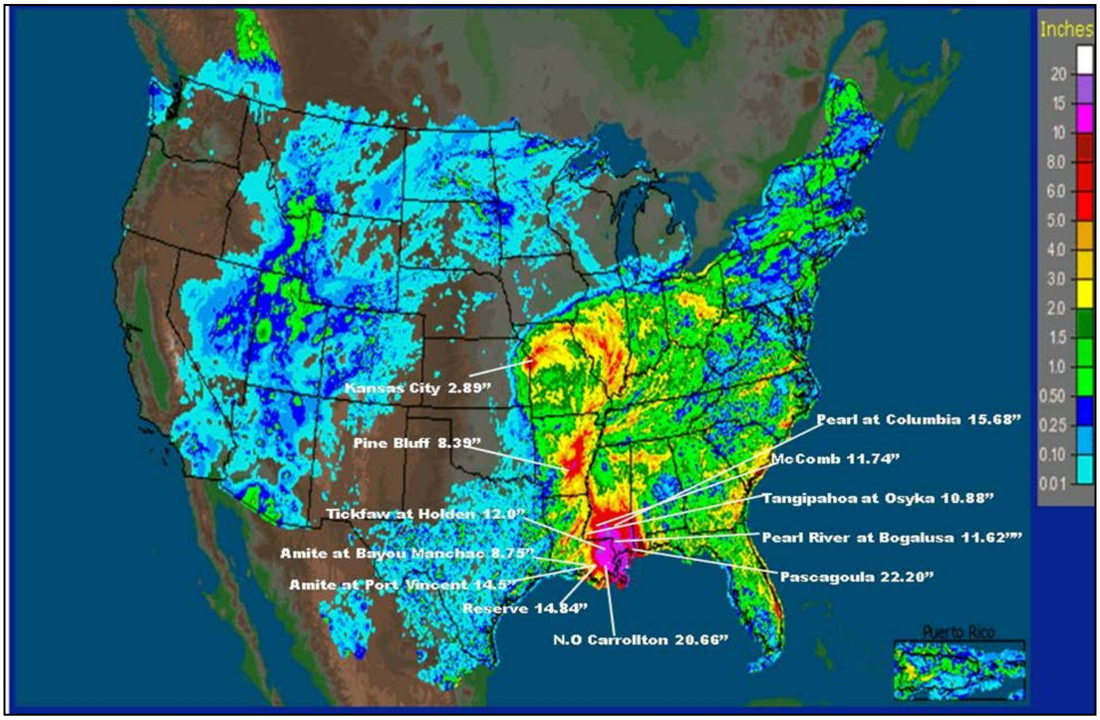


Figure 3.32 Total precipitation, in inches, during Hurricane Isaac (2012). Figure courtesy of NOAA Hydrometeorological Prediction Center.

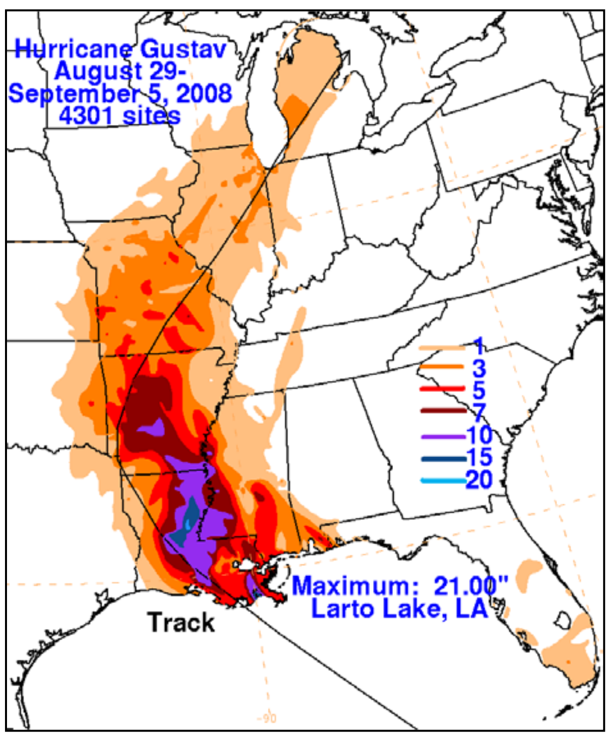


Figure 3.33 Total precipitation, in inches, during Hurricane Gustav (2008). Figure courtesy of NOAA Hydrometeorological Prediction Center.

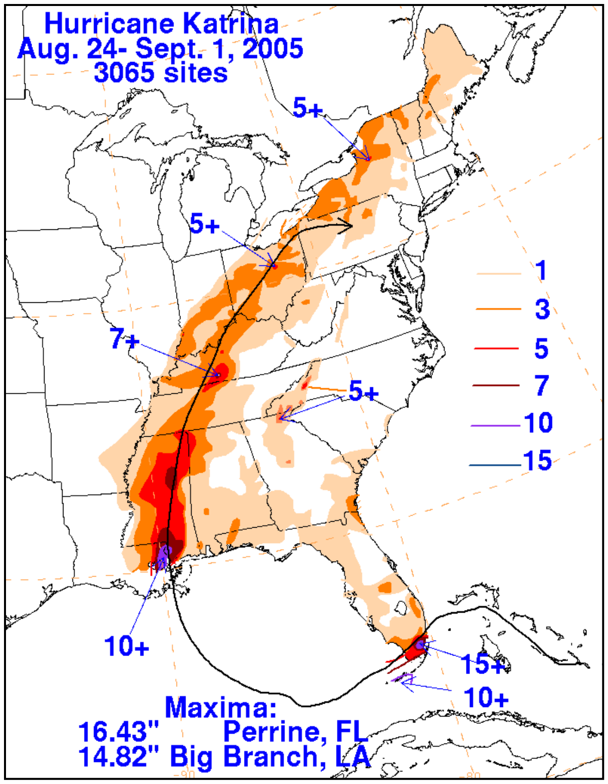


Figure 3.34 Total precipitation, in inches, during Hurricane Katrina (2005). Figure courtesy of NOAA Hydrometeorological Prediction Center.

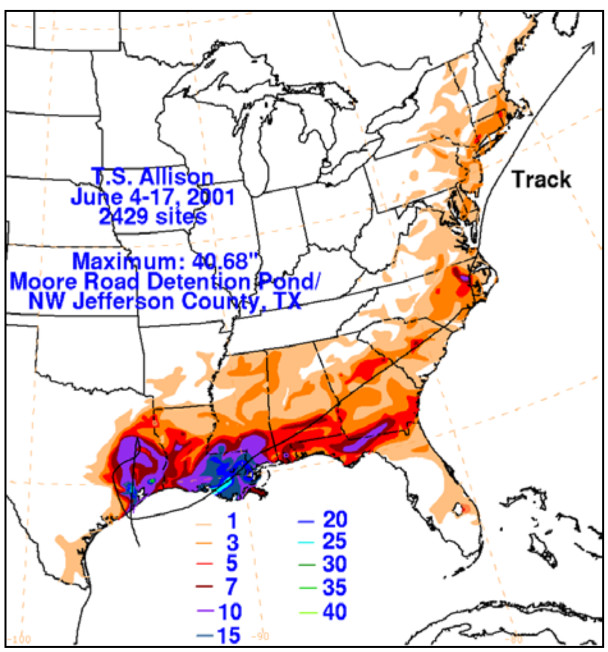


Figure 3.1.35 Total precipitation, in inches, during Tropical Storm Allison (2001). Figure courtesy of NOAA Hydrometeorological Prediction Center.

Comparison of Isaac with Modeled Synthetic Storms

Following Hurricane Katrina, a team of USACE, FEMA, NOAA, private sector, and academic researchers developed a new system for estimating hurricane inundation probabilities (IPET 2009). The approach is a modified Joint Probability Method (JPM) referred to as the JPM with Optimal Sampling (JPM-OS). For developing the JPM-OS for the Mississippi and Louisiana coasts, a basic data set of 22 hurricanes, which had central pressures less than 955 mb, were analyzed. The hurricane sample covers the interval 1941 through 2005. Based on this analysis, a suite of synthetic storms was defined for simulation in the various risk reduction studies conducted by USACE in coastal Louisiana and Mississippi. Figure 3.36 shows the synthesized primary tracks for the southeast Louisiana storm suite. The tracks essentially mimic the behavior of landfalling historical storms in the record, while preserving the geographic constraints related to land-sea boundaries. These storms preserve the historical pattern of the tracks better than simply shifting the same storm tracks east or west along the coast, since they capture the observed variations in mean storm angles along the coast.

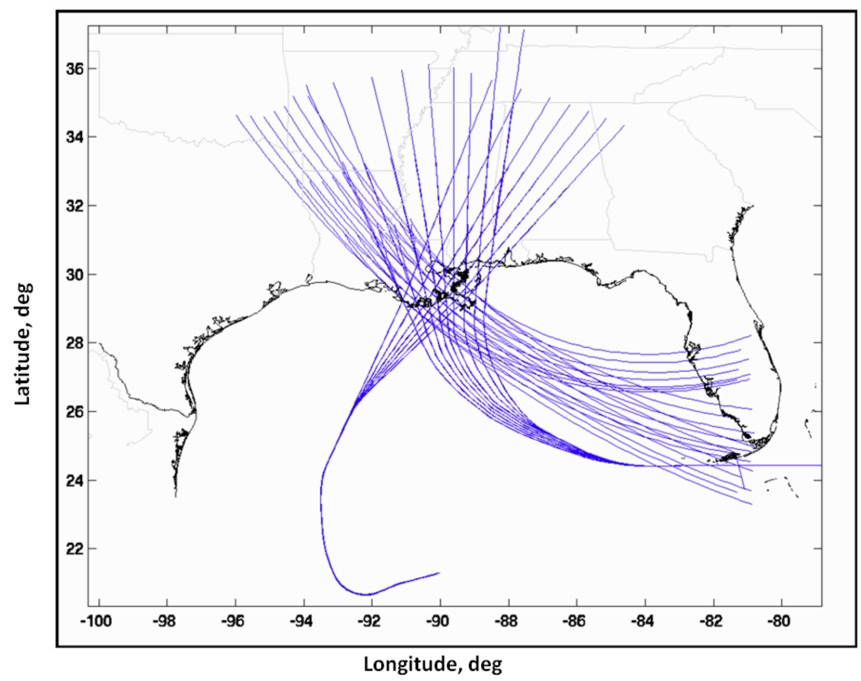


Figure 3.36 Synthetic storm tracks used for the southeast Louisiana storm suite.

Along each of the tracks, the central pressure is allowed to vary during a simulated intensification interval until its intensity reaches a minimum offshore central pressure. The minimum pressure is maintained until the storm comes within 90 nautical miles of the coast. At that time, the central pressure increases (the storm loses intensity) to simulate the pre-landfall filling phenomenon observed in the historical record for intense storms. The storms lose intensity at a greater rate one hour past landfall. The size of the storm (defined by a size scaling radius, R_{max}) increases linearly over the same distance as the central pressure for all storms except the smallest storm class. The forward speed of the synthetic storms ranges from 6.9 to 19.6 mph. The majority of storms in the suite have a forward speed of 12.7 mph. Storm speed is important in that it changes the duration that a flood wave has to propagate inland. Thus, a slowly moving storm may produce more extensive inland flooding than a faster moving storm. Table 3.4 summarizes the central pressure, size scaling radius, and forward speed combinations used to define the JPM-OS storm suite.

Table 3.4 Central Pressure, Size Scaling Radius, Forward Speed Combinations used to define the JPM-OS storm suite. In comparison, Hurricane Isaac had an offshore central pressure of 975, a radius to maximum wind of 40-45 nm and a forward speed of 7-8 mph.

Central Pressure (mb)	R_{max} nautical miles (nm)					
	Forward Speed (mph)					
900	6.0	12.5	14.9	17.7	18.4	21.8
	12.7	12.7	12.7	6.9, 12.7	12.7	12.7
930	8.0	17.7	25.8			
	12.7	6.9, 12.7, 19.6	12.7			
960	11.0	17.7	18.2	21.0	24.6	35.6
	12.7	6.9, 12.7	12.7	12.7	12.7	12.7
975	11.0	17.7	18.2	21.0	24.6	35.6
	12.7	6.9, 12.7, 19.6	12.7	12.7	12.7	12.7

Hurricane Isaac differed from the specific storms that make up the synthetic storm suite. Isaac had an offshore minimum pressure of approximately 975 mb. However, Isaac did not lose intensity within 90 nm of landfall, but actually intensified as it approached the coast. It reached a minimum central pressure of approximately 968 mb in the early morning hours of 29 August just before making landfall. Hurricane Isaac was also larger than the storms in the synthetic suite as defined by the size scaling radius (which is approximately the distance from the core of the hurricane to the band of maximum wind speeds). The greatest offshore size scaling radius in the synthetic storm suite was approximately 36 nm. Hurricane Isaac had a radius of approximately 40-45 nm as it approached and made landfall on the Louisiana coast.

Perhaps the greatest distinguishing factor between Hurricane Isaac and the storms in the JPM-OS synthetic suite was its forward motion. The synthetic storm tracks are idealized and therefore smooth and relatively straight as they approach and cross the coastline (see Figure 3.36). Isaac, however approached the coast and "drifted" to the west near landfall, which is not typical, especially for more intense storms. Figure 3.37 plots the tracks for Hurricanes Katrina, Gustav, and Isaac as they approach and cross the coast. The tracks for Katrina and Gustav are consistent with the synthetic tracks depicted in Figure 3.36. The Isaac track, however, has a "kink" as the storm drifted to the west near the coastline. The result of this is a longer period of time for winds to push water toward the coast. The forward speed of Isaac was also slow. Hurricanes Katrina and Gustav approached and made landfall with a forward speed of approximately 15 – 16 mph. Isaac approached the coast at approximately 7-8 mph, became stationary near the mouth of the Mississippi River, then proceeded to make landfall moving forward at approximately 6 mph. Isaac maintained this forward speed until the center of the storm was north of Baton Rouge. None of the storms in the synthetic suite replicate this behavior as they move at a constant forward speed.

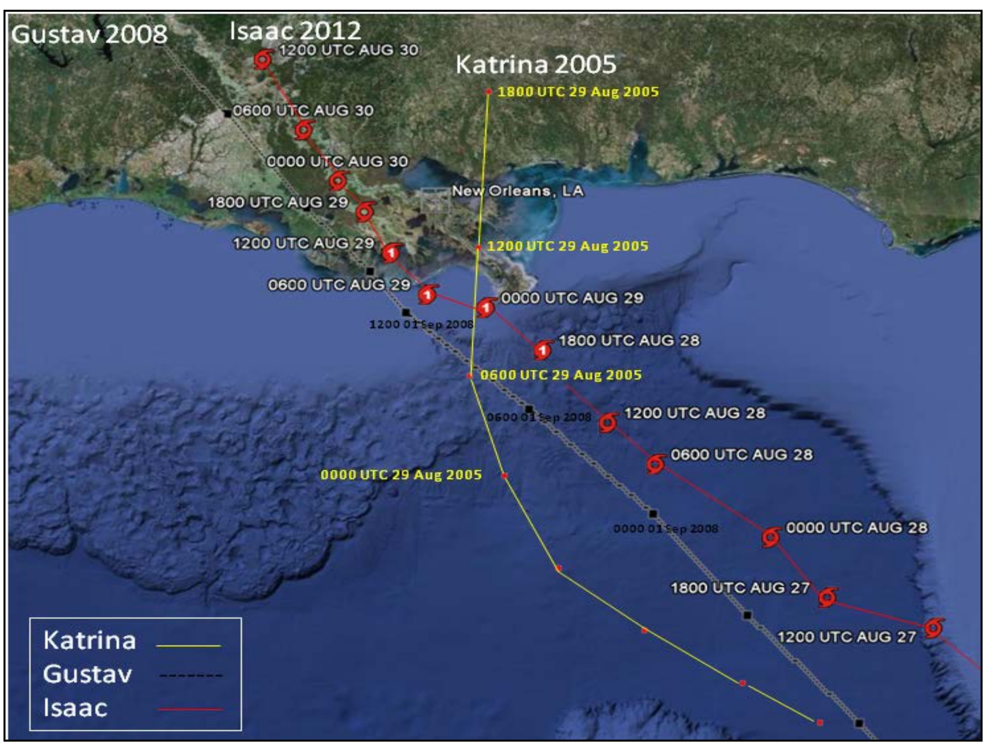


Figure 3.37 Tracks for Hurricanes Katrina, Gustav, and Isaac.

From Table 3.4 it can be seen that the largest storms in terms of radius in the suite, which were only about 80% the size of Isaac, were only run with a forward speed of 12.7 mph, 70% faster than Isaac. The combination of Hurricane Isaac's intensifying as it approached the coast, halting of forward motion and drifting near landfall, extremely large size, and slow forward speed made it unlike any storm in the JPM-OS suite.

References

Interagency Performance Evaluation Task Force, 2009. Performance evaluation of the New Orleans and southeast Louisiana hurricane protection system, vol VIII – Engineering and Operational Risk and Reliability Analysis. Appendix 8 – Hazard Analysis. U.S. Army Corps of Engineers, Washington, DC. Available at: https://ipet.wes.army.mil/

4.0 COMPARISON OF SYSTEM CHARACTERISTICS AND PERFORMANCE

Chapter Summary

This chapter summarizes the performance of the 100-year HSDRRS during Hurricane Isaac based on gage data, high water marks, and photographs taken during the damage assessment site visits. The likely performance of the system without the 100-year HSDRRS for Hurricane Isaac is also provided.

High water mark data was collected by the New Orleans District, the U.S. Geological Survey, Lake Pontchartrain Basin Foundation, and SLFPA-East. The U.S. Geological Survey also deployed temporary gages in the greater New Orleans area for the storm. The data was combined with data from existing gages and compared to with and without 2012 100-year HSDRRS 100-year levee and floodwall elevations in a qualitative assessment of the hydraulic performance of the system.

Based on analysis of the collected data, there is no indication of wave overtopping or surge overflow along the 2012 100-year HSDRRS, including the Mississippi River levees between river mile 80 and 130.

When the Hurricane Isaac peak gage and high water mark data are compared to elevations without the 100-year HSDRRS, it can be concluded that the surge was below the old system elevations in all but three areas: St. Bernard Parish – Caernarvon to Highway 46, St Charles Parish West Return Floodwall reach, and the IHNC-GIWW corridor. Additionally, surge could have inundated short reaches of the Harvey and Algiers Canals and Western Tie-In where Federal levees did not exist prior to the 100-year HSDRRS being built.

The majority of the 2012 100-year HSDRRS levees, floodwalls, and structures were constructed generally following the existing alignment of the LPV and WBV features that comprise the without 2012 100-year HSDRRS condition. Considering the information compiled, by inspection, a small portion of the HSDRRS without 100-year elevations, approximately 1 percent of the length of the HSDRRS, including the Mississippi River levees, would have overtopped by surge. Thus, the old system would have displaced about the same amount of water as the new system. The effects of Isaac in the communities external to the HSDRRS area would likely have been similar with or without 2012 100-year HSDRRS.

Unless otherwise noted, elevation and gage data presented in this chapter is in feet NAVD88 2004.65.

Hurricane Isaac and Post Storm Data

The New Orleans District Emergency Operation Center mobilized on 25 August and remained active throughout Hurricane Isaac. For the hurricane, District staff and the various levee districts closed over 280 access gates, structure gates, road gates, railroad gates, drainage, and other closures. Between 26 August and 29 August, major HSDRRS structures, such as the IHNC surge barrier sector gate and Western Closure Complex (WCC), were closed as per elevation triggers. Figure 4.1 is a snapshot of the major structure status during the event; Figure 4.2 shows decision support model output projecting the possible time when elevation triggers would occur, based on ADCIRC modeling of National Hurricane Center (NHC) forecast track and hurricane characteristics conducted by the University of North Carolina and Seahorse Consulting under contract to the New Orleans District.

Major structures were opened in a similar manner, considering hydraulic and structural design load conditions for gate operation. Figure 4.3 shows date and time gates were opened. Figure 4.4 shows projections of water levels from decision support modeling to determine when gates could be safely opened.

Damage assessment teams were deployed by the Corps and the levee districts. While the teams assessed damage due to Hurricane Isaac, they also collected information that was useful in portraying the performance of the 100-year HSDRRS during the storm.

High water mark teams were deployed by USGS and the Corps to collect high water mark information. Available high water mark information and gage data from the USGS storm sensors, Coastwide Reference Monitoring System (CRMS) stations, USGS gages, and Corps gages were compiled. The Lake Pontchartrain Basin Foundation and the Louisiana Flood Protection Authority East also collected high water mark information.

Major Structure Status – All Closures Closed

as of 1800 29-AUG-2012

Structure	Trigger Elevation FT NAVD88	Details	Structure Status	Time/Date Closed
Harvey Sector Gate	2.0 and rising	125 ft sector gate. 750 CFS pumps.	Closed	0830 29-Aug-2012
Bayou Segnette Complex	2.0	56 ft sector gate. 400 CFS pumps.	Closed	1145 29-Aug-2012
Bayou Verret Sector Gate	2.0	56 ft sector gate. 5 each 5 X 5 sluice gates. 48 hrs prior to landfall.	Closed	1545 28-Aug-2012
West Closure Complex	2.0 - 3.8	With predicted surge of 4.0 ft, close within trigger range.		
Estelle Canal	2.0 - 3.8	2 each 8 X 8 sluice gates.	Closed	0725 27-Aug-2012
Sluice Gates	2.0 - 3.8	5 each 16 X 16 sluice gates.	Closed	0930 29-Aug-2012
Sector Gate	2.0 - 3.8	225 ft sector gate. 19,140 CFS pumps.	Closed	0920 29-Aug-2012
London Ave Canal ICS	2.5 and rising	11 vertical lift gates. Max operating level 5.0 ft.	Closed	1500 28-Aug-2012
Hero Canal Stoplogs	2.5 and rising	56 ft opening. Stoplogs placed by crane. Must be placed before winds reach 25 mph.	Closed	1500 26-Aug-2012
Caernarvon Sector Gate	2.9	50 ft sector gate.	Closed	2015 28-Aug-2012
Bayou Dupre Sector Gate	3.0	56 ft sector gate.	Closed	2300 26-Aug-2012
IHNC Surge Barrier	3.0 and rising	With predicted surge of 5.0 ft, close at trigger		
Barge Gate	3.0	150 ft barge gate. 6 hrs to close. 72 hrs prior.	Closed	Pre Event
Bienvenue Lift Gate	3.0	56 ft lift gate.	Closed	1100 28-Aug-2012
Surge Barrier Sector Gate	3.0 and rising	150 ft sector gates. 15 min to close.	Closed	1100 28-Aug-2012
Seabrook Structure	3.0 and rising	With predicted surge of 5.0 ft, close at trigger		
Lift Gates	3.0 and rising	2 each 50 ft lift gates.	Closed	1330 28-Aug-2012
Sector Gate	3.0 and rising	95 ft sector gate.	Closed	1330 28-Aug-2012
17th St Canal ICS	5.0 and rising	11 vertical lift gates. Max operating level 6.0 ft.	Closed	1730 28-Aug-2012
Orleans Ave Canal ICS	5.0 and rising	5 vertical lift gates. Max operating level 8.0 ft.	Closed	1100 27-Aug-2012

Figure 4.1 Status of major HSDRRS structures on 29 August.

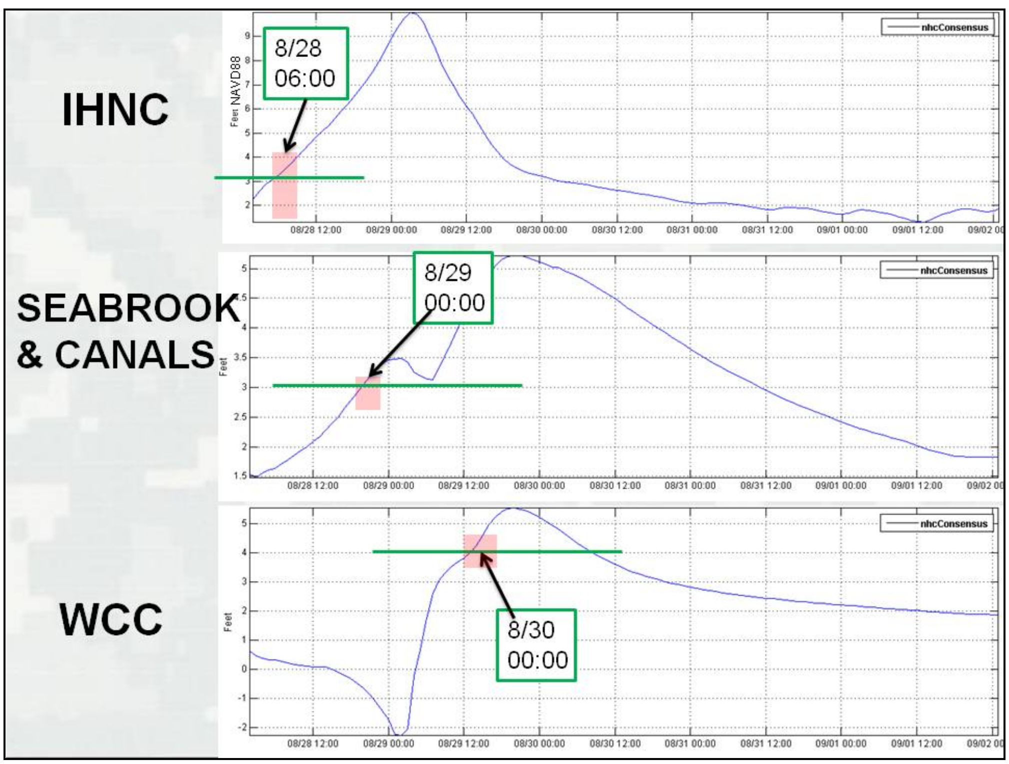


Figure 4.2 Forecast model outputs indicating possible timeline for

HSDRRS structure closure.

Major Structure Status – Opening Plan

as of 0600 1-SEP-2012

Structure	Closing Trigger	Opening Rationale	Structure Status	Projected Time/Date Open
Hwy 23 Closure			Open	1600 30 Aug 12
Hwy 90 Closure			Open	1600 30 Aug 12
IHNC Surge Barrier	3.0 and rising			
Barge Gate	3.0	Zero head differential, to control the swing of the barge	Closed	Remain Closed
Bienvenue Lift Gate	3.0	1.0' head differential, to prevent scouring velocities	Open	0930 30 Aug 12
Surge Barrier Sector Gate	3.0 and rising	50% open until 1.5' head differential, 100% for < 1.5' head differential	Open	1230 30 Aug 12
Bayou Dupre Sector Gate	3.0	Open with a negative head differential so that water flows away from areas pumped into by St. Bernard Parish 5.0' structural design differential, 0.5' scour limitation	Open	1530 1 Sep 12
Caernarvon Sector Gate	2.9	5.0' structural design differential, 0.5' scour limitation	Closed	2 – 3 Sep 12
Bayou Segnette Complex	2.0	1.0' head differential, to prevent scouring velocities	Closed	2 - 3 Sep 12
Bayou Verret Sector Gate	2.0	5.0' reverse head structural limitation	Closed	2 - 3 Sep 12
West Closure Complex	2.0 - 3.8			
Estelle Canal	2.0 - 3.8	1.0' head differential, to prevent scouring velocities	Closed	2 - 3 Sep 12
Sluice Gates	2.0 - 3.8	25% opening for head < 10', 50% for < 3', 100% for < 1'	Closed	2 - 3 Sep 12
Sector Gate	2.0 - 3.8	Reduce pumping to lower head differential 1.0' head differential limitation to prevent scouring velocities	Closed	2 - 3 Sep 12
Hero Canal Stoplogs	2.5 and rising	No head limitation; upper stoplog must be removed to allow drainage to expose the lower stoplog	Closed	1 – 2 Sep 12
Harvey Sector Gate	2.0 and rising		Open	2130 30 Aug 12
Seabrook Structure	3.0 and rising			
Lift Gates	3.0 and rising	Open lift gates after sector gate	Closed	2 Sep 12
Sector Gate	3.0 and rising	Opening IHNC will help drain protected side. Based upon future level at lake Pontchartrain. 1.0' head differential limit to prevent scouring velocities	Closed	2 Sep 12
London Ave Canal ICS	2.5 and rising	Based upon future level at Lake Pontchartrain. If continuing to pump will have a larger head differential than Seabrook	Closed	2 Sep 12
17th St Canal ICS	5.0 and rising	Based upon future level at Lake Pontchartrain. If continuing to pump will have a larger head differential than Seabrook	Closed	2 Sep 12
Orleans Ave Canal ICS	5.0 and rising	Based upon future level at Lake Pontchartrain. If continuing to pump will have a larger head differential than Seabrook	Open	1415 1 Sep 12

* On-site gauge readings required on each site

22

Figure 4.3 Status of HSDRRS major structures on 1 September. Note – Bayou Dupre structure opened at 1200 on 31 August for a few hours.

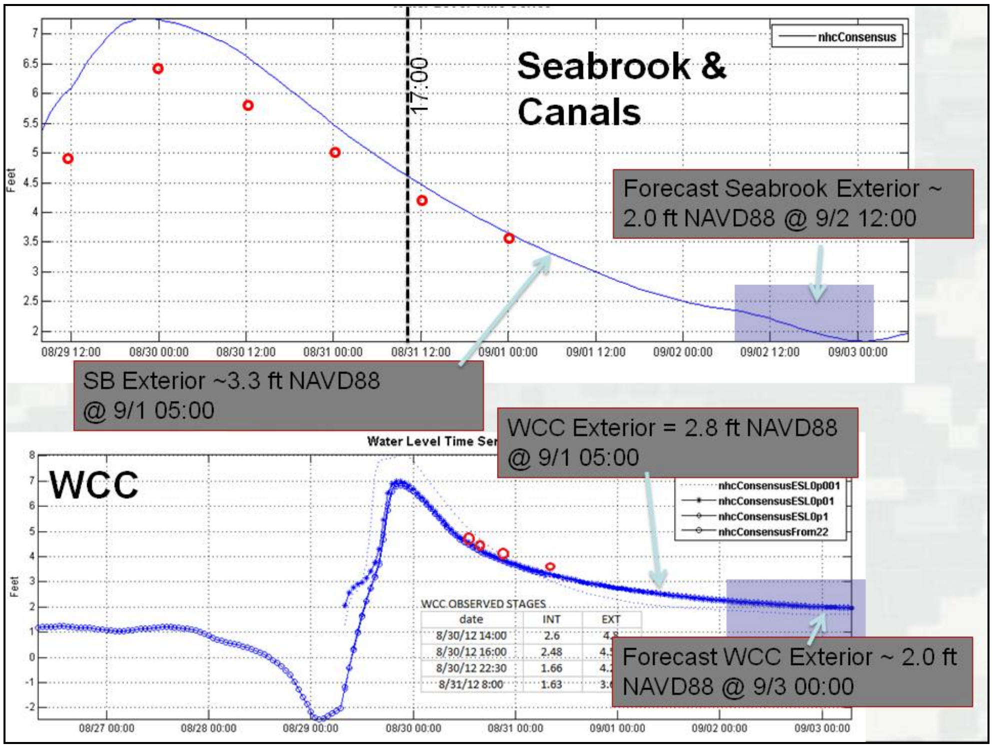


Figure 4.4 Forecast model outputs indicating possible timeline for HSDRRS structure re-opening.

For the Corps high water marks, points or areas to mark and survey high water were identified by a senior hydraulic engineer; coordinates and a Google Map kmz file was furnished to the field teams. The field teams consisted of a hydraulic engineer and a survey crew. The Corps survey office developed survey data collection packages for each team that contain coordinates identified for survey, primary project control points for ties to the national spatial reference system, and sample deliverables. The high water marks were collected in NAVD88 (2004.65) by constraining to published National Geodetic Survey (NGS) benchmarks and using Geoid 12A.

Geoid models define the separation from the ellipsoid (what GPS measures natively) to NAVD88, but not to a particular epoch of a datum (e.g. 2004.65, 2006.81). Passive benchmarks that were used in the NAVD88 (2004.65) NGS height modernization project define the 2004.65 epoch. The Corps high water marks were surveyed to an accuracy of 0.25 foot vertically and 30 feet horizontally with a 95% confidence level.

The field survey data was post processed, and a quality check performed by senior survey staff. The data was transferred to the Integrated Benchmark Baseline Information System (IBBIS) and delivered to senior hydraulic engineers in Hydraulics and Hydrologic Branch for a second quality control check. The data was compared to storm surge modeling and known flooding in areas.

The high water marks were collected by the USGS in NAVD88 by constraining to published National Geodetic Survey (NGS) benchmarks and using Geoid 09. USGS performed quality control checks using USGS established procedures. High water mark data are posted on the USGS Isaac storm tide mapper and marked as approved. The high water marks collected by the Lake Pontchartrain Basin Foundation were collected using Geoid 09.

Survey accuracy of the USGS, Lake Pontchartrain Basin Foundation, and SLFPA-East high water marks should be similar to the survey accuracy of the Corps high water marks.

High water marks consist of a combination of debris lines and water level or seed lines. Generally, high mark data from debris lines are considered a poor mark for purposes of determining surge heights. Measurable difference between the high water mark and the surge height can exist because of the dynamics of the surge and wave climate. However, these marks and the pictures of debris can be used to qualitatively assess if surge overflow occurred. It is highly unlikely that surge overflow occurred if the debris line is many feet below the top of the levee or floodwall.

USGS noted that gage data are provisional and subject to revision until they have been thoroughly reviewed and received final approval. Real-time data relayed by satellite or other telemetry are automatically screened to not display improbable values until they can be verified. Provisional data may be inaccurate due to instrument malfunctions or physical changes at the measurement site. Subsequent review based on field inspections and measurements may result in revisions to the data. USGS gage data is displayed in the NAVD88 datum unless otherwise noted.

Similarly, Corps real-time data are also provisional; an initial assessment of data quality has been performed by a senior hydraulic engineer and obvious errors removed.

Gage data, with proper gage operation, maintenance, and inspection, will have an error of plus or minus of 0.01 ft. Gages such as the radar gages installed in portions of the HSDRRS, can have accuracy of 0.01 feet with a range of 5 to 20 feet between the target and the gage.

Maximum still water elevations from USGS, CRMS, and Corps gages are shown on Plate 2 A thru C. High water mark data from USGS and Corps are shown on Plate 3 A thru D. Although the data is provisional and subject to revision, the data can be used for this preliminary assessment.

Using the gage data, high water marks, damage assessment photos and information on the levee elevations, a qualitative assessment of the performance of the with and without 2012 100-year HSDRRS condition can be determined.

Performance of the HSDRRS With and Without 2012 100-year Elevations and Features

St Bernard levee-floodwall reach – Caernarvon to Highway 46.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 32.0 feet for the levee-floodwall portion of this reach and 26.0 feet for the Caernarvon gate area (HSDRRS Project Number LPV-148-149). The HSDRRS without 2012 100-year elevations range from 13.0 feet to 19.0 feet. Figure 4.5 shows information pertaining to this reach from the damage assessment site visit. For the majority of this reach, the debris is on the flood side slope of the levee portion of the levee-floodwall. Corps high water mark (a debris line which is from surge and wave) for this area is 13.19 feet. In the vicinity of the Caernarvon Sector Gate, the pattern of debris is indicative of water on the flood side of the floodwall. Peak USGS gage data in the vicinity of Caernarvon Sector gate is 13.82 feet NAVD88. Peak Corps gage data at the Caernarvon gate is 14.01 feet.

Gage data and debris lines on the flood side of the levee-floodwall demonstrate that for the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Within this reach, approximately 2,600 feet of HSDRRS without 2012 100-year elevations is less than 14.0 feet. Given the peak stages in the vicinity of Caernarvon Sector gate, it can be assumed that surge overflow would likely have occurred over a portion of the 2,600 feet of levee and floodwall without the 2012 100-year HSDRRS in place.

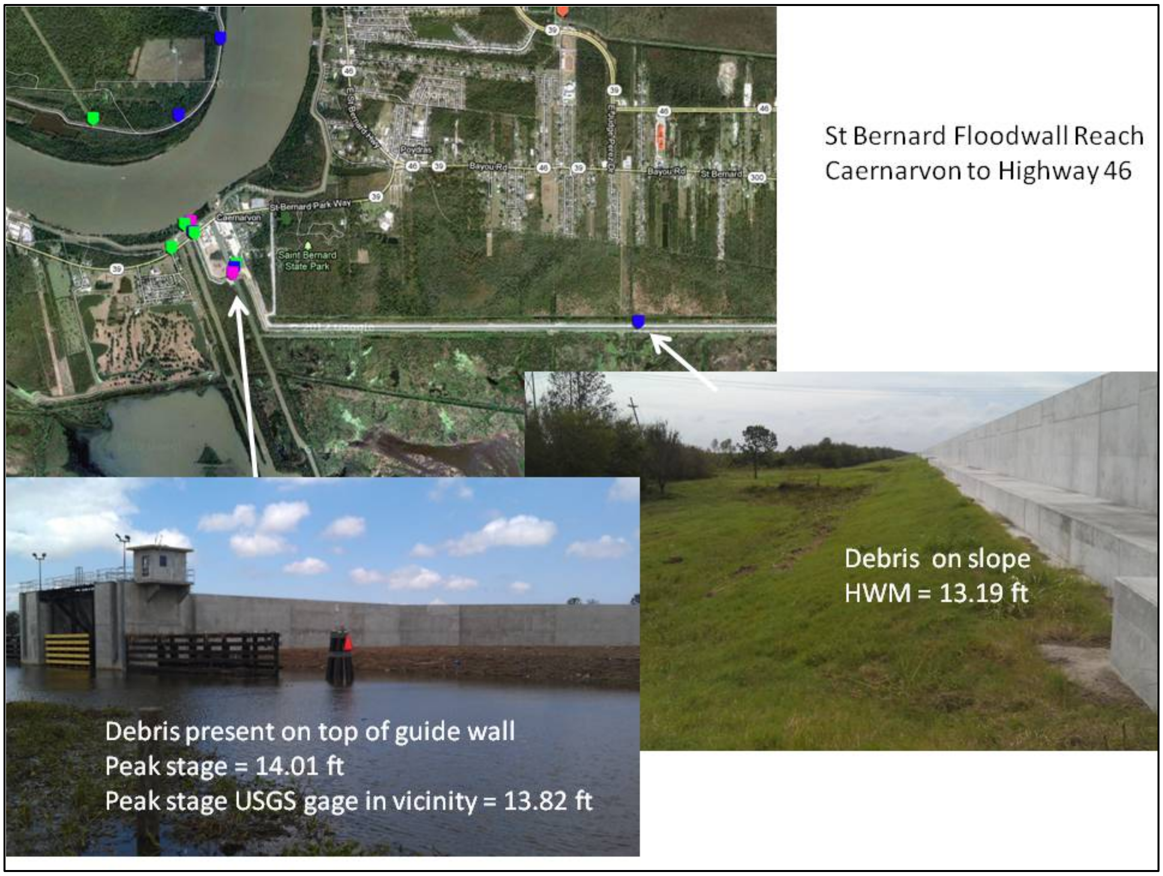


Figure 4.5 Damage assessment data from the Caernarvon to Highway 46 Reach.

St Bernard levee-floodwall reach - Highway 46 to the IHNC surge barrier.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 28.0 to 32.0 feet (HSDRRS Project Number LPV-145 – 147). The HSDRRS without 2012 100-year elevations range from 16.0 to 17.0 feet. Figures 4.6 and 4.7 show information pertaining to this reach from the damage assessment site visit. For the majority of this reach, the debris is on the slope of the levee portion of the levee-floodwall. A Corps high water mark in the vicinity is 13.00 feet, a debris line which is from surge and waves.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the high water mark of 13.0 ft, it can be assumed that surge overflow would not have occurred without the 2012 100-year HSDRRS in place.

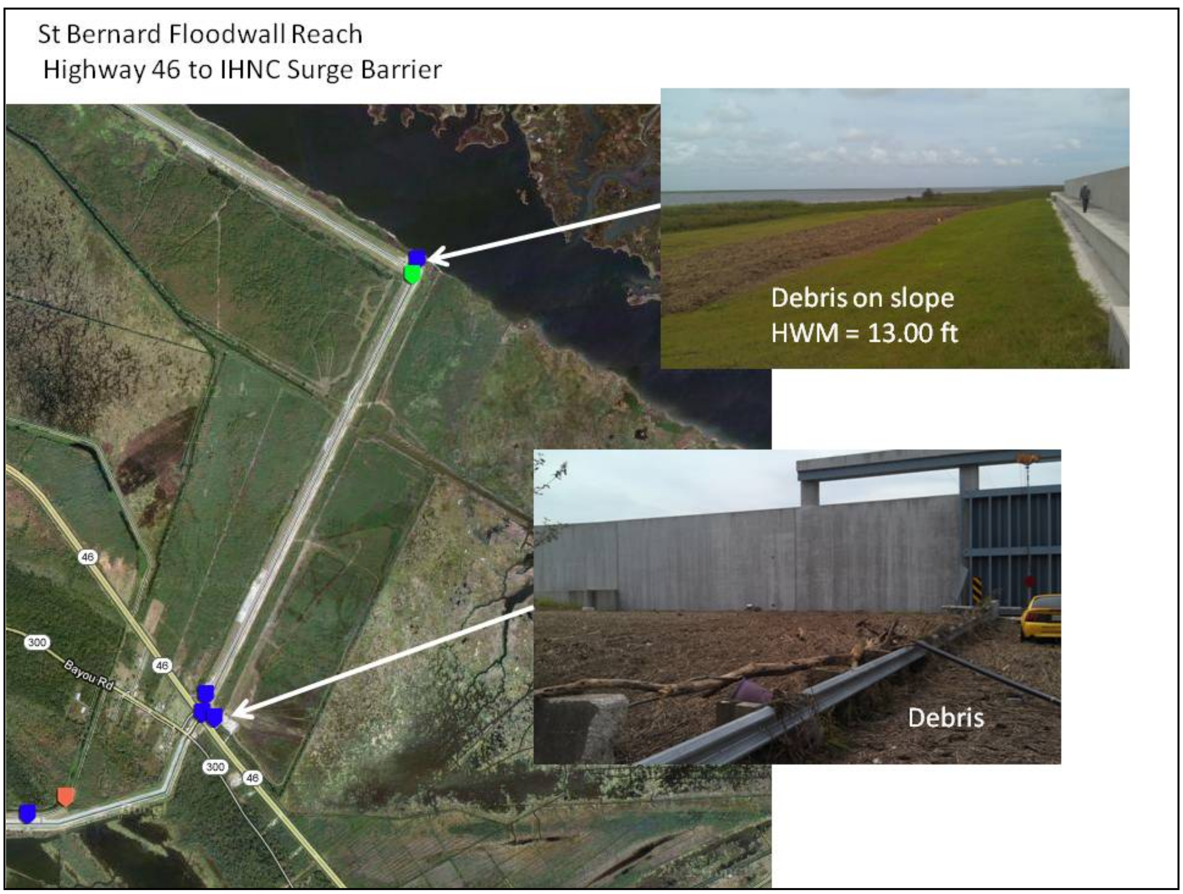


Figure 4.6 Damage assessment data from the Highway 46 to IHNC Surge Barrier Reach.

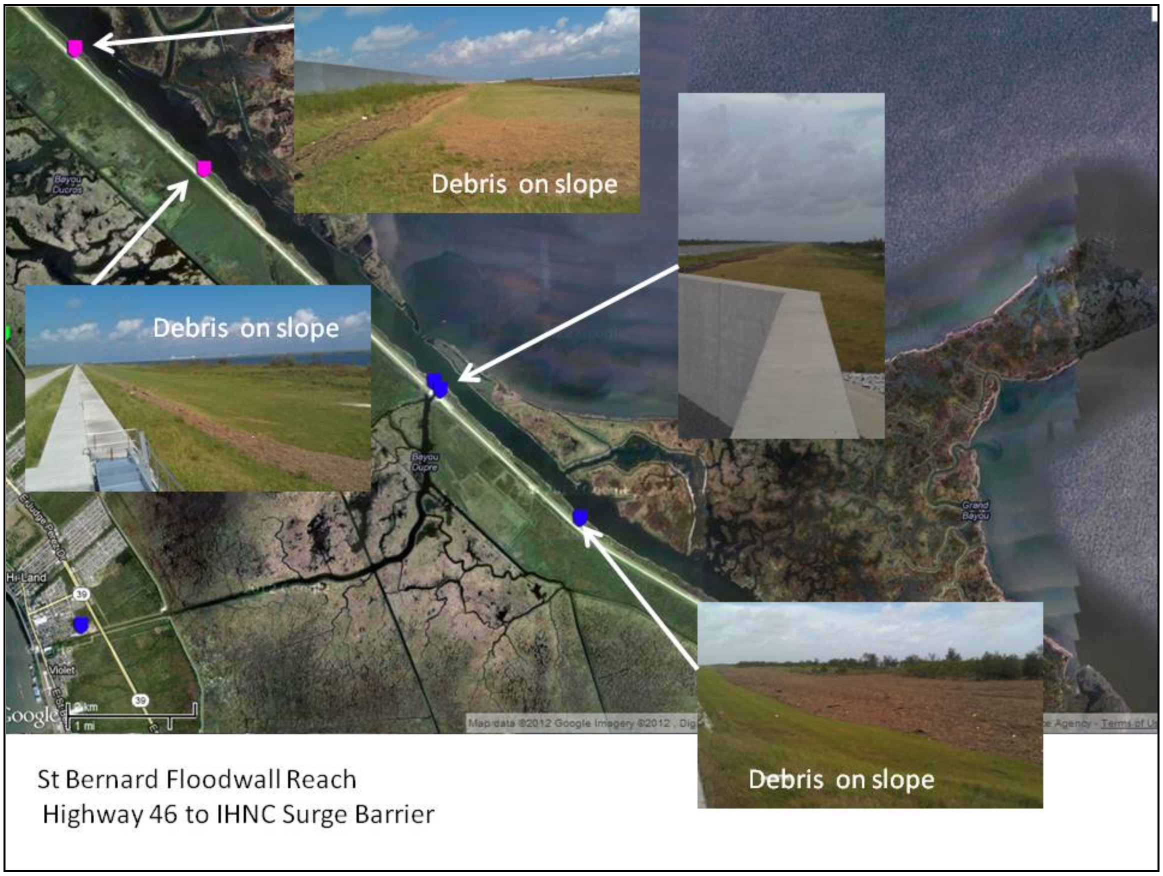


Figure 4.7 Damage assessment data from the Highway 46 to IHNC Surge Barrier Reach.

IHNC Surge Barrier.
As indicated on Plate 1, the 2012 100-year HSDRRS elevation is 25.0 and 26.0 feet (HSDRRS Project Number IHNC-02). Figure 4.8 shows information pertaining to the floodwall from the damage assessment site visit. At the IHNC surge barrier, gage data are intermittent. The highest recorded stage was 12.37 feet. Debris was noted on the top of the guide walls for the sector gate, verifying that water levels exceeded 12 feet. For this analysis, it is assumed the 12.37 feet is a peak stage.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place at the IHNC surge barrier.

The IHNC surge barrier did not exist in the prior to the 2012 100-year HSDRRS. Given the peak stage at the IHNC surge barrier and the elevation of the levees and floodwalls along the IHNC-GIWW corridor, 11.0-15.0 feet, wave overtopping may have been possible. Given the peak stage of 6.50 feet in Lake Pontchartrain in the vicinity of the IHNC, a significant gradient would occur within the corridor. For Hurricanes Gustav and Ike, the peak stage at the IHNC Lock was within a foot of the peak stage at the Bayou Bienvenue structure along the MRGO reach of the St Bernard levee, and the majority of the drop in water levels occurred in the IHNC between the Almonaster Blvd bridge and Lake Pontchartrain. A similar situation would likely have occurred during Isaac. If the peak stage at IHNC Lock would have reached 11 or 12 feet, portions of the floodwall along the IHNC would probably have experienced surge overflow.

Figure 4.8 Damage assessment data from the IHNC Surge Barrier.

New Orleans Back Levee Reach.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 25.0 to 28.0 feet (HSDRRS Project Number LPV-110-111). The HSDRRS without 2012 100-year elevations range from 14.0 to 15.0 feet. Figure 4.9 shows information pertaining to this reach from the damage assessment site visit. For the majority of this reach, the debris was on the flood side slope of the levee portion of the levee-floodwall or just reaching the floodwall base. A Corps high water mark (a debris line from surge and waves) in the vicinity was measured at 8.61 feet.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the peak stage at the IHNC surge barrier and the high water mark of 8.6 ft, it can be assumed that surge overflow would not have occurred without the 2012 100-year HSDDRS in place.

Figure 4.9 Damage assessment data from the New Orleans Back Levee Reach.

Southpoint to GIWW Reach.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 17.0 to 24.5 feet (HSDRRS Project Reach LPV-109). The HSDRRS without 2012 100-year elevations ranged from 13.0 to 19.0 feet. Figure 4.10 shows information pertaining to this reach from the damage assessment site visit. For the majority of this reach, the debris was on the flood side of the levee. USGS high water marks (debris lines from surge and waves) in the vicinity measured 5.87 feet and 6.87 feet NAVD88. The peak stage from a USGS gage in the vicinity measured 6.30 feet NAVD88. The South Louisiana Flood Protection Authority East (SLFPA-East) measured a high water mark on the flood side of the Highway 90 floodgate of 7.58 feet NAVD88.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the peak stage and the high water mark values between 5.9 and 6.9 feet, it can be assumed that surge overflow would not have occurred without the 2012 100-year HSDRRS in place.

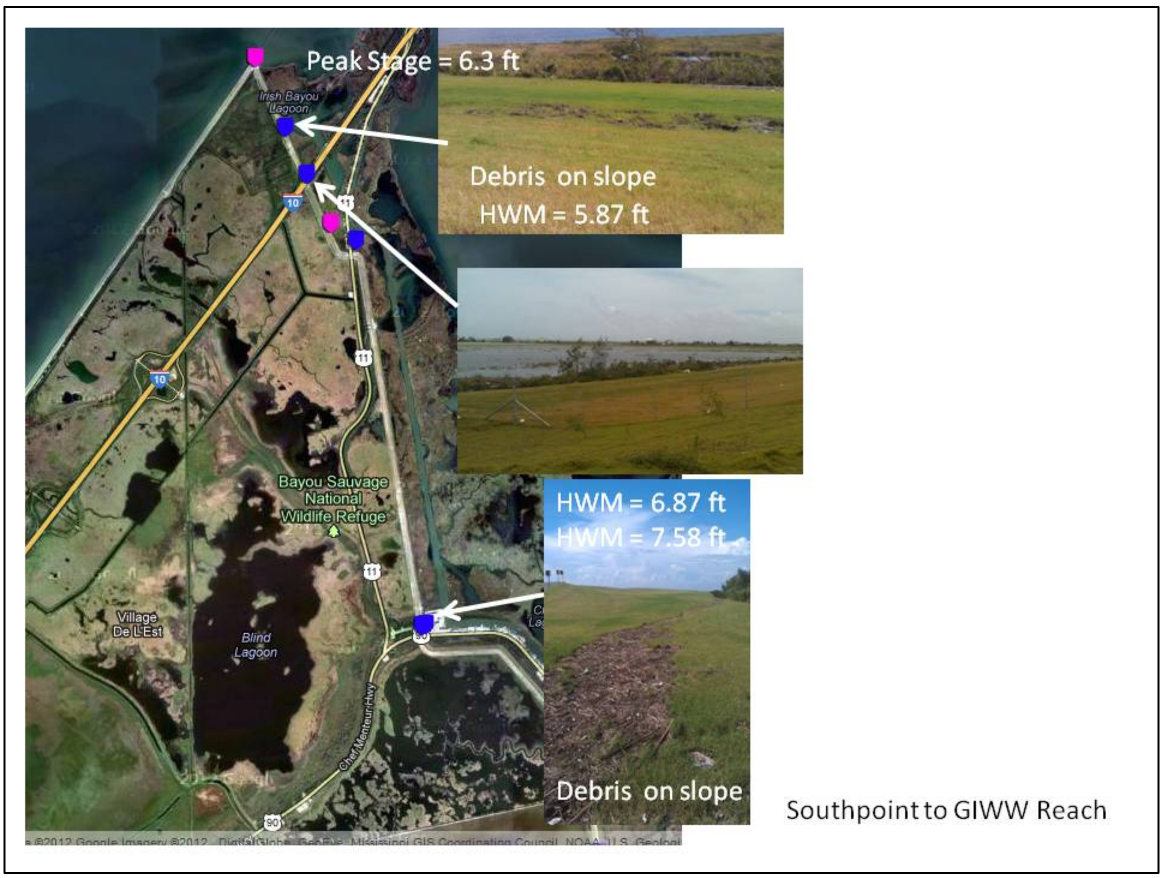


Figure 4.10 Damage assessment data from the Southpoint to GIWW Reach. One high water mark courtesy of South Louisiana Flood Protection Authority-East.

New Orleans East Lakefront Reach.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations range from 14.50 to 15.50 feet in the reach where a breakwater is located to 17.0 to 20.0 feet in the eastern portion of this reach (LPV-105-108). The HSDRRS without 2012 100-year elevations range from 12.0 to 14.0 in the reach where the breakwater is location and 17.0 to 19.5 feet in the eastern portion of the reach. The breakwater was part of the HSDRRS prior to the 2012 condition. Figure 4.11 shows information pertaining to this reach from the damage assessment site visit. Peak stages from USGS and Corps gages range from 6.30 to 6.50 feet (USGS data in NAVD88). SLFPA-East measured a high water mark of 6.07 feet at the Lakefront Airport.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the peak stage values between 6.3 to 6.5 feet, it can be assumed that surge overflow would not have occurred without the 2012 100-year HSDRRS in place.

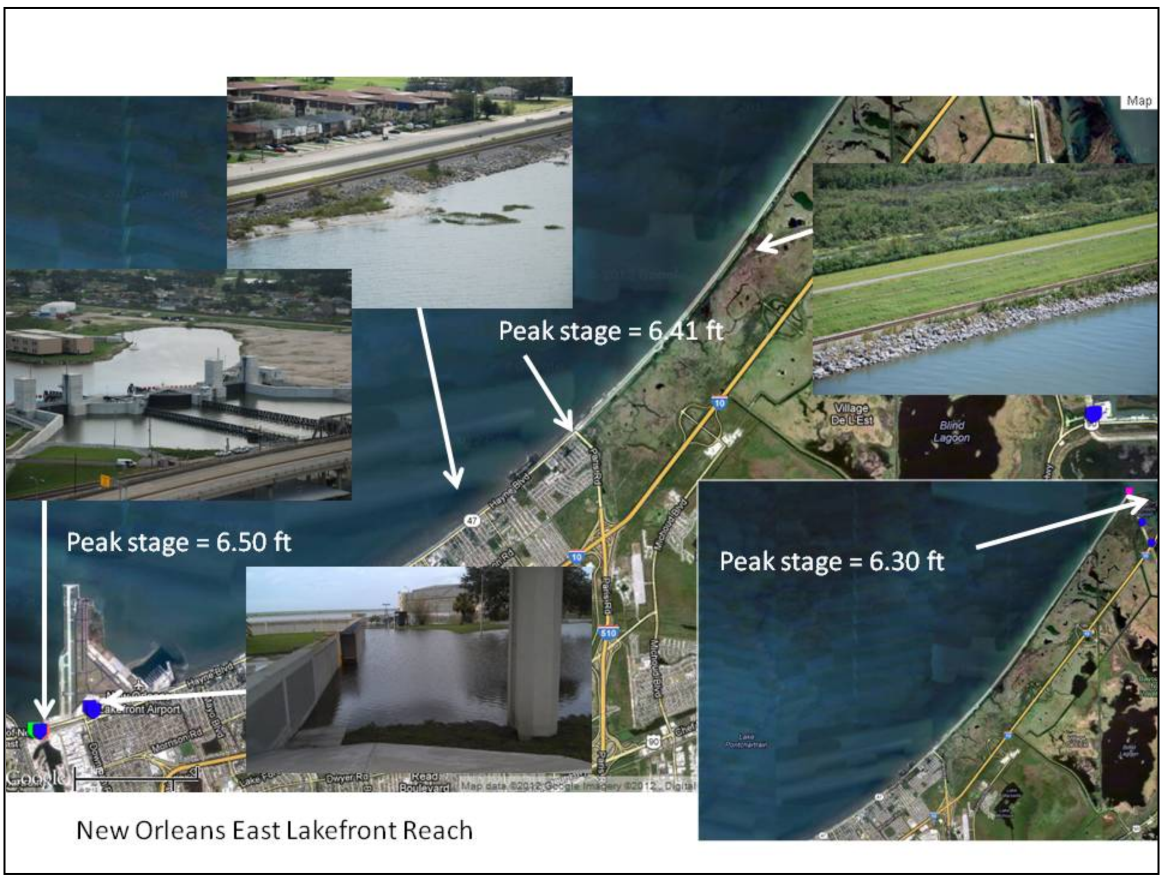


Figure 4.11 Damage assessment data from the New Orleans East Lakefront Reach

New Orleans Metro Reach.

As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 15.0 to 18.0 feet, including Seabrook Gate Complex (HSDRRS Project Number LPV-101-104 and IHNC-01). The HSDRRS without 2012 100-year elevations range from 15.0 to 19.5 feet. Figure 4.12 shows information pertaining to this reach from the damage assessment site visit. Peak stages from USGS and Corps gages range from 6.40 to 6.50 feet (USGS data in NAVD88). SLPFA-E measured several high water marks in the reach, with elevations ranging from 7.56 feet to 11.83 feet NAVD88. In addition, SLFPA-East measured a high water mark at the Orleans Marina of 6.35 feet NAVD88, on the Orleans Avenue Canal north of the Robert Lee Bridge (4.28 feet NAVD88), and on the 17th St Canal south of I-610 (6.50 feet NAVD88).

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place along the lakefront levee or at the Seabrook Gate Complex.

The Seabrook Gate Complex did not exist prior to the 2012 100-year HSDRRS. Surge would have entered or exited the IHNC-GIWW corridor through this opening.

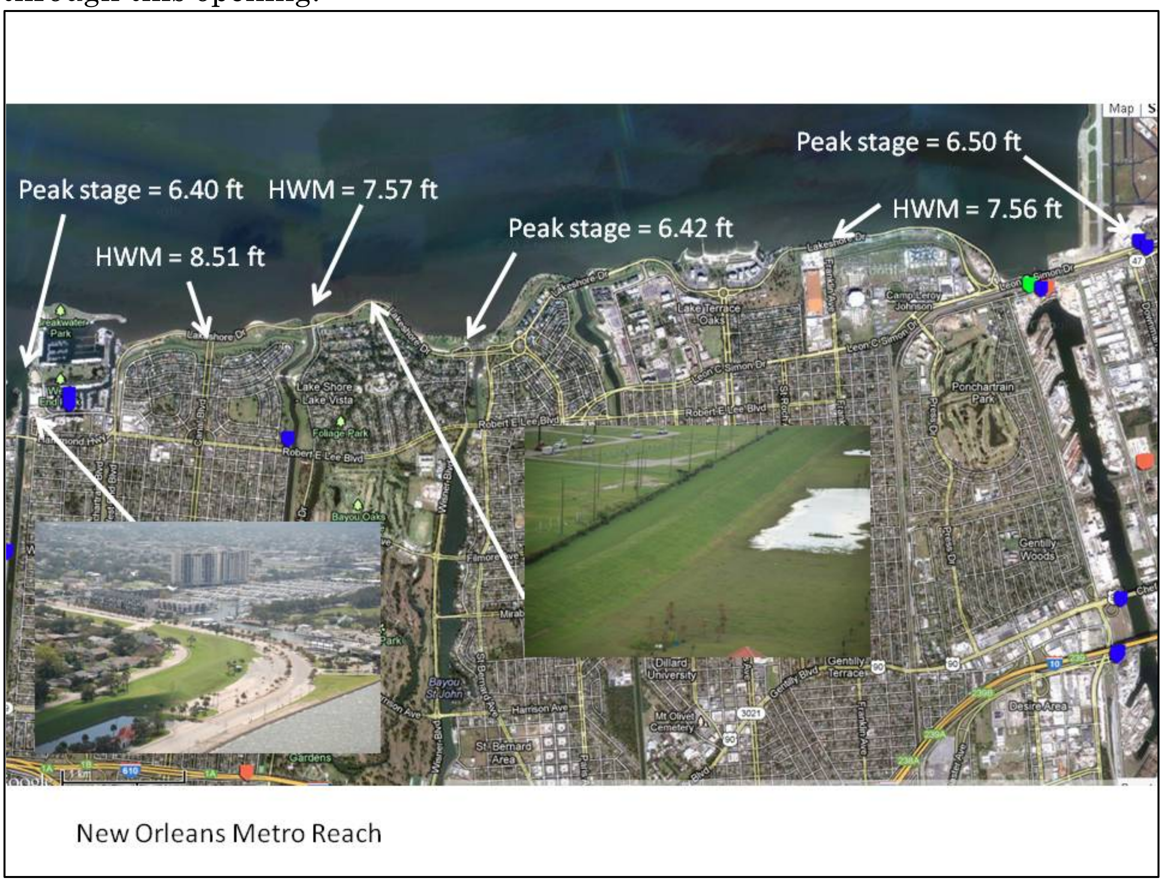


Figure 4.12 Damage assessment data from the New Orleans Metro Reach. High water mark data courtesy of South Louisiana Flood Protection Authority-East.

Jefferson Lakefront Reach.

As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 16.5 feet (HSDRRS Project Number LPV-1-2 and LPV-20). Rock protection for the wave attenuation berm exists along the reach of this levee. The HSDRRS without 2012 100-year elevations range from 13.0 to 16.5 feet. Figure 4.13 shows information pertaining to this reach from the damage assessment site visit. Peak stages from USGS and Corps gages range from 6.40 to 6.72 feet (USGS data in NAVD88). A high water mark elevation of 8.37 feet NAVD88 was recorded by USGS at the same location as the peak gage stage of 6.72 feet NAVD88; the higher high water mark is reflective of wave action or debris.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the peak stage value of 6.62 feet, it can be assumed that surge overflow would not have occurred without the 2012 100-year HSDRRS in place.

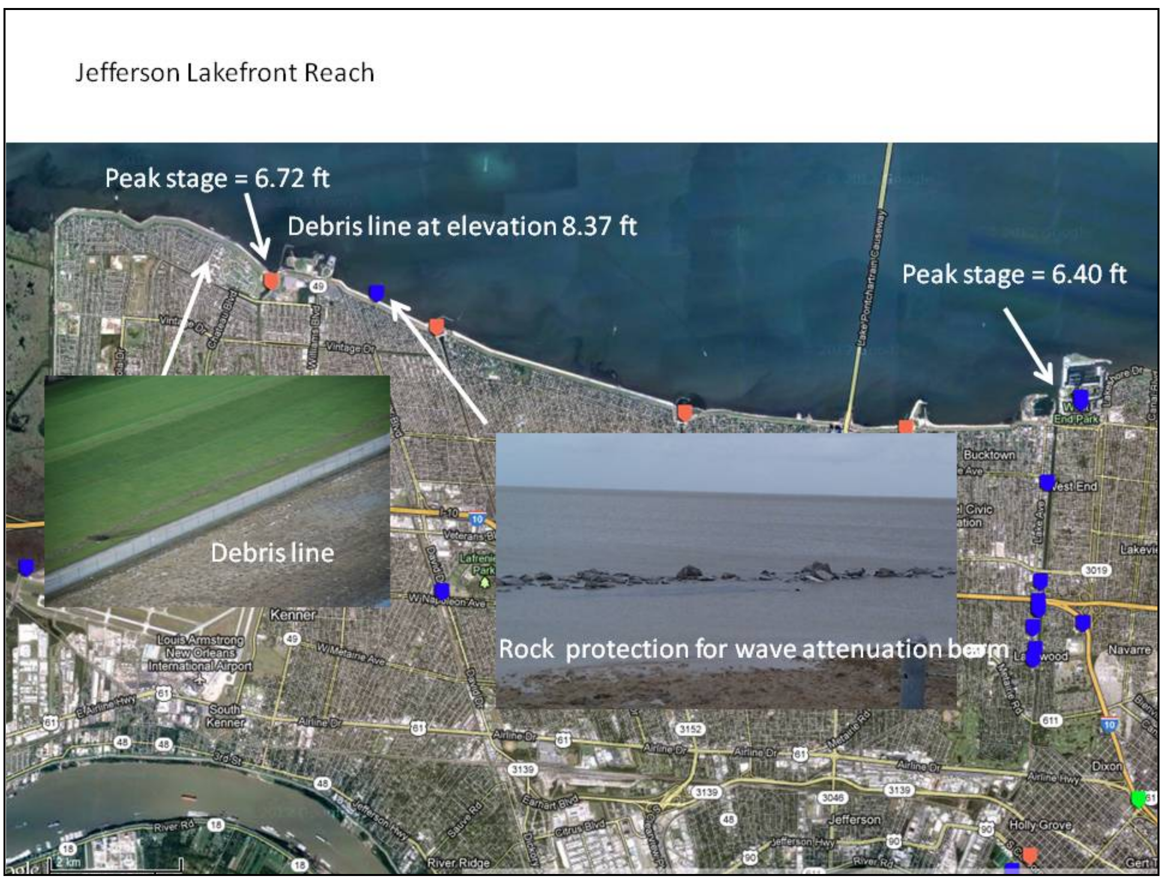


Figure 4.13 Damage assessment data from the Jefferson Lakefront Reach.

St Charles Parish Reach, including West Return Floodwall.

As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 15.0 to 17.0 feet (HSDRRS Project Number LPV-03-07). The HSDRRS without 2012 100-year elevations range from 6.5 feet to 14.0 feet. Figure 4.14 shows information pertaining to this reach from the damage assessment site visit. Peak stage at a Corps gage at Cross Bayou was measured at 8.02 feet. Corps high water mark data ranged from 8.26 feet along the HSDRRS levee to 9 feet on the Bonnet Carré lower guide levee. The railroad tracks south of, and paralleling, Interstate 10 experienced overtopping from Lake Pontchartrain surge. The sill elevation at the railroad gate is 6.5 feet.

Gage data demonstrates that for the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Within this reach, approximately 4,600 feet of pre-HSDRRS levee in St Charles parish was less than 8.0 feet. Given the peak stage at Cross Bayou, it can be assumed that surge overflow would likely occur over this portion of the levee without the 2012 100-year HSDRRS in place.

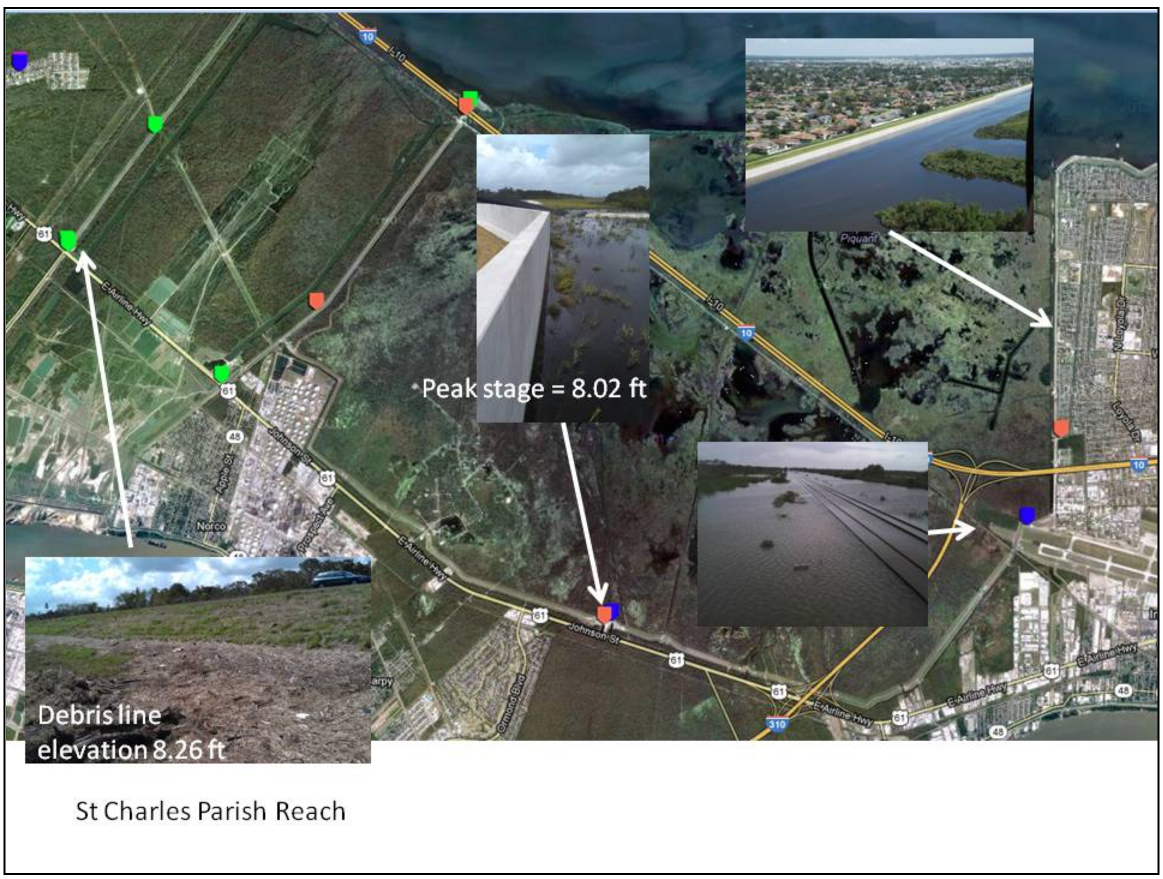


Figure 4.14 Damage assessment data from the St. Charles Parish Reach.

Western Tie-In – Lake Cataouatche Reach.

As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 10.0 to 14.0 feet (HSDRRS Project Number WBV-71-77, WBV-15-18 and WBV-24). Pre-HSDRRS elevations ranged from 5.0 to 6.0 feet. There was no HSDRRS levee present in a portion of the reach prior to the 2012 100-year HSDRRS. Figure 4.15 shows information pertaining to this reach from the damage assessment site visit. Peak stage at a USGS gage at the Davis Pond Freshwater Diversion Structure was measured at 4.63 feet NAVD88. USGS gages in the area had maximum stages ranging from 4.71 feet to 5.12 feet NAVD88.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the peak stage value of 4.63 feet and ground elevations in the area where there was no HSDRRS levee present, surge inundation would have been likely. Culverts under Highway 90 would convey water north of the highway.

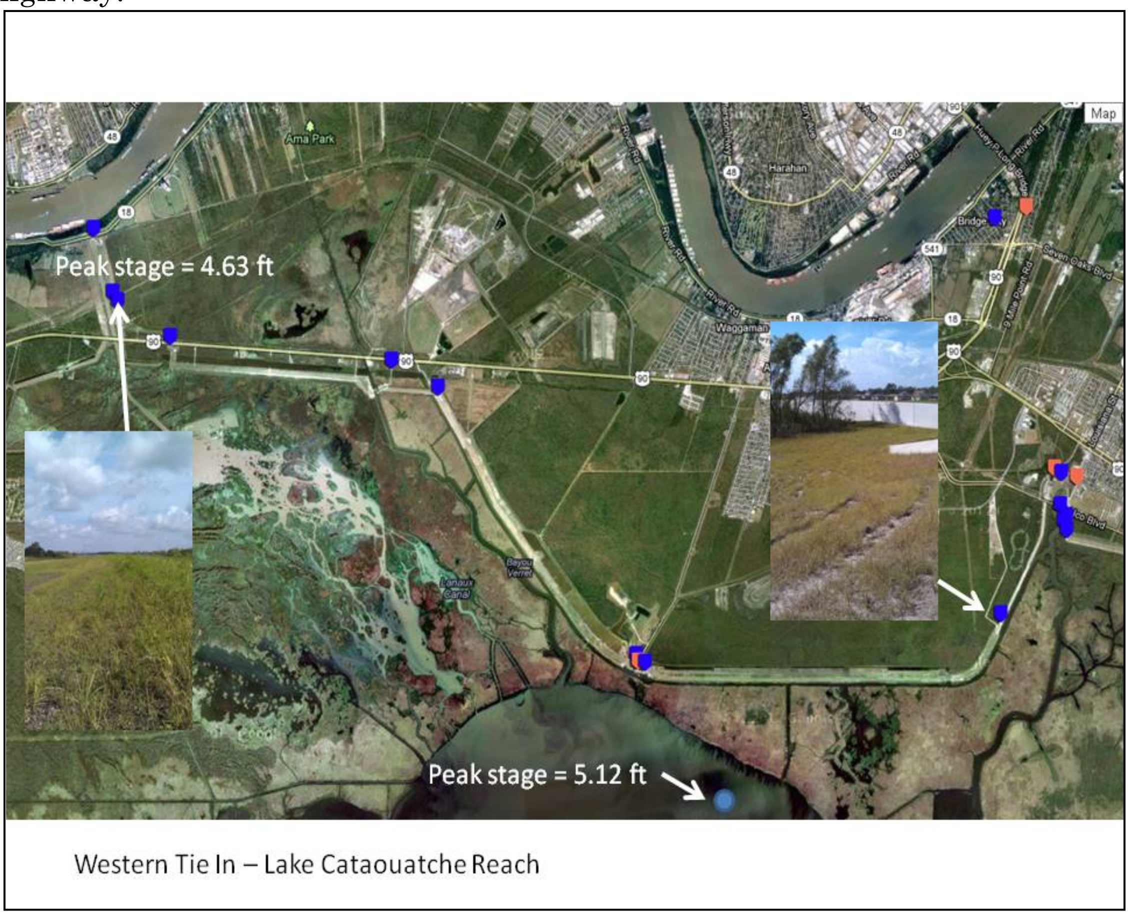


Figure 4.15 Damage assessment data from the Western Tie-In Lake Cataouatche Reach.

Westwego to Harvey Reach.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 12.5 to 14.0 feet (HSDRRS Project Number WBV-14), with the West Closure Complex (HSDRRS Project Number WBV-90) at elevation 16.0 feet. The HSDRRS without 2012 100-year elevations range from 8.0 to 13.5 feet. Figure 4.16 shows information pertaining to this reach from the damage assessment site visit. Peak stage at a CRMS gage south of the reach was measured at 4.28 feet NAVD88. The peak stage of approximately 5 feet was observed at the West Closure Complex.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Given the peak stage values between 4.6 and 5 feet, it can be assumed that surge overflow would not have occurred along the Westwego to Harvey levee reach without the 2012 100-year HSDRRS in place.

On the Algiers Canal, the Corps had raised all the levees to 9.5 between 1999 and 2004, with gaps at the access ramps in the industrial corridor for future floodgates. The gaps were at approximately elevation 5.5 feet. For pre-HSDRRS, it is assumed the Harvey Sector Gate is in place.

Along Harvey Canal, the levee on the west side between the Sector Gate and New Estelle Pumping station was higher than 6 feet. On the eastside there was no "levee", just a spoil bank around elevation 5.0 or 6.0 feet.

Given the levee and ground elevations along Harvey Canal south of the Harvey Sector Gate and the Algiers Canal, surge inundation might have been possible for the pre-HSDRRS without the presence of the WCC.

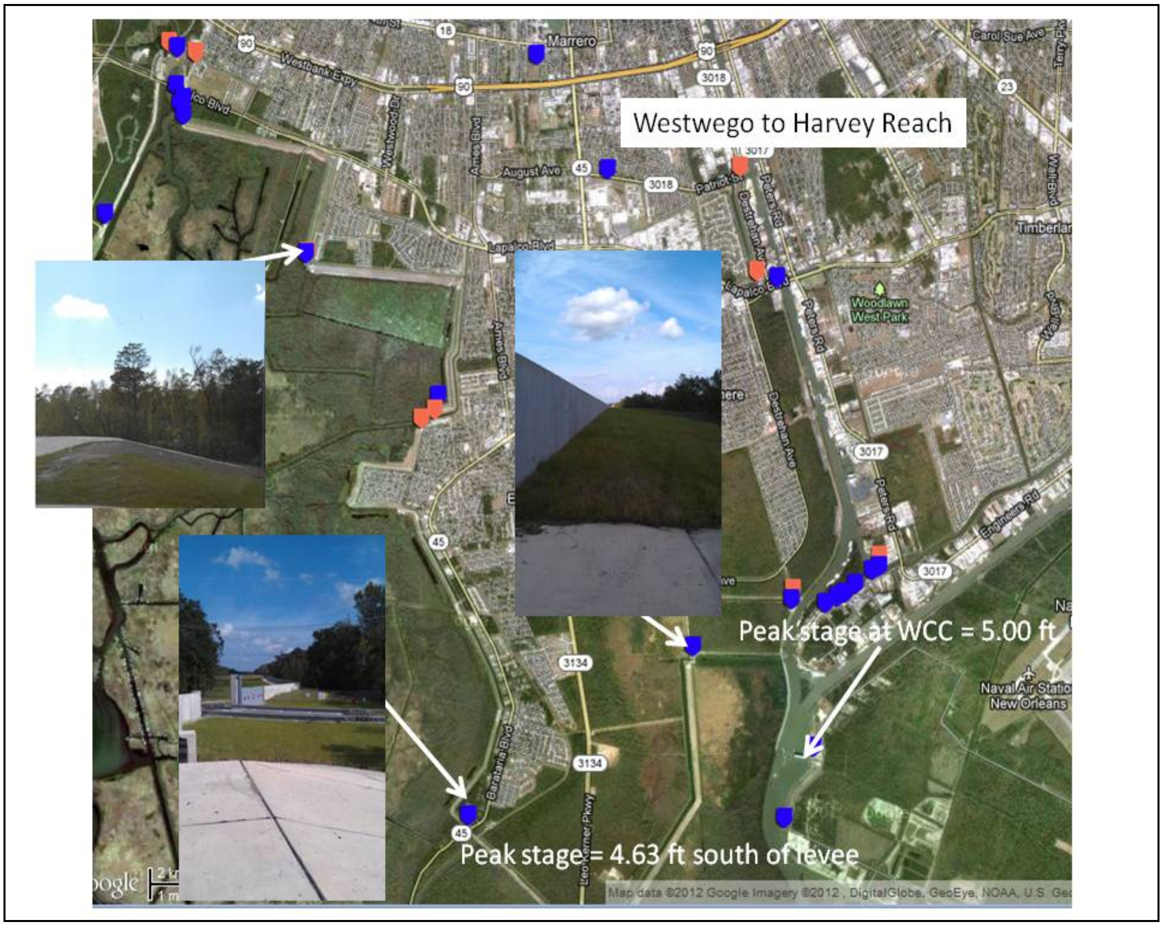


Figure 4.16 Damage assessment team data from the Westwego to Harvey Reach.

Eastern Tie-In Reach.
As indicated on Plate 1, the 2012 100-year HSDRRS elevations are 12.0 to 15.5 feet (HSDRRS Project Number WBV-9 and 12). Pre-HSDRRS elevations range from 8.5 to 9.5 feet. There was no levee in a portion of this reach for the pre-HSDRRS condition; the non-Federal levee south of Oakville and the high ground provided some protection to the Belle Chasse area. Figure 4.17 shows information pertaining to this reach from the damage assessment site visit. The peak stage of approximately 5 feet was observed at the West Closure Complex.

For the 2012 100-year HSDRRS, there is no evidence that surge overflow took place.

Assuming the peak stage value of 5 feet at the WCC is representative of surge in this reach, it can be assumed that surge overflow would not have occurred with the pre-HSDDRS in place.

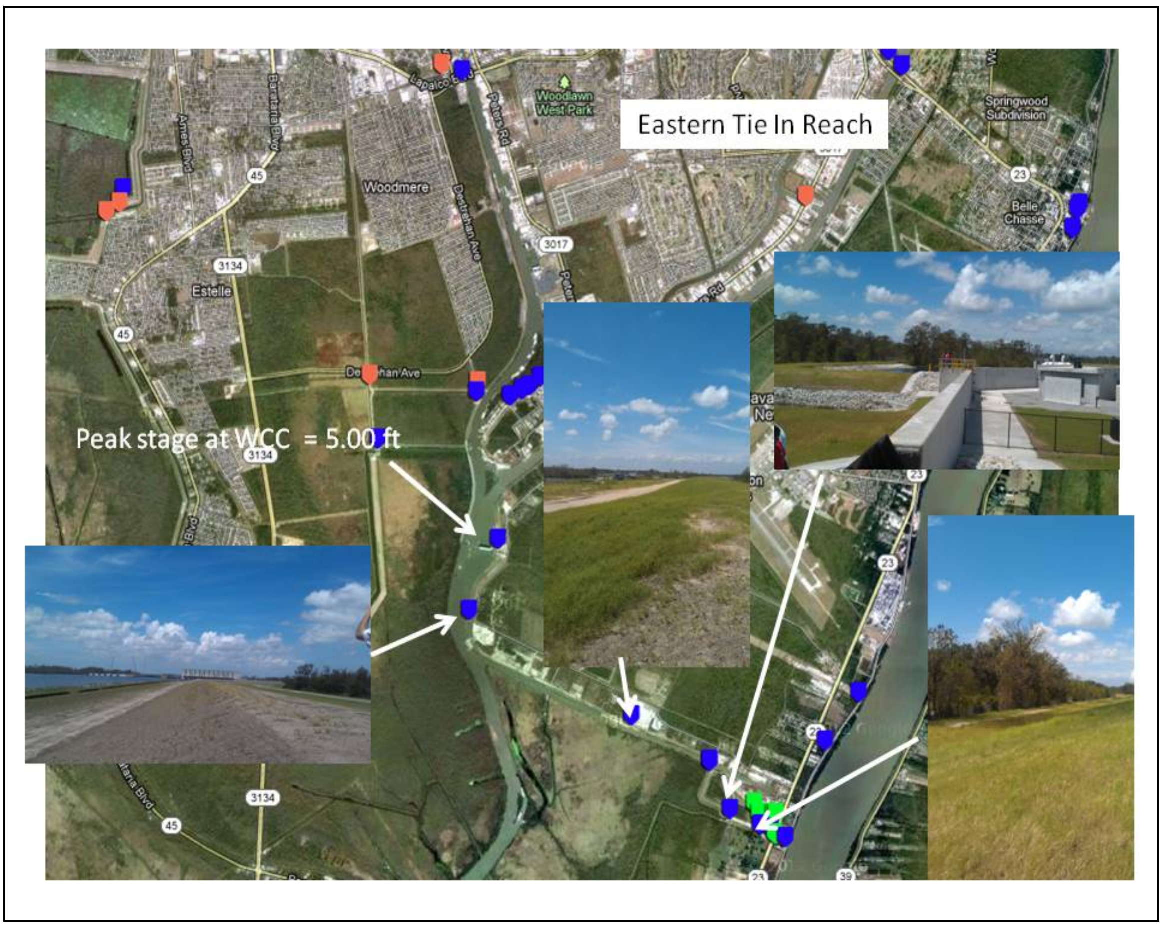


Figure 4.17 Damage assessment team data from the Eastern Tie-In Reach.

Mississippi River Levees.

Gage data along the river can be used to qualitatively assess the performance of the Mississippi River levees during Hurricane Isaac. Peak stages from Corps gages are shown on Table 4.1. The highest peak stage recorded for the entire river was 12.52 feet at the West Pointe a la Hache gage.

Debris at the toe of the west bank river levee in the vicinity of Triumph in Plaquemines Parish, near river mile 21.7 above Head of Passes, was evidence that significant wave overtopping or surge overflow may have occurred in that area. The levee elevation in that reach is 12.5 feet. In the vicinity of Mile 40 above Head of Passes near Port Sulphur in Plaquemines Parish, debris was found one foot below the top of the west bank river levee on the flood side; the levee height is around 14.5 feet. In the reach of the river below Mile 40, the peak water level was likely higher than 12.5 feet.

The Lake Pontchartrain Basin Foundation recorded high water marks along the Mississippi River on the west river levee near Buras (Figure 4.18), the high water marks confirm peak water levels greater than 12.5 feet. High water marks include wave action and therefore would be higher than gage data.

Table 4.1 Peak stages recorded at Corps gages during Hurricane Isaac.

Mississippi River Peak Stages for Hurricane Isaac

		River Mile AHP	Isaac Peak Stage **Ft NAVD88**	Date/Time CST
01160	Miss River at Baton Rouge	228.4	12.15	8/29/12 5:00
01220	Miss River at Donaldsonville	173.6	11.13	8/29/12 2:00
01275	Miss River @ Bonne Carre-North of Spillway	129.2	11.45	8/29/12 1:00
01300	Miss River at Carrollton	102.8	11.59	8/29/12 0:00
01320	Miss River at Harvey Lock	98.3	11.28	8/29/12 0:00
01340	Miss River at IHNC Lock	92.7	11.28	8/29/12 0:00
01380	Miss River at Algiers Lock	88.3	11.06	8/28/12 23:00
01390	Miss River at Alliance	62.5	11.68	8/28/12 23:00
01400	Miss River at West Pt A La Hache	48.7	12.52	8/28/12 22:00
01440	Mississippi River at Empire	29.5	no record	
01480	Miss River at Venice	10.7	no record	
01515	Miss River at West Bay	6.7	8.33	8/28/12 19:00
01545	Miss River at Head Of Passes	-0.6	7.11	8/28/12 22:30
01575	Southwest Pass at Mile 9.2	-7.5	5.93	8/28/12 22:00
01670	Miss River (SW Pass) East Jetty (Pilot Station)	-18.2	4.17	8/28/12 10:00

Figure 4.18 Recorded high water marks on the west bank Mississippi River Levee near Buras courtesy of the Lake Pontchartrain Basin Foundation.

Mississippi River Levees within the 2012 100-year HSDRRS region

Portions of the Mississippi River Levees between river mile 80 and 130 above Head of Passes serve an integral purpose within the 2012 100-year HSDRRS. On the west bank, from Oakville upriver to Davis Pond Freshwater Diversion Structure, the Mississippi River West Bank levee helps to form the west bank polder. Similarly, on the east bank, from Caernarvon to the Bonnet Carré Spillway, the Mississippi River East Bank levee forms the east bank polders.

Engineering advanced measures have been constructed on the Mississippi River/HSDRRS co-located levees, located on the west bank of the Mississippi River from river mile 70 to river mile 87, raising the height of the levees from 16.0 to 20.0 feet (pre-HSDRRS) to 21.5 to 22.5 feet (2012 100-year HSDRRS). These engineering advance measures provide 100-year level of risk reduction. Permanent construction has not been completed.

For the remaining Mississippi River levees and floodwalls within the 2012 100-year HSDRRS region, the pre-HSDRRS and 2012 100-year HSDRRS elevations are the same.

The Lake Pontchartrain Basin Foundation furnished high water mark data on the east bank river levee near Caernarvon (Figure 4.19). At Caernarvon, the high water marks ranged from 9.6 to 10.7 feet (Figure 4.19). The elevation of the levee in this reach is 18 to 20 feet; wave overtopping was not likely.

To evaluate performance, Figure 4.20 shows information pertaining to the portion of the Mississippi River from river mile 80 through 85 from the damage assessment site visit. As the Lake Pontchartrain Basin Foundation data and damage assessment photographs indicate, wave overtopping was not evident in this portion of the river.

Given that wave overtopping did not occur between river mile 80 through 85, it can be concluded that wave overtopping did not occur between river mile 85 and 130, where observed surge levels were similar, while the levee heights are higher.

The same conclusion holds for the pre-HSDRRS system. The data indicate that the pre-HSDRRS elevations would not have been overtopped by Hurricane Isaac surge.

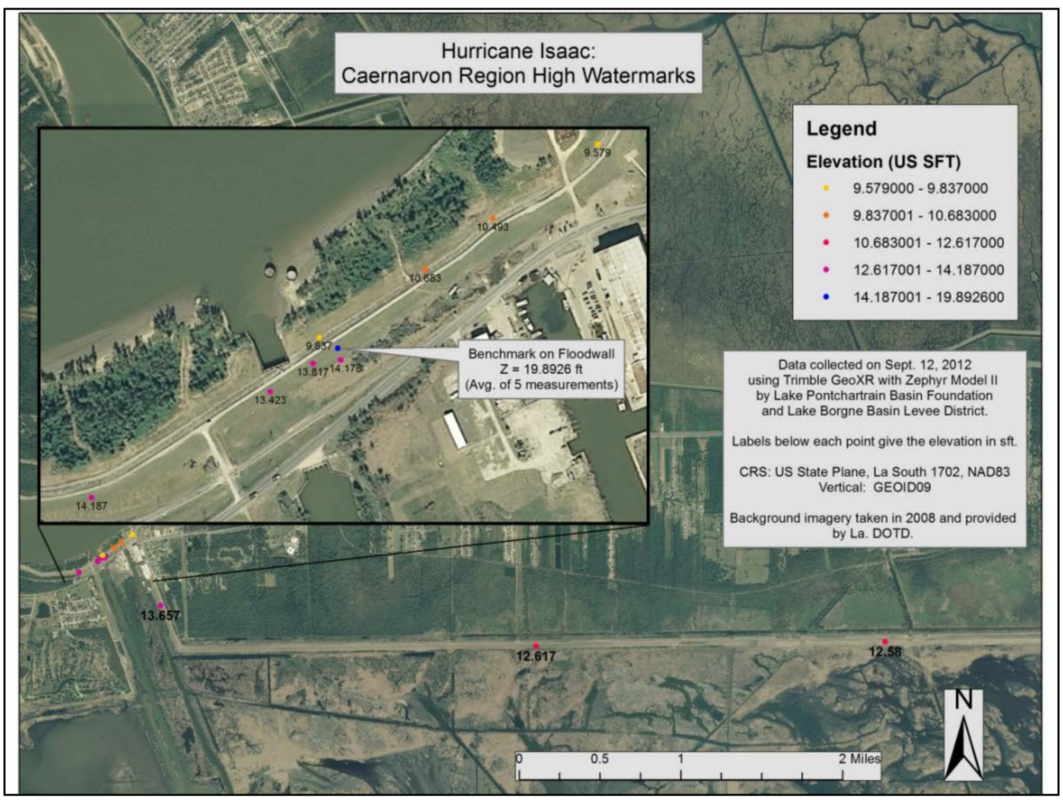


Figure 4.19 Recorded high water marks on the east bank Mississippi River Levee near Caernarvon courtesy of the Lake Pontchartrain Basin Foundation.

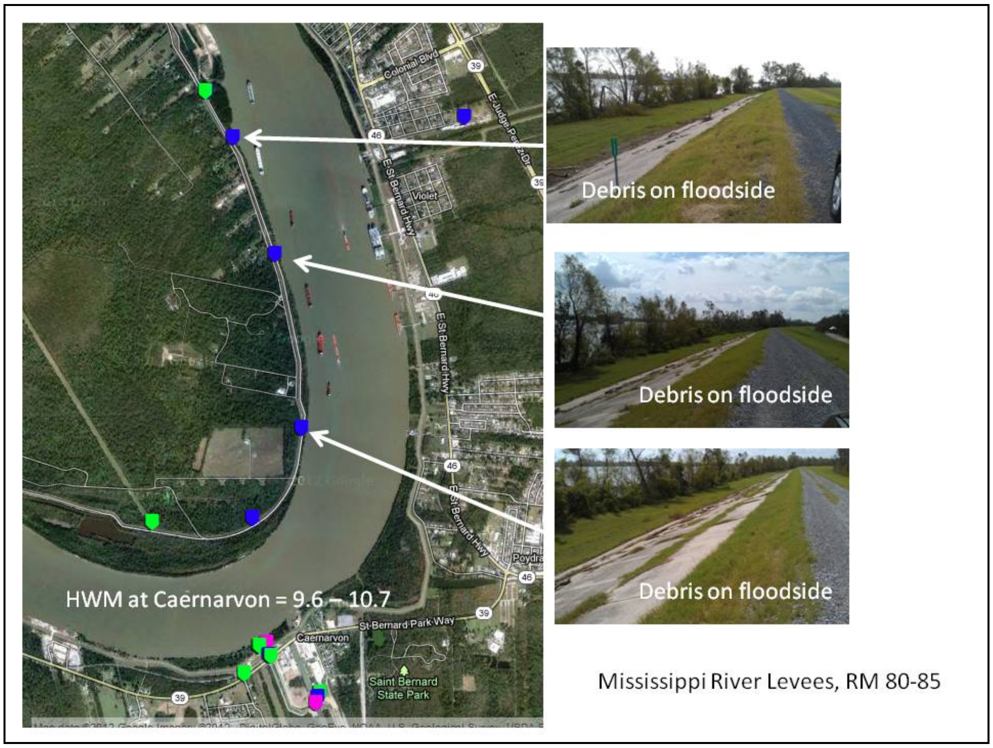


Figure 4.20 Damage assessment team photos and Lake Pontchartrain Basin Foundation data from west bank of Mississippi River Levee near river mile 80 - 85.

Conclusions

The gage high water mark data collected for Hurricane Isaac can be used to make a qualitative assessment regarding likely hydraulic performance of the 2012 100-year and pre-100-year HSDRRS levees and floodwalls.

There has been no data collected to date that would indicate there was wave overtopping or surge overflow along the 2012 100-year HSDRRS or the portion of the Mississippi River levees integral to the 2012 100-year HSDRRS. Overtopping was evident on the Mississippi River levees, but it was downstream of river mile 80 and therefore outside the 2012 100-year HSDRRS area. Therefore, it can be concluded that no surge overflow took place along the 200 plus miles of levee and floodwall that provide risk reduction to the greater New Orleans area that were in place for Hurricane Isaac.

Based on analysis of these data with the pre-100-year HSDRRS levee elevations shown on Plate 1, there are three areas where wave overtopping and or surge overflow would have been possible with the pre-100-year HSDRRS in place at the time of Hurricane Isaac.

For the St. Bernard levee-floodwall reach, Caernarvon to Highway 46, the peak recorded stage in the vicinity of Caernarvon was 13.82 feet; surge overflow would have been possible over a portion of 2,600 feet of levee-floodwall. The portion of this reach with elevation 14.0 feet would likely have experienced wave overtopping.

At the IHNC surge barrier, a stage of 12.37 feet was observed for Isaac. Given this stage and the elevation of the levees and floodwalls along the IHNC-GIWW corridor, 11.0-15.0 feet, wave overtopping may have been possible. Given the peak stage of 6.50 feet in Lake Pontchartrain, a significant gradient would occur within the corridor. For Hurricanes Gustav and Ike, the peak stage at the IHNC Lock was within a foot of the peak stage at the Bayou Bienvenue structure along the MRGO reach of the St Bernard levee, and the majority of the drop in water levels occurred in the IHNC between the Almonaster Blvd bridge and Lake Pontchartrain. A similar situation would likely have occurred during Isaac. If the peak stage at IHNC Lock would have reached 11 or 12 feet, portions of the floodwall along the IHNC would probably have experienced surge overflow.

Given peak stage 0f 8.0 feet and the pre-100-year HSDRRS elevations of 6.5 to 12.5 feet, approximately 4,600 feet of the St Charles parish levee would probably have experienced surge overflow, and additional length of levee would have experienced wave overtopping.

In addition, the Western Tie-In reach and Eastern Tie-In reach had no levees for the pre-100-year HSDRRS. In the Western Tie-In reach, ground elevations show surge inundation would have been likely.

Similarly, given the ground and levee elevations along Harvey Canal and Algiers Canal for the pre-HSDRRS, surge inundation might have been possible along short stretches of the canals.

Figure 4.21 shows the locations of likely surge overflow and inundation for the pre-100-year HSDRRS. Most of the new 100-year HSDRRS was built on the same alignment as the old system. High water marks and gage data show that there were only a few places where Isaac surge would have overtopped the pre-HSDRRS, adding up to approximately one percent of over 200 miles of levee and floodwalls. Thus, the old system would have displaced about the same amount of water as the new system.

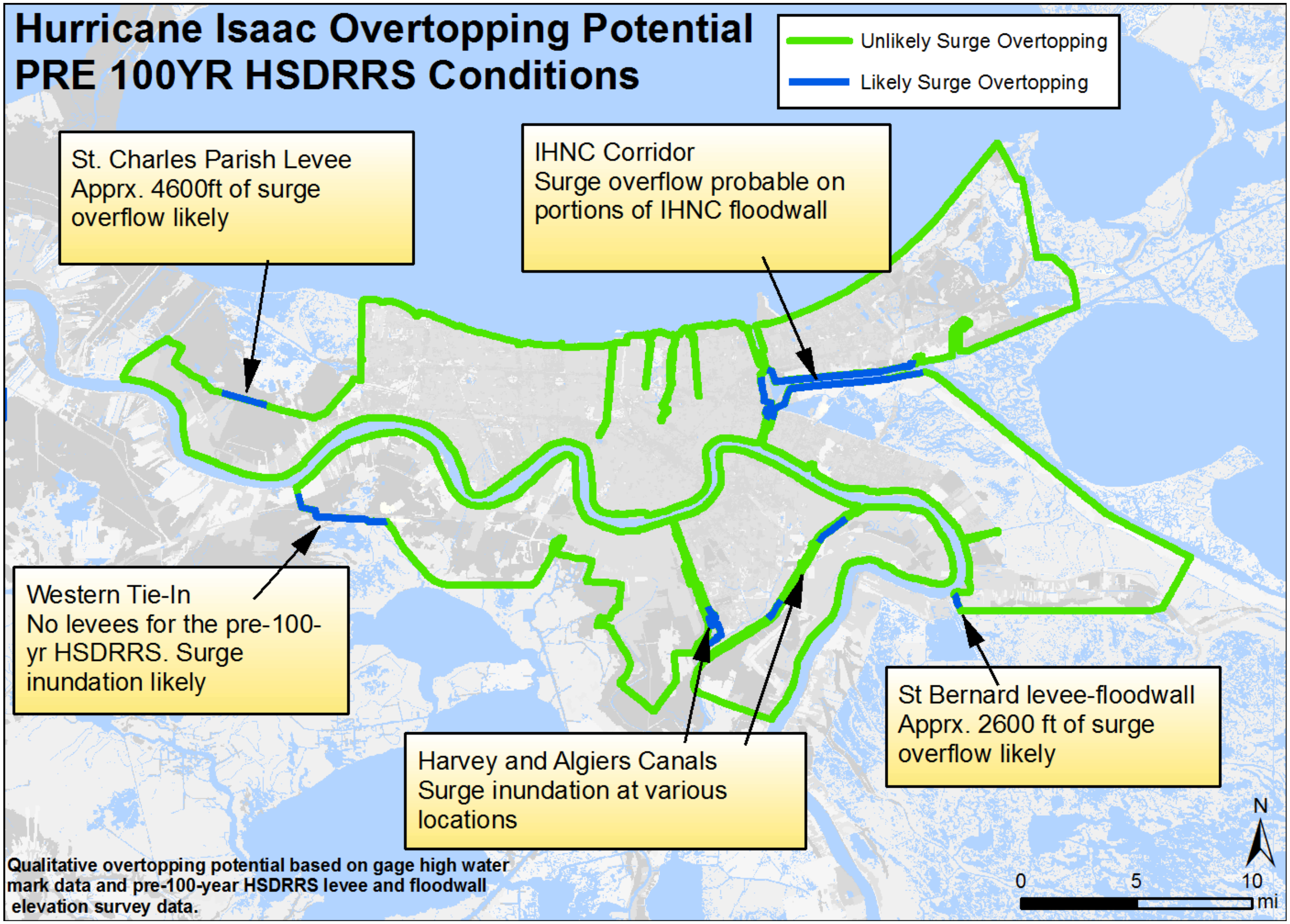


Figure 4.21. Locations of likely surge overflow and inundation for the pre-100-year HSDRRS from Hurricane Isaac.

5.0 PRIOR EVALUATIONS OF EXPECTED 100-YEAR HURRICANE STORM DAMAGE RISK REDUCTION SYSTEM (HSDRRS) PERFORMANCE

Chapter Summary

During the design of the 100-year HSDRRS, multiple models and ADCIRC runs were made in order to describe both the positive and unintended effects of the system on storm surge elevations. The purpose of this chapter is to compile and consolidate previous sensitivity analyses conducted for features of the HSDRRS from existing model runs. The modeling system applied for the analyses documented in this chapter was initially developed as part of the Interagency Performance Evaluation Task Force (IPET) work to examine the response of the southeast Louisianan hurricane protection system to Hurricane Katrina. It is the modeling system applied for the Louisiana Coastal Protection and Restoration Study (LACPR) as well as the FEMA flood mapping study for Louisiana, and has been extensively peer reviewed.

Sensitivity analyses documented in this report are based on simulations executed as part of the LaCPR study, a storm surge modeling study of the IHNC barrier, the WCC storm surge study, and the MRL storm surge study. The sensitivity analyses conducted from the LaCPR 2010 condition model simulations indicate that the HSDRRS components included in that modeling analysis reduce risk for the greater New Orleans area and significantly reduce 100-year water levels in the IHNC/GIWW. These analyses also indicate that increases in 100-year water levels outside the system are typically less than 0.3 feet near communities, which is within model uncertainty. These results were confirmed by a storm surge modeling study that focused on the IHNC barrier. Extensive sensitivity analyses were also conducted to examine changes in water levels due to the presence of the WCC. Analyses examined both the change in peak water levels during storm surge events due to the blocking of the canal as well as the increase in stage due to the pump outflow from the WCC pump station. Increase in stage due to operation of the barrier was predicted to be 0.2 feet or less at communities on the unprotected side of the WCC.

The conclusion of all sensitivity analyses with respect to potential increase in water levels outside the HSDRRS is consistent; the model generally predicts increases in estimated peak water levels of less than 0.2 feet at communities outside the HSDRRS, although it produces about 0.9 feet of increase immediately adjacent to the IHNC Surge Barrier.

Introduction

Extensive modeling and analysis was performed during the design phase of the 100-year HSDRRS. Multiple runs using ADCIRC and other models were made in order to describe both positive and unintended effects of the system on storm surge elevations. Detailed documentation of the coastal and hydraulic engineering analysis performed to determine project design elevations for the HSDRRS is provided in USACE (2011). Included in the analyses were studies to determine what effect, if any, the HSDRRS system has had on other areas. Public meetings were held across the area at which the modeling and analyses were discussed. Environmental documentation included discussions on effects of the HSDRRS on adjacent areas. The purpose of this chapter is to compile and consolidate previous sensitivity analyses conducted for features of the HSDRRS from existing model runs. It should be noted that all reported elevations are relative to the NAVD88 2004.65 datum.

The modeling system applied for the analyses documented in this chapter was initially developed as part of the Interagency Performance Evaluation Task Force (IPET) work to examine the response of the southeast Louisiana hurricane protection system to Hurricane Katrina. It is the system applied for the Louisiana Coastal Protection and Restoration (LaCPR) (USACE 2009) as well as the FEMA flood mapping study for Louisiana (Westerink et al. 2007a). Extensive peer reviews have been conducted on the modeling work including reviews by the distinguished External Review Panel of the American Society of Civil Engineers, and the National Academy of Sciences. Bunya et al. (2008) and Dietrich et al. (2008) document the development and validation of the coupled riverine flow, tide, wind, wave, and storm surge model for South Louisiana. Predictions had an uncertainty characterized by a standard deviation of 1.5 feet. For synthetic storms, the TC96 Planetary Boundary Layer (PBL) model (Thompson and Cardone 1996) is applied to construct a time-series of wind and atmospheric pressure fields for driving surge and wave models. For hindcasts of historical storms, the winds are typically constructed using data assimilation techniques as described by Bunya et al. (2008). The storm surge is modeled with ADCIRC (Luettich et al. 1992, Westerink et al. 1994, Luettich and Westerink 2004) which computes the pressure- and wind-driven surge component. In parallel with the initial ADCIRC simulation, the large-domain, discrete, time-dependent spectral wave generation model WAM (Komen et al. 1994) calculates directional wave spectra that serve as boundary conditions for the near-coast wave model STWAVE (Smith, Sherlock, and Resio 2001, Smith and Sherlock 2007). STWAVE calculates wave generation and transformation. The radiation stress fields calculated by STWAVE are applied as forcing to ADCIRC to estimate final water level. A complete description of the models is provided in USACE (2009) and in the chapter on numerical modeling of

Hurricane Isaac in this report.

Sensitivity analyses documented in this report are based on simulations executed from 2007 to 2012 as part of the LaCPR study, a storm surge modeling study of the Inner Harbor Navigation Canal (IHNC) barrier, the West Closure Complex (WCC) storm surge study, and the Mississippi River Levee (MRL) storm surge study. These studies have been conducted by the New Orleans District, their contractors, and the U.S. Army Engineer Research and Development Center, and were peer reviewed. A list of source material is provided at the end of this chapter.

LACPR Study (2007-2009)

As part of the LaCPR study, hydrodynamic modeling was performed to provide engineering based estimates on extreme surge and wave heights for evaluation of both existing (base) and alternative future conditions to the levee design (Source 1). The LaCPR 2010 base condition was part of this analysis and represented the proposed improvements to the HSDRRS that were expected to be completed by 2010. These included restoring the levees to their authorized levels and, in and around the metropolitan area of New Orleans, raising the levee heights to provide a 100-year level of protection; permanent gates and closures at the three outfall canals; and the IHNC surge barrier. It should be noted that the 2010 ADCIRC grid also included a non-overtopping levee around LaPlace, LA which is not part of the existing HSDRRS. The presence of this levee in the 2010 grid causes changes not associated with the HSDRRS as discussed in the next section.

A suite of storms was simulated with the state-of-the-art coastal ocean hydrodynamic modeling system on the LaCPR 2010 grid and a Joint Probability Method with Optimal Sampling (JPM-OS) analysis conducted to estimate 100-year water levels. An overview of the JPM-OS is provided in USACE (2009). The 100-year water level estimated from the 2010 grid can be compared to the 100-year water level estimates for the system in 2007. The 2007 grid was configured with levee elevations post Katrina but before the HSDRRS improvements to 100-year water levels. The 100-year water levels were simulated for LaCPR and FEMA flood mapping to assess the impact of major components of the HSDRRS improvements, including raising the Lake Pontchartrain and Vicinity (LPV) and West Bank and Vicinity (WBV) levees, and the barrier at the confluence of the IHNC, Gulf Intracoastal Waterway (GIWW), and the Mississippi River Gulf Outlet (MRGO).

Lake Pontchartrain Area

Figure 5.1 documents change in the 100-year water level between the 2007 and 2010 grids around the HSDRRS system in the Lake Pontchartrain area. The 100-year peak water levels increase by 0.2 feet or less on both the North and South shores on the Lake. In the vicinity of Slidell, LA 100-year water levels also increase by 0.2 feet or less. The largest differences around Lake Pontchartrain occur in St. John the Baptist Parish with increases in the 100-year water level as much as 0.6 feet. However, this increase is due to the presence of a proposed levee around La Place, LA that was included in the 2010 base grid and set to not overtop. Therefore, the increase at this location is not due to HSDRRS features. While the LaPlace levee was not intended to be part of the HSDRRS, it was included in LaCPR modeling runs to evaluate the value of such a proposed feature in the future.

IHNC Barrier Vicinity

Figure 5.2 documents change in the 100-year water level between the 2007 and 2010 grids around the HSDRRS system at the IHNC/GIWW, West Bank, St. Bernard, and Plaquemines Parish areas. The benefit of the IHNC barrier is clearly evident from this figure. Peak 100-year water levels are reduced by as much as 9.4 feet in the IHNC/GIWW. Figure 5.2 also shows an increase in the 100-year water level on the unprotected side of the barrier, but the area of increased water levels is relatively limited in spatial extent and is less than 0.5 feet outside the Golden Triangle marsh area immediately seaward of the barrier. Table 5.1 shows selected points with a description of the point location and the corresponding 100-year return period water level for the 2007 grid and the 2010 grid.

Table 5.1. 100-year return period water level for selected points - LACPR.

Description	Longitude	Latitude	100-year Water Level (ft, NAVD88 2004.65)	
			2007 grid	2010 grid
Braithwaite Vicinity	-89.879028	29.852369	17.3	17.8
Lake Borgne	-89.68755	30.00857	13.2	13.5
East of IHNC Barrier	-89.89189	30.01722	17.1	18
West of IHNC Barrier	-89.91771	30.00982	17.4	8.0
Inner Harbor Navigation Canal	-90.02742	30.00935	13.1	7.9
East Slidell Vicinity	-89.72583	30.164009	12.0	12.2
West Slidell Vicinity	-89.86615	30.248459	9.9	10.0
South Shore Lake Pontchartrain	-90.14263	30.02444	8.8	8.8
North Shore Lake Pontchartrain (near Mandeville)	-90.16120	30.37636	9.8	9.8

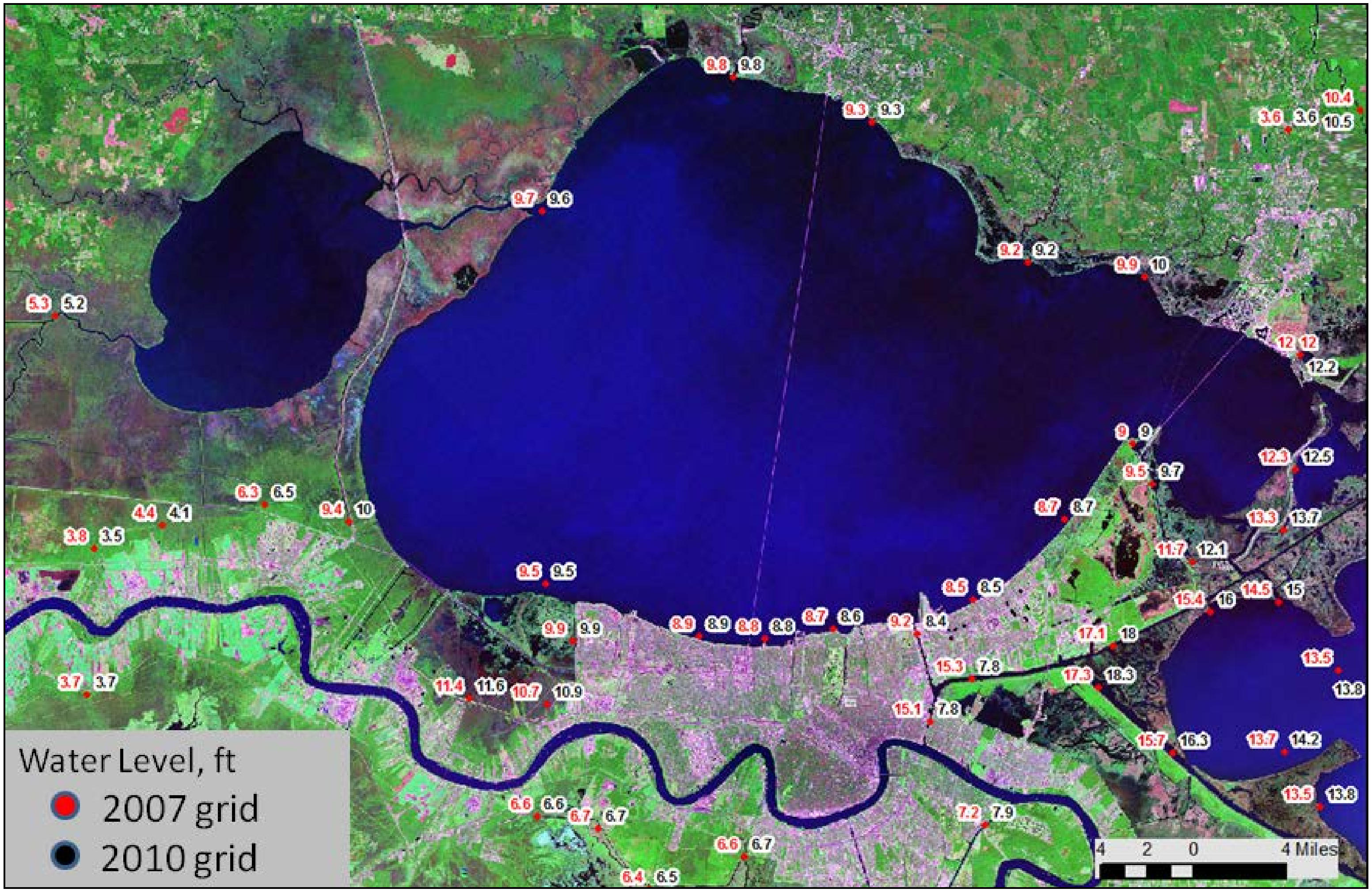


Figure 5.1. 100-year water level (ft, NAVD88 2004.65) on 2007(red) and 2010 (black) grids - Lake Pontchartrain area.

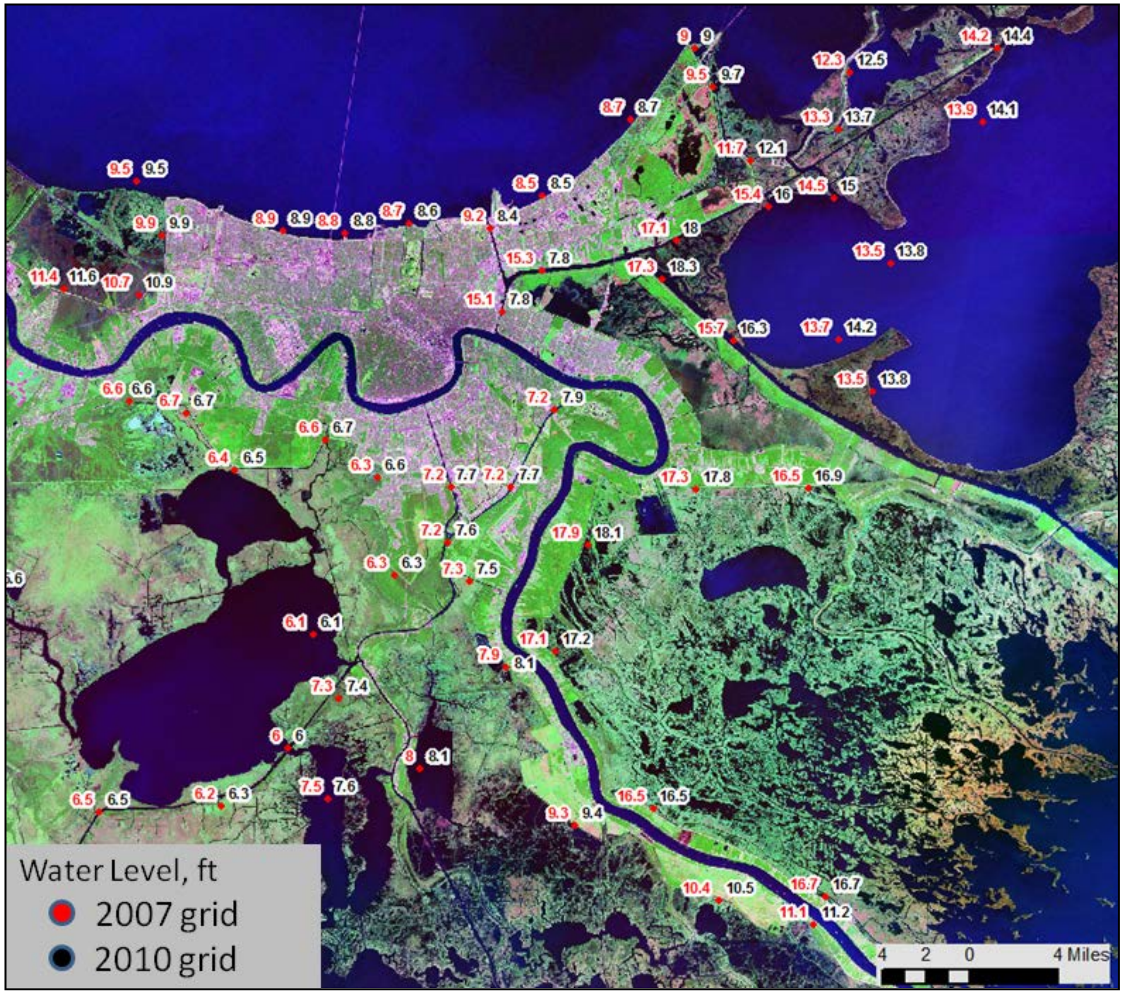


Figure 5.2. 100-year water level (ft, NAVD88 2004.65) on 2007 (red) and 2010 (black) grids – IHNC/GIWW, West Bank, St. Bernard, and Plaquemines.

Westbank

Figure 5.2 shows that increases in 100-year water levels along the Westbank between 2007 and 2010 grids range from 0.0 to 0.2 feet, with changes generally increasing as one moves from west to east. The 2010 grid did not include the WCC and 100-year water levels in the canals increased by as much as 0.7 feet. Sensitivity to the presence of the WCC is provided in a subsequent section of this chapter.

Plaquemines Parish

Figure 5.2 also shows that 100-year water levels increase by approximately 0.2 feet in northwest Plaquemines Parish south of Oakville. This conclusion was documented in the Addendum to the Draft Individual Environmental Report #13 (Source 2). As stated in the Addendum: "Analyses indicate that the WBV project may slightly increase the 1 percent annual chance-of-occurrence storm surge levels south of Oakville, by amounts of up to a few tenths of foot (i.e., up to several inches). The general trend is for the WBV storm surge increase to decrease the further distance south of the WBV projects one is. Differences south of Myrtle Grove/Alliance area are negligible. The small increased risk of flooding due to wave overtopping, which is attributable to the WBV project, exists primarily for lesser surge events, where the surge level is well below the top of the levee. In light of the low levee crest elevations, 5 to 7 feet, higher surge levels such as the 1 percent exceedence event surge level events can overwhelm the existing Plaquemines Parish non-Federal Levee system and completely flood the interior polder, regardless of any added increase in surge levels induced by the WBV project." In northeast Plaquemines, in the vicinity of Braithwaite, Figure 5.2 indicates that 100-year water levels increase by 0.2 to 0.5 feet. This increase is primarily due to raising the St. Bernard – Verret to Caernarvon levee and was documented in IER #9 (USACE 2010). However, it should be noted that this levee was higher than the adjacent Plaquemines Parish non-Federal levee elevations before it was raised for the HSDRRS. Differences in predicted water levels along the levees in southern Plaquemines Parish are 0.1 feet or less, essentially no change, as expected.

Mississippi Coast

Changes in 100-year water levels were also assessed on the Mississippi coast. Figure 5.3 plots the difference in 100-year water level between the 2010 levee configuration and the 2007 base grid for the entire 2010 storm suite. As can be seen in the figure, the change in the 100-year water level is 0.1 feet or less along the entire Mississippi coast.

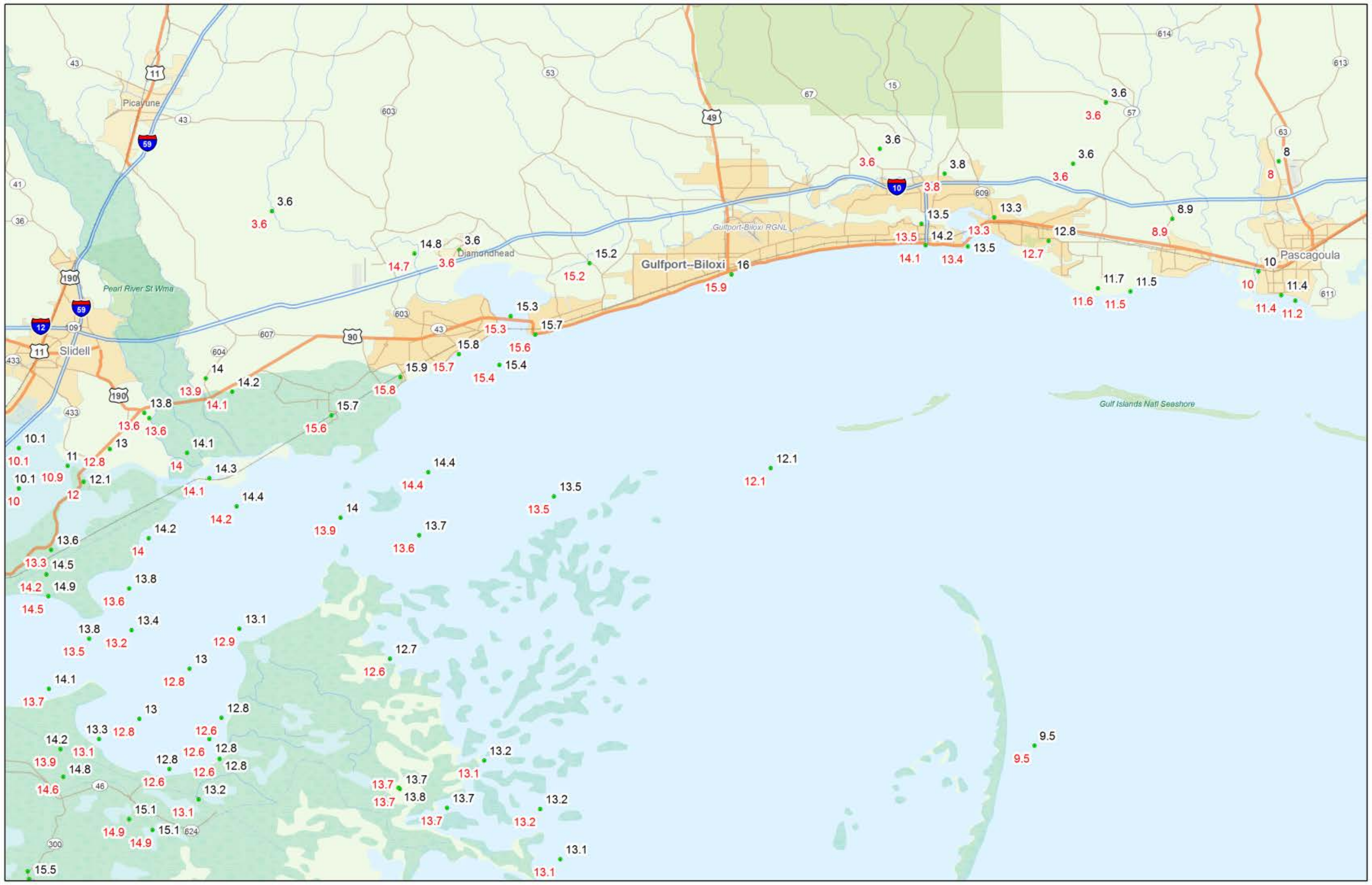


Figure 5.3. 100-year water level (ft, NAVD88 2004.65) on 2007 (red) and 2010 (black) grids – Mississippi Coast

Summary of LACPR Evaluation

The sensitivity analyses conducted from the LaCPR 2010 condition model simulations indicate that the HSDRRS components included reduce risk to the greater New Orleans area and reduces 100-year water levels in the IHNC/GIWW by more than 8 feet. These analyses also indicate that increases in 100-year water levels outside the system are typically less than 0.3 feet near the surrounding communities. The results of the LACPR evaluations have been presented to local officials and the public in numerous meetings. Most notable have been those held in St Tammany Parish, LA and Hancock County, MS beginning in May 2009 and continuing to as recent as July 2012.

IHNC Storm Surge Barrier Modeling Study (2011)

A detailed study was conducted to investigate the spatial and temporal extent of the effects of the proposed IHNC storm surge barrier on storm surge inundation in the area at the confluence of the IHNC, GIWW, and MRGO (Source 3). The study developed storm surge and wave data, including the 1 percent annual chance storm surge height, for the study area considering effects of the IHNC barrier. The modeling system for the IHNC study was established by fine-tuning existing models used previously for the LaCPR project, as well as the flood insurance rate map modernization study conducted by the FEMA (USACE 2008; Westerink et al. 2007a).

The base grid for the IHNC barrier analysis was the 2007 LaCPR and FEMA production grid. However, resolution was increased in the area adjacent to the barrier, including the MRGO, IHNC, GIWW, Bayou Bienvenue, and the Lake Borgne marsh area. In addition, multiple updates to the grid were made throughout St. John the Baptist Parish and Plaquemines Parish, including the Mississippi River delta. Due to these modifications, direct comparison to water levels computed on the 2007 grid is problematic as small (typically less than 0.5 feet) differences are expected as a result of changes in resolution and may not be related to changes in protective features. For these simulations, the proposed IHNC barrier was implemented with a 28-foot top-of-wall elevation (NAVD88 2004.65).

The 152 storm suite developed for the LaCPR and FEMA studies were simulated on the IHNC grid. Maximum water surface elevations for all 152 storms were utilized to produce water surface elevation return period information at 274 points. Table 5.2 shows selected points with a description of the point location and the corresponding 100-year return period water level for the 2007 and IHNC grids. Consistent with the LaCPR study, results indicate that the barrier reduces 100-year peak water levels in the IHNC/GIWW by more than 8 feet and increases in 100-year water levels

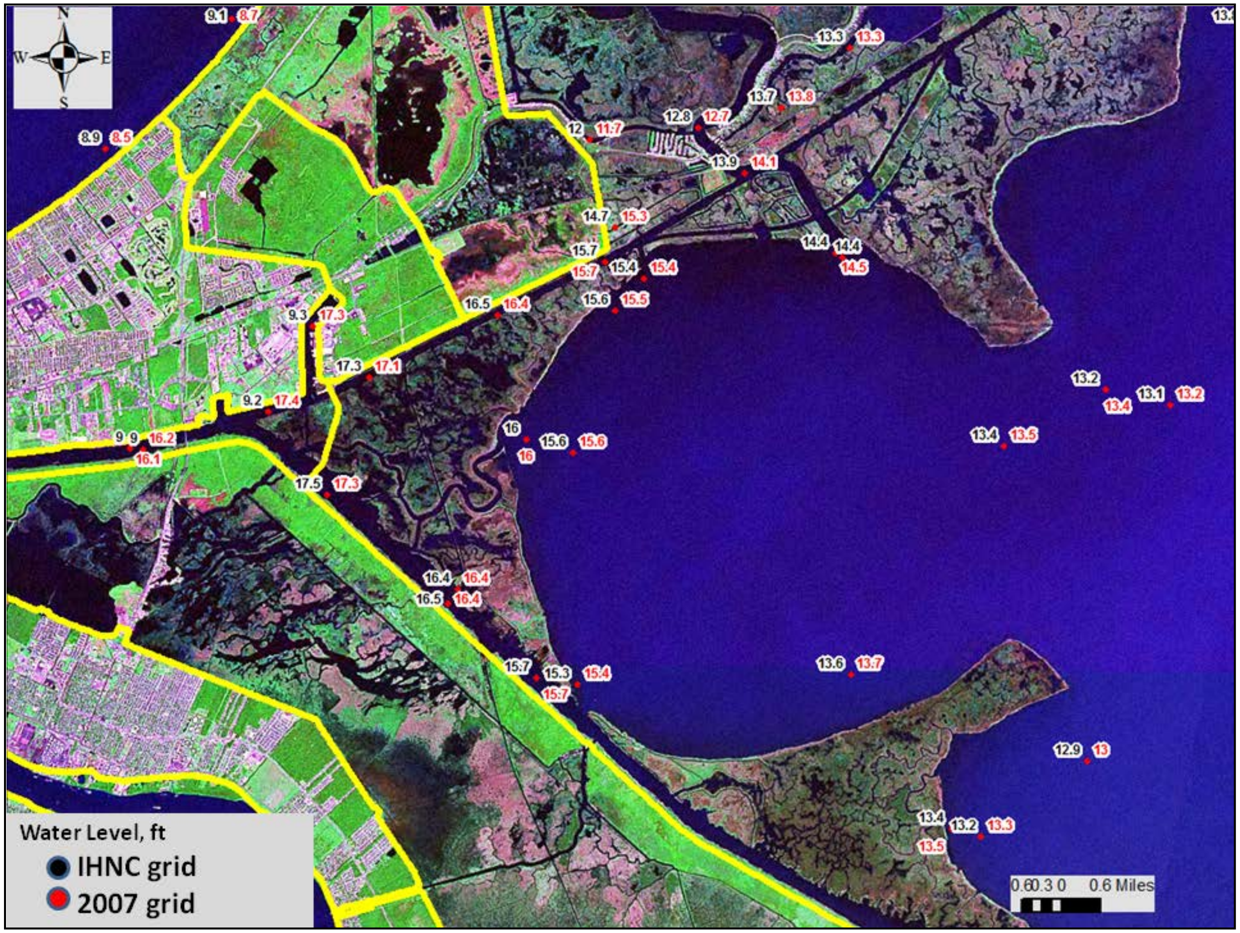


Figure 5.4. 100-year water level on 2007 (red) and IHNC (black) grids in the vicinity of the IHNC closure.

outside the system are less than 0.3 feet. The differences outside the system in regions relatively far from the IHNC barrier are small but slightly larger than those seen in the 2010 grid comparisons. The changes in the differences primarily result from the changes in grid resolution previously discussed.

Table 5.2. 100-year return period water level for selected points – IHNC Barrier.

Description	Longitude	Latitude	100-year Water Level, ft	
			2007 grid	IHNC grid
Braithwaite Vicinity	-89.879028	29.852369	17.3	17.4
Lake Borgne	-89.68755	30.00857	13.2	13.1
East of IHNC Barrier	-89.89189	30.01722	17.1	17.3
West of IHNC Barrier	-89.91771	30.00982	17.4	9.2
Inner Harbor Navigation Canal	-90.02742	30.00935	13.1	8.7
East Slidell Vicinity	-89.72583	30.164009	12.0	12.3
West Slidell Vicinity	-89.86615	30.248459	9.9	10.3
South Shore Lake Pontchartrain	-90.14263	30.02444	8.8	9.1
North Shore Lake Pontchartrain (near Mandeville)	-90.16120	30.37636	9.8	10.1

Figure 5.4 plots changes in the 100-year water level between the 2007 and IHNC grids in the vicinity of the IHNC barrier. These results can be compared to the sensitivity documented in Figure 5.2 and confirm the conclusions from the LaCPR study work that reductions in water level are attributable to the barrier in the IHNC/GIWW and increases on the unprotected side are limited in reach and on the order of 0.5 feet or less.

Hurricanes Ike and Gustav Sensitivity Analysis

A sensitivity analysis was also conducted to assess the impact of changes in the hurricane storm damage reduction system after Hurricane Katrina on water levels in the vicinity of Slidell, LA and Mississippi during Hurricanes Ike and Gustav (Source 4). For this analysis, major projects in the HSDRRS included the IHNC surge barrier and the Sea Brook surge barrier. Along with these new features, existing levees and floodwalls were raised to assure 1% chance exceedence risk reduction for greater New Orleans. The 2005 condition represents pre-Katrina conditions, with levee heights and alignments as they were in 2005. The 2011 grid included the features above as well as the WCC on the West Bank.

The ADCIRC model was run for Gustav and Ike on the pre-Katrina (2005) conditions grid and the 2011 conditions grid. Results were compared at save locations identified in Figure 5.5.

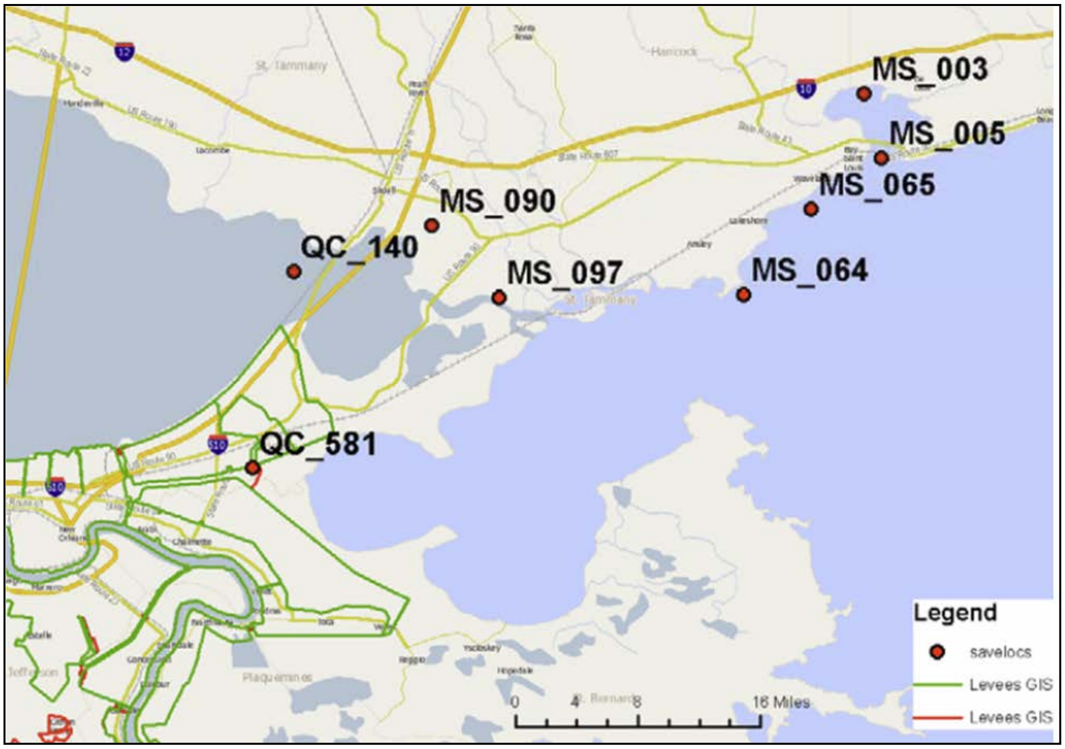


Figure 5.5. Save point set for Hurricanes Ike and Gustav sensitivity analysis.

Peak surge results at the 10 points for the 2005 and 2011 conditions for Hurricanes Ike and Gustav are summarized in Tables 5.3 and 5.4, respectively. The benefit of the IHNC barrier is again clearly evident at point QC-581, which is located on the protected side of the barrier. Outside the HSDRRS, there is a 0.2 foot or less increase in water level in the vicinity of Slidell, LA and even smaller differences in Hancock County, MS.

Table 5.3. Peak surge results for Hurricane Ike

Point ID	Peak Surge (ft. NAVD88 2004.65)		Difference (ft)	Percent Difference (%)
	2005	2011		
MS-003	5.80	5.82	0.01	0.22%
MS-005	5.68	5.69	0.01	0.23%
MS-047	5.20	5.21	0.01	0.13%
MS-064	5.84	5.87	0.02	0.38%
MS-065	5.81	5.82	0.01	0.24%
MS-069	4.64	4.65	0.01	0.13%
MS-090	5.22	5.16	-0.06	-1.13%
MS-097	5.73	5.76	0.04	0.64%
QC-140	5.21	5.11	-0.09	-1.82%
QC-581	6.87	1.21	-5.66	-82.42%

Table 5.4. Peak surge results for Hurricane Gustav

Point ID	Peak Surge (ft. NAVD88 2004.65)		Difference (ft)	Percent Difference (%)
	2005	2011		
MS-003	9.82	9.81	0.00	-0.04%
MS-005	9.48	9.48	-0.01	-0.05%
MS-047	8.70	8.68	-0.02	-0.20%
MS-064	9.35	9.36	0.01	0.10%
MS-065	9.67	9.66	0.00	-0.02%
MS-069	7.44	7.42	-0.02	-0.26%
MS-090	6.18	6.33	0.14	2.31%
MS-097	8.22	8.44	0.22	2.72%
QC-140	5.39	5.31	-0.08	-1.47%
QC-581	9.54	1.20	-8.34	-87.42%

Caernarvon Floodwall Evaluation (2010)

The Caernarvon Floodwall is a short piece of floodwall that ties the LPV alignment to the Mississippi River Levee (MRL) alignment at the St. Bernard and Plaquemines Parish line that was not included in the 2010 grid. An induced flooding analysis was conducted for this small feature of the HSDRRS (Source 5). Figure 5.6 shows the location of the Caernarvon Floodwall.

Several storms were simulated for design considerations. However, due to differences in the non-federal Braithwaite levee heights in the two grids, only storms with a surge elevation lower than the approximate 8 feet non-federal levee height at Braithwaite in the IHNC grid are applicable for an induced flooding analysis (Storms 032 and 035 from the LaCPR JPM-OS storm suite). The water level in the blue shaded area, which is the zone for which differences with and without the floodwall is greatest, is 5.4 feet for Storm 032 and 5.0 feet for Storm 035 with the floodwall in place. For the grid without the Caernarvon Floodwall (IHNC grid), the water in the blue shaded area is 5.7 feet for Storm 032 and 5.4 feet for Storm 035, suggesting that induced flooding is not attributable to the Caernarvon Floodwall as an increase in surge is not predicted by the model. This is consistent with the conclusions presented in IER #9 (USACE 2010). IER#9 refers to the floodwall as LPV-149 and the St. Bernard – Verret to Caernarvon levee as LPV-148 and states that "Construction of the new floodwall (approximately 1,500 feet) at LPV-149 would shift the alignment west into Plaquemines Parish by nearly 1,100 feet. The dimensions of the proposed LPV-149 levee alignment change are very small when compared to the scale on which differences in levee elevations and storm surge are observed. Therefore, minimally-increased water levels (in addition to those caused by LPV-148 in

Plaquemines Parish) would be expected from construction of the LPV-149 floodwall and gates under the proposed action."

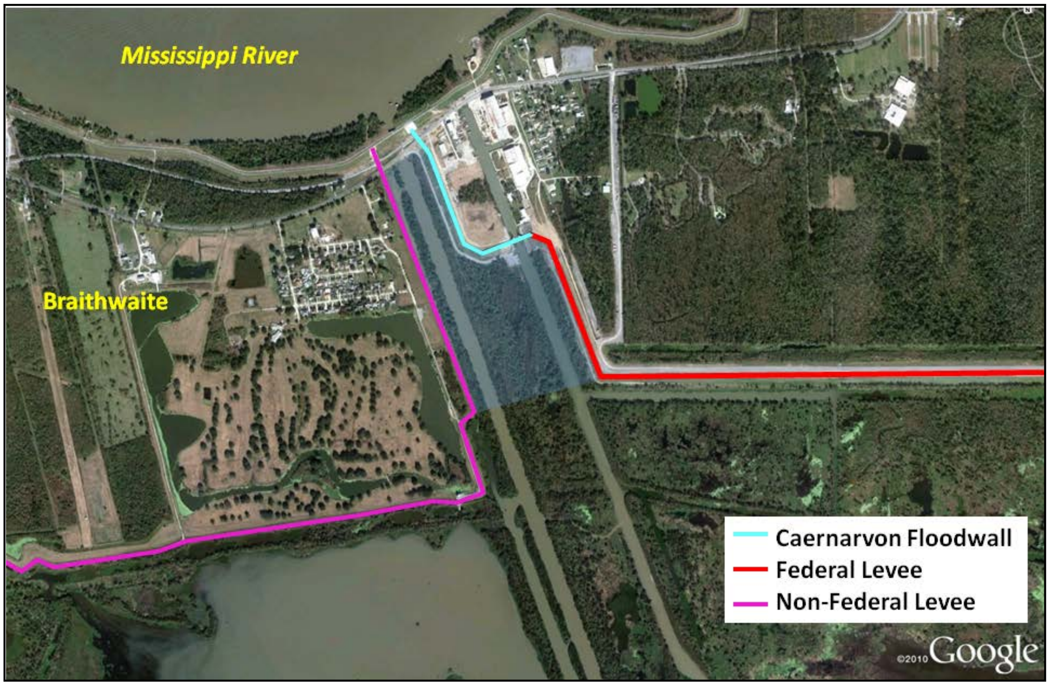


Figure 5.6. Caernarvon Floodwall Alignment.

Western Closure Complex Evaluation (2009-2012)

The Gulf Intracoastal Waterway West Closure Complex (WCC) is a key link in the hurricane risk reduction system of greater New Orleans. The purpose of the WCC is to reduce flooding north of the gate location during storm events. The WCC also includes the world's largest pump station, capable of pumping 20,000 cfs, which drains the interior canals of rainfall runoff. A sensitivity analysis was conducted in phases to examine any induced flooding from the WCC. Phase 1 examined change in peak water levels during storm surge events due to blocking of the canal (Source 6). Phase 2 examined the increase in stage due to the pump outflow at various points downstream from the WCC pump station (Source 7). Finally, the WCC was analyzed with historical storms Juan, Gustav, Isidore, and Lee (Source 8).

5.1.1 Storm Surge Analysis

The 2010 grid previously developed for LaCPR/FEMA was updated to include the WCC. Storm water levels were computed with the WCC project in place and compared with the results from the 2010 grid, which served as the base condition. A suite of 10 storms (003, 006, 008, 017, 050, 066, 069, 083, 101, and 160) was selected for simulation from the JPM-OS storm suite database. Storms were selected according to the following criteria:

1) three storms having a surge level corresponding to a 50-year water level in the vicinity of the WCC within +/- 0.5 feet;
2) three storms having a surge level corresponding to a 100-year water level in the vicinity of the WCC within +/- 0.5 feet;
3) three storms having a surge level corresponding to a 500-year water level in the vicinity of the WCC within +/- 0.5 feet; and lastly,
4) Storm 050 because the characteristics of that synthetic storm were most similar to recently occurring Hurricane Gustav (2008).

In general, the changes in maximum surge as a result of the WCC project are small for all storms simulated for areas south of the project floodgate, on the order of 0.2 feet or less. For the with-project condition, surge is prevented from propagating north of the floodgate into the Harvey Canal and Intracoastal Waterway. Instead, this volume of water is distributed over a much larger area south of the floodgate. For areas north of the WCC floodgate, the maximum storm surge is reduced by 2-11.5 feet in the Harvey Canal and Intracoastal Waterway, depending on the storm characteristics (such as track) and statistical surge level (return frequency). The maximum storm surge is reduced by 4-6 feet in the Harvey Canal and Intracoastal Waterway for those storms which produce the 50-year water level (Storm 003, Storm 066, and Storm 101), 4.5-7 feet for those storms which produce the 100-year water level (Storm 006, Storm 008, and Storm 160), and 7.5-11.5 feet for those storms which produce the 500-year water level (Storm 017, Storm 069, and Storm 083). For Storm 050 (Gustav-like storm), the maximum storm surge is reduced by 2-4 feet in the Harvey Canal and Intracoastal Waterway.

Six save locations were selected to examine the possibility of induced flooding on the seaward side of the closure. The save locations sites are shown in Figure 5.7 and the corresponding latitudes and longitudes are given in Table 5.5. Table 5.6 gives maximum surge values for each of the ten storms at the six save locations for base (2010) and with-project (WCC) conditions. Note that data marked "Dry" indicates the particular save locations did not inundate for a given storm event. For all of the six save locations, difference in maximum surge is small, on the order of 0.2 feet or less for all storms simulated. The average difference in maximum surge is 0.03 feet.

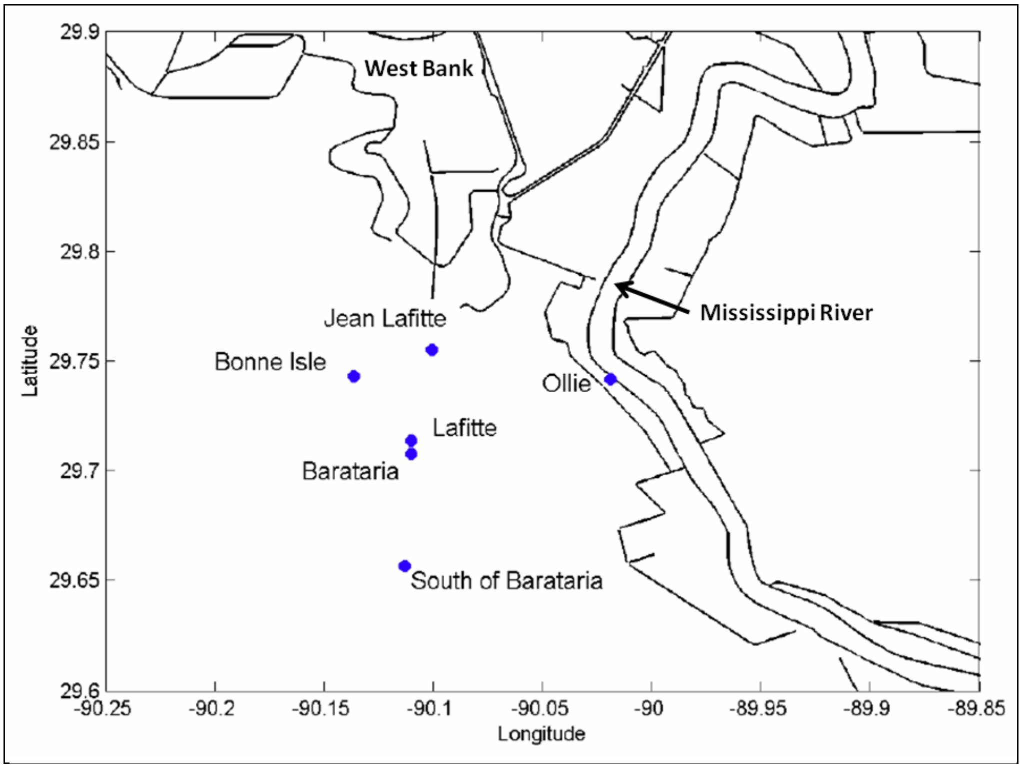


Figure 5.7. Location of WCC evaluation save points analyzed as part of the storm selection procedure. The background image is the base condition levee alignment.

Table 5.5. Coordinates for WCC save points.

Save Point	Name	Longitude	Latitude
1	South of Barataria	-90.112850000	29.656869444
2	Jean Lafitte	-90.100408333	29.755002778
3	Bonne Isle	-90.136361111	29.743013889
4	Lafitte	-90.110091667	29.713788889
5	Barataria	-90.110086111	29.708047222
6	Ollie	-90.018895800	29.741990400

Table 5.6. Maximum surge values at save locations for 2010 and WCC conditions and difference (WCC-2010). Stages (feet NAVD88 2004.65) for each of the ten storms at each of the six save locations for the base (2010) and with-project (WCC) conditions

Storm	South of Barataria			Jean Lafitte			Bonne Isle			Lafitte			Barataria			Ollie		
	2010	WCC	Diff	2010	WCC	Diff	2010	WCC	Diff	2010	WCC	Diff	2010	WCC	Diff	2010	WCC	Diff
003	5.8	5.8	0.0	5.1	5.2	0.1	4.7	4.7	0.0	5.6	5.6	0.1	5.7	5.7	0.0	5.0	5.0	0.0
006	7.6	7.6	0.0	6.8	6.9	0.1	6.1	6.2	0.1	7.3	7.3	0.0	7.4	7.4	0.0	6.4	6.4	0.0
008	7.8	7.8	0.0	6.9	7.0	0.1	6.3	6.3	0.1	7.4	7.4	0.0	7.6	7.6	0.0	6.4	6.5	0.1
017	11.2	11.2	0.0	10.8	10.8	0.0	8.4	8.6	0.2	11.2	11.2	0.0	11.3	11.3	0.0	12.6	12.6	0.0
050	4.7	4.7	0.0	4.1	4.1	0.0	3.6	3.6	0.0	4.4	4.4	0.0	4.6	4.6	0.0	Dry	Dry	0.0
066	5.3	5.3	0.0	5.3	5.4	0.1	4.7	4.8	0.1	5.4	5.4	0.0	5.5	5.5	0.0	5.3	5.3	0.0
069	10.5	10.5	0.0	11.0	11.1	0.1	9.7	9.8	0.1	10.8	10.9	0.1	10.9	10.9	0.0	12.3	12.3	0.0
083	10.2	10.2	0.0	10.1	10.2	0.1	9.8	9.8	0.0	10.0	10.0	0.0	10.1	10.1	0.0	10.1	10.2	0.1
101	6.0	6.0	0.0	5.2	5.3	0.1	4.7	4.8	0.1	5.7	5.7	0.0	5.8	5.8	0.0	5.0	5.0	0.0
160	7.9	7.9	0.0	7.8	7.9	0.1	6.3	6.4	0.1	7.9	7.9	0.0	7.9	8.0	0.0	9.1	9.2	0.0

5.1.2 Pump Impact Assessment

The purpose of this modeling effort was to quantify the increase in stage due to pump discharge at various points downstream from the WCC pump station. Simulations presented in the analysis were of a single hurricane that would produce approximately 3.0 feet of surge in the area of interest. This surge elevation was selected because it represents an approximate elevation at which structures begin to flood in communities located on the floodside of the WCC. The simulations provide one example of what could happen when 1% pumping occurs during hurricane conditions. Hydrology models (HEC-HMS) and pump records were used to determine the 1% rainfall runoff hydrograph with and without the WCC in place. This is the hydrograph that would result from the 100-year rainfall event. The with and without WCC conditions were simulated with no pumping, the 1% peak discharge occurring at peak surge, the 1% peak discharge occurring 12 hours before peak surge, and the 1% peak discharge occurring 24 hours before peak surge to give a total of eight simulations.

A subset of save points was chosen to provide model results for certain areas. Figure 5.8 shows the location of the subset of extracted points. These points were chosen to be representative of the communities located downstream of the WCC. Table 5.7 compares the peak surge elevation with and without the WCC condition for the eight simulations. The difference column is calculated as with the WCC stage minus the without WCC (base condition) stage, so a positive number would reflect an increase due to the WCC and a negative difference reflects a decrease due to the WCC. Table 5.7 provides the save-points sorted by distance from the WCC. Point 6 is closest to the barrier and point 247 is furthest away. The differences in stage between the existing and with-project condition are largest near the WCC.

Table 5.7. Results for With and Without-WCC, 1% Pump Discharge Hydrograph

	Peak Surge Elevation with No Pumping				Peak Surge Elevation with Peak Pumping Occurring at Peak Surge			
Point ID	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference
6	3.46	3.53	0.08	2.2%	5.61	5.45	-0.16	-2.9%
224	2.29	2.31	0.02	1.0%	3.02	3.10	0.08	2.7%
20	3.43	3.51	0.08	2.3%	5.12	4.92	-0.20	-3.9%
33	3.34	3.43	0.09	2.8%	4.95	4.77	-0.18	-3.6%
85	2.96	3.00	0.04	1.4%	3.22	3.26	0.04	1.2%
61	3.39	3.47	0.07	2.2%	4.11	4.03	-0.08	-1.9%
102	3.34	3.37	0.04	1.1%	3.44	3.48	0.04	1.2%
210	3.28	3.29	0.01	0.2%	3.30	3.31	0.01	0.3%
170	3.39	3.40	0.00	0.1%	3.40	3.40	0.00	0.1%
145	3.70	3.70	0.00	0.0%	3.70	3.70	0.00	0.0%
175	3.76	3.76	0.00	0.0%	3.76	3.76	0.00	0.0%
247	3.70	3.70	0.00	0.0%	3.70	3.70	0.00	0.0%

	Peak Surge Elevation with Peak Pumping Occurring -12.0 hrs Before Peak Surge				Peak Surge Elevation with Peak Pumping Occurring -24.0 hrs Before Peak Surge			
Point ID	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference
6	5.40	5.55	0.15	2.7%	5.27	5.58	0.31	**6.0%**
224	3.02	3.13	0.11	3.8%	3.08	3.23	0.15	4.9%
20	4.96	5.03	0.06	1.3%	4.80	4.99	0.19	3.9%
33	4.82	4.88	0.06	1.2%	4.55	4.80	0.25	5.5%
85	3.28	3.38	0.10	3.2%	3.25	3.36	0.11	3.3%
61	4.17	4.20	0.03	0.7%	3.96	4.18	0.21	**5.4%**
102	3.63	3.65	0.02	0.5%	3.64	3.69	0.05	1.3%
210	3.35	3.36	0.01	0.3%	3.38	3.39	0.02	0.5%
170	3.46	3.47	0.02	0.5%	3.52	3.54	0.02	0.6%
145	3.71	3.72	0.01	0.3%	3.78	3.81	0.02	0.7%
175	3.76	3.77	0.01	0.2%	3.81	3.83	0.02	0.5%
247	3.70	3.71	0.00	0.1%	3.74	3.75	0.01	0.3%

For the storm simulated, the largest increase in water level occurs near the barrier at point 6, with a 0.3 feet (6%) increase in peak water surface for the with-WCC and a 24 hr pump discharge lag time. Points 85, 61, 102, 210, 170, 145, 175, 247 were selected to represent the communities downstream of the WCC. At these locations, the maximum increase in stage for with-WCC is 0.2 feet (5.4%). At most points, the increase is less than 0.1 feet. The largest increase in stage happens when peak pumping occurs 24 hrs before peak surge.

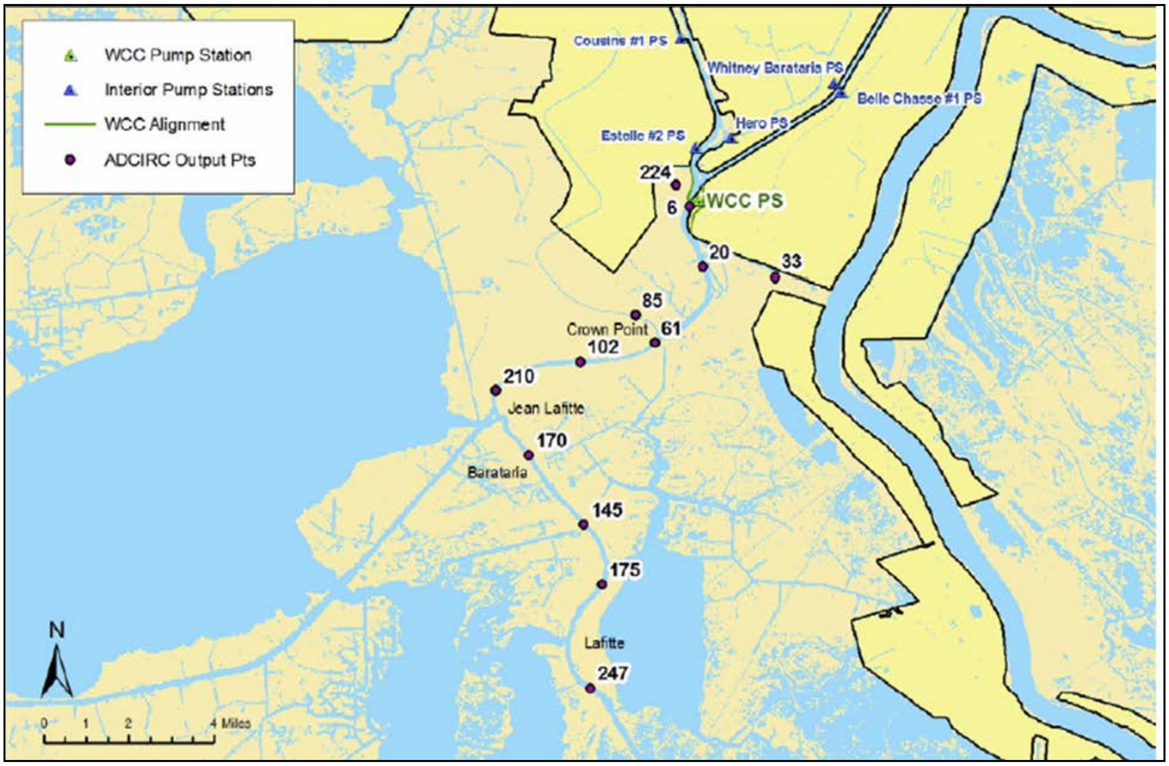


Figure 5.8. Location of pump analysis save points.

Pump Analysis for Historical Storms

The performance of the WCC was also evaluated for several historic storms with high impact on the West Bank. In this analysis, hydrology and surge models were validated with observational data from the historic storms and then a sensitivity analysis was performed to determine if any increase in water level would have been experienced if the WCC was in place. The storms simulated were Hurricane Juan (1985), Hurricane Isidore (2002), Hurricane Gustav (2008), and Tropical Storm Lee (2011). The save locations for these analyses are consistent with the set plotted in Figure 5.8. Details on the model setup, execution, and validation are provided in Source 8.

Table 5.8 compares peak surge elevation for the with- and without-WCC condition for four historical storm simulations with pump hydrograph forcing. The difference column is calculated as with-WCC stage minus without-WCC stage, so a positive number would reflect an increase due to the WCC and a negative difference reflects a decrease due to the WCC. Table 5.8 provides the save points sorted by distance from the WCC. Point 6 is closest to the barrier and point 247 is furthest away. Differences in stage between the with- and without-WCC are again largest near the WCC.

Table 5.8. Historic Storm Peak surge results with and without WCC.

	Hurricane Juan 1985				Hurricane Isidore 2002			
Point ID	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference
6	5.10	5.37	0.27	5.3%	3.34	3.84	0.50	14.8%
224	3.93	3.97	0.04	0.9%	2.10	2.11	0.02	0.8%
20	4.94	5.12	0.18	3.7%	3.29	3.66	0.37	11.2%
33	4.85	4.96	0.11	2.2%	3.20	3.59	0.39	12.3%
85	4.01	4.03	0.01	0.4%	2.49	2.50	0.01	0.4%
61	4.73	4.78	0.04	0.9%	3.15	3.29	0.13	4.1%
102	4.31	4.30	-0.01	-0.2%	2.96	2.99	0.02	0.7%
210	4.05	4.04	-0.01	-0.3%	2.86	2.86	0.00	0.1%
170	4.19	4.19	0.00	0.1%	2.94	2.94	0.00	0.0%
145	4.49	4.50	0.01	0.2%	3.00	3.00	0.00	0.1%
175	4.51	4.52	0.01	0.2%	2.95	2.96	0.00	0.1%
247	4.33	4.34	0.01	0.1%	2.84	2.84	0.00	0.0%

	Hurricane Gustav 2008				Tropical Storm Lee 2011			
Point ID	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference	Without-WCC Peak SWL (ft. NAVD88 2004.65)	With-WCC Peak SWL (ft. NAVD88 2004.65)	Difference (ft)	Percent Difference
6	4.93	5.44	0.51	10.4%	4.20	4.60	0.40	9.6%
224	2.72	2.87	0.15	5.7%	2.99	3.05	0.05	1.8%
20	4.63	5.04	0.41	8.9%	4.14	4.39	0.25	6.0%
33	4.53	4.91	0.38	8.3%	4.15	4.34	0.18	4.4%
85	3.17	3.27	0.10	3.0%	3.33	3.36	0.03	0.9%
61	4.11	4.27	0.16	3.9%	3.97	4.04	0.07	1.8%
102	3.60	3.67	0.07	2.0%	3.70	3.73	0.03	0.8%
210	3.13	3.16	0.03	0.9%	3.49	3.49	0.00	0.1%
170	3.36	3.39	0.02	0.7%	3.55	3.56	0.01	0.2%
145	3.68	3.67	0.00	-0.1%	3.61	3.62	0.00	0.1%
175	3.82	3.81	0.00	-0.1%	3.65	3.65	0.00	0.1%
247	3.78	3.77	0.00	-0.1%	3.53	3.53	0.00	0.1%

For all four storms, the modeling shows a relatively small increase in peak water level near the barrier induced by construction and operation of the WCC. At point 6, immediately adjacent to the WCC and not near a community, the peak water level increases approximately 0.3 to 0.5 feet due to construction and operation of the WCC. Increase in peak water level was concentrated near the barrier. The largest percentage increase occurs at point 6 for Hurricane Isidore, with a 0.5 feet (14.8%) increase in peak water surface due to operation of the WCC. Points 85, 61, 102, 210, 170, 145, 175, 247 were selected to represent the communities identified in Figure 5.8 downstream of the WCC. At these locations, the maximum increase in stage due to operation of the barrier was 0.1 feet (a 3.0% increase) for Hurricane Gustav. At most points, maximum increase in stage was less than 0.1 feet.

List of Prior Reports and References

Source List

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6.0 HURRICANE ISAAC MODEL SIMULATIONS

Chapter Summary

The purpose of this chapter is to document model simulations of Hurricane Isaac with and without the 2012 100-year HSDRRS in place to make a preliminary estimate of changes in water levels within communities outside the risk reduction system. The purpose of the work documented in this chapter is to provide preliminary assessment of the model performance given that the data at the time of producing this report is provisional. When the data is finalized, a formal validation process will be conducted for Hurricane Isaac. The measured data available is provisional and the wind and pressure data to force the model is preliminary. The modeling system applied for the analyses documented in this chapter was initially developed as part of the Interagency Performance Evaluation Task Force (IPET) work to examine the response of the southeast Louisianan hurricane protection system to Hurricane Katrina. It is the system applied for the Louisiana Coastal Protection and Restoration (LACPR) (USACE 2009) as well as the FEMA flood mapping study for Louisiana (Westerink et al. 2007a). Extensive peer reviews have been conducted on the modeling work including reviews by the distinguished External Review Panel of the American Society of Civil Engineers, and the National Academy of Sciences.

A preliminary assessment of the model made through comparison of measured data to model predictions indicates the model does reasonably well in simulating the effects of Hurricane Isaac across southeast Louisiana and Mississippi. The greatest differences are in Breton Sound. The model over predicts water levels at the upper end of Caernarvon marsh near Braithwaite by as much as approximately 3 feet.

A sensitivity analysis was conducted to determine the impact that the 100-year HSDRRS features had on water levels within and at communities outside the system. A sensitivity analysis compares results between two simulations to determine the change caused by a specific parameter or system modification of interest. Therefore, the grid to which the 2012 100-year HSDRRS simulation water level estimates are compared was built to only reflect changes in the 100-year HSDRRS, thereby isolating the impact of the 100-year HSDRRS features and levee elevations. No other landscape or resolution changes were made to the model grid. In general, for Isaac simulations water levels are relatively higher in Breton Sound and lower in Lake Pontchartrain with the HSDRRS in place. The differences between the with and without 2012 100-year HSDRRS condition are generally 0.2 feet or less. The largest difference is an increase in water level of approximately 0.8 feet in the immediate vicinity of the Western Closure Complex but diminishes significantly to 0.4 feet at Crown Point and 0.2 feet or less at other communities in the area. The Western Closure Complex and the raising of the WBV levees prevented water from entering the West Bank polder and increased water levels on the seaward side of the HSDRRS. These features, along with the Eastern Tie-In also resulted in a 0.5 foot increase in water elevations at the levees on the west bank of Plaquemines just south of Oakville. Water levels at Crown Point increase by approximately 0.4 feet. Increases in water level along the majority of the West Bank and further south in Barataria basin are 0.2 feet or less.

Since the model over-estimates the surge height by nearly 3.0 feet near Braithwaite, the sensitivity analysis results at this location likely over estimate the increase in water level due to the HSDRRS as the over prediction by the model resulted in the levees for the Without HSDRRS simulations to overtop. The conveyance of water over the levee into the St. Bernard polder likely reduces estimated peak water levels for the Without HSDRRS condition that would not have occurred if estimated water levels at this location would have matched measured high water marks. Regardless, the increase was still generally only about 0.1 feet. Finalizations of the wind field and model validation will likely improve model predictions in this area and further analysis can then be conducted.

For Hurricane Isaac water levels on the north and south shores of Lake Pontchartrain as well as in LaPlace and throughout West Shore Lake Pontchartrain were all estimated to be reduced due to the presence of the HSDRRS. This results from the IHNC barrier eliminating conveyance from Breton Sound to Lake Pontchartrain through the IHNC.

Model Input and Simulations

6.1.1 Introduction

Hurricane Isaac's impacts to the coastal Louisiana area were considerable. The HSDRRS prevented storm surge from inundating areas within its system, but flooding occurred in areas without federal levee systems including, but not limited to, Slidell, Mandeville, Madisonville, LaPlace, Braithwaite, and Lafitte. As this was the first major test of the HSDRRS system, concerns have been raised that the system caused unintended induced flooding to some communities outside the HSDRRS. The purpose of this chapter is to document model simulations of Hurricane Isaac with and without the 2012 100-year HSDRRS in place to make a preliminary estimate of changes in water levels at communities outside the risk reduction system. It should be noted that this is a sensitivity analysis based on the best available data and was conducted in less than three weeks. The purpose of the work documented in this chapter is not to validate a storm surge model for Hurricane Isaac and should not be interpreted as absolute values. Measured data available is provisional and the wind and pressure data to force the model is preliminary. The purpose is to perform model simulations to help understand how the presence of 100-year HSDRRS features may have modified surge propagation and increased or decreased water levels within and at communities outside the system.

6.1.2 Overview of Modeling System

The modeling system applied for the analyses documented in this chapter was initially developed as part of the Interagency Performance Evaluation Task Force (IPET) work to examine the response of the southeast Louisianan hurricane protection system to Hurricane Katrina. It is the system applied for the Louisiana Coastal Protection and Restoration (LACPR) (USACE 2009) as well as the FEMA flood mapping study for Louisiana (Westerink et al. 2007a). Extensive peer reviews have been conducted on the modeling work including reviews by the distinguished External Review Panel of the American Society of Civil Engineers, and the National Academy of Sciences. Bunya et al. (2008) and Dietrich et al. (2008) document the development and validation of the model for South Louisiana. Predictions applying a "best-estimate" wind field crafted by experts to assimilate all the observations of the hurricane had an uncertainty characterized by a standard deviation of 1.5 feet.

Realistic coastal storm modeling requires the integration of several complex and sophisticated numerical models. The US Army Corps of Engineers Engineer and Research Development Center's (ERDC) Coastal Storm Modeling System (CSTORM-MS) (Massey et al. 2011) includes a tropical planetary boundary layer model, TC96 MORPHOS-PBL (Thompson and Cardone, 1996), to generate the cyclone wind and pressure fields. Winds can also be simulated with the Holland wind models (Holland 1980, Fleming et al. 2007, and Mattocks and Forbes 2008). For hindcasts of historical storms, winds can be constructed using data assimilation techniques as described by Bunya et al. (2008). The storm surge and current fields are modeled with the ocean hydrodynamic model ADCIRC (Luettich et al. 1992, Westerink et al. 1993, Luettich and Westerink 2004) which computes the pressure- and wind-driven surge component. The regional and nearshore ocean wave models, WAM (Komen et al 1994) and STWAVE (Smith et al 2001) generate the wave fields.

In Figure 6.1 the workflow of a typical CSTORM simulation is given. The wind and pressure fields are input to all the other models as a primary forcing function. The wave model WAM generates the deepwater waves which provide boundary forcing conditions to the nearshore wave model STWAVE. Within CSTORM-MS, ADCIRC and STWAVE are tightly-coupled to each other. Tightly coupled means that the two models are able to communicate and share information with each other via computer memory without the use of file input/output.

Figure 6.2 shows the set of domains applied for this analysis. The ADCIRC domain covers the largest area and allows for basin-to-basin and basin-to-region transference without crossing computational boundaries. The PBL and WAM domains cover the Gulf of Mexico in order to allow the storm surge generation ample room. The STWAVE domains cover the smallest areas and represent key areas of interest for storm surge results. The ADCIRC mesh has unstructured triangular finite elements that range in size from approximately 60 km in the deep waters along the boundary in the Atlantic down to 30 meters in the canals in the New Orleans, Louisiana area. The PBL model uses an outer nest cell size of 0.05 degrees. WAM uses a grid cell size of 6 minutes. STWAVE uses cell sizes of 200 meters.

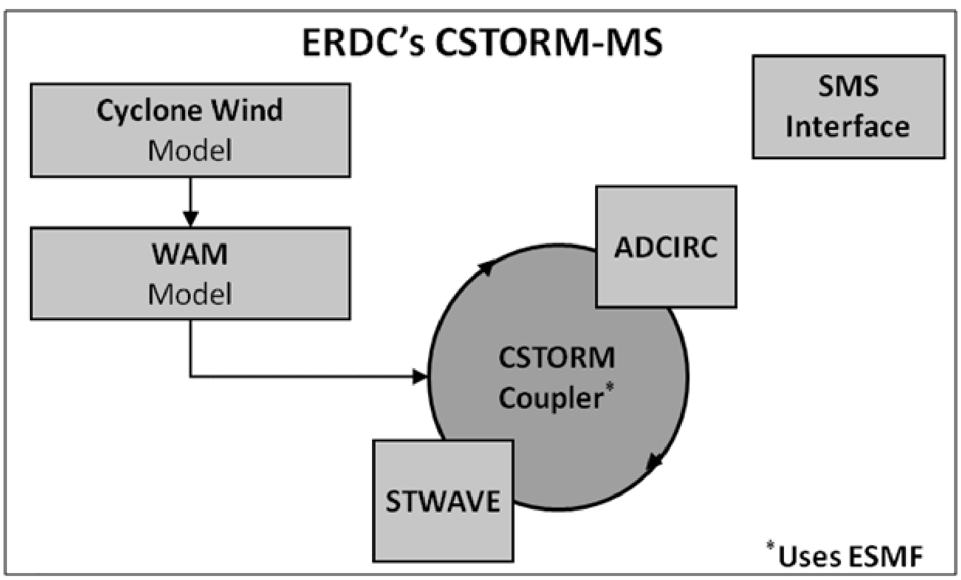

Figure 6.1 Flow chart for the spiral one version of ERDC's CSTORM-MS.

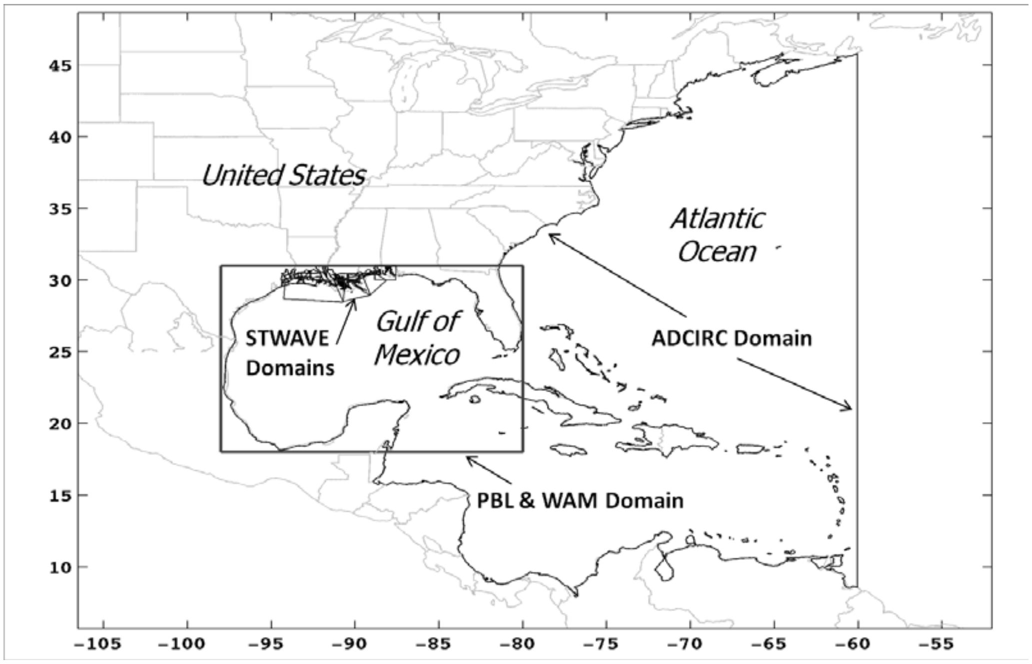

Figure 6.2 Model domains for simulation.

Wind and Pressure Fields

The atmospheric modeling components provide the dominant driving force for coastal storm simulations. The accuracy of modeled waves, surges, and morphologic response is critically dependent on the accuracy of the wind and pressure fields used to force the coastal processes models. It is possible to use a variety of wind products including modeled, measured or hindcast winds.

For hindcasts of actual historical storms such as Isaac, winds are typically constructed by an expert meteorologist through a careful and time consuming process of assimilating best available data collected during the storm into the calculation of the wind and pressure fields (as described in Bunya et al.2008). Due to the compressed time line for the present study, winds of this quality are not available. Three atmospheric forcing products were evaluated for the hindcast of Hurricane Isaac based on the best available data at the time the wind and pressure fields were created. Wind and pressure fields were computed with the dynamic asymmetric Holland Model (Holland 1980, Fleming et al. 2007, and Mattocks and Forbes 2008), the TC96 MORPHOS-PBL (Thompson and Cardone, 1996), and a product developed with data assimilation techniques from preliminary, best available data. The data assimilation wind and pressures applied the MORPHOS-PBL model with analysis of track and storm parameters from real time data sources obtained from the National Hurricane Center and Hurricane Research Division. Model output was blended into a background wind and pressure field provided by the Global Forecast System global model obtained from the

National Center for Environmental Prediction. Figures 6.3a to 6.3c show a comparison of the computed winds with measured winds for all three products at three offshore stations. The figures show that the data assimilated wind product (PBL + Data) provides the best agreement with the measured data at all stations. The data assimilated winds were therefore selected to force the wave and storm surge model simulations.

These wind products are marine-exposure at a 10-m elevation and do not take into account land effects on winds, which can be important to calculations for surge and waves in the nearshore. Rotating winds that impact land with trees, shrubs, buildings, etc are necessarily reduced in magnitude. ADCIRC has a spatially varying input parameter file that specifies physically relevant conditions related to the terrain features in the domain. The features include such parameters as Manning's n friction values, surface submergence states, surface canopy coefficients and surface directional effective roughness length which is described in the ADCIRC user's guide (available at http://adcirc.org) as a measure of the "roughness" of the land that can impede wind flow and reduce the surface wind stress. ADCIRC reduces wind magnitudes based on land use information for calculations within ADCIRC and also passes the wind fields to STWAVE.

The winds measured at nearshore stations were compared to the data assimilated winds once they were modified by ADCIRC. These comparisons are provided in the model assessment section (Figures 6.9a, 6.9b, and 6.9f) along with a comparison of atmospheric pressure (Figure 6.9f) and water level at the same stations. Additional model assessment plots comparing winds are available in Appendix A.

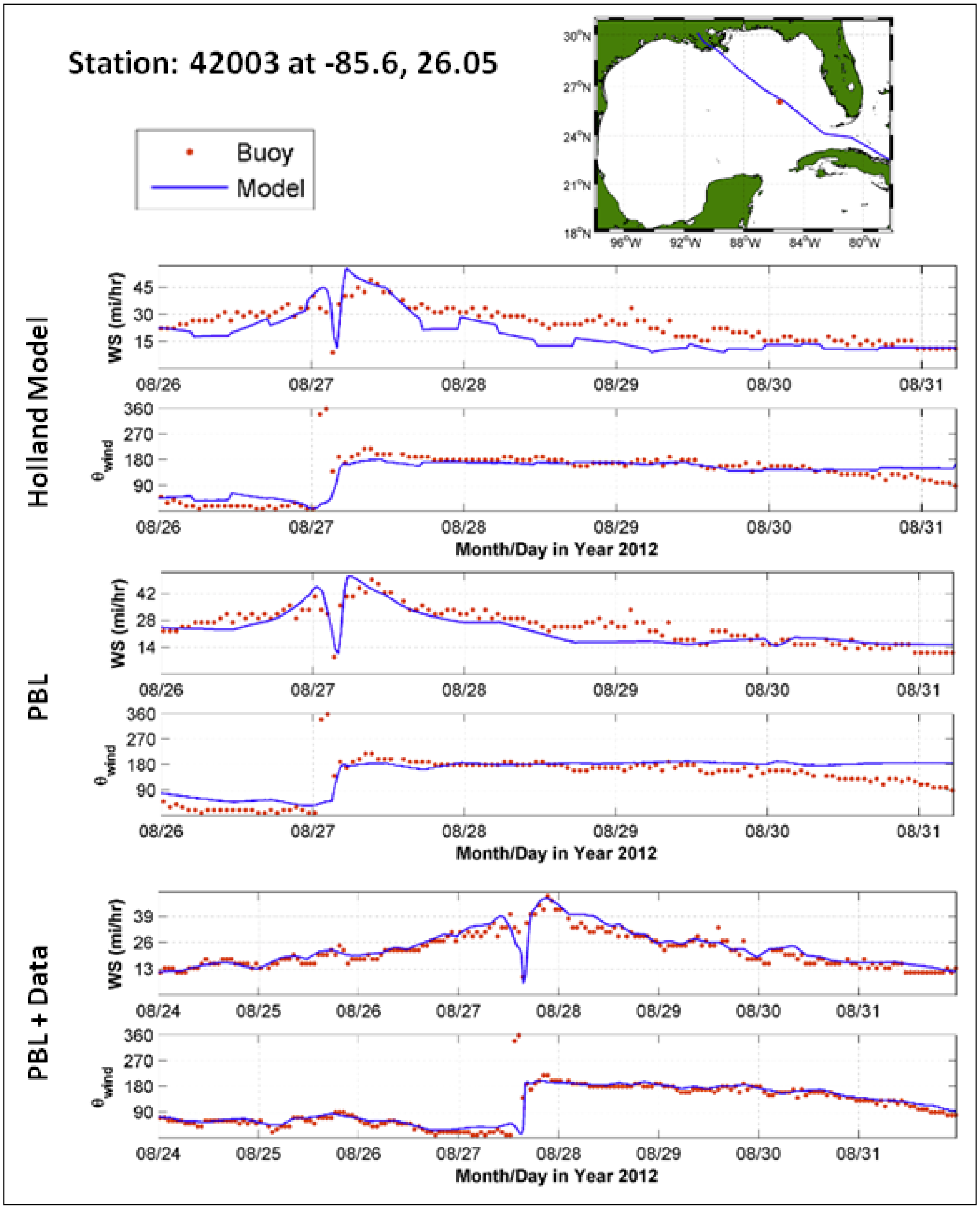

Figure 6.3a Comparison of measured (red dot) and modeled (blue) wind speed (WS) and direction (θ_{wind}) at Station 42003 for the Holland, PBL, and data assimilated wind products. Datum: NAVD88.

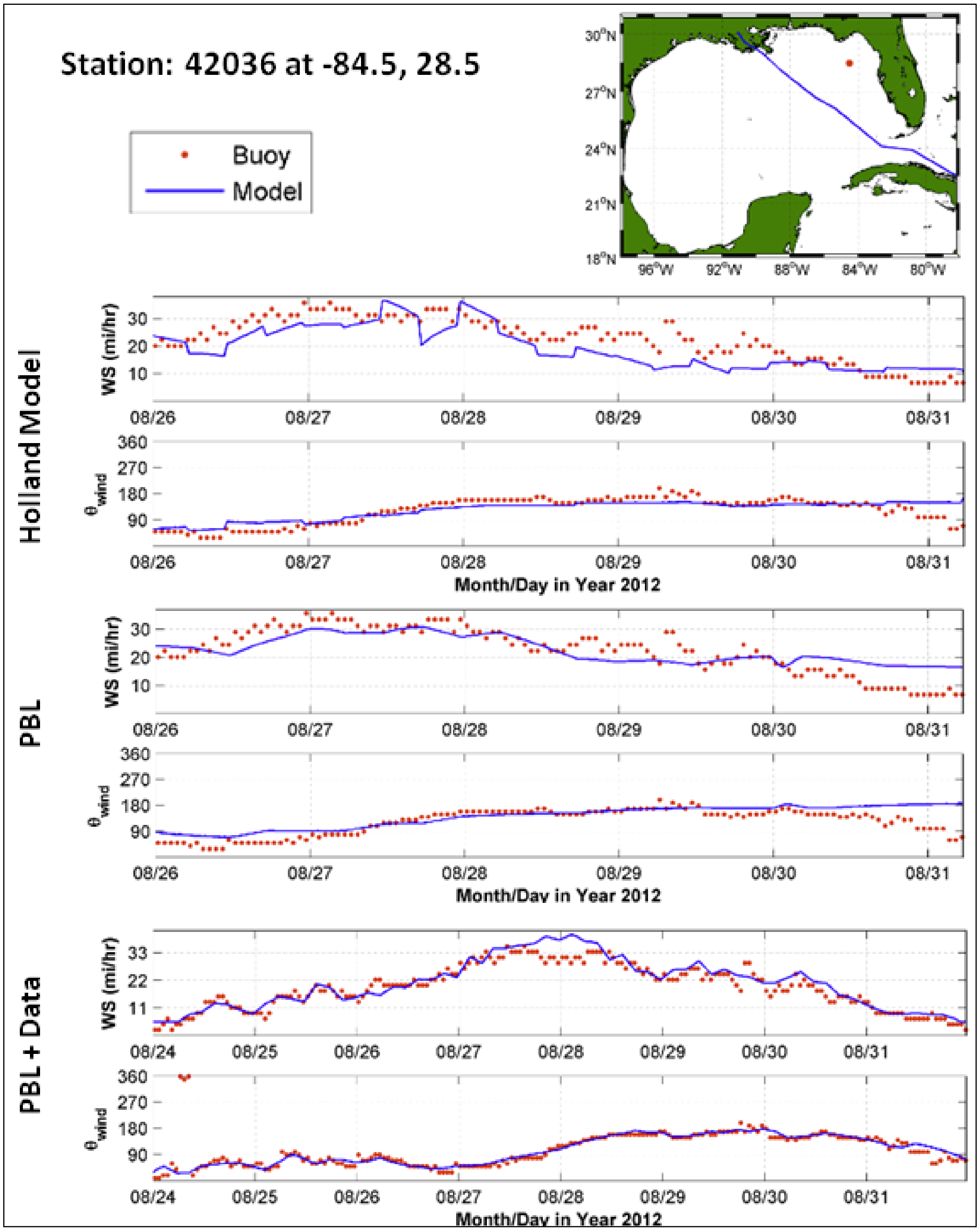

Figure 6.3b Comparison of measured (red dot) and modeled (blue) wind speed (WS) and direction (θ_{wind}) at Station 42036 for the Holland, PBL, and data assimilated wind products. Datum: NAVD88.

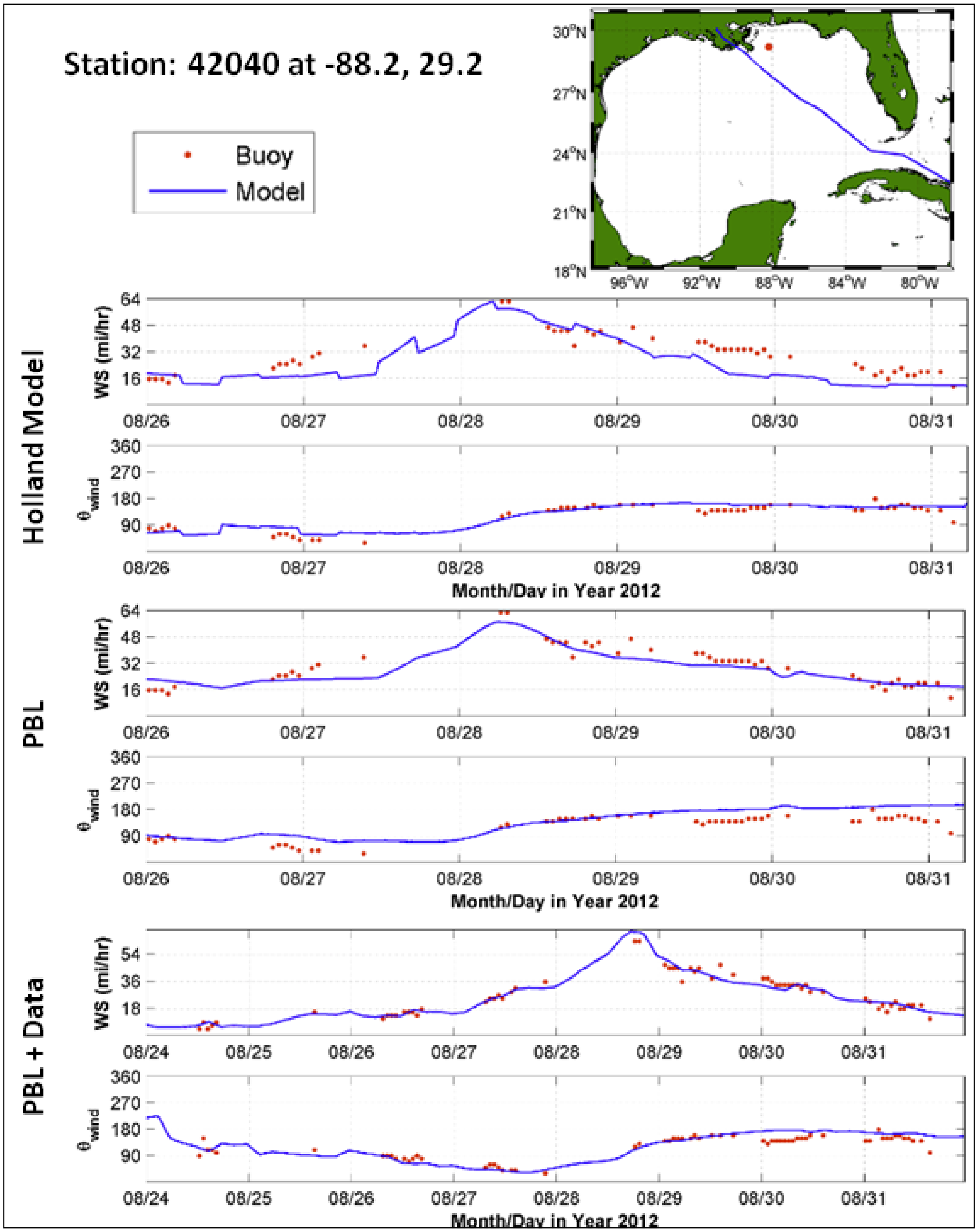

Figure 6.3c Comparison of measured (red dot) and modeled (blue) wind speed (WS) and direction (θ_{wind}) at Station 42040 for the Holland, PBL, and data assimilated wind products. Datum: NAVD88.

Offshore Waves

The generation of the wave field and directional wave spectra for Hurricane Isaac is based on the implementation of a third generation discrete spectral wave model WAM (Komen et al, 1994). This model solves the action balance equation for the spatial and temporal variation of wave action in frequency and direction, over a fixed longitude latitude grid. The advection term is solved first accounting for the propagation of wave energy. After every propagation step, the solution to the time rate change of the action density is solved including the source term integration. The wind field is read, and the atmospheric input source is applied. The nonlinear wave-wave interaction source term is the mechanism that self-stabilizes the spectral energy, transferring portions of the energy to the forward face and high frequency tail. Dissipation removes portions of energy that become too energetic for the given frequency band. For application in arbitrary depths, energy is removed via the wave-bottom sink. In very shallow water, the spectrum releases much of its available energy due to breaking. A more complete theoretical derivation and formulation of the source terms can be found in Komen et al. (1994).

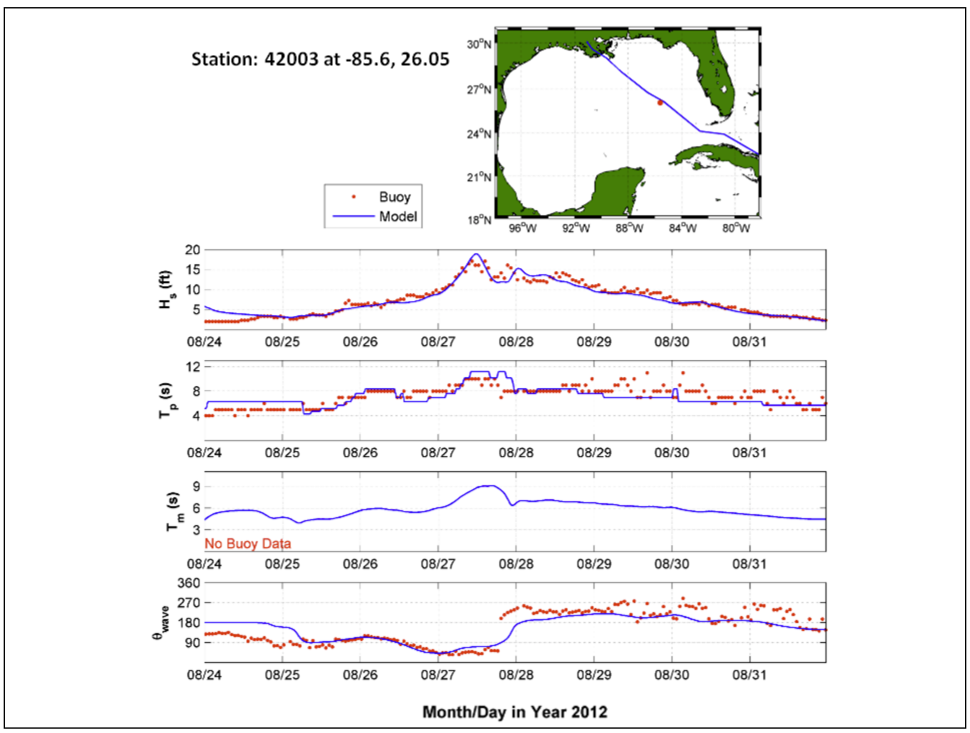

Figure 6.4a Comparison of measured (red dot) and modeled (blue) significant wave height (H_s), peak period (T_p), mean period (T_m), and direction (θ_{wave}) at Station 42003. Datum: NAVD88.

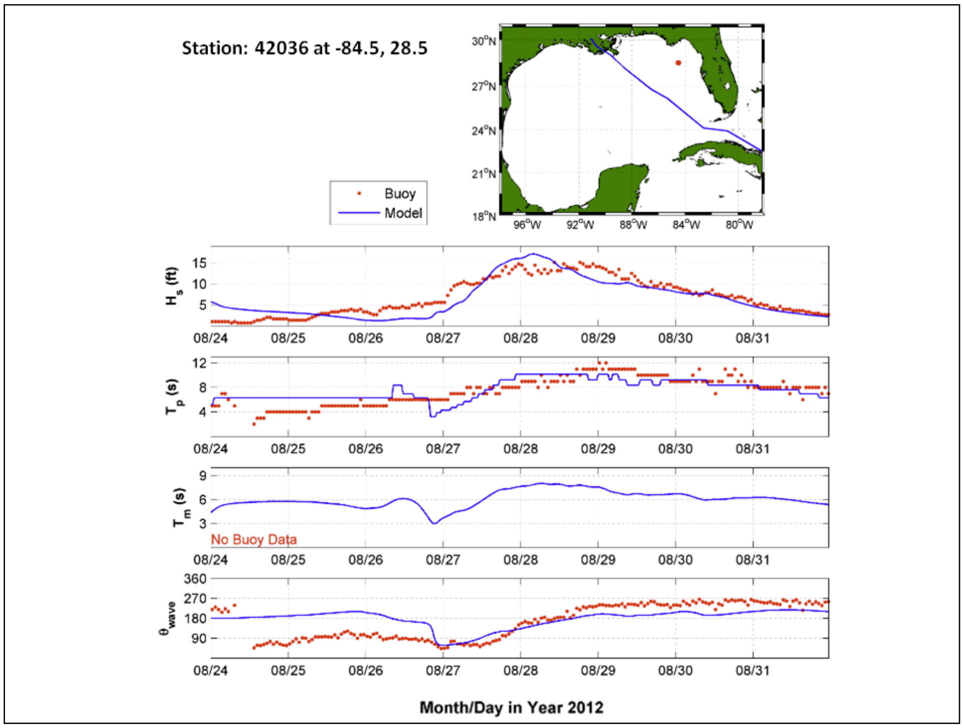

Figure 6.4b Comparison of measured (red dot) and modeled (blue) significant wave height (H_s), peak period (T_p), mean period (T_m), and direction (θ_{wave}) at Station 42036. Datum: NAVD88.

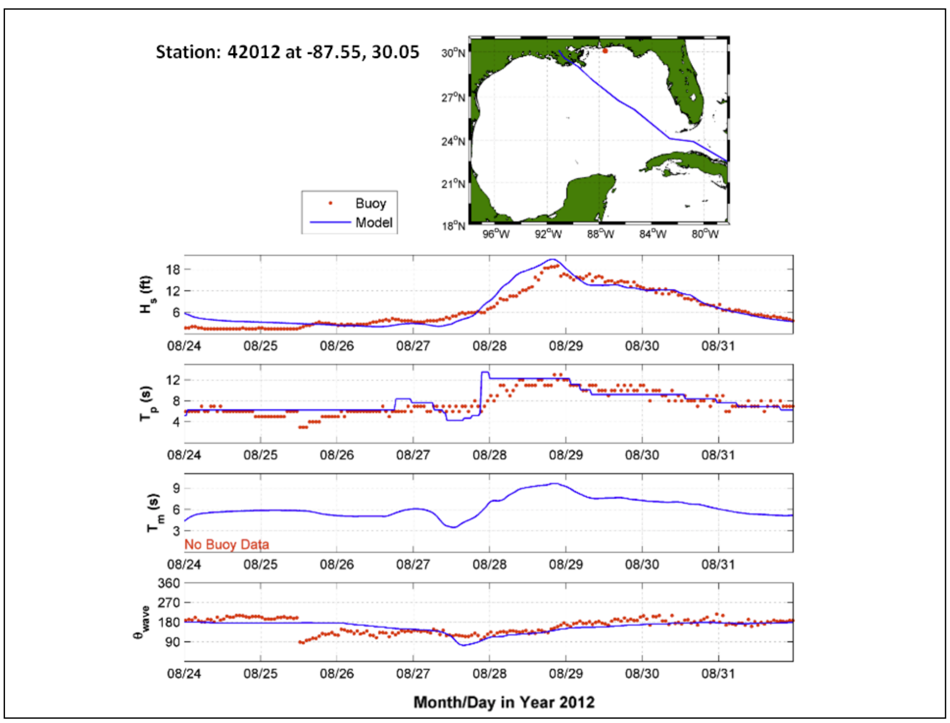

Figure 6.4c Comparison of measured (red dot) and modeled (blue) significant wave height (H_s), peak period (T_p), mean period (T_m), and direction (θ_{wave}) at Station 42012. Datum: NAVD88.

The WAM computational model domain is shown in Figure 6.3 and includes the entire Gulf of Mexico basin. Two-dimensional wave spectra in the coastal area were calculated and output by WAM to be applied as the input boundary condition to the nearshore wave model STWAVE. Wave height, period, and direction estimates were also saved at wave buoy measurement locations. Figures 6.4a - 6.4c show a comparison of modeled wave height, period, and direction to the measurements at wave buoy stations 42003, 42036, and 42012. Station 42040 did not collect wave data during Hurricane Isaac and station 42012 did not collect wind data. Overall, the model results compare well with the measurements and are considered sufficient for the storm surge sensitivity analysis to be conducted in this study. The results are considered acceptable based on the comparison of the wind speed, wind direction, wave height, wave period, and wave direction between the model and the measurements. Figures 6.3 and 6.4 show that values are predicted well over the entire storm and the peaks are also well predicted. These comparisons are similar to those documented in other model validation studies.

6.1.3 Storm Surge Modeling

Coupled ADCIRC and STWAVE

ADCIRC and STWAVE run sequentially during a CSTORM simulation, with ADCIRC going first and then STWAVE completing the cycle. ADCIRC computes surge elevations and depth integrated water currents for a given set of input conditions, which are typically dominated by wind and pressure inputs, followed by wave surface stresses, and then river flow conditions and tidal dynamics.

The numerical model STWAVE (Smith et al. 2001) was used to generate and transform waves to the shore and calculated radiation stress gradients for forcing ADCIRC. STWAVE numerically solves the steady-state conservation of spectral action balance along backward-traced wave rays. The source terms include wind input, nonlinear wave-wave interactions, dissipation within the wave field, and surf-zone breaking. Assumptions made in STWAVE include mild bottom slope and negligible wave reflection; steady waves, currents, and winds; linear refraction and shoaling, and depth-uniform current. STWAVE can be implemented as either a half-plane model, meaning that only waves propagating toward the coast are represented, or a full-plane model, allowing generation and propagation in all directions. For Hurricane Isaac, the full plane model was applied for Lake Pontchartrain and the half plane version applied elsewhere, consistent with previous peer reviewed model applications for this area. Wave breaking in the surf zone limits the maximum wave height based on the local water depth and wave steepness.

STWAVE is a finite-difference model and calculates wave spectra on a rectangular grid. The inputs to execute STWAVE include the bathymetry grid (including shoreline position and grid size and resolution); incident frequency-direction wave spectra on the offshore grid boundary; current field, surge and/or tide fields, wind speed, and wind direction; and bottom friction coefficients. The outputs generated by STWAVE include fields of wave height, peak spectral wave period, and mean direction and radiation stress gradients to use as input to ADCIRC.

A two-dimensional, depth-integrated implementation of the ADCIRC coastal ocean model, was used to perform the hydrodynamic computations in this study (Luettich et al. 1992, Westerink et al. 1993, Luettich and Westerink 2004). Imposing wind and atmospheric pressure fields, and wave radiation stresses, the ADCIRC model can replicate tide induced and storm-surge water levels and currents. In two dimensions, the model is formulated with depth-averaged shallow water equations for conservation of mass and momentum. Furthermore, the formulation assumes that water is incompressible, hydrostatic pressure conditions exist, and that the Boussinesq approximation is valid. The ADCIRC model solves the Generalized Wave Continuity Equation (GWCE) The GWCE-based solution scheme eliminates several problems associated with finite-element programs that solve primitive forms of the continuity and momentum equations, including spurious modes of oscillation and artificial damping of the tidal signal. Forcing functions include time-varying water-surface elevations, wind shear stresses, and atmospheric pressure gradients.

The ADCIRC model uses a finite-element algorithm in solving the defined governing equations over complicated bathymetry encompassed by irregular sea/-shore boundaries. This algorithm allows for extremely flexible spatial discretizations over the entire computational domain and has demonstrated excellent stability characteristics. The advantage of this flexibility in developing a computational grid is that larger elements can be used in open-ocean regions where less resolution is needed, whereas smaller elements can be applied in the nearshore and estuary areas where finer resolution is required to resolve hydrodynamic details.

Computational Grids

The STWAVE computational domains for Louisiana are shown in Figure 6.5. The STWAVE grids are built from the ADCIRC mesh and each has a 200 m (656 ft) resolution.

The ADCIRC grid utilized for this study was derived from that which was calibrated and validated for IPET with Hurricane Katrina data and subsequently validated with data from Hurricane Rita. The development of an accurate unstructured grid storm surge model of Southern Louisiana and Mississippi requires appropriate selection of the model domain and optimal resolution of features controlling surge propagation. The model domain, shown in Figure 6.2, has an eastern open ocean boundary that is primarily located in the deep ocean and lies outside of any resonant basin. There is little geometric complexity along this boundary. Tidal response is dominated by the astronomical constituents and nonlinear energy is limited due to the depth. This boundary allows the model to accurately capture basin-to-basin and shelf-to-basin physics.

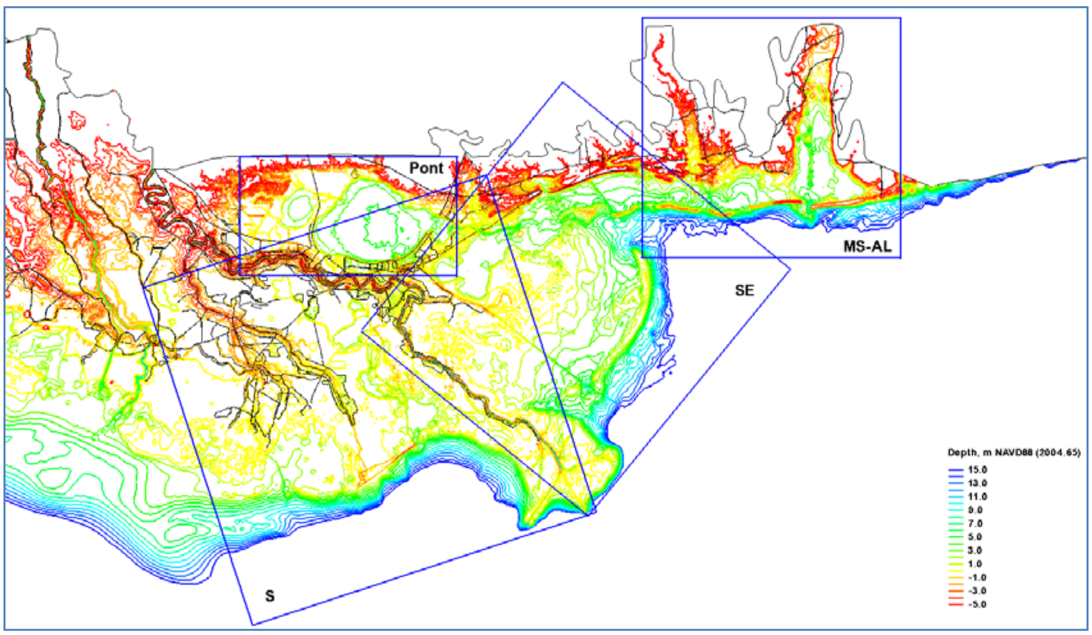

Figure 6.5 STWAVE model domains.

The grid design provides localized refinement of the coastal floodplains of Southern Louisiana and Mississippi and of the important hydraulic features. Features such as inlets, rivers, navigation channels, levee systems and local topography/bathymetry are all well resolved. In addition, wave breaking zones have been identified based on local bathymetric gradients to ensure that the grid scale of the flow model is consistent with that of the STWAVE models. The STWAVE forcing function is accommodated by adding a high level of resolution where significant gradients in the wave radiation stresses and forcing of surge through wave transformation and breaking are the largest. The high resolution zones allow for the strong wave radiation stress gradients to fully force the water body in these important regions and ensures that the resulting wave radiation stress induced set up is sufficiently accurate. The high grid resolution required for the study region leads to a final grid with more than 90% of the computational nodes placed within or upon the shelf adjacent to Southern Louisiana and Mississippi, enabling sufficient resolution while minimizing the cost of including such an extensive domain.

Levee and road systems that are barriers to flood propagation are features that generally fall below the defined grid scale and represent a non-hydrostatic flow scenario. It is most effective to treat these structures as sub-grid scale parameterized weirs within the domain. ADCIRC defines these as barrier boundaries by a pair of computational nodes with a specified crown height. Once the water level reaches a height exceeding the crown height, the flow across the structure is computed according to basic weir formulae. This is accomplished by examining each node in the defined pair for their respective water surface heights and computing flow according to the difference in water elevation. The resulting flux is specified as a normal flow from the node with the higher water level to the node with the lower water level for each node pair. Weir boundary conditions also are implemented for external barrier boundaries, which permit surge that overtops levee structures at the edge of the domain to transmit flow out of the computational area.

6.1.4 2012 100-year HSDRRS

Based on multiple simulations, the 2010 grid applied for the peer reviewed USACE Louisiana Coastal Protection and Restoration (LACPR) study was chosen as the starting point for creating the 2012 / 100-year HSDRRS condition grid. The first step for implementing the 2012 100-year HSDRRS condition was to add the Seabrook closure, MRGO closure, Caernarvon Floodwall, Eastern Tie-in, and Western Closure Complex (see Figure 6.6a). The incorporation of these features required new sub-grid scale parameterized weirs within the domain and additional resolution in some cases. Representations of the IHNC surge barrier and the Western Tie-In were included in the LACPR 2010 grid but were modified to reflect the proper alignment. Once all the features were added, the elevations for these features and all other levees in the domain were updated with the most recent survey data available. Figure 6.6b plots the topography / bathymetry and sub-grid scale parameterized weirs in the 2012 100-year HSDRRS condition grid. The sub-grid scale parameterized weir elevations are given in Figure 6.7.

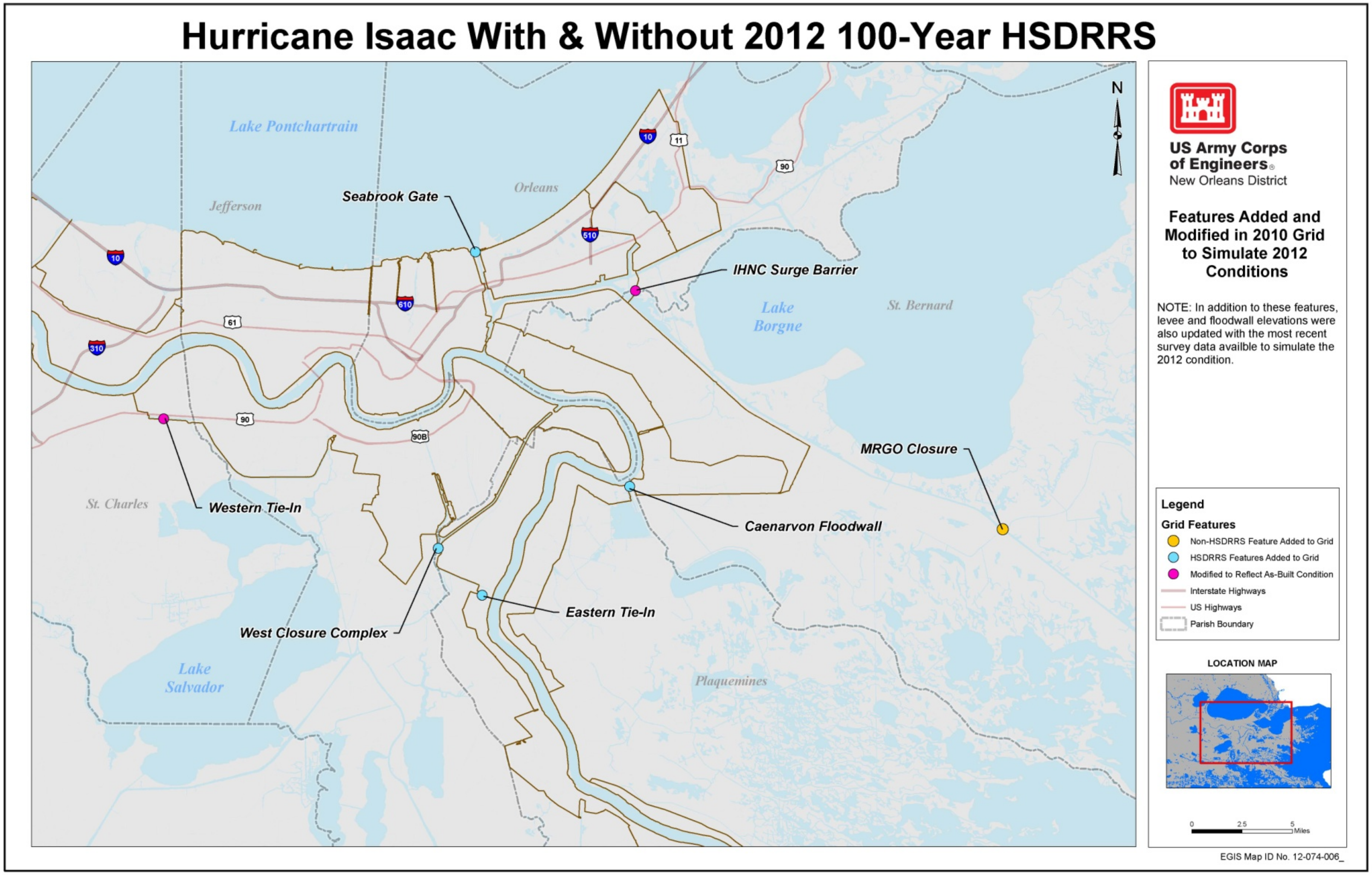

Figure 6.6a Features added and modified in 2010 grid to create 2012 HSDRSS Condition.

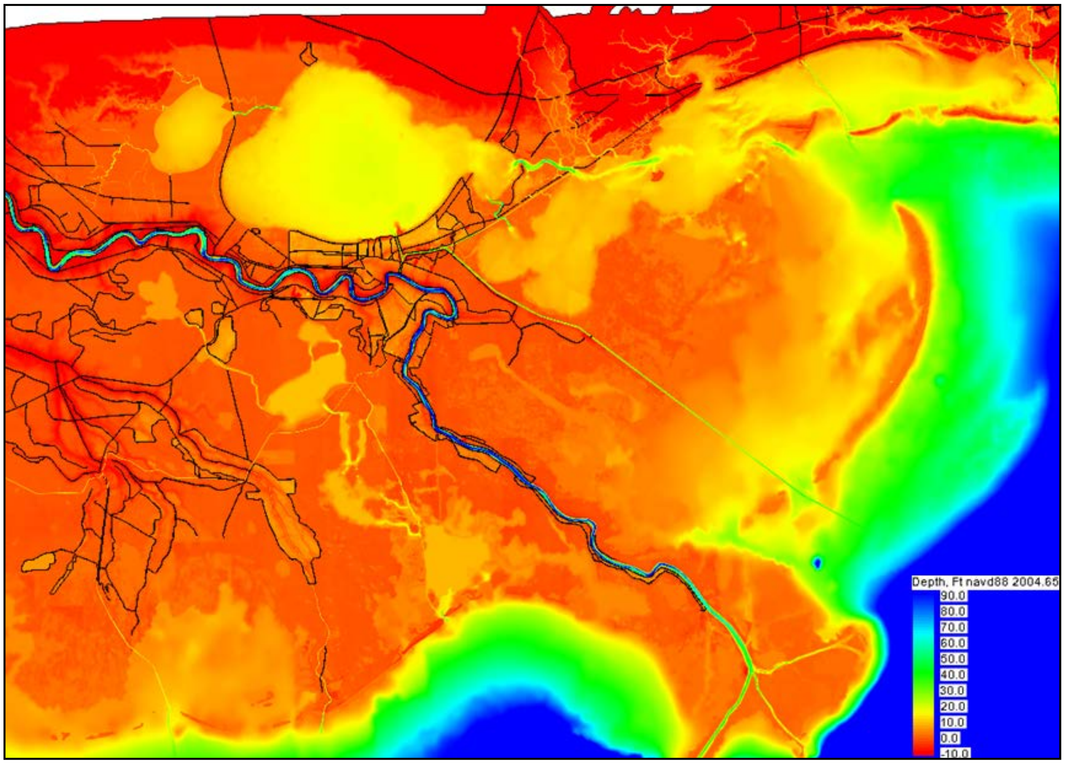

Figure 6.6b Topography / bathymetry and sub-grid scale features in the 2012 100-Year HSDRRS condition ADCIRC grid.

Figure 6.7 Elevations of levees, road systems and other structures represented as sub-grid scale features in the 2012 100-Year HSDRRS condition ADCIRC grid

6.1.5 Without 2012 100-Year HSDRRS

The purpose of this analysis is to determine the impact that the 100-year HSDRRS features had on water levels within and at communities outside the system. Therefore, the grid to which the 2012 100-year HSDRRS is compared was built to only reflect changes in the 100-year HSDRRS. As stated elsewhere in this report, it is assumed that any changes in surge levels are due to changes in the HSDRRS only. No other landscape or resolution changes were made to the model grid. To accomplish this, the Without HSDRRS condition grid was developed from the 2012 100-year HSDRRS grid. The first step was to remove the sub-grid scale parameterized weirs used to represent the following HSDRSS features: outfall canal structures, Seabrook closure, IHNC surge barrier, MRGO closure, Caernarvon Floodwall, Eastern Tie-in, Western Closure Complex, and Western Tie-In. The remaining 100-year HSDRSS levee elevations were then changed to values obtained from 2007 survey data. The sub-grid scale parameterized weir elevations for the Without HSDRRS grid are given in Figure 6.8.

Figure 6.8. Elevations of levees, road systems and other structures represented as sub-grid scale features in the Without HSDRRS condition ADCIRC grid.

Preliminary Hurricane Isaac Storm Surge Model Assessment

The preliminary model assessment was conducted by simulating conditions from Hurricane Isaac on the 2012 100-year HSDRRS condition grid. The comparison presented is preliminary and based on best available information at the time the study was conducted. A complete and proper validation takes months. The modeling effort documented in this chapter was required to be completed in less than three weeks. The data to which the model is compared is therefore provisional.

The model was assessed through comparison of high water marks across southeast Louisiana and western Mississippi as well as comparison to measured hydrographs at various locations. Figures 6.9a – 6.9f plot provisional measured and modeled water levels at various locations. All available measured data for these stations is plotted. Stations with available data also plot comparisons of wind and atmospheric pressure. Additional stations are available in Appendix A. At most stations the model results compare reasonably well to the measured provisional data. The shapes of the hydrographs are well replicated and the magnitudes are generally within 2 feet.

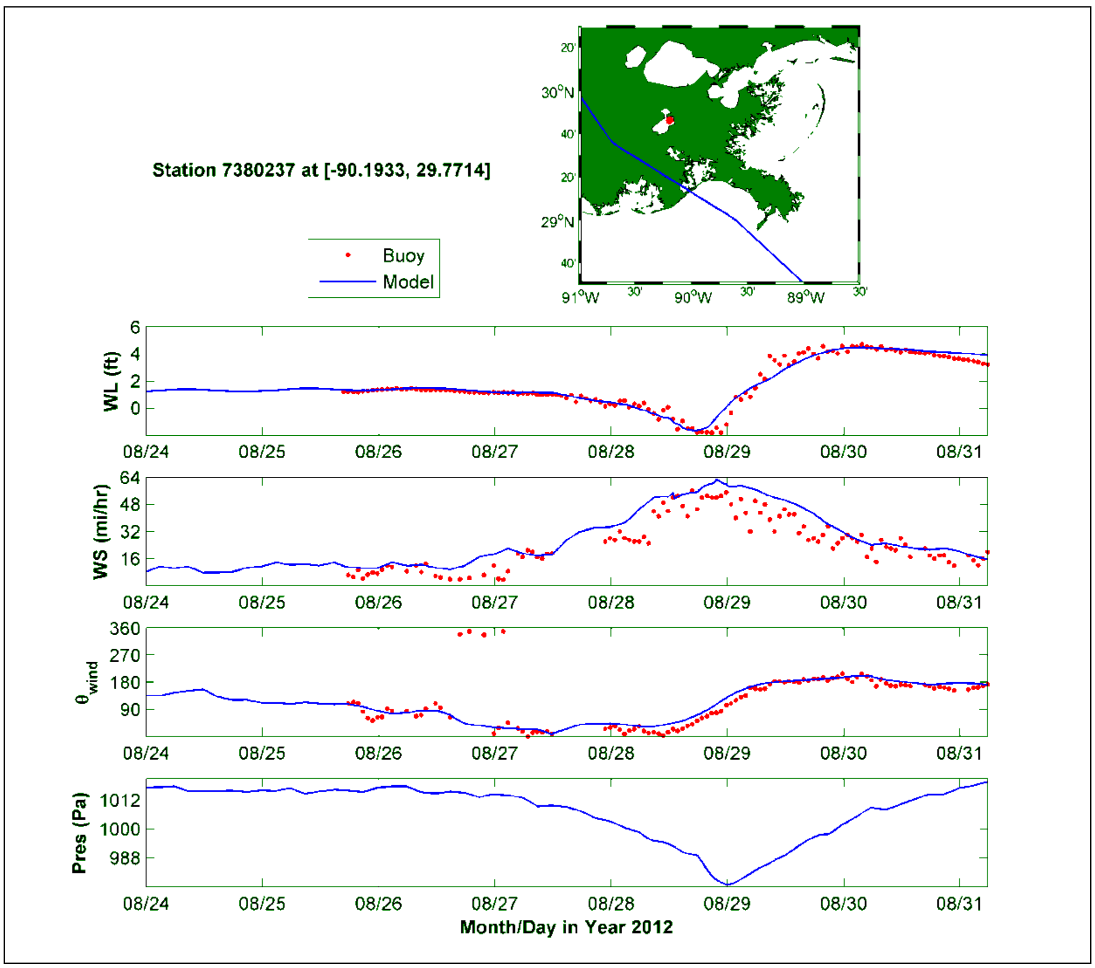

Figure 6.9a. Modeled (blue) versus measured (red dot) water level (WL), wind speed (WS), wind direction (θ_{wind}), and pressure for Hurricane Isaac in Barataria Bay at Lake Salvador. Model output is in feet NAVD88 2004.65; gage datum NAVD88.

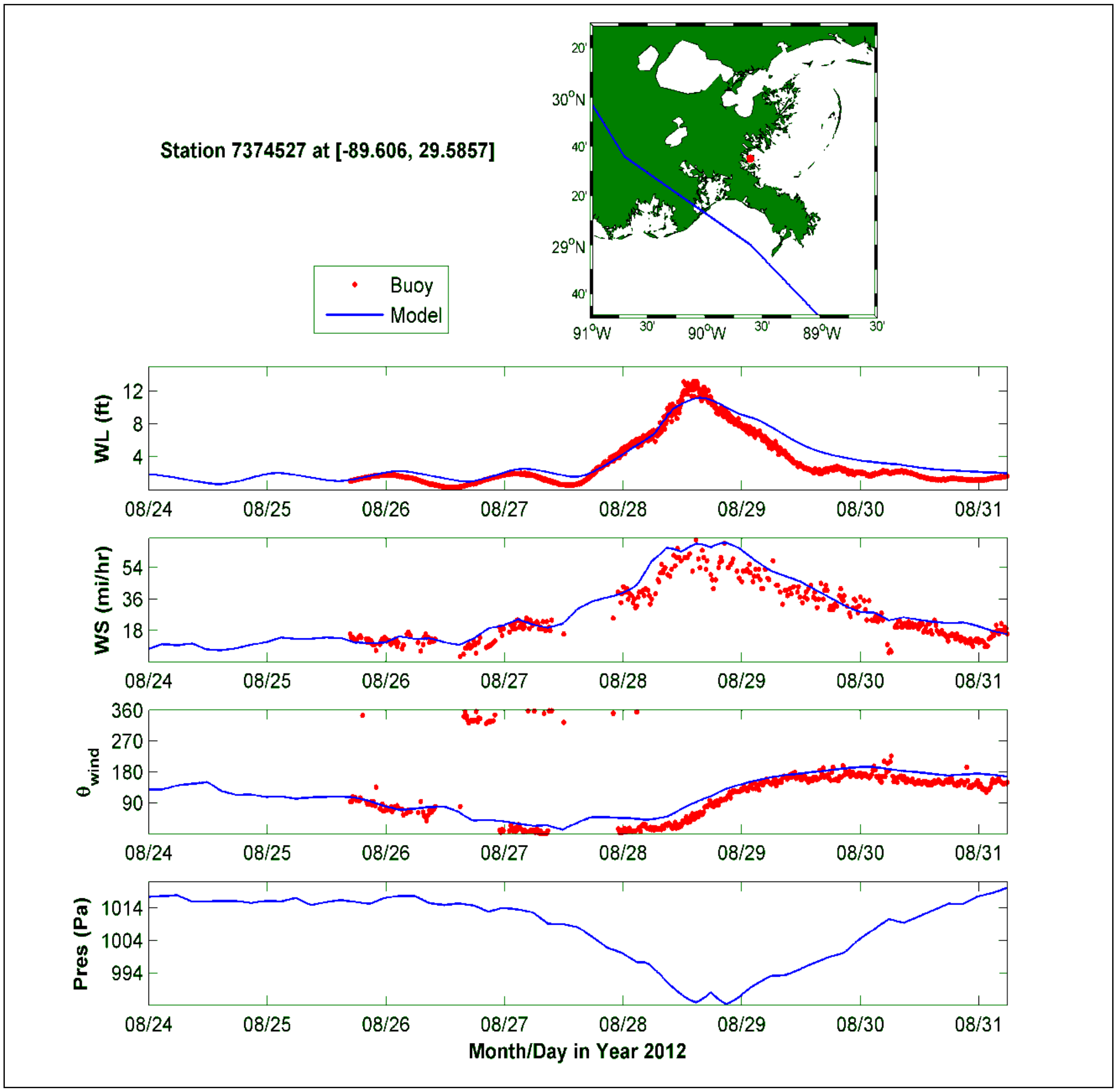

Figure 6.9b. Modeled (blue) versus measured (red dot) water level (WL), wind speed (WS), wind direction (θ_{wind}), and pressure for Hurricane Isaac in Breton Sound. Model output is in feet NAVD88 2004.65; gage datum: NAVD88.

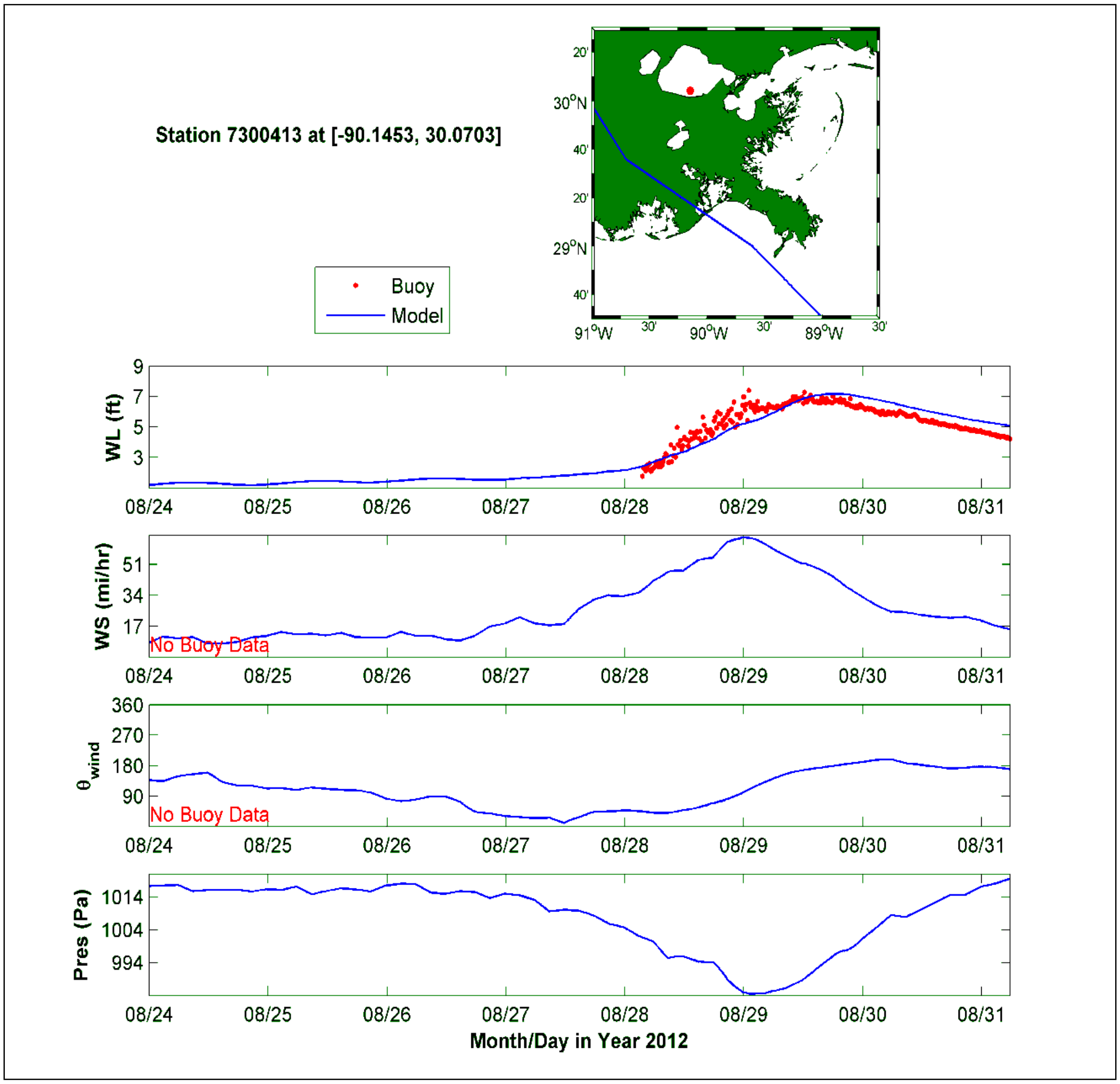

Figure 6.9c. Modeled (blue) versus measured (red dot) water level (WL), wind speed (WS), wind direction (θ_{wind}), and pressure for Hurricane Isaac in Lake Pontchartrain at Causeway. Model output is in feet NAVD88 2004.65; gage height, no datum.

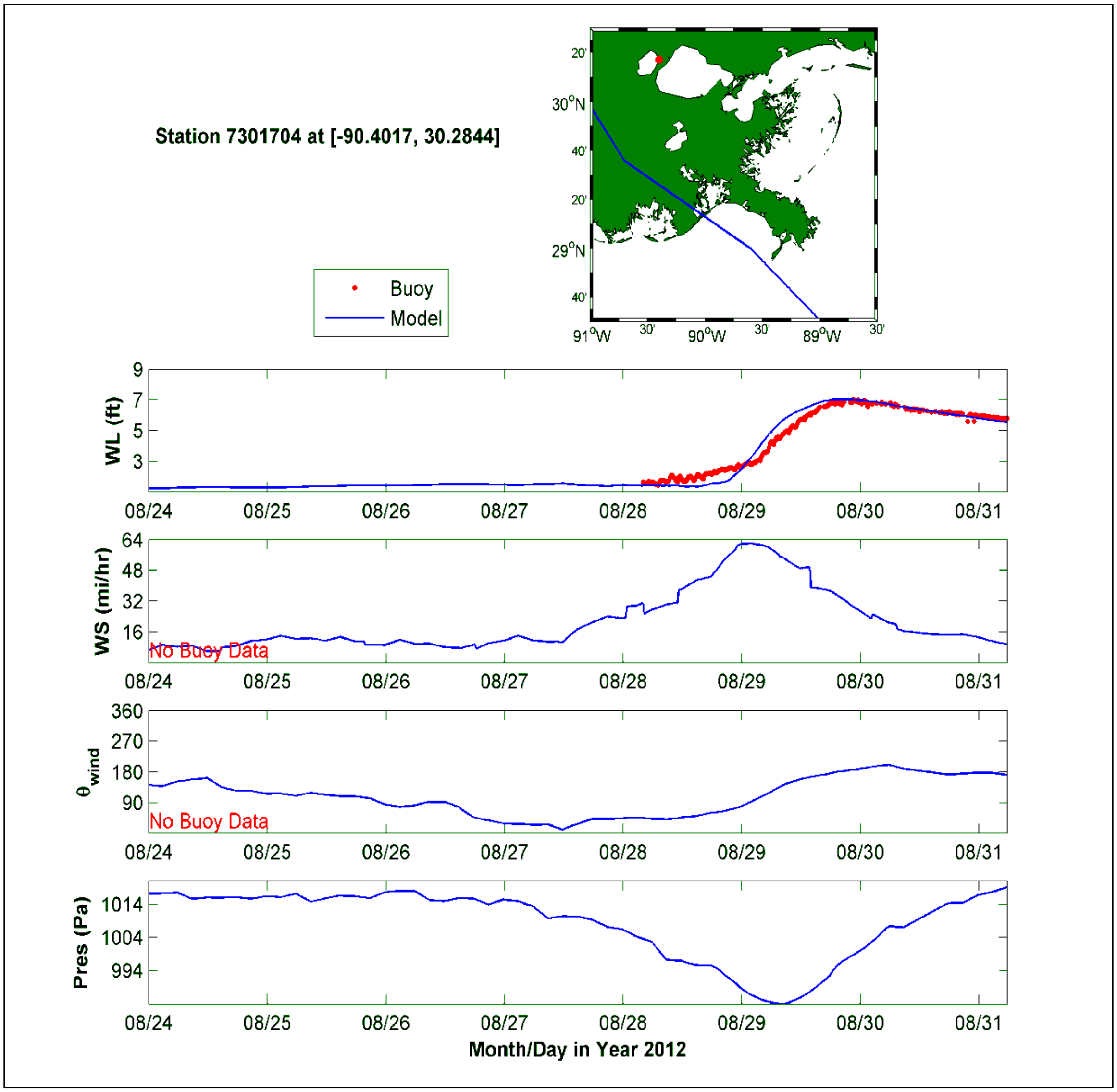

Figure 6.9d. Modeled (blue) versus measured (red dot) water level (WL), wind speed (WS), wind direction (θ_{wind}), and pressure for Hurricane Isaac at Pass Manchac. Model output is in feet NAVD88 2004.65; gage datum NAVD88.

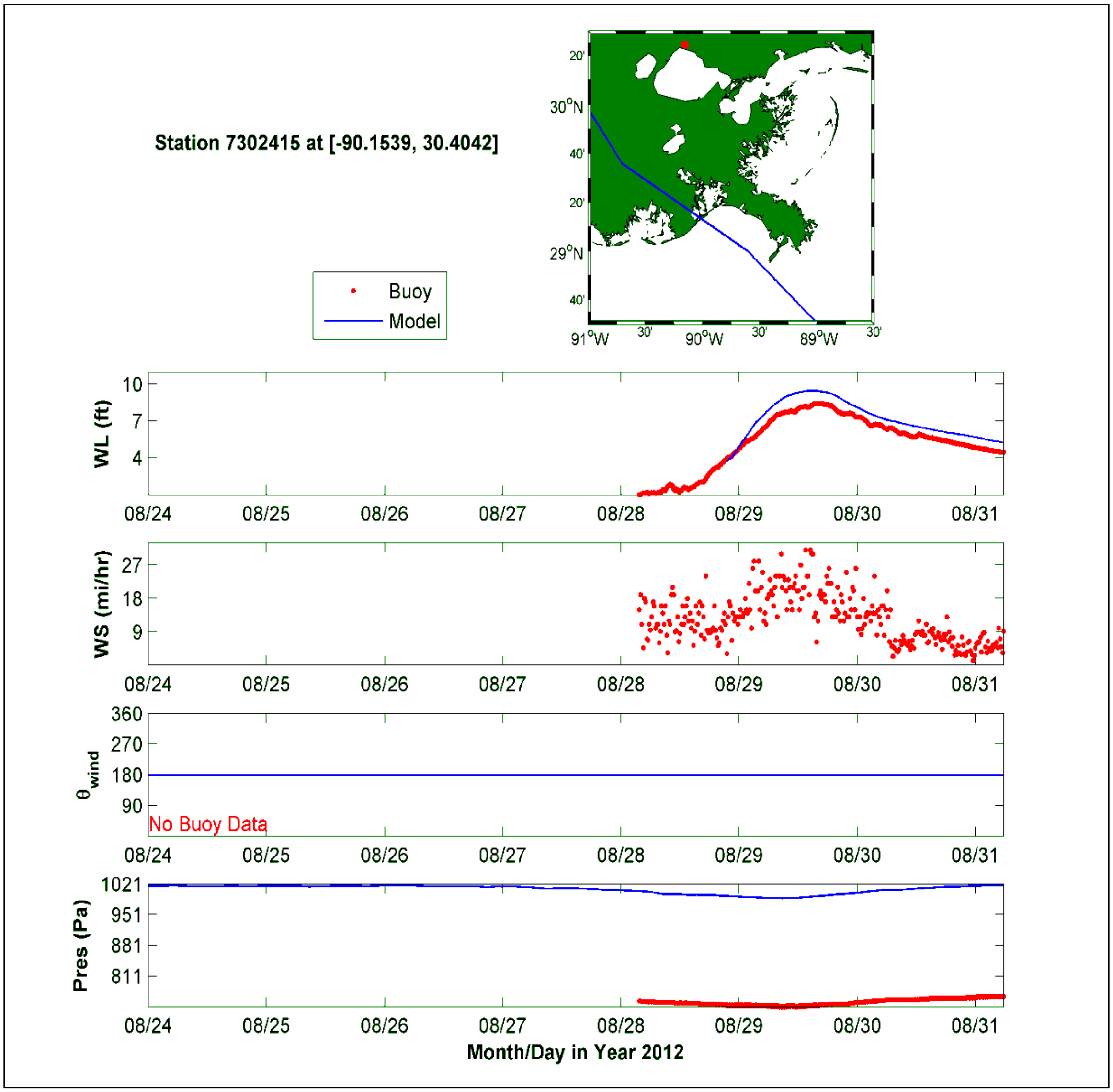

Figure 6.9e. Modeled (blue) versus measured (red dot) water level (WL), wind speed (WS), wind direction (θ_{wind}), and pressure for Hurricane Isaac on north shore of Lake Pontchartrain. Model output is in feet NAVD88 2004.65; gage height, no datum.

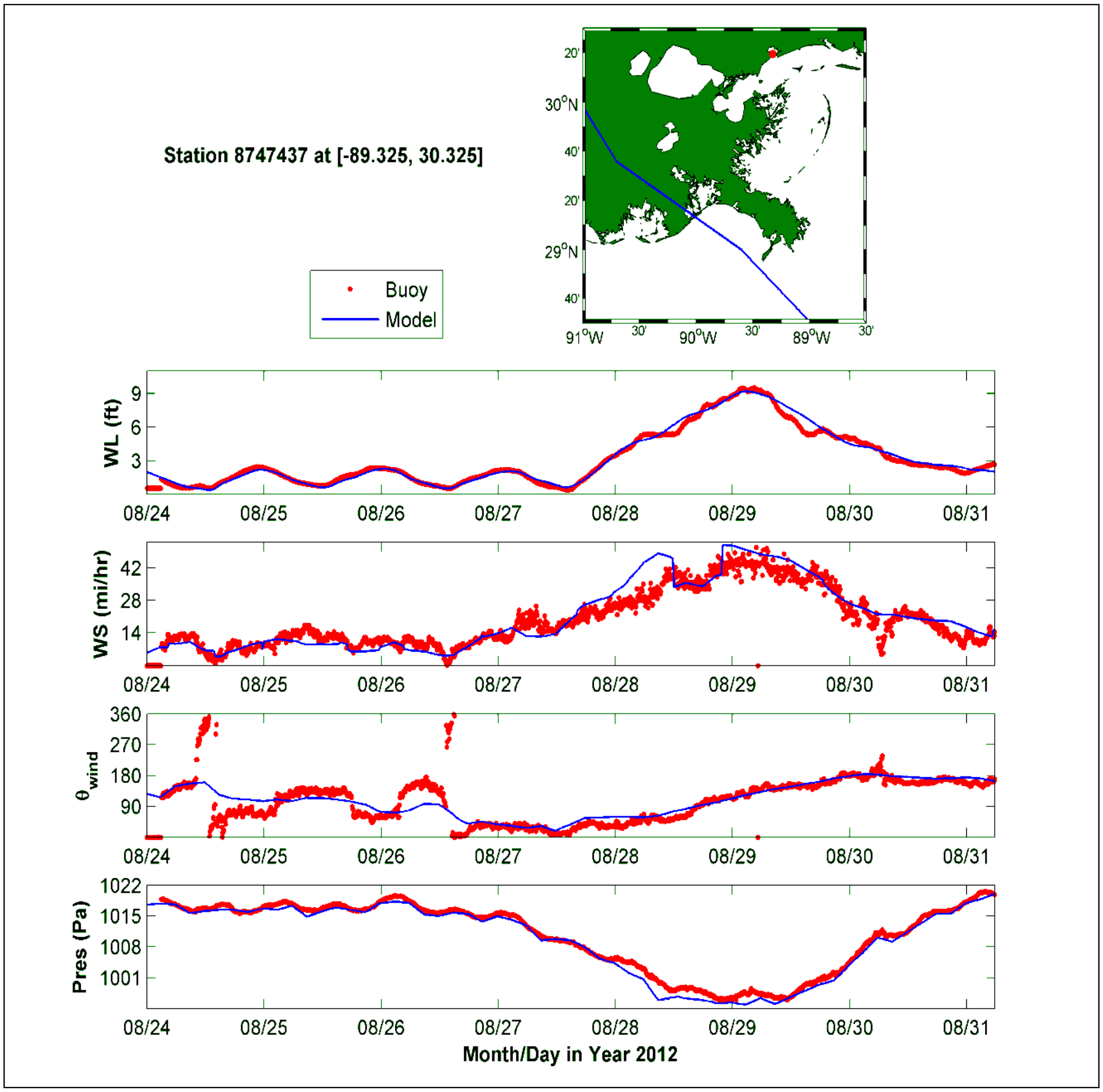

Figure 6.9f. Modeled (blue) versus measured (red dot) water level (WL), wind speed (WS), wind direction (θ_{wind}), and pressure for Hurricane Isaac on Mississippi coast at Bay St. Louis. Datum: NAVD88.

Figure 6.10 plots the difference between the provisional measured and modeled high water marks at numerous locations. The white circles indicate that the model is within +/- 1.5 feet of the provisional measured data. The model compares well with the data on the Mississippi coast, the south and north shores of Lake Pontchartrain, in the vicinity of LaPlace, and in south Plaquemines Parish. The model to measurement comparison indicates that the model slightly over predicts water levels in the vicinity of the Western Closure Complex and at the Pontchartrain land bridge. The biggest difference between the modeled and measured provisional data is in Breton Sound. Figure 6.10 indicates that the model over predicts water levels at the upper end of Caernarvon marsh near Braithwaite by as much as approximately 3 feet. The most likely cause of the over prediction at this location is errors in the wind field. The water pushed into this area continues to build up with levees on three sides, amplifying any errors in the modeled forcing.

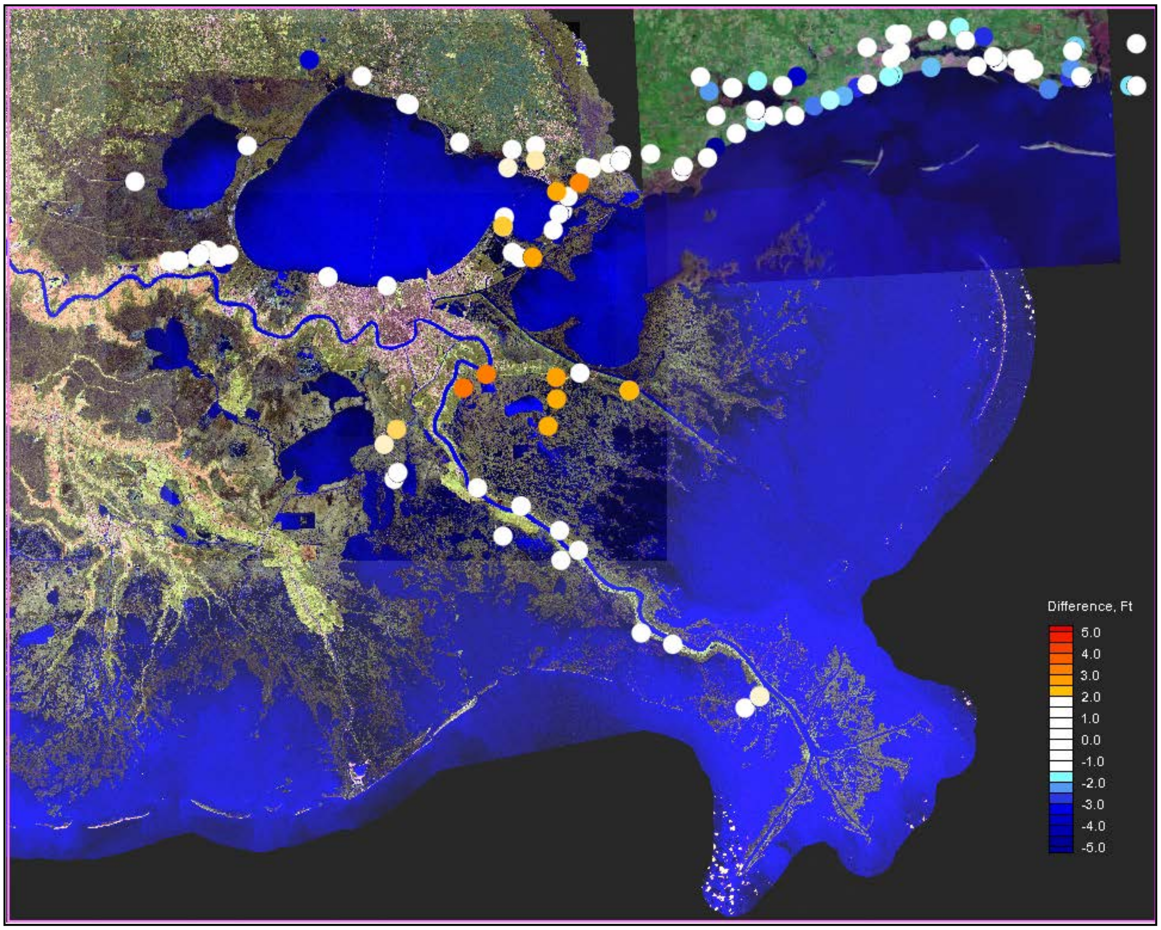

Figure 6.10. Difference between provisional measured and modeled high water marks for Hurricane Isaac.

Results

The ADCIRC simulations provide a preliminary estimate of overall peak water level for Hurricane Isaac across the entire study area. This involves an examination of the entire spatial domain every 900 seconds (15 minutes) to determine if water levels exceeded the previous time steps maximum water level at any point in the domain. The result of this analysis is a maximum envelope of water level for the simulation. Output generated from the ADCIRC model for Hurricane Isaac on with and without 2012 100-year HSDRRS grids are provided in Figures 6.11 and 6.12, respectively. Results from the two grids are very similar. Peak water elevations in Lake Pontchartrain range from approximately 7 to 9 feet. The upper end of Barataria Bay has predicted water levels of 4 to 6 feet in both grids and water levels increase to the south with the highest water levels against the levees in south Plaquemines. Water levels on the Mississippi coast range from 6 to 7 feet near Biloxi to 11 feet in Hancock County. In both grids the maximum water surface elevations are in Breton Sound at the upper end of the Caernarvon marsh near Braithwaite. Predicted surge elevations reach approximately 17 feet. Actual measured high water marks in this area were only 14 feet.

The greatest difference between the results for the two grids is evident inside the HSDRRS. In the without HSDRRS simulation, flooding is predicted on the West Bank, suggesting that the presence of the Western Closure Complex and the raising of levees prevented flooding in this region. Flooding in St. Bernard, East Orleans and New Orleans is also predicted in the Without HSDRSS simulation. Flooding in these areas resulted from elevated water levels in the IHNC that overtopped the levees. Flooding in the St. Bernard polder was also predicted due to overtopping of the St. Bernard – Verret to Caernarvon levee. The flooding predicted here is predominantly due to the over prediction of the model in this area. Based on high water marks, water levels actually only reached 14 feet in this area. This would have been just above the lowest without HSDRRS levee elevations for this reach, which range from 13 to 17.5 feet.

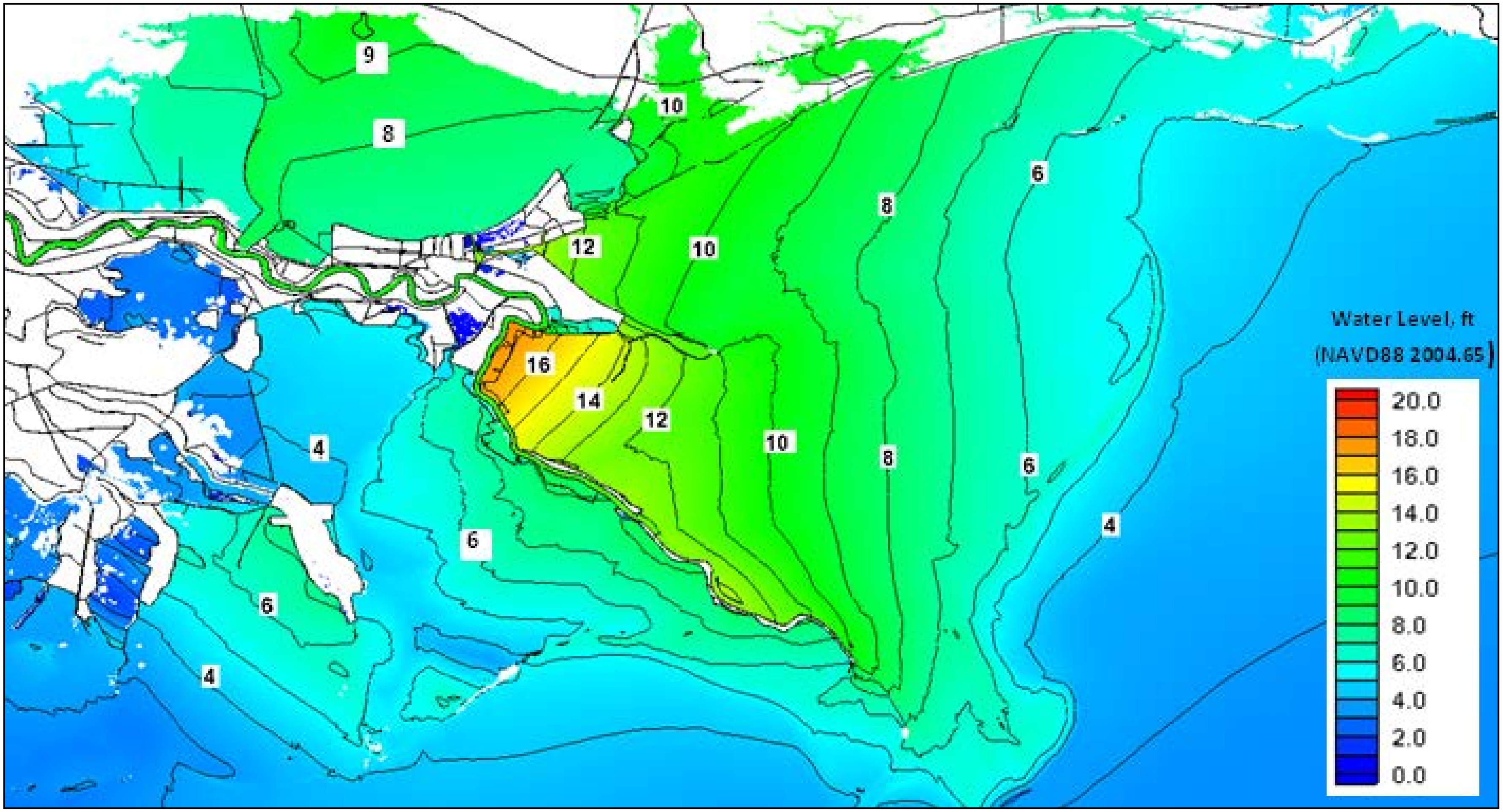

Figure 6.11. Envelope of maximum water level for Hurricane Isaac for the Without HSDRRS condition.

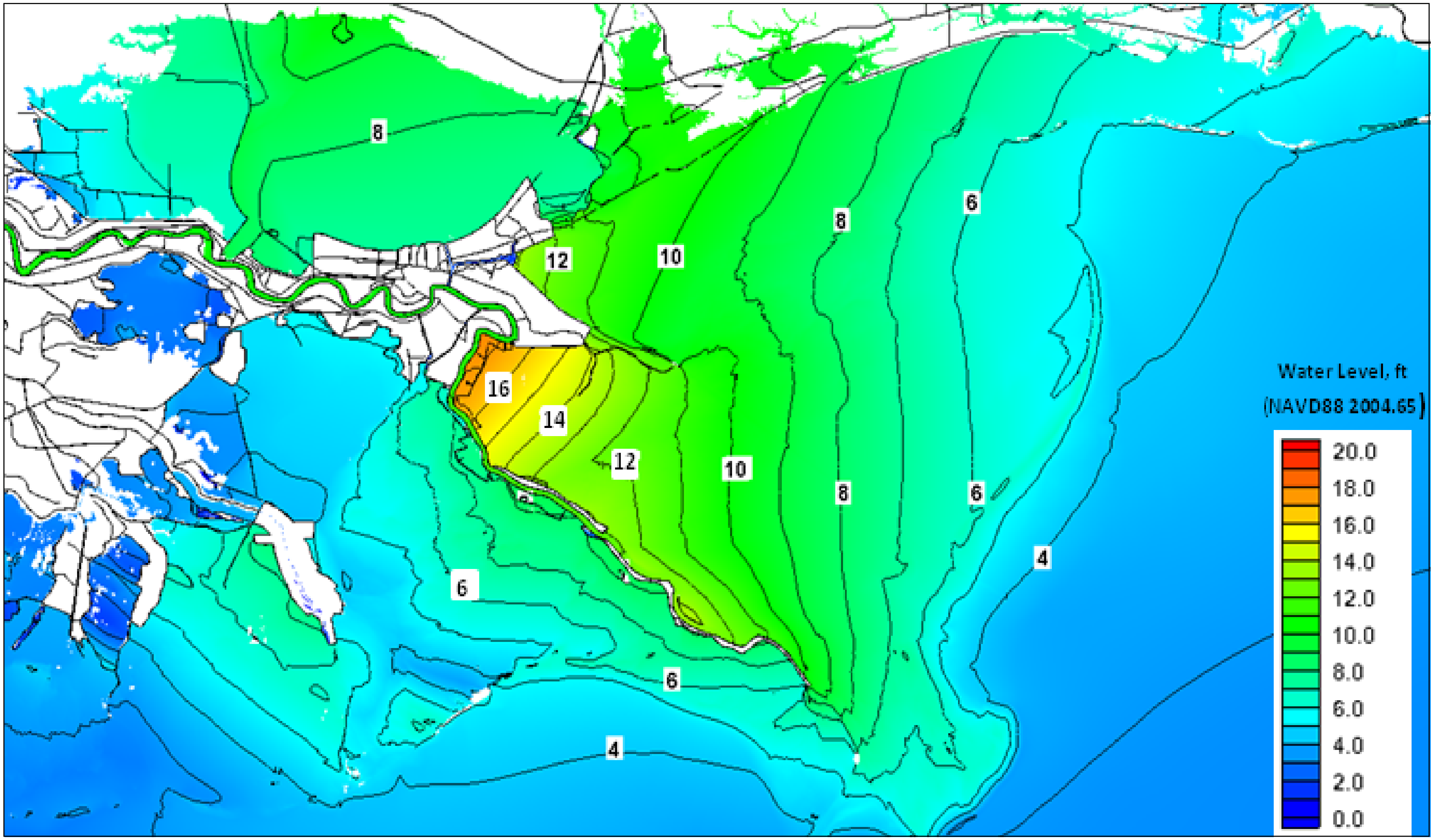

Figure 6.12. Envelope of maximum water level for Hurricane Isaac for the 2012 100-Year HSDRRS condition.

6.1.6 Sensitivity Analysis

The primary purpose of this analysis is to determine the impact that the 100-year HSDRRS features on water levels at communities outside the system during the passage of Hurricane Isaac. This is achieved through comparison of the 2012 100-year HSDRRS simulated peak water surface elevations and the Without HSDRRS simulation estimates.

6.1.6.1 General Overview

Figure 6.13 plots the difference between the 2012 100-year HSDRRS and the Without HSDRRS simulations. A positive difference indicates that water levels are higher for 2012 100-year HSDRRS, negative values indicate lower predicted water levels for the 2012 100-year HSDRRS. The dark blue regions represent flooding within polders that was prevented by the HSDRRS. Outside the HSDRRS, water levels are relatively higher in Breton Sound and lower in Lake Pontchartrain. These differences are generally 0.2 feet or less and results from the presence of the IHNC barrier which eliminates conveyance from Breton Sound to Lake Pontchartrain through the GIWW/IHNC. The largest difference outside of polders shown in Figure 6.13 is an increase in water level of approximately 0.8 feet in the immediate vicinity of the Western Closure Complex but this increases is greatly reduced at nearby communities. Increases in water level outside the immediate vicinity of the West Closure Complex diminish to 0.4 feet near Crown Point, 0.2 feet at Jean Lafitte and less than 0.1 feet in the majority of the Barataria basin.

6.1.6.2 Areas of Orleans and St Bernard Parishes Immediately Outside the HSDRRS

In addition to the specific areas addressed in more detail in the next chapter there are areas in both Orleans and St. Bernard parishes that lay outside the HSDRRS. This includes the communities on the Lake Catherine land bridge in Orleans Parish as well as communities in lower St. Bernard adjacent to the former Mississippi River Gulf Outlet. These areas were impacted by surge from Hurricane Isaac. The ADCIRC model hindcast of Hurricane Isaac forecasts stages in the range of 10-12 feet on the Lake Catherine land bridge and 10-14 feet throughout lower St Bernard Parish. Assessment of the Hurricane Isaac hindcast simulations reveals slight over prediction of surge, by the ADCIRC model in these areas, on the order of 1-2 feet versus collected high water mark data. Figure 6.13 provides an indication of estimated differences in surge for with and without 2012 100-year HSDRRS conditions for these areas. The model sensitivity analysis indicates differences of no more than 0.1 feet in any of these areas. Due to models relative accuracy in forecasting surge elevations potential change in the sensitivity results is unlikely. As a result additional detail evaluation was not performed in these areas.

6.1.6.3 Mississippi Coast

Figure 6.14 plots the difference in peak water levels along the Mississippi coast. As can be seen in this plot, predicted increases in water levels along the Mississippi coast are less than 0.1 feet. The model also demonstrated close correlation to the actual storm data collected at Bay St. Louis, MS (Figure 5.10f). Based on the general agreement between the with and without 2012 100-year HSDRRS conditions, coupled with the model accuracy in hindcasting the storm for this area, no further detail evaluation was performed.

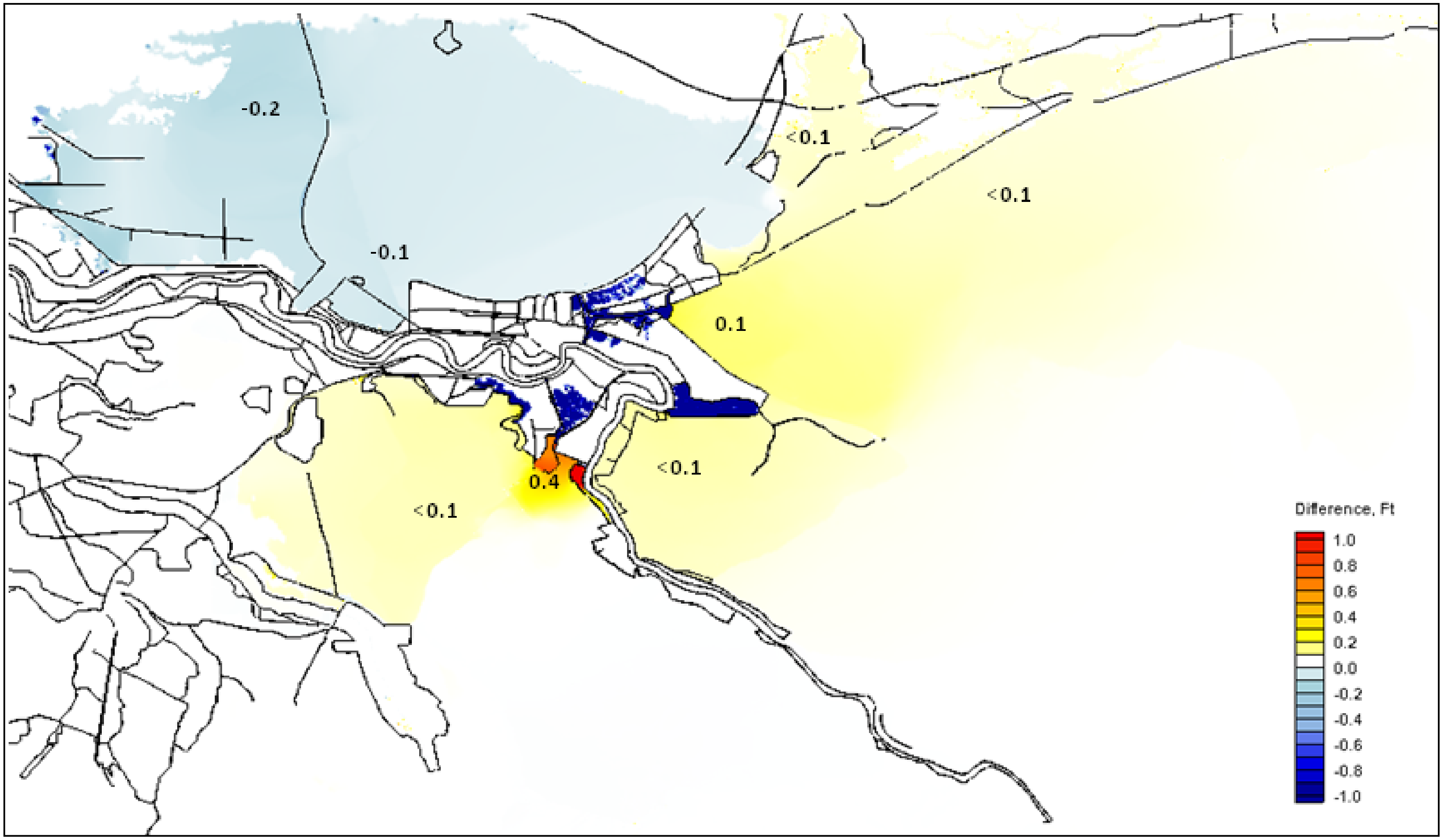

Figure 6.13. Difference in maximum water level for Hurricane Isaac (With and Without 2012 100-Year HSDRRS).

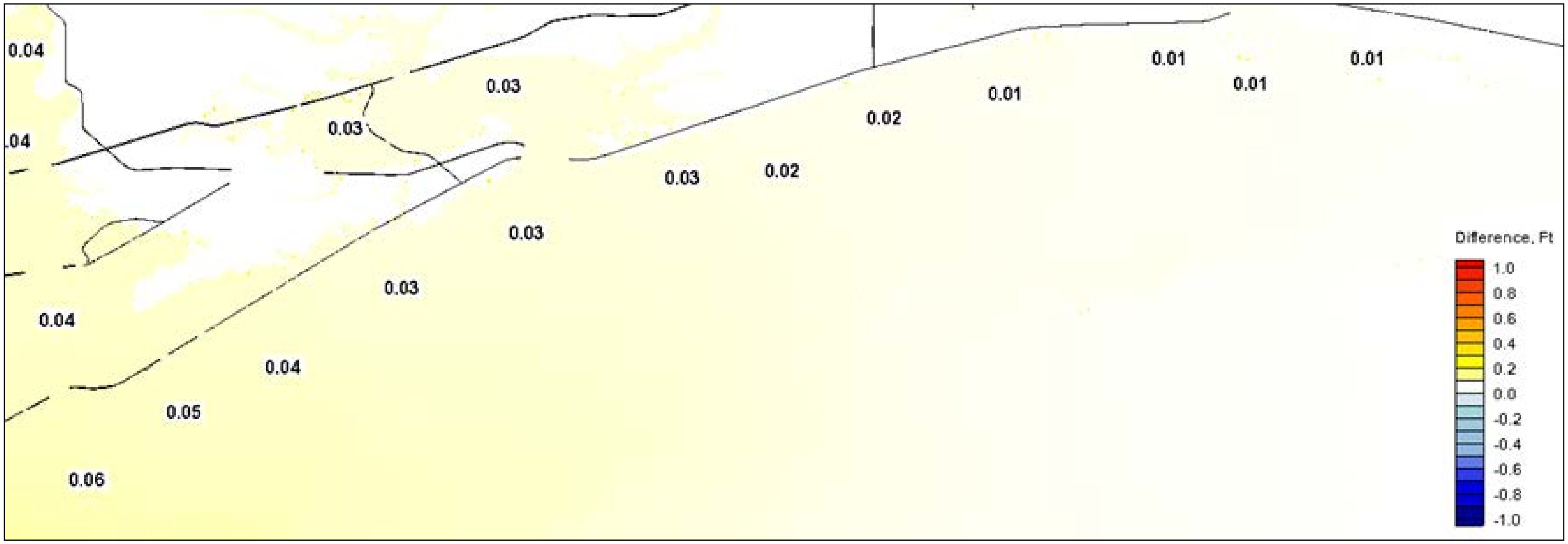

Figure 6.14. Difference in maximum water level for Hurricane Isaac on the Mississippi coast (With and Without 2012 100-Year HSDRRS).

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7.0 DETAILED EVALUATIONS

This section provides a summary of the hydrodynamic model results for certain areas outside the 2012 100-year HSDRRS adversely impacted by Hurricane Isaac, describing likely causes of flooding for these areas. This section analyzes the effects, if any, of new HSDRRS construction, rainfall runoff and how the rainfall may have contributed to prolonged elevated water elevations that impacted these particular areas outside of the 2012 100-year HSDRRS.

East Bank Plaquemines Parish

The East Bank of Plaquemines Parish area refers to the relatively narrow developed area adjacent to the east bank of the Mississippi River that runs from Caernarvon to Scarsdale. An area of specific interest is the Braithwaite polder immediately adjacent to the Caernarvon freshwater diversion and outfall canal. This area is confined by a non-federal levee along its eastern, gulfward side and the Mississippi River Levee on its western side. General drainage in the area flows from the west to the east away from the Mississippi River. Runoff is collected in large drainage canals that run along the interior of the eastern levees and is pumped over the levees into the adjacent marsh.

7.1.1 ADCIRC Model Results

Figure 7.1.1 plots the difference in peak water levels on the east bank of Plaquemines. The greatest difference is in the immediate vicinity of the Caernarvon floodwall where the predicted water level increases by about 0.3 feet. In general, predicted water levels increase by about 0.1 feet or less. The results in this area are influenced by the over prediction of peak water levels by the model. The model predicts water levels that overtop the without HSDRRS St. Bernard Parish – Verret to Caernarvon levee. The measured high water marks in this area are less than 14 feet, which would not have been significantly higher than levee elevations prior to the HSDRRS that ranged up to 17.5 feet. The filling of the St. Bernard polder in the without 2012 100-year HSDRRS simulation results in increased water level differences between the two simulations.

7.1.1 Rainfall and Runoff Analysis

This section covers precipitation and observed stages in the area of the East Bank Plaquemines Parish (non-federal) levees with special emphasis on the Braithwaite polder immediately adjacent to the Caernarvon freshwater diversion and outfall canal.

Figure 7.1.2 displays the locations of a USGS stage gage at Scarsdale (SSS-LA-PLA-019BP) and a synthetic precipitation gage (R1) at the Braithwaite polder. For this assessment, rain data has been extracted from the National Mosaic & Multi-Sensor QPE dataset produced by NOAA for Hurricane Isaac. This precipitation dataset is developed by adjusting radar data to actual precipitation gage data, giving high resolution precipitation information at areas were gages do not exist. The data is available at http://nmq.ou.edu/.

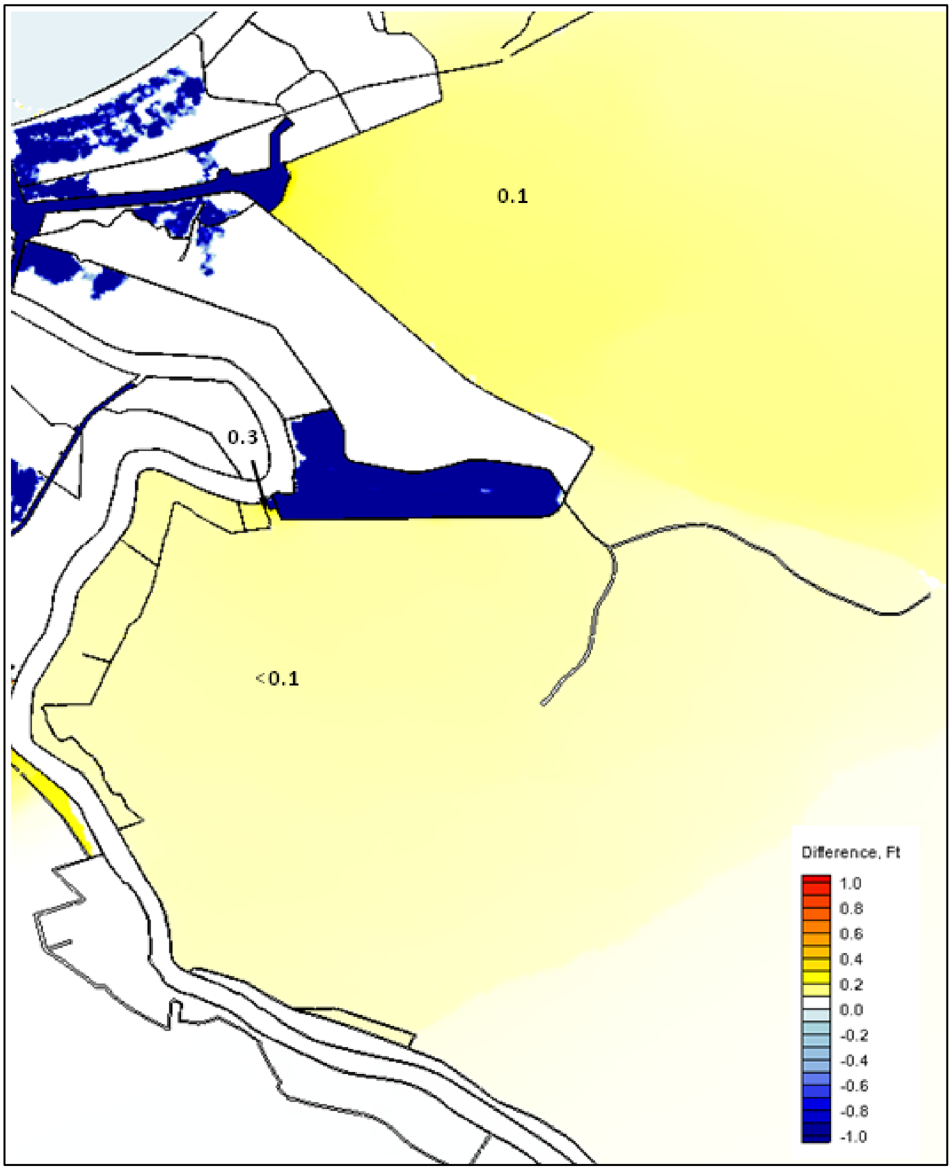

Figure 7.1.1 Difference in ADCIRC predicted maximum water level for Hurricane Isaac on the east bank of Plaquemines Parish (With & Without 2012 100-Year HSDRRS).

Figure 7.1.3 displays the estimated hourly precipitation at the synthetic R1 gage. The total amount of precipitation at this location was 10.6 inches. With the majority of the total accumulation occurring on 29 August. The peak precipitation rate was nearly 1.0 inch per hour in the morning of 29 August. Because of the surge related stage conditions in the area accumulated rainfall was a minor contributor to peak stages.

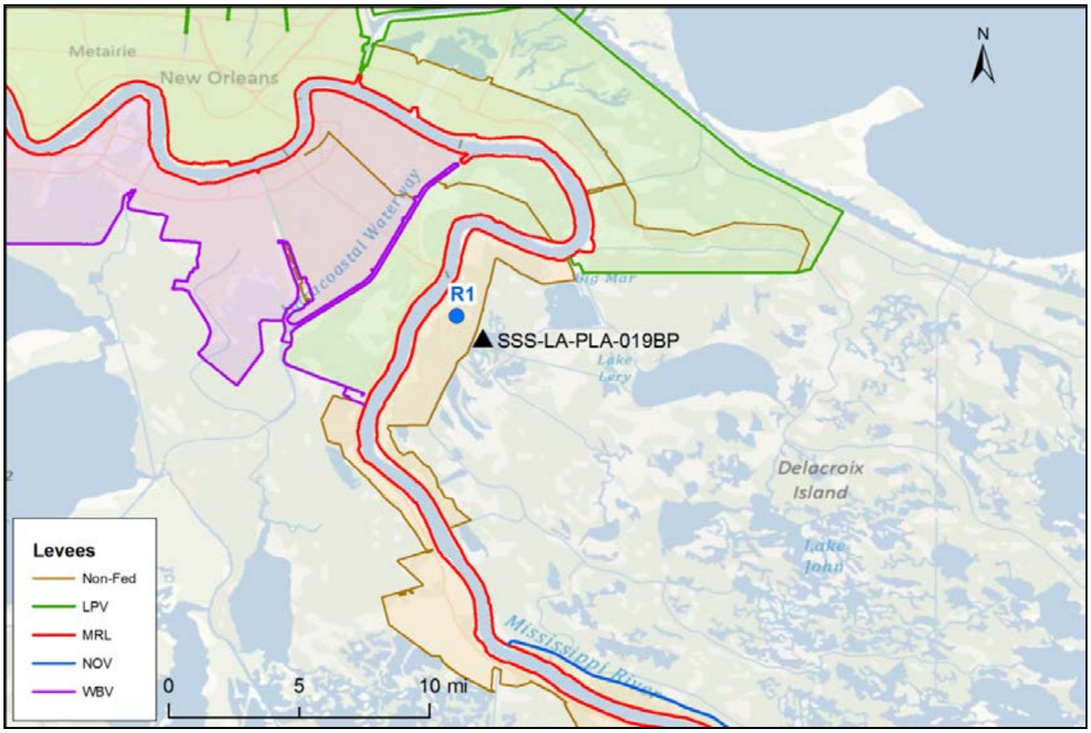

Figure 7.1.2 Map of subset of USGS/USACE gages and precipitation output points in East Bank Plaquemines Parish.

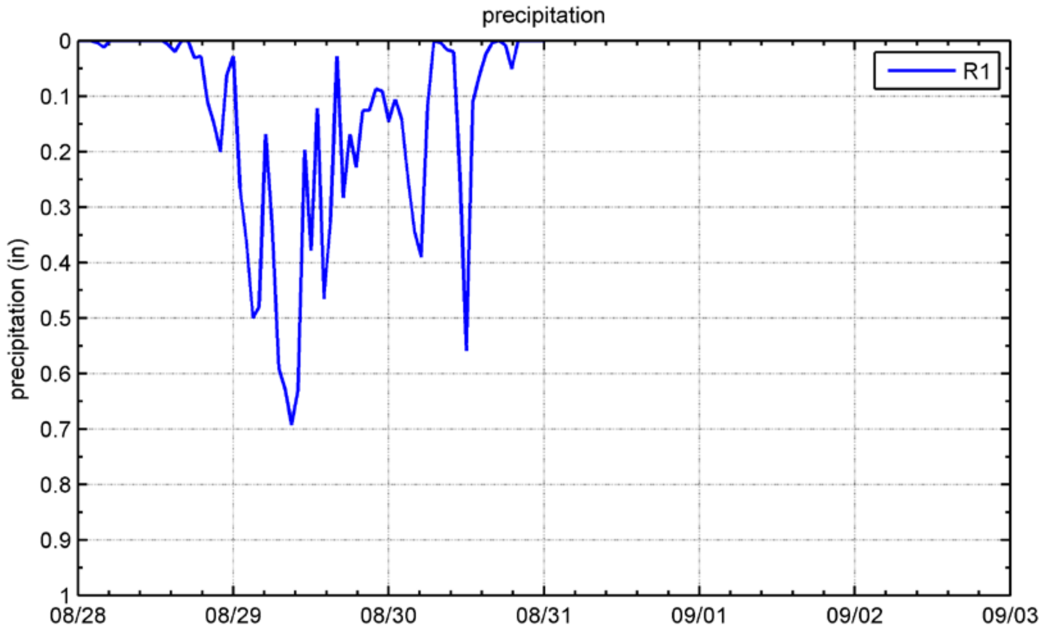

Figure 7.1.3 Hourly precipitation data at synthetic R1 gage during Hurricane Isaac.

Observed stages from the USGS Scarsdale gage are displayed in the gage hydrograph presented in Figure 7.1.4. Peak stage at the Scarsdale gage was 13.9 feet NAVD88 on 29 August at 1125 LST (1425 UTC). The Braithwaite non-federal levee elevation varies from approximately eight feet to twelve feet. The non-federal levee of the Braithwaite polder was overwhelmed by incoming surge on the morning and early afternoon of 29 August. Measured peak interior high water marks were on the same order as measured exterior stages.

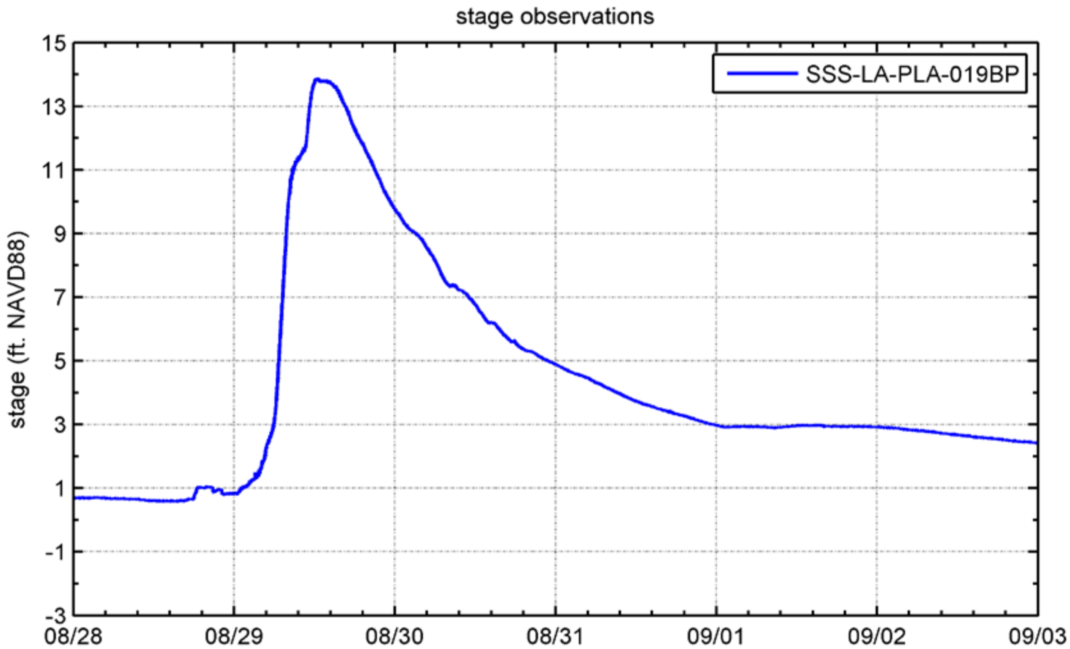

Figure 7.1.4 Stage observations at the Scarsdale gage during Hurricane Isaac.

7.1.2 Summary of Effects

Rainfall likely played a minor role in the interior inundation since the peak surge overwhelmed the Braithwaite non-federal levee. Model results for both with and without 2012 100-year HSDRRS conditions estimated stages of approximately 16 feet in this area. While the model tends to overpredict stages in this area, sensitivity analysis generally indicates potential increases of less than 0.1 feet between the with and without HSDRRS condition in the East Bank Plaquemines Parish area. A maximum increase of 0.3 feet is identified in a limited area immediately adjacent to the Caernarvon floodwall. Both model simulations and actual gage data indicate the Braithwaite levee completely overwhelmed by surge. Rainfall runoff volumes are estimated to have contributed approximately as much as 0.5 feet additional stage in the area of interest, both interior and exterior to the non-federal levee.

St Tammany & Tangipahoa Parishes

The north shore of Lake Pontchartrain (Northshore) is comprised of Tangipahoa and St. Tammany Parishes. The area is not typical of coastal Louisiana and in fact shares more similarities with coastal Mississippi, in terms of topographic relief. Land usage within the study area is a mix of undeveloped marsh, farmland/pasture, residential, commercial, and industrial. The area has numerous rivers and streams that extend northward into southwestern Mississippi. Watersheds within these parishes include the Tangipahoa, Tchefuncte, Abita, and Pearl River Basins, and Bayous Lacombe and Liberty, all of which drain into Lake Pontchartrain. The Pearl River Basin was excluded from this evaluation because the majority of the discharge goes directly into the Gulf of Mexico and would have little if any effect on Lake Pontchartrain water levels.

7.1.3 ADCIRC Model Results

Figure 7.2.1 plots the difference in peak water levels on the north shore of Lake Pontchartrain in St. Tammany and Tangipahoa Parishes. The simulated water levels in these areas for Hurricane Isaac are generally lower with the 2012 100-year HSDRRS in place. Peak water levels on the order of 8 to 10 feet are essentially unchanged or are decreased by 0.2 feet or less. Generally lower values in the lake result from the IHNC barrier eliminating conveyance from Breton Sound through the IHNC.

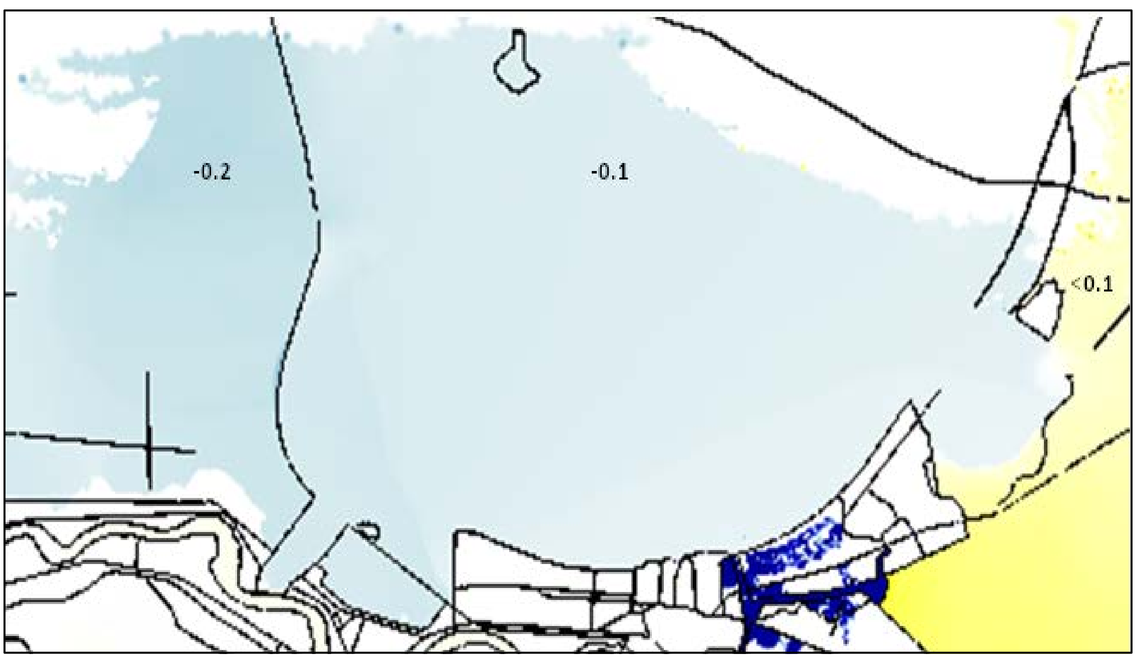

Figure 7.2.1 Difference in ADCIRC predicted peak water level for Hurricane Isaac in St. Tammany and Tangipahoa Parishes

7.1.4 Rainfall and Runoff Analysis

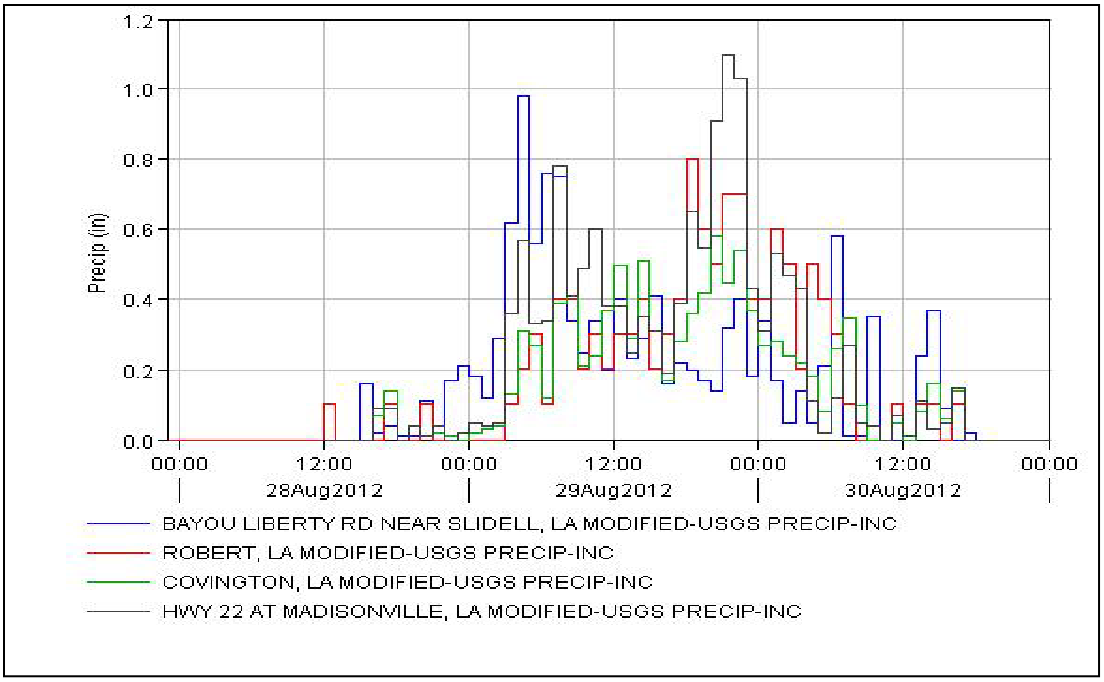

Figure 7.2.2 Hourly incremental precipitation data from available USGS gages on the north shore of Lake Pontchartrain during Hurricane Isaac.

Rainfall

Based upon an average of rainfall amounts measured at the available USGS precipitation gages, shown in Figure 7.2.2, a total of 11.3 inches of rain fell across the Northshore area. This is consistent with National Weather Service's reports of "8-12 inches being the norm across southeastern Louisiana and southern Mississippi" and the National Weather Service's data regarding estimated rainfall, shown in Figure 7.2.3.

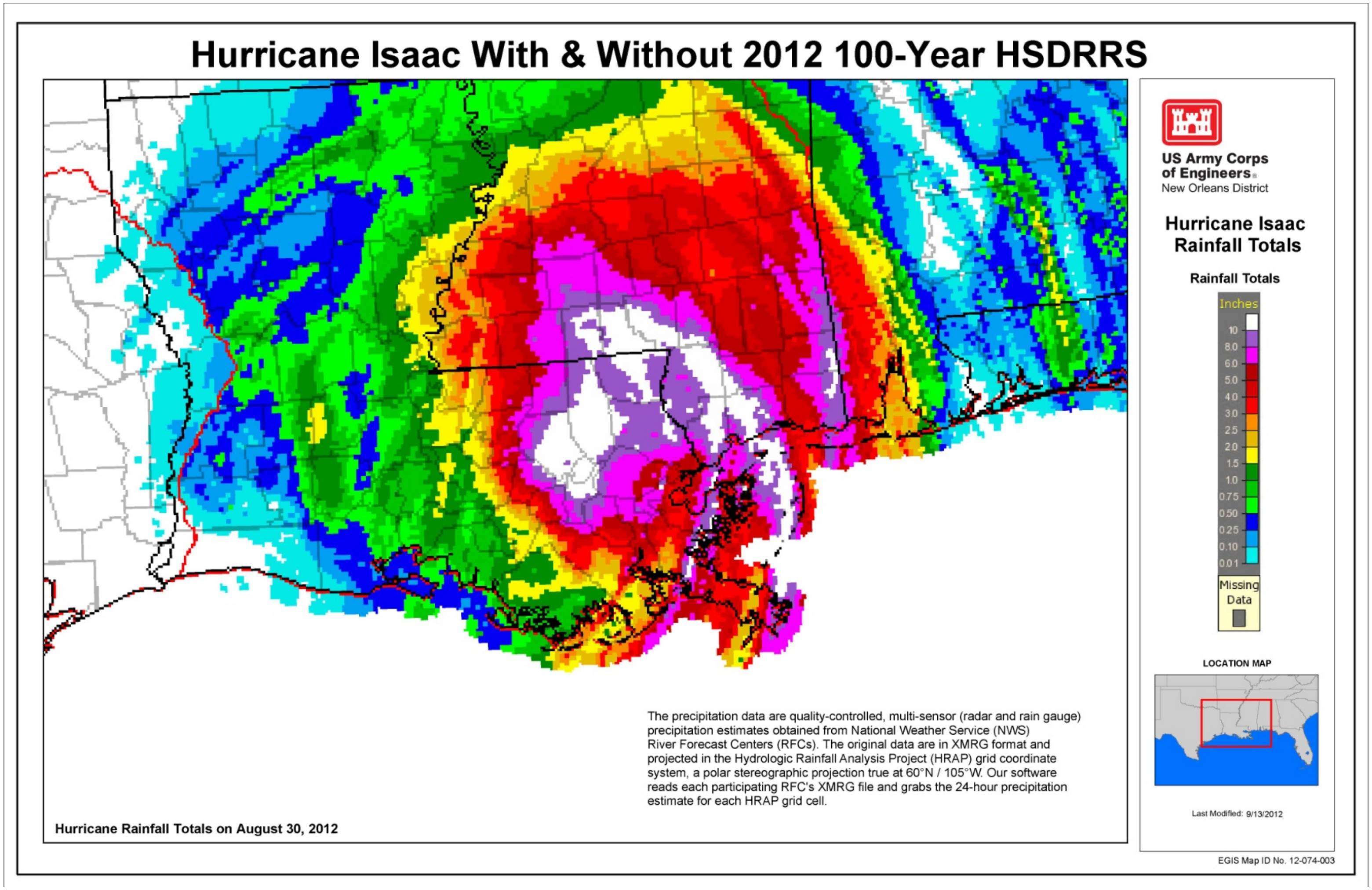

Figure 7.2.3 Louisiana and Mississippi Rainfall Totals for Hurricane Isaac

Timing and Duration of Stage, Flow, and Volume of Rainfall Runoff

As illustrated in Figure 7.2.4, measured peak stages in several streams on the north shore and in Lake Pontchartrain occurred roughly two thirds of the way through the rain event associated with Hurricane Isaac. Measured stages continually dropped with no secondary peaks after the initial peak. After peaking, the north shore stages fell at the same rate as Lake Pontchartrain or faster, suggesting there was not a secondary build up of water. At their peaks, stages along the north shore were roughly one foot higher than the Lake Pontchartrain Causeway (middle of the lake) likely due to winds pushing the surge up against the northern shore of the lake.

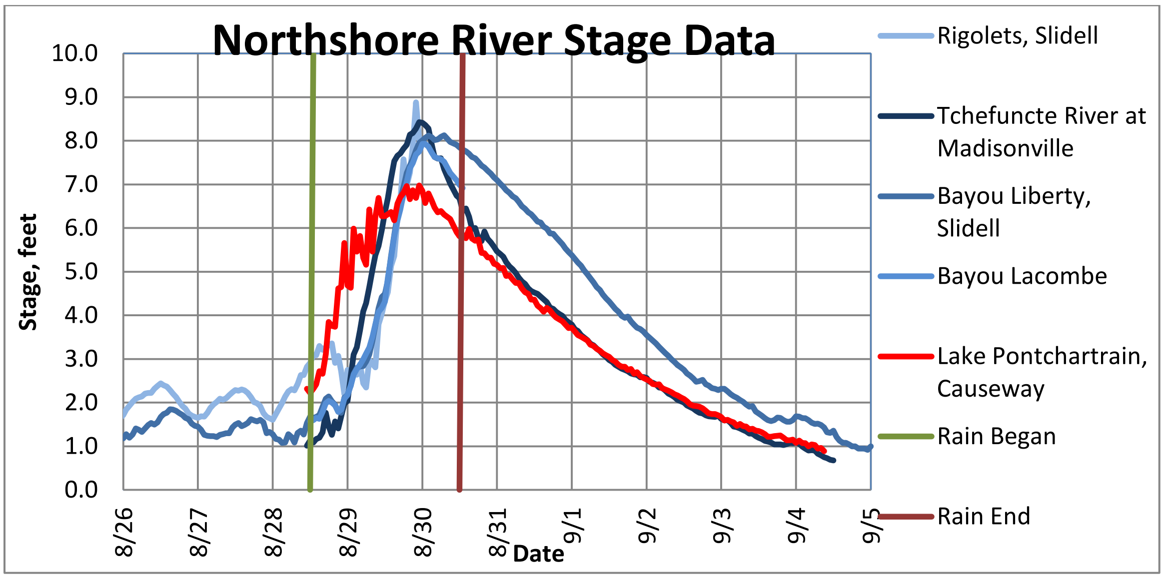

Figure 7.2.4 Stage Hydrograph plots of Lake Pontchartrain and a few of the rivers on the north shore of Lake Pontchartrain. Madisonville: gage height, no datum; Liberty: NAVD88; Lacombe: NAVD88; Causeway: gage height, no datum.

Figure 7.2.5 shows Tangipahoa and Tchefuncte river flows substantially increasing after both the rainfall stopped and the peak stage event that occurred on 30 August.

The graph in Figure 7.2.6 shows the accumulative discharge volumes for the Tangipahoa and Tchefuncte Rivers. The river runoff volume did not start accumulating until one to two days after the rainfall ended. The total river discharge volume did not reach a combined discharge volume of 400,000 acre-feet until six days after Isaac made landfall. 400,000 acre-feet is the volume of water equivalent to a one-foot rise in the level of Lake Pontchartrain. Due to the timing, relative to peak stages in the lake, runoff would not have contributed significantly to the extent of surge inundation.

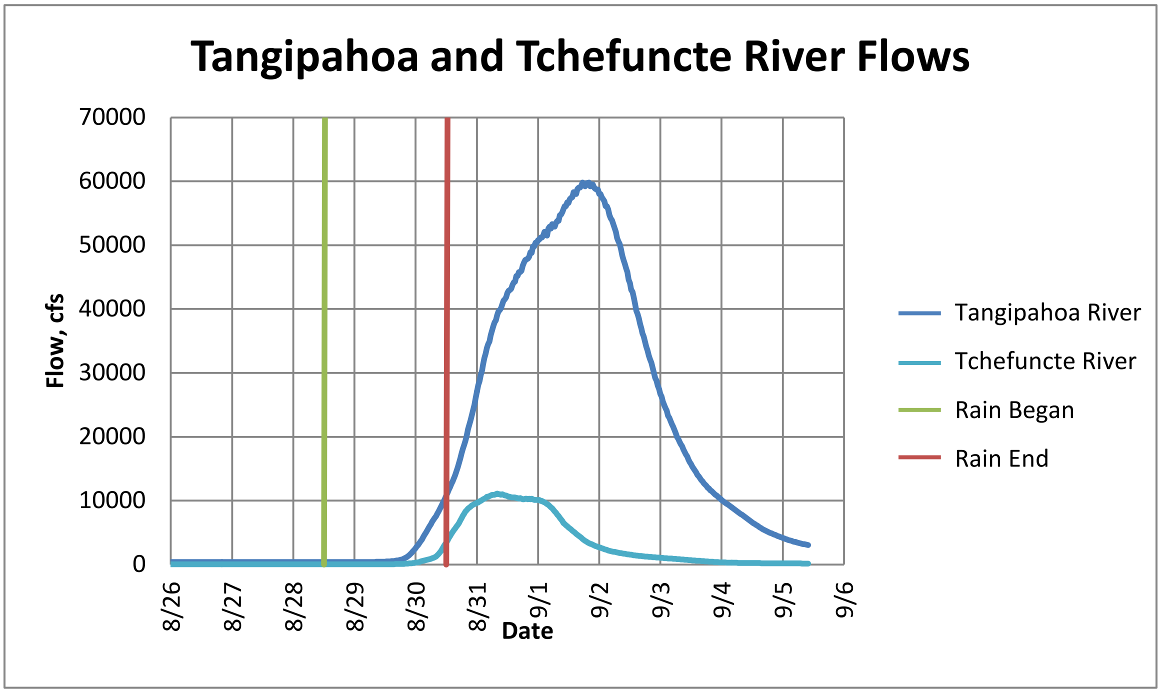

Figure 7.2.5 Tangipahoa and Tchefuncte River Flows. Timing of river discharge relative to the Isaac rainfall event.

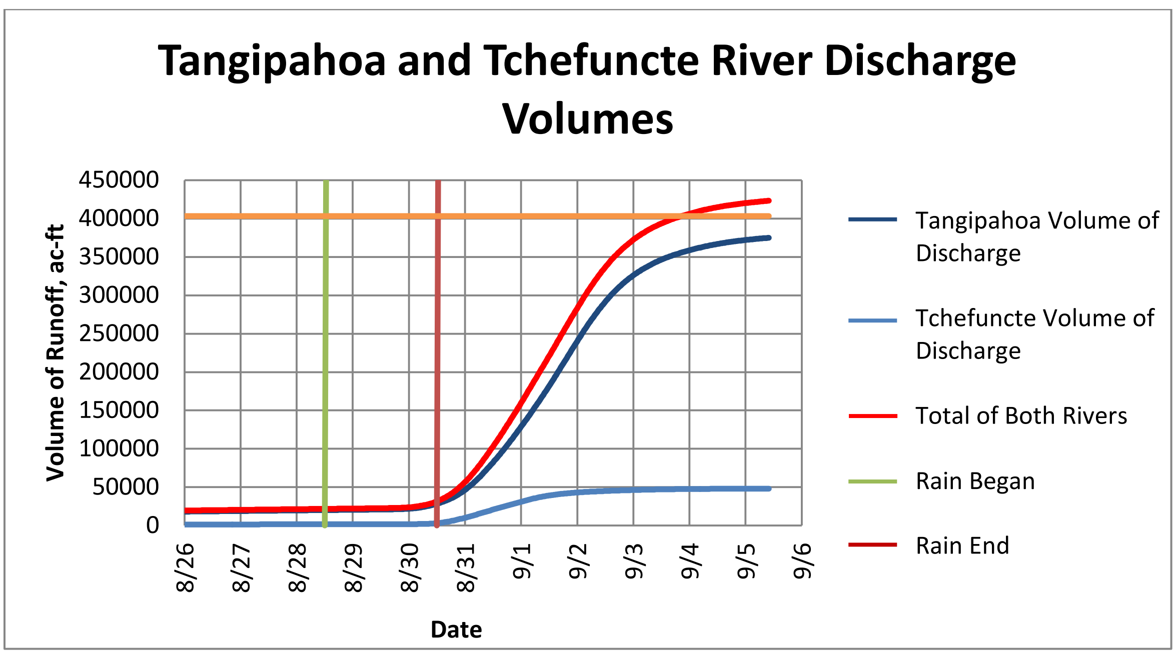

Figure 7.2.6 Discharge Volume accumulation plots of the Tangipahoa and Tchefuncte Rivers on the north shore of Lake Pontchartrain. Timing of volume of river runoff relative to Isaac rainfall event

Lake St. Catherine Area

The community of Lake Catherine is located in eastern Orleans Parish, within the city limits of New Orleans, between Lake Pontchartrain and Lake Borgne in Louisiana. This community is made up of several distinct residential areas: the Rigolets, Chef Pass, Greens Ditch, Lake St. Catherine, and Fort Pike Subdivision; all of which border Highway 90 in New Orleans East.

The community is situated on a nine mile long geomorphic feature referred to as the New Orleans East Land Bridge. The land bridge is also made up of numerous distinct hydrologic features including: Chef Menteur and Rigolets Passes, the GIWW, and Lake Catherine. In addition Highway 90 and the CSX railroad each extend across the entire length of the land bridge. These are continuous elevated features that allow the land bridge to act as a hydrologic barrier.

During Hurricane Isaac, the New Orleans East Land Bridge was overtopped in its entirety by storm surge. Figure 7.2.7 below shows a typical cross section of the Rigolets and Chef pass. These are the two main channels that cut through the New Orleans East land Bridge and connect Lake Pontchartrain to Lake Borgne.

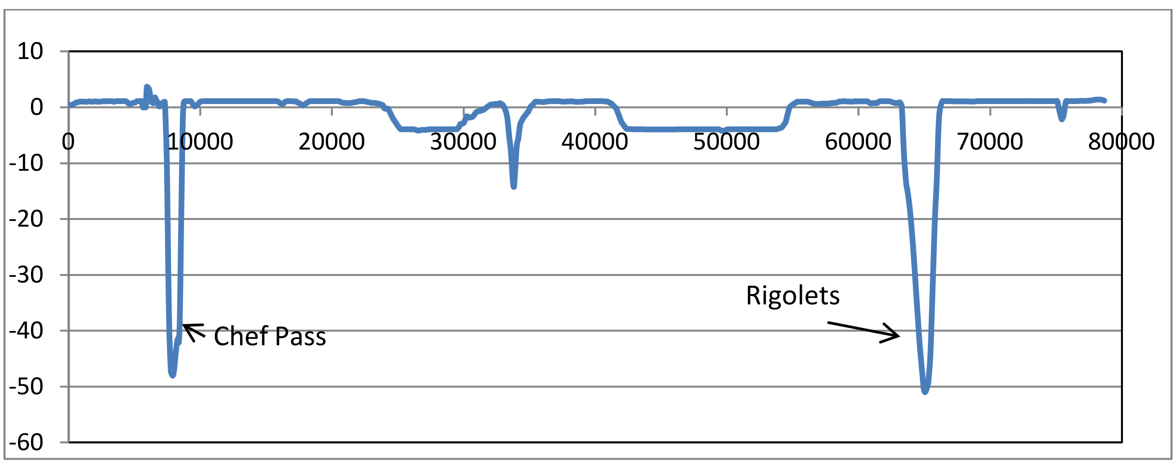

Figure 7.2.7 Cross-section of Lake Catherine Land Bridge. NAVD88.

A color-shaded relief map (figure 7.2.8) made from LiDAR shows the topography of the New Orleans East Land Bridge along with the Rigolets Pass and Chef Menteur Pass within the New Orleans East Land Bridge. The colors on this map indicate ground elevation. Red is the highest ground, approximately 5.0 feet NAVD 88, and Blue is the lowest approximately 0.0 feet NAVD 88. Based on the elevation of the natural ground it seems likely that any storm surge elevation higher than 5 feet NAVD88 would completely inundate the New Orleans East Land Bridge and flow into Lake Pontchartrain.

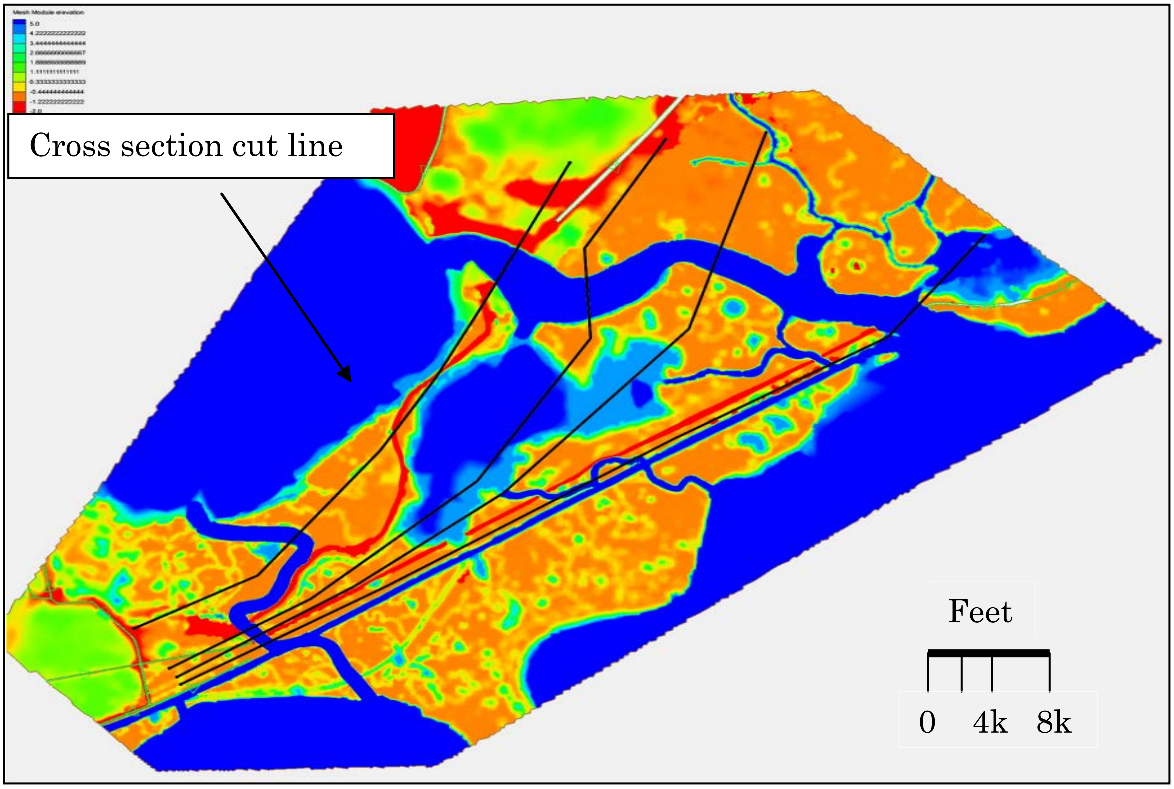

Figure 7.2.8 Color-shaded LiDAR relief map of the New Orleans East Land Bridge

Comparison of Isaac with Historic Storms

Storm surge elevations for Hurricane Isaac have been compared to water elevations for past tropical events within the Lake Pontchartrain System. Table 7.1 below compares the storm surge from Hurricane Isaac to the peak water elevations observed during Hurricanes Gustav, Ike, Katrina, and Juan.

Table 7.1 Comparison of Stages at Select Gages for Isaac, Gustav, Katrina & Juan

Gage Name	8/29/12 Isaac Peak Stage FT NAVD88 2004.65	9/1/08 Gustav/Ike Peak Stage FT NAVD88 2004.65	8/29/05 Katrina Peak Stage FT NAVD88 2004.65	10/3/85 Juan Peak Stage FT NAVD88 2004.65
Lake Pontchartrain at Mandeville	8.3	6.2	No data	7.3
Rigolets near Lake Pontchartrain	8.3*	No data	No data	5.1
Bayou St John at Lake Pontchartrain	6.4	No data	No data	No data

*Rigolets read 8.3 before malfunction.

7.1.5 Summary of Effects

Model results for both with and without 2012 100-year HSDRRS conditions estimated stages ranging from approximately 8 to 12 feet throughout the Lake Pontchartrain area. Approximate modeled stages throughout the area of 10 to 12 feet along the Lake Catherine land bridge and 8 to 9 feet along the Northshore and Maurepas land bridge. The model sensitivity analysis indicates a slight reduction of roughly 0.1 feet in stages between the with and without 2012 100-year HSDRRS condition within the entire area for Hurricane Isaac. The likely cause for this effect is a reduction in the volume flowing into the lake due to the closure of the IHNC.

Although Hurricane Isaac produced a significant amount of rainfall runoff, it had no noticeable effect on the peak level of Lake Pontchartrain. As the winds subsided, the lake levels fell at approximately two feet per day. It took approximately four days for the runoff to reach an equivalent volume of one foot of lake rise, by which time lake stages had receded back to pre-storm levels. The bulk of the rainfall runoff occurred after the storm surge has passed and thus allowing the river discharge to exit the lake system. The sustained tropical storm force winds effectively blocked the lake's outlets at the Chef Menteur and Rigolets Passes during the immediate passage of the event. Without those winds, the lake's artificially high stages were free to drain through these outlets carrying the rainfall runoff with it.

There is little doubt that the sheer volume of rainfall runoff produced significant localized flooding on the north shore of Lake Pontchartrain as river stages exceeded flood stage and artificially high lake stages hindered normal drainage of rainfall. However, additional in-depth study would be required to determine stages and timing of localized flooding.

West Shore Lake Pontchartrain

The West Shore of Lake Pontchartrain area (Figure 7.3.1) encompasses the parishes of St. John and St. James, which are located along the southwest and western shore of Lake Pontchartrain and the southern shore of Lake Maurepas. This area contains the communities of LaPlace, Lutcher, Gramercy, Reserve, and Garyville. St. John Parish is located approximately 30 miles northwest of downtown New Orleans. This section will also discuss the effects of the Marvin J. Braud Pumping Station, which is located in Ascension Parish but may have an influence on water levels in St. James Parish.

Much of this area lies within the Lake Maurepas Watershed. This watershed includes Lake Maurepas itself, the large expanse of wetlands and shallow open water areas to the south and southwest of Lake Maurepas, the Amite River basin, Natalbany River basin, the Tickfaw River basin, and the Blind River basin. The Blind River basin runs through the Maurepas swamp. This river has a very mild slope, which makes it more sensitive to back water effects. This area contains a mixture of developed and undeveloped areas from undeveloped marsh, farmland/pasture, residential, commercial, and industrial. Also located in this area is the Manchac Land Bridge. This is a narrow strip of low lying marsh land that separates Lake Pontchartrain from Lake Maurepas. The only connection between these two lakes is a cut through the land bridge called Manchac Pass.

Lake Maurepas is a shallow, brackish tidal estuarine system. It is approximately 92.7 mi^2 in area and has a mean depth of about 10 feet. The lake receives freshwater input through four river systems: Blind River, Amite River, Tickfaw River, and the Natalbany River. The average freshwater input to Lake Maurepas from these rivers and other minor terrestrial sources is approximately 3,400 cubic feet per second (cfs). At the northeast, Lake Maurepas is connected to Lake Pontchartrain by two passes: Pass Manchac and North Pass. Tidal exchange with Lake Pontchartrain through Pass Manchac is a more significant influence on Lake Maurepas' volumetric and elevation characteristics than tributary freshwater discharge.

Figure 7.3.1 West Shore Lake Pontchartrain Area

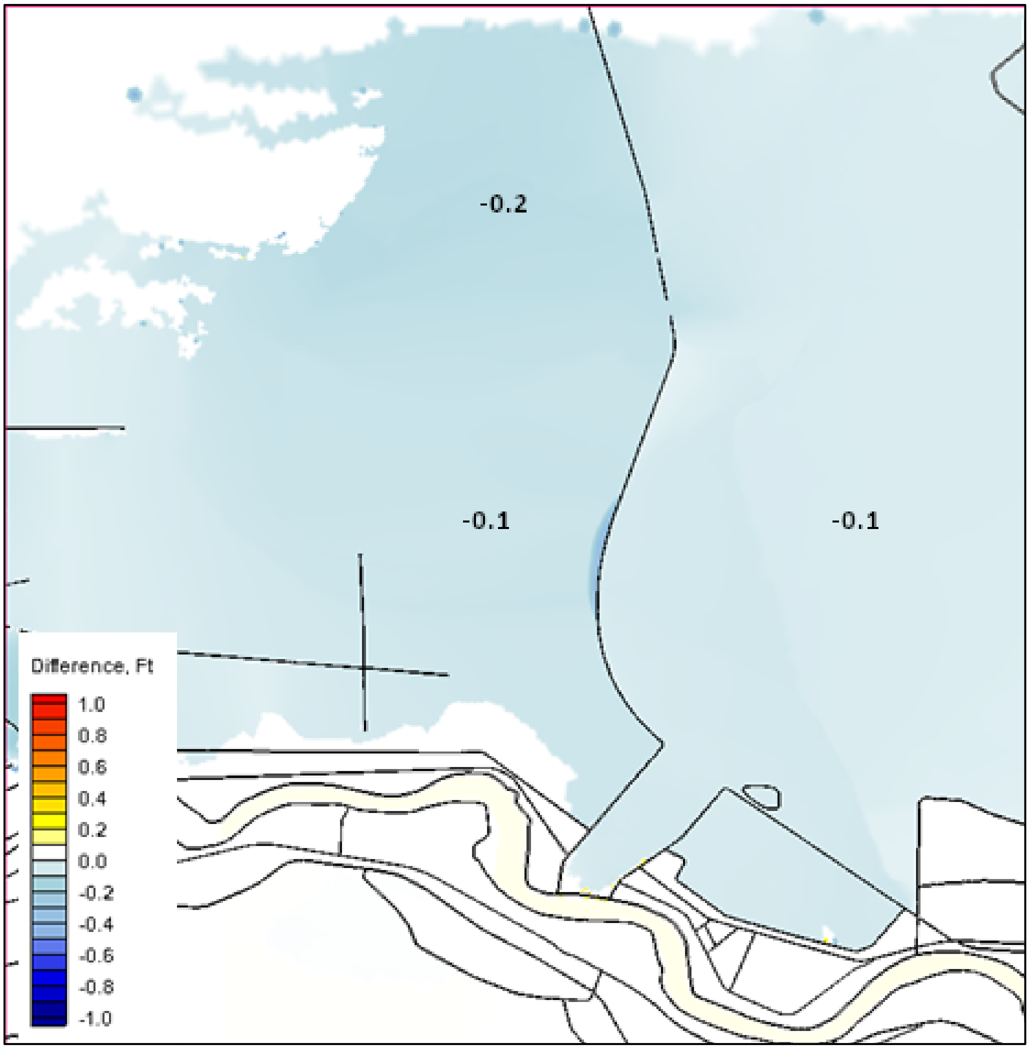

Figure 7.3.2 Difference in ADCIRC predicted maximum water level for Hurricane Isaac in West Shore Lake Pontchartrain (With & Without 2012 100-Year HSDRRS).

7.1.6 ADCIRC Model Results

Figure 7.3.2 plots the difference in peak water level between the 2012 HSDRRS and the without 2012 100-year HSDRRS simulations in more detail for West Shore Lake Pontchartrain. Water levels in this area decrease by approximately 0.1 to 0.2 feet or less. This results from the IHNC barrier eliminating conveyance from Breton Sound to Lake Pontchartrain through the IHNC.

7.1.7 Rainfall and Runoff Analysis

The focus of this section is on the significance of rainfall runoff contribution to the timing and magnitude of peak water levels in the Lake Maurepas

Watershed, and how it affected drainage in St. John and St. James Parishes. The timing and duration of high water elevations in Lake Pontchartrain and Lake Maurepas also hampered the ability of the local interior drainage systems to function as designed.

A distribution of the available raw daily precipitation data was determined by using hourly recorded precipitation data at New Orleans International Airport (MSY). The MSY recording gage was the only gage within the area recording reliable hourly precipitation during Hurricane Isaac; therefore it was determined suitable to use the rainfall distribution recorded at this location. A plot of the MSY gage is shown in Figure 7.3.3.

To determine the time pattern for distribution, the hourly incremental precipitation is divided by the total precipitation for the specific duration to allow application to other non–hourly rainfall totals from other locations. A plot of the time pattern is shown in Figure 7.3.4.

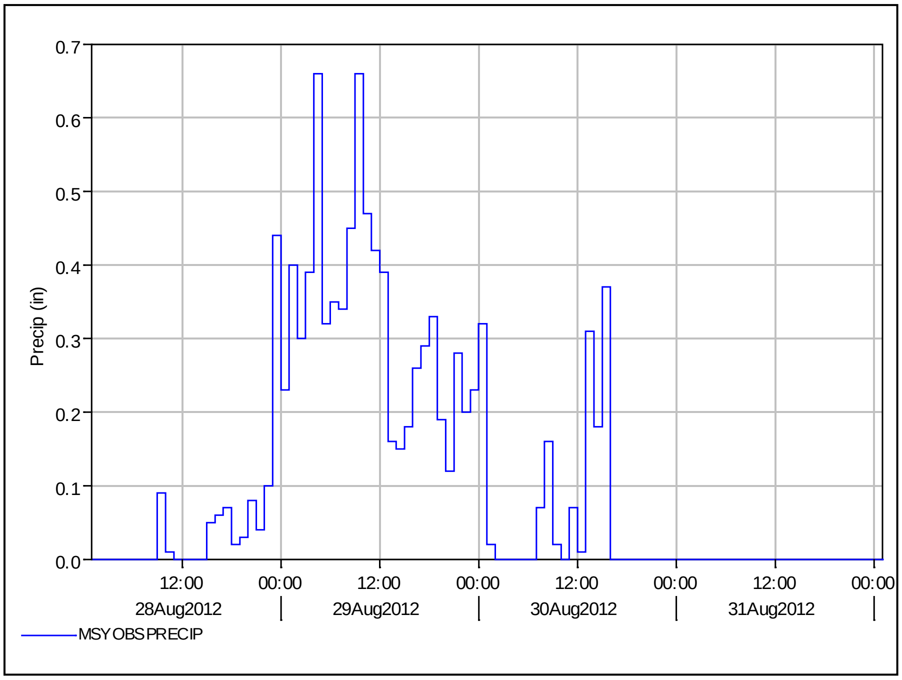

Figure 7.3.3 Hourly incremental precipitation for Hurricane Isaac at New Orleans International Airport

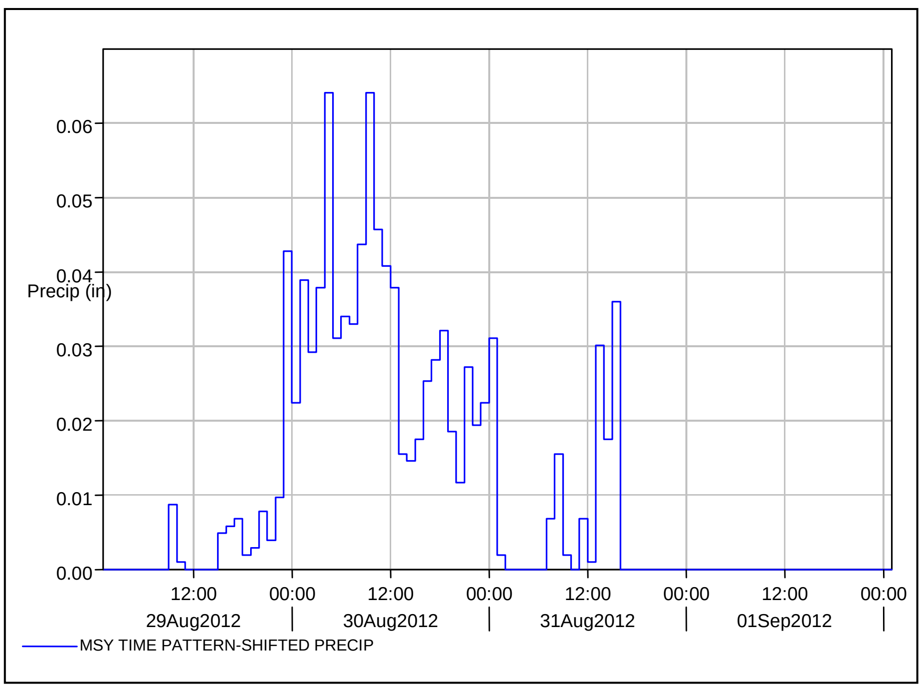

Figure 7.3.4 Time pattern for Hurricane Isaac (shifted). Rainfall Distribution at New Orleans International Airport shifted 24 hours to represent the rainfall as it occurred in St. John Parish

Analysis of the rainfall gages in the West Shore area show the rainfall from Hurricane Isaac occurred approximately 24 hours later than it did at MSY. Due to this lag in local rainfall, the MSY gage time pattern was shifted forward by 24 hours. This shift was necessary to correlate the daily recorded rainfall throughout the area to the hourly time pattern distribution at MSY.

The rainfall totals in the West Shore area as recorded by the national weather service's rain gage network, ranges from 10 inches to nearly 15 inches for the entire event. These rainfall amounts are preliminary as the NWS is currently reviewing their rainfall data. As shown in table 7.2 below, the rainfall amount decreased in the region from east to west. The Carrollton gage recorded more than 21 inches of rain, where as Baton Rouge only reported just above 9 inches for rain.

Table 7.2 Rainfall Totals in the Upper Pontchartrain Basin

Rainfall Totals – West Shore Lake Pontchartrain	
Gage Location	Rainfall Amount
Lutcher	10.4"
Armstrong International Airport	10.4"
Gramercy	13.6"
Reserve	14.8"
Baton Rouge	9.2"
Carrollton	21.3"

7.1.8 Rainfall runoff amounts in the watershed

Direct Rainfall Effects

Direct rainfall totals for Hurricane Isaac reached as high as 15 inches in some locations in the West Shore area. Most of the developed area of West Shore is drained by gravity drainage systems, meaning water can only exit the area through the drainage system by the force of gravity. There are no pump stations to force water out of the area. The coupling of this rainfall along with extremely high lake stages would cause these rainfall runoff collection systems to perform less than optimally.

7.1.8.1 St. John Parish

The watershed in St. John Parish predominately slopes from the Mississippi River levee to Lake Pontchartrain and Lake Maurepas. The natural drainage of the watershed is from the south, at the Mississippi River levee, through existing local drainage system, into large outfall canals and then to

Lake Pontchartrain and Lake Maurepas. The elevation varies from +16 feet elevation NAVD 88 at the toe of the Mississippi River levee to 0 feet elevation at the wetlands near Lake Pontchartrain and Lake Maurepas.

To determine the direct effects of the rainfall from Hurricane Isaac on St. John Parish, an existing HEC-HMS hydrologic model of the area was used to perform a preliminary assessment of the direct rainfall impacts to the area. This modeling software, developed by the Hydrologic Engineering Center, was also used to quantify the volume of rainfall runoff that was experienced in the West Shore area during Hurricane Isaac. Since this existing model was not constructed to handle the backwater effects from storm surge and so some of the assumptions use to construct the model may not be appropriate in this scenario. As a result actual internal inundation and input to the lake system from rainfall may be different than what is estimated by this analysis. This model provided value to this assessment by enabling conversion of rainfall amounts to runoff hydrographs. The volume of rainfall, associated water surface elevations, and the timing of the rainfall runoff were determined by using the HEC-HMS model.

The flooding impacts experienced in St. John Parish may have been attributable to more than one source of water. There was a storm surge component and a rainfall runoff component, the effects of which were compounded by the lack of adequate gravity drainage resulting from the elevated Lake Pontchartrain and Lake Maurepas stages. The impact of elevated lake stages on the drainage of St. John Parish were examined by analyzing the rainfall distribution over the area and comparing the timing between peak rainfall and when lake stages were elevated.

Hydrologic Model Results

An existing hydrologic model for St. John the Baptist Parish was used to assess the effects of the rainfall from Hurricane Isaac. The hydrologic model produced rainfall runoff hydrographs for each sub-basin. A sample hydrograph is shown below in Figure 7.3.5. The hydrologic model produced flow hydrographs for each of several defined basins, based on the Hurricane Isaac rainfall amounts. The results show the peak discharge for each of the basins as well as the time the peak occurred and the total runoff volume. The runoff hydrographs computed by the program are provided as a boundary condition for a hydraulic model of the area.

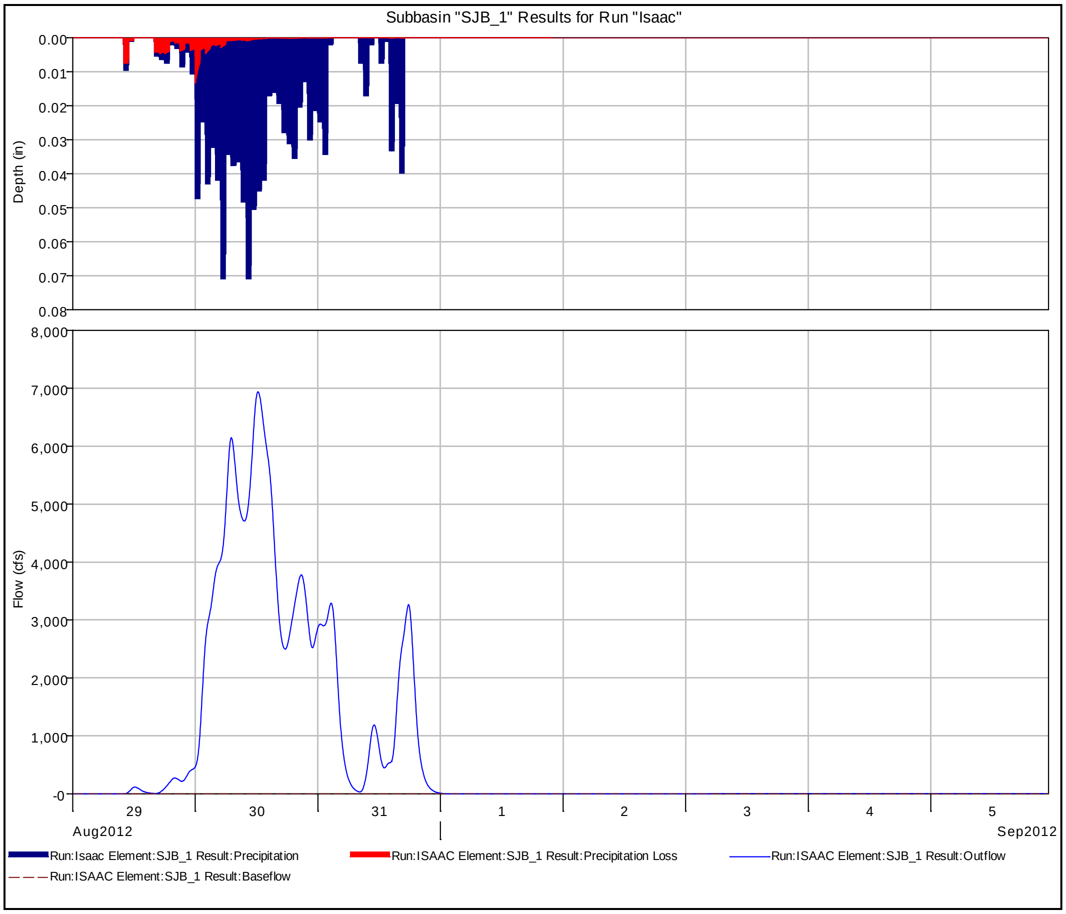

Figure 7.3.5 Rainfall runoff hydrograph produced by the HEC-HMS model for St. John the Baptist Parish.

Hydraulic Assessment

A HEC-RAS hydraulic model of the St. John Parish area was also used to determine the water surface elevations that occurred during Hurricane Isaac as a result of the combination of direct rainfall and the high lake stages. The model was used to route Hurricane Isaac rainfall runoff hydrographs through a series of storage areas that were defined in the hydraulic model to compute maximum water surface elevations through the St. John Parish area. With Lake Pontchartrain as a boundary, the measured surge hydrographs from the ADCIRC model were used as boundary conditions of the hydraulic models.

Hydraulic Assessment Results

Rainfall runoff hydrographs from HEC-HMS were entered directly in to the storage areas. The model boundaries were set at the conditions from the Isaac Advisory 39 forecast results from ADCIRC. Three separate runs were made and compared using the hydraulic model. The first run was made using only the storm surge hydrographs in Lake Pontchartrain as the source of inundation. No rainfall was used in this simulation. The second simulation was made using only the rainfall runoff hydrographs that were computed by the HEC-HMS model. No storm surge hydrographs were used elevate lake levels in this model simulation. Finally, a hydraulic model simulation illustrating the combined effects of both rainfall and surge in the St. John Parish area was completed. The inundation map of the rainfall only and the storm surge plus rainfall scenarios can be see below in figure7.3.6.

The results of the hydraulic assessment reveal that the Hurricane Isaac rainfall added very little volume of water to the inundation of the West Shore area. The surge began impacting the area as much as 24 hours prior to any significant rainfall observations. The water levels in the area continued to rise because the high water levels in Lakes Maurepas and Pontchartrain continued to travel through and fill up the large wetland areas of the Maurepas Swamp for an extended time after peaking in the lakes. Even as water levels had begun to fall in Lake Pontchartrain. Once these areas were inundated with storm surge water, the rainfall began in the areas. The volume of rainfall runoff that occurred prior to the peak stage in Lake Maurepas paled in comparison to the volume of storm surge. The additional volume of rainfall that fell after peak stages occurred in Lake Maurepas acted to extend recession of the high water in the Lake Maurepas basin. As a result high water elevations and significant inundation lasted into the early days of September.

The initial storm surge entered St. John Parish along the shores of Lake Pontchartrain. As the water levels in the Lake continued to increase, the surge moved further inland. Once the storm surge came over the railroad tracks along Interstate 55 and Interstate 10, the interior areas filled quickly. The residents of LaPlace reported that the flooding came very quickly, on the order of 5 feet in approximately 20 minutes.

Understanding how the storm surge water moved into St. John Parish and the role of the railroad tracks and the interstate is critical in explaining why other previous hurricanes did not flood St. John Parish as severely. Hurricane Isaac produced tropical storm force winds for over a period of 45 hours. These winds built up a very large storm surge on the western shores of Lake Pontchartrain. Other previous hurricanes did not have this extended time to build up surge and overtop the interstate due to their greater forward speed.

Within St. John Parish, as Lake Pontchartrain receded, only water above the elevation of Interstate 10 and railroad tracks was able to quickly recede back into the lake. All additional water below the elevation of these barriers was not able to be evacuated from the area until the local sub-surface drainage was free from backwater effect of Lake Maurepas.

Storm surge also entered Lake Maurepas peaking after Lake Pontchartrain and raising its level to a point to where it also began flooding the wetlands along its shores. The water elevations in Lake Maurepas remained high, and receded at a much slower rate than Lake Pontchartrain. Water from Lake Maurepas continued to move into the Maurepas Swamp in the northern areas of St. John and St. James parishes approximately two days after Isaac made landfall. This deferred inundation is what was observed by people in this area.

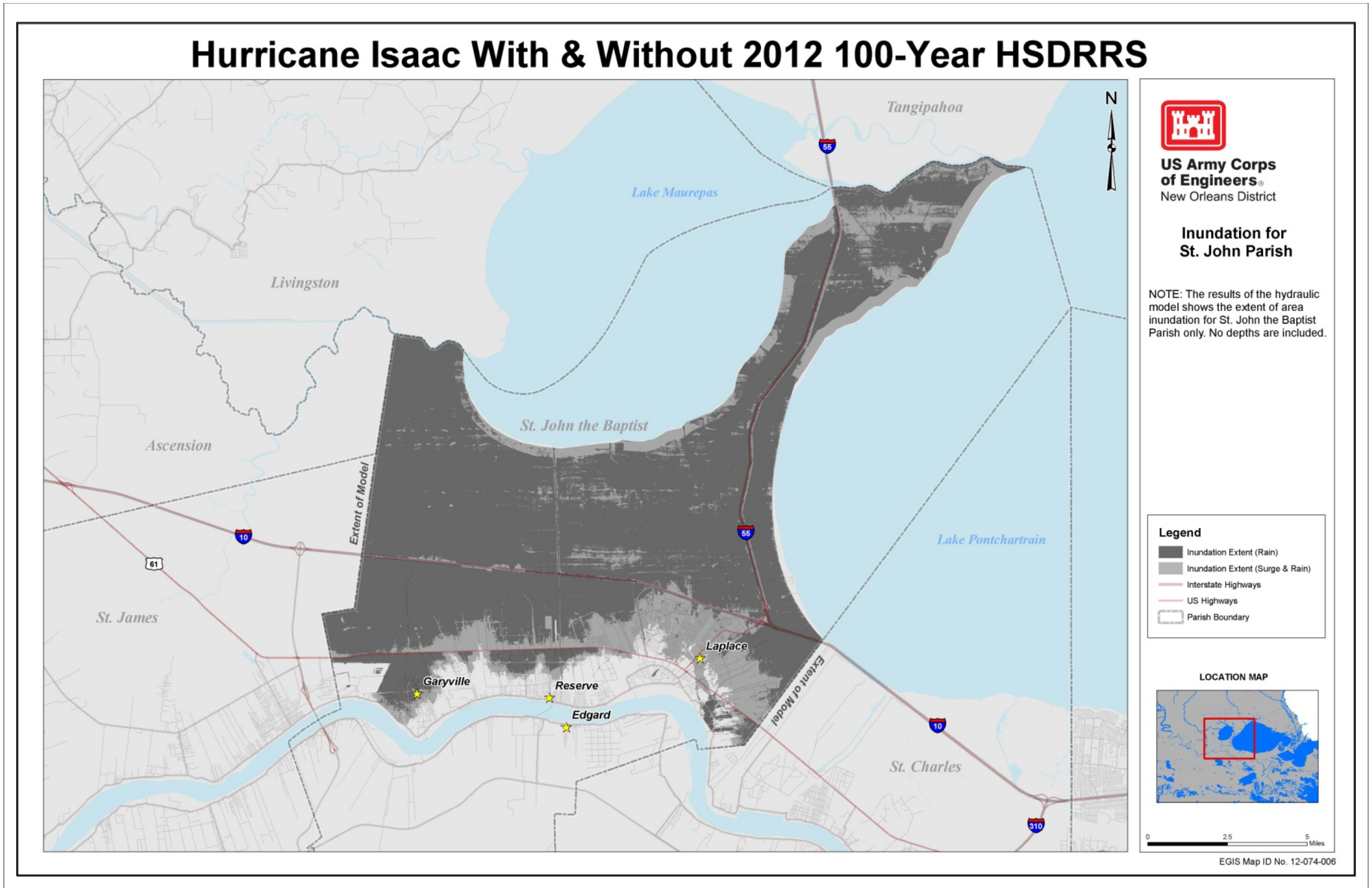

Figure 7.3.6 Combined Rainfall – Surge Inundation Map St John the Baptist Parish. Comparison of the inundation effects of rainfall only compared to combined storm surge plus rainfall for Hurricane Isaac.

7.1.8.2 St. James and Ascension Parishes

St. James Parish lies just to the west of St. John Parish and is midway between New Orleans and Baton Rouge. St. James Parish does not border either Lake Pontchartrain or Lake Maurepas, but part of the parish's northern areas lie within the Maurepas Swamp. The east bank of St. James Parish drains south to north. The land slopes from the Mississippi River to the Maurepas Swamp.

Ascension Parish lies predominately to the north of St. James Parish. Like St. James Parish, Ascension Parish does not border Lake Maurepas, but its far eastern areas lie along the lower Amite River and sit within the Maurepas Swamp. Areas in the southeastern part of the parish near Sorrento, LA experienced prolonged high water during Hurricane Isaac.

There were no existing hydrologic or hydraulic models for St. James or Ascension Parishes as in St. John Parish. A qualitative assessment was performed to determine the impact of direct rainfall on the area. There are many similarities between the hydrology of St. John and St. James Parishes. The surge in St. James may have taken a little longer to make its way to populated areas, but the primary source of flooding is believed to be from the surge propagation from Lake Maurepas.

The rainfall in the St. James and Ascension Parish areas peaked near the same time Hurricane Isaac made landfall in Louisiana. By this time surge in Lake Maurepas had been building up for some time. Figure 7.3.7 is a hyetograph of the rainfall in various locations of Ascension Parish. By comparing the peak rainfall in this plot to the peak flows in the local rivers, the difference can be seen in timing of the peaks for each.

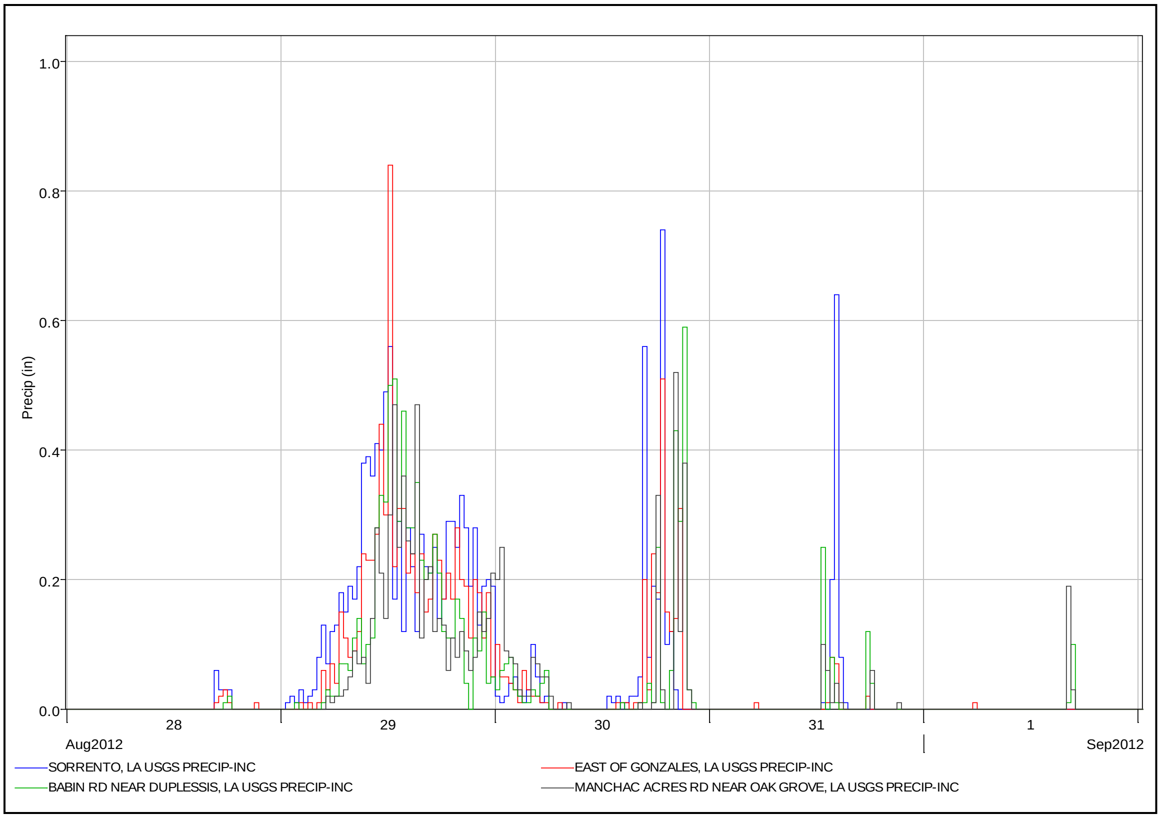

Figure 7.3.7 Rainfall Hyetographs at four locations in Ascension Parish, Louisiana. Measured hourly rainfall at four locations over the duration of Hurricane Isaac.

Observed Stages in St. James and Ascension Parish

Bayou Francois is part of the headwaters of the Blind River. Bayou Francois is not located very close to the tidal areas of the watershed therefore it is not as influenced by storm surge. Based on gage data, and illustrated by the close timing of the two peaks (Figure 7.3.8), it seems that the storm surge and peak rainfall runoff may have occurred at nearly the same time. The two peaks on the stage hydrograph could have also been caused by the timing of various upstream tributaries.

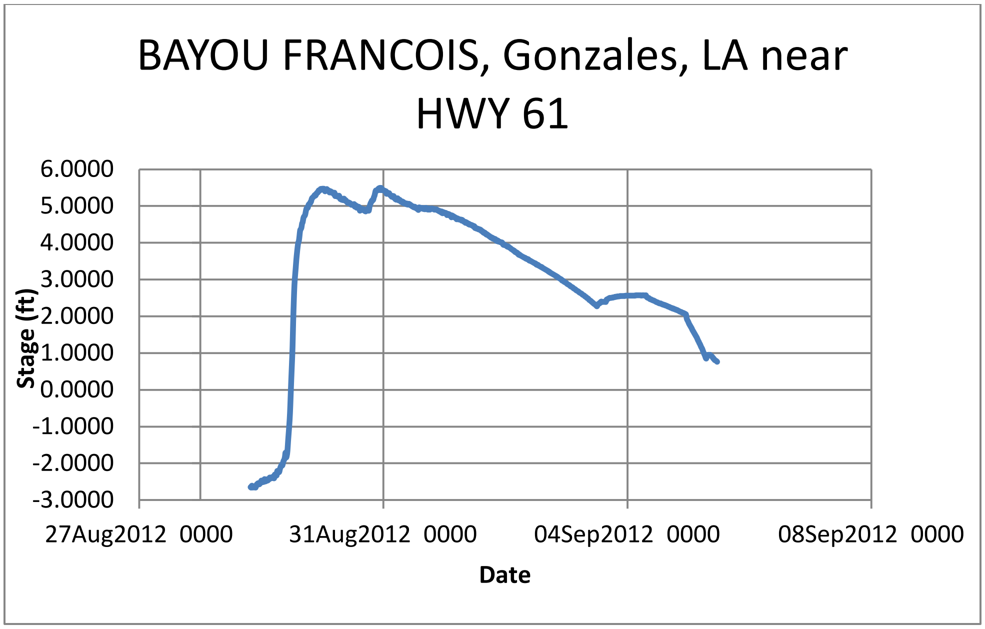

Figure 7.3.8 Measured gage data at Bayou Francois near Gonzales, LA.
Peak stage occurred on 30 August at 2330 LST (0430 UTC on 31 August). Datum: NAVD88

Black Bayou near Prairieville, Louisiana is located upstream of the Marvin Braud Pump Station. There are no effects of storm surge observed at this location. The peak stages shown in Figure 7.3.9 that occurred in this location during Hurricane Isaac is the direct result of rainfall only.

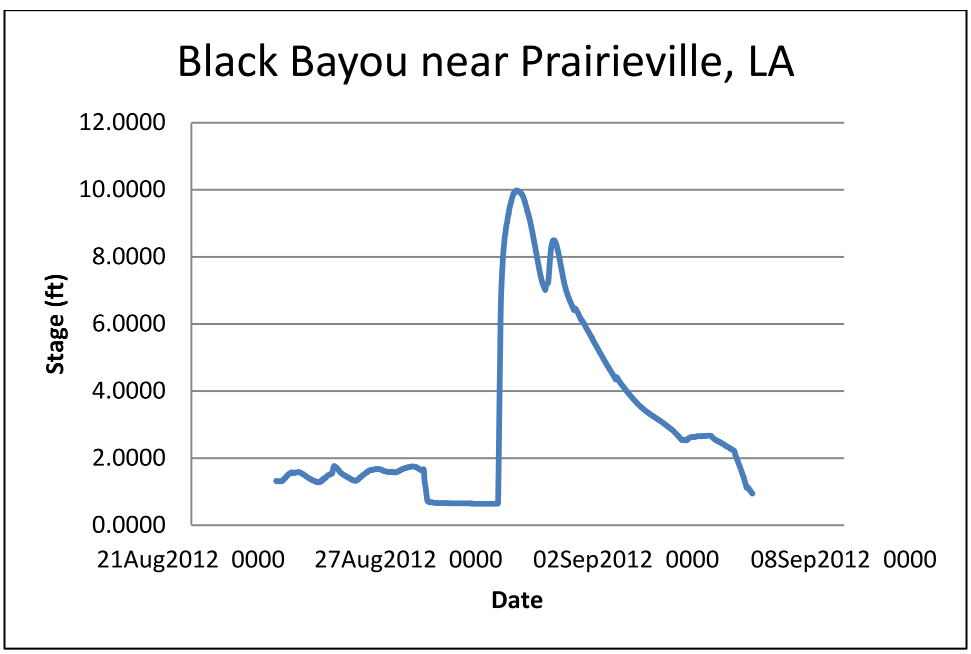

Figure 7.3.9 Measured gage data at Black Bayou near Prairieville, LA.
Peak stage occurred on 30 August at 2330 LST (0430 UTC on 31 August). Datum: NAVD88

Muddy Creek is a tributary of Bayou Manchac which joins the Amite River just upstream of Port Vincent, LA. This area is located in the lower Amite watershed and is susceptible to changes in Lake Maurepas elevations. As seen in Figure 7.3.10, the first stage peak is likely attributed to the storm surge and local rainfall and the subsequent peak is likely attributed to upstream rainfall.

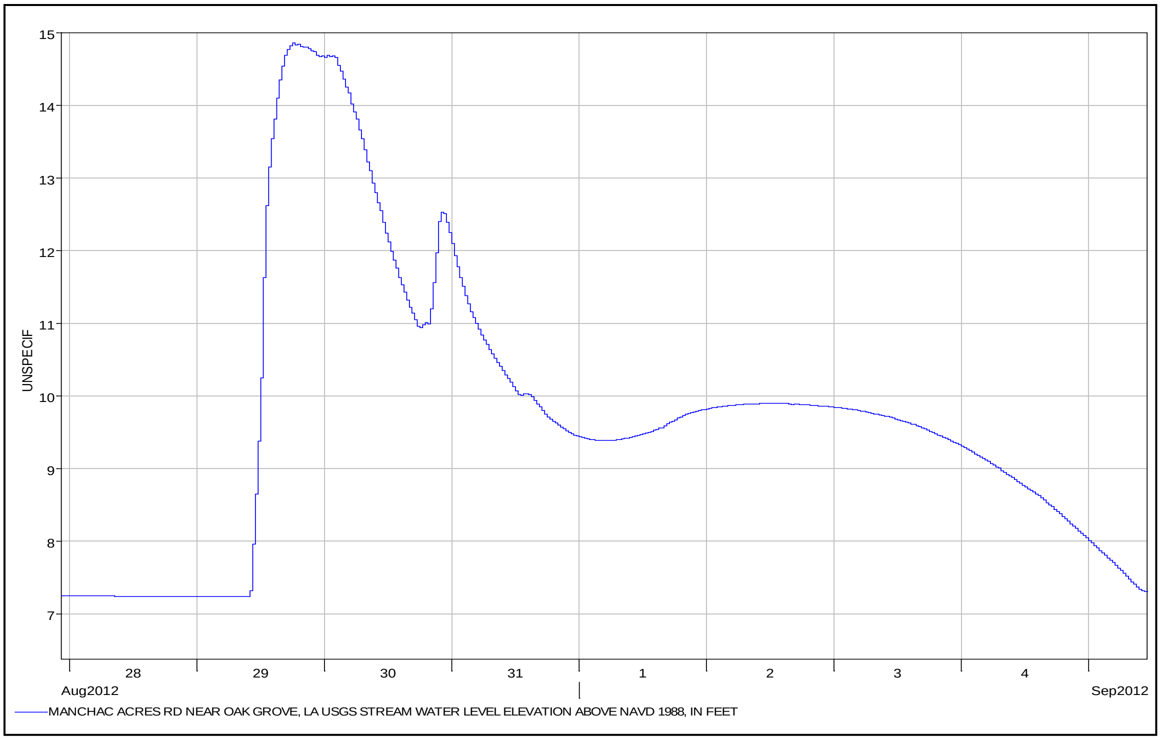

Figure 7.3.10 Measured gage data at Muddy Creek near Oak Grove, LA. Peak stage of 14.8 feet (gage height) occurred on 29 August at 1800 LST (2300 UTC). Datum: NAVD88

Marvin J. Braud Pumping Station

McElroy Swamp is an area in the far eastern portion of Ascension Parish, Louisiana, bounded on the west by Hwy 22, on the south by Highways 70 and 3125, on the east by Blind River and the north by the Amite River Diversion Canal that is comprised of thousands of acres of cypress and tupelo swamps.

McElroy Swamp, being the nearest lowland basin to East Ascension Parish's inhabited land mass, serves as a sump receiving most of the west to east run-off from this area before passing it on to Lakes Maurepas and Pontchartrain. The flooding typically observed in this area is caused by extreme tidal surges or excessive rainfall associated with tropical storms or hurricanes.

In the early 1990's, the implementation of Ascension Parish's forced drainage system saw the construction of the Marvin J. Braud Pumping Station. This pump station located on the border of St. James and Ascension Parishes has five 1,000 cfs pumps. The pump station was operated at full capacity for 41 hours during Hurricane Isaac, beginning late at night on 29 August until 1900 LST (0000 UTC) 31 August.

Figure 7.3.11 Aerial image of Marvin J. Braud Pump Station in Ascension Parish during normal operations.

During Hurricane Isaac, water levels on the discharge side of the Marvin J. Braud Pumping Station reached a higher point than at any time in the station's history going back to the early 1990s. Storm surge from Isaac pushed water from Lake Maurepas up around the pump station, nearly inundating all five pumps. Water on the discharge side of the station reached a maximum of 6.3 feet on a station gage surpassing the previous record of 4.8 feet (gage height, no datum).

7.1.8.3 Lake Maurepas

Lake Maurepas lies just west of Lake Pontchartrain and contains vast areas of marsh lands along its western, southern, and eastern shores. The lake is the terminus of four rivers which drain areas extending into southwestern Mississippi. The Blind River originates in St. James Parish and flows northeast through Ascension Parish. The Amite River basin contains a large portion of the Baton Rouge metropolitan area. The Natalbany and Tickfaw River basins drain large areas of land north of Lake Maurepas.

Storm surge for Hurricane Isaac initially raised water levels in Lake Borgne, then Lake Pontchartrain, and finally Lake Maurepas. The peak stages in Lake Maurepas did not occur until well after the stages in Lake Borgne and Lake Pontchartrain had peaked and begun to recede. Observed water elevation gages illustrate this propagation of the storm surge from east to west throughout the Lake Pontchartrain Basin. A comparison of this progression is shown in figure 7.3.17 at the end of this sub-section.

Flooding that occurred on the West Shore of Lake Pontchartrain seemed to have occurred much later and last much longer than areas on the south, north and eastern shores of Lake Pontchartrain. Water elevations in Lake Maurepas remained elevated long after Lake Pontchartrain receded. The topography of the land around Lake Maurepas may have been a factor in how the surge water receded out of the watershed.

Manchac Pass

Lake Maurepas has only one outlet, Manchac Pass, which connects it to Lake Pontchartrain. Manchac Pass acts as the hydraulic control for water flowing out of Lake Maurepas. The topography of Manchac Pass as well as a smaller channel called North Pass is shown in Figure 7.3.12 below. This color-shaded relief map made from LiDAR shows the topography of the Manchac Land Bridge. The colors on the map represent ground elevation. Red is the highest ground, approximately 5.0 feet NAVD 88, and Blue is the lowest approximately 0.0 feet NAVD 88.

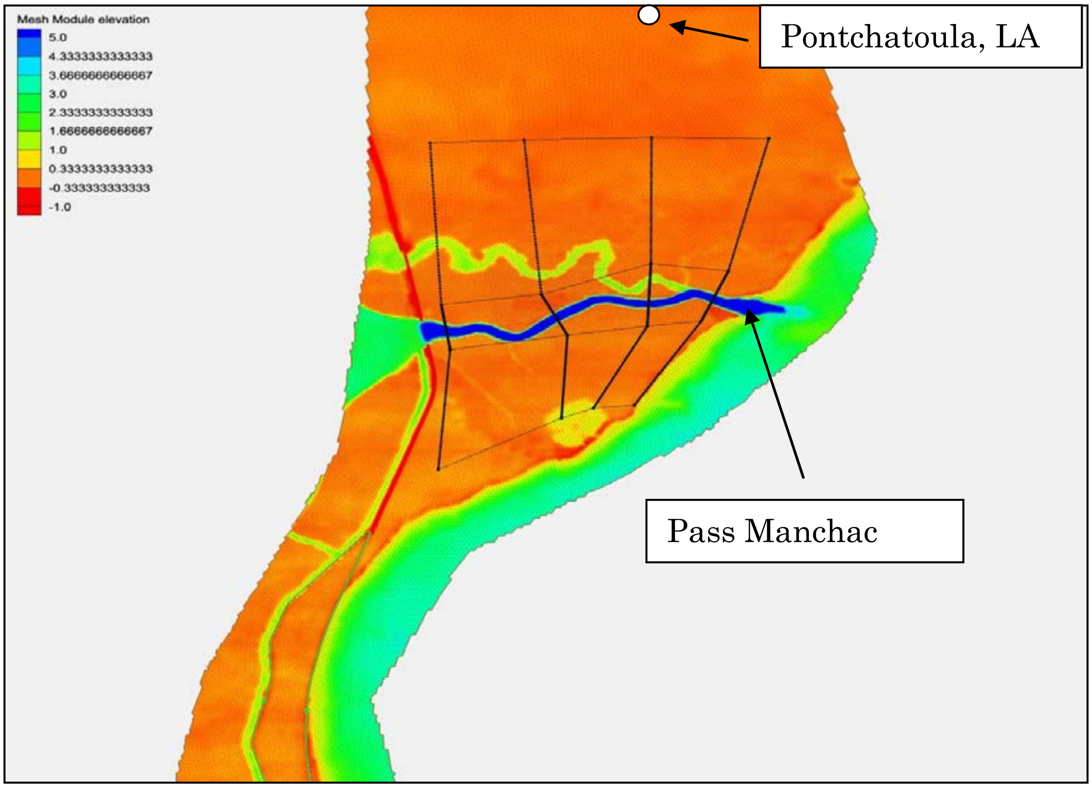

Figure 7.3.12 Manchac Pass and North Pass Topography

The channel of Manchac Pass is approximately 1,000 feet to 2,000 feet wide with an average depth of approximately of 30 feet. The elevation of the natural ground to the north and south of Manchac Pass is approximately in the range 1 to 3 feet. However, highway 51 forms a nearly continuous barrier at roughly 5 feet NAVD 88. Therefore any storm surge or Lake elevations higher than 5 feet would overflow across the Manchac Land Bridge. A typical cross section of Manchac Pass can be seen in Figure 7.3.13 below. Notice the elevation of the channel overbank is much lower than the peak surge elevation.

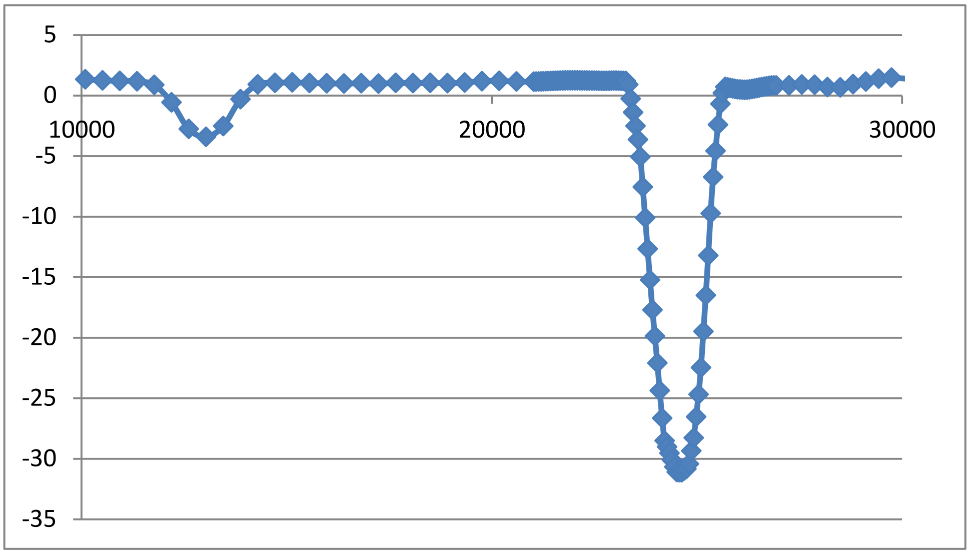

Figure 7.3.13. Typical Cross Section of Manchac Pass. Datum: NAVD88.

Stage observations at Manchac Pass during Hurricane Isaac clearly show that peak water elevations exceeded the land elevation of the Manchac Land Bridge near Manchac Pass. Peak surge recorded at Manchac Pass was approximately 7.0 feet NAVD 88 as shown in Figure 7.3.14. This is 4 to 6 feet higher than the elevation of the natural ground. Therefore the initial storm surge from Hurricane Isaac may have entered Lake Maurepas much more rapidly through overland flow than would be expected from only considering the conveyance of Manchac Pass.

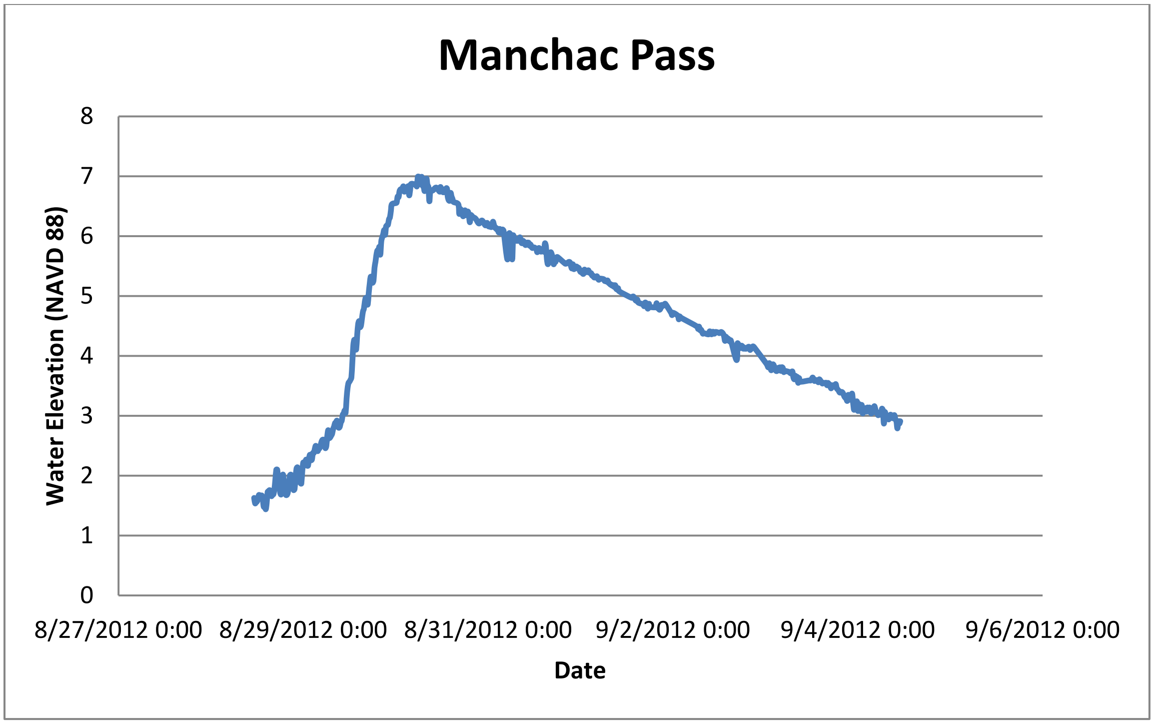

Figure 7.3.14. Stage hydrograph for Manchac Pass. Peak stage of 7.0 feet NAVD 88 occurred on 30 **August. Datum: NAVD88**

River Runoff into Lake Maurepas

As Hurricane Isaac approached the Louisiana coast and made landfall, large bands of heavy precipitation moved inland over the Lake Maurepas Watershed. The slow forward speed of Hurricane Isaac allowed some areas to receive large accumulations of the precipitation. The effect of the rainfall in the Lake Maurepas watershed can begin to be understood by determining the volume of water the lake received from its watershed to the north.

The total volume of water for the three largest rivers that discharge into Lake Maurepas, the Tickfaw, Natalbany, and Amite Rivers, was computed using discharge hydrographs received from the NWS and the USGS. The discharge hydrographs used for this volume computation covered the period from 28 August at 0100 LST (0600 UTC) to 7 September at 1300 LST (1800 UTC). Table 7.3 shows the river discharge locations and the total volume of water that entered Lake Maurepas during Hurricane Isaac.

The Amite River basin contains a large portion of the Baton Rouge metropolitan area. The Natalbany and Tickfaw River basins drain large areas of land north of Lake Maurepas. A portion of the Amite River is diverted via the Petite Amite River and Amite River Diversion Canal to the Blind River, which also flows to Lake Maurepas. The Blind River and Lower Amite run through the wetland areas west of Lake Maurepas. This area is highly susceptible to elevated lake stages. These two rivers have a very mild slope, thus any increase in downstream water elevations would result in backwater effects very far upstream. In addition, as this area is a wetland, it has a large amount of storage capable of storing large amounts of rainfall.

In order to quantify the rainfall runoff entering the Lake Maurepas system from the North Shore Rivers, stage and flow hydrographs for each of these rivers were obtained from the National Weather Service and the US Geological Survey. The total volume of water for each of these rivers was estimated by computing the area under the flow hydrograph for the entire hurricane duration. In cases where only a stage hydrograph is available, the total volume of river water was computed by using a rating curve to convert the stages to flows.

Table 7.3 Total Rainfall Volume entering Lake Maurepas from local rivers during Hurricane Isaac

River	Volume (acre-feet)
The Tickfaw River at Holden, LA	60,000
The Natalbany River at Robert, LA	42,000
The Amite River at Port Vincent, LA	350,000

The incremental increase in stage for Lake Maurepas from rainfall was computed by summing the water volume entering Lake Maurepas from the rivers and direct rainfall onto the lake itself and understanding the bathymetry of the lake as well as the outlet at Manchac Pass. Analyzing the timing of surge in both Lake Pontchartrain and Lake Maurepas, in additional to the timing of the river peak discharges, clearly indicated that the rivers had an effect on prolonging the durations of high water elevations in Lake Maurepas.

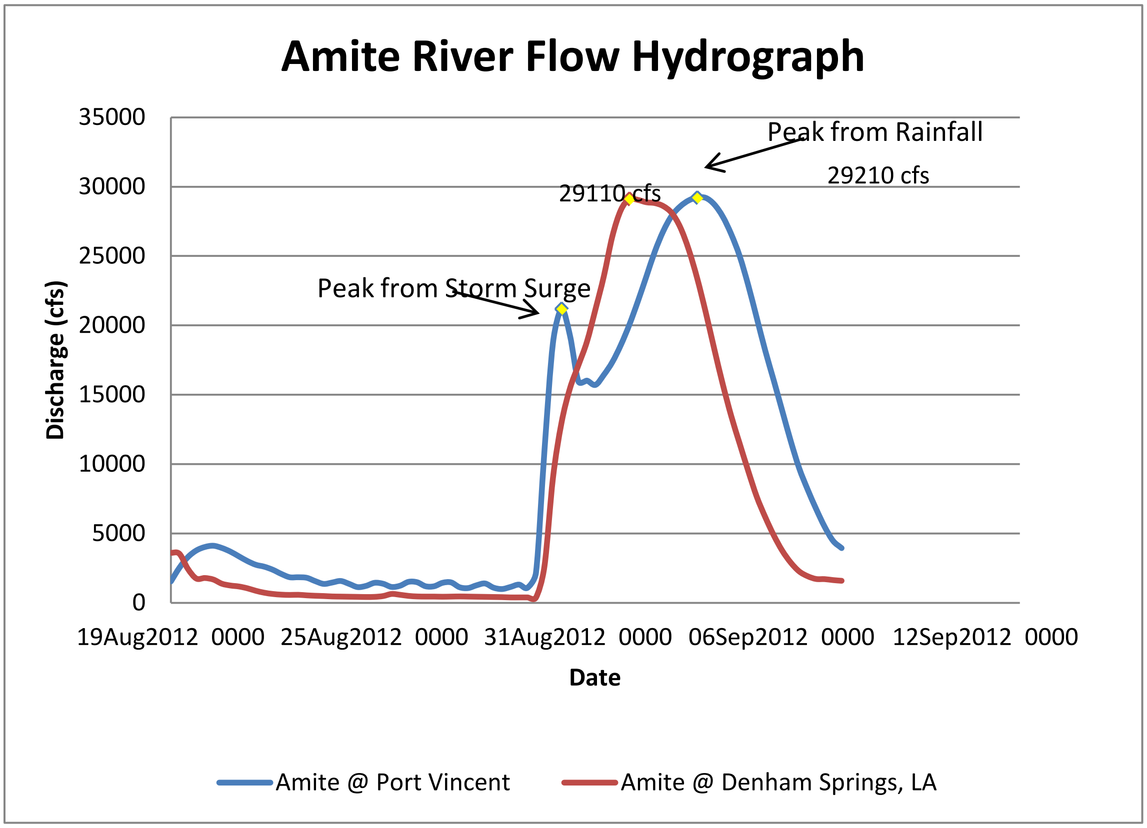

Figure 7.3.15 Amite River Flow Hydrograph. The Port Vincent gage clearly shows the peak surge compared to the rainfall peak. Notice the rainfall peak is much larger. At Denham Springs, the storm surge is not noticeable.

Based on the timing of the peak stages observed during the storm, as shown in Figure 7.3.15, it seems that the areas along the rivers experienced higher water from the rainfall runoff than from the storm surge propagation up the rivers.

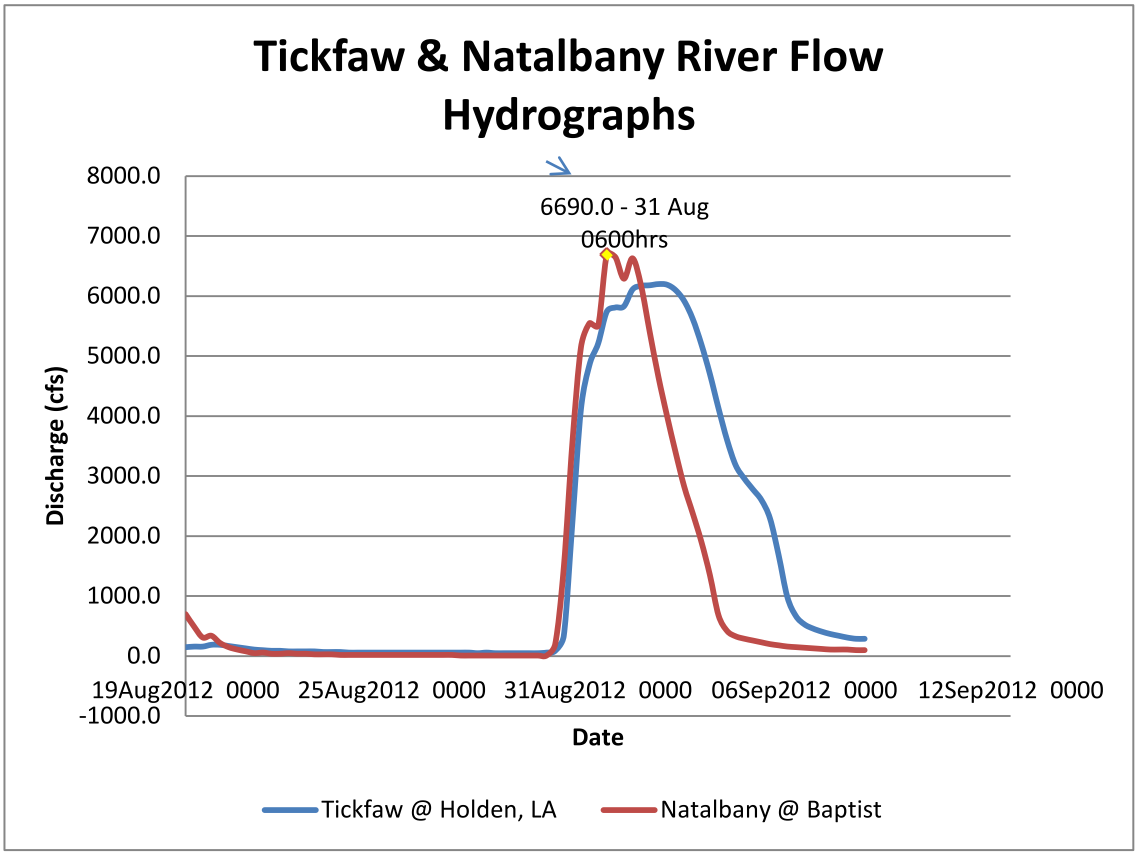

Figure 7.3.16. Flow Hydrographs Flow Hydrograph plots of Tickfaw and Natalbany Rivers on the north shore of Lake Maurepas

Total volume of water from rivers into Lake Maurepas

The approximate volume of Lake Maurepas is 600,000 acre-feet. The river discharge hydrographs and volumes were taken from the locations previously displayed in Table 7.3.

The flow contribution from The Blind River, Hope Canal, and the Reserve Diversion Canal were not considered as a major flow contributor to Lake Maurepas. These channels have small watersheds as compared with the rivers on the north shore of the lake. In addition, during Hurricane Isaac, the surge in Lake Maurepas completely inundated these rivers making the rainfall runoff in their watersheds a direct rainfall computation.

Assuming approximately 10.0 inches of rainfall, the total volume of runoff would amount to approximately 60,000 acre-feet of water entering Lake Maurepas from rainfall. This would raise the total volume of water entering the lake to 510,000 acre-feet. The near shore areas of the lake are not included in this simple rainfall runoff assessment. The correct rainfall runoff volume of water would most likely be closer to 600,000 acre-feet. All of this water would be in addition to the enormous volume of storm surge that entered Lake Maurepas during Hurricane Isaac.

Of the total rainfall volume of water that entered Lake Maurepas from rainfall runoff out of the upstream watersheds, only approximately 20,000 acre-feet enter before the lake reached its peak stage. This only represents about a 0.3 foot rise in the lake. This increase in lake stage excludes the volume of water from direct rainfall in the lake. The majority of rainfall fell after the lake peaked, contributing to the prolonged recession.

Comparison of Isaac with Historic Storms

Storm surge and river elevations for Hurricane Isaac have been compared to water elevations for past tropical events for the Lake Maurepas System. Table 7.4 below compares the storm surge from Hurricane Isaac to the peak water elevations observed during Hurricanes Gustav, Ike, Katrina, and Juan.

Table 7.4 Peak Water Elevations of Past Tropical Events

GAGE_NAME	8/29/2012 Isaac Peak Stage	9/2008 Gustav/Ike Peak Stage	8/29/2005 Katrina Peak Stage	10/3/1985 Juan Peak Stage
Tickfaw River near Springfield (NAVD 88)	6.68	5.27	-	4.98
Pass Manchac near Pontchatoula (NAVD88 2004.65)	6.64	-	-	5.12
Lake Pontchartrain at Bonnet Carré Spillway (NAVD88 2004.65)	-	3.00	-	-
Cross Bayou Canal at Hwy61 - North of CS (NAVD88 2004.65)	8.02	4.95	-	-
Walker PS (S) (NAVD88 2004.65)	3.15	-	-	-
Amite River near Denham Springs (NGVD 29)	29.77	35.23	14.40	-
Tickfaw River at Holden (NAVD 88)	33.46	28.60	-	-
Natalbany River near Baptist (NAVD 88)	29.48	24.93	20.62	-
Amite River near French Settlement (NGVD 29)	6.87	5.16	3.68	-
Amite River at Hwy22 near Maurepas (NAVD88)	6.58	5.23	4.78	-
Blind River, 3 miles West of Lake Maurepas (NAVD88)	6.24	-	-	-
Hope Canal North of Garyville (NAVD88)	5.83	-	-	-
B. Manchac at Alligator Bayou nr Kleinpeter (NAVD88)	10.54	10.26	-	-

7.1.9 Summary of Effects

7.1.9.1 Surge Peak Timing and Duration

Model results for both with and without 2012 100-year HSDRRS conditions estimated stages of ranging from approximately 5 to 7 feet throughout the Lake Maurepas and 8 to 9 feet along the Maurepas land bridge in Lake Pontchartrain. Model sensitivity analysis indicates that water levels throughout Lake Pontchartrain and Maurepas areas decrease by approximately 0.1 to 0.2 feet or less for the with and without 2012 100-year HSDRRS conditions. Stage hydrographs presented in Figure 7.3.17 clearly show that the timing and duration of high water levels in Lake Maurepas happened much later than the peak water levels in Lake Pontchartrain and Lake Borgne. Also, the hydrograph plots below clearly show that the high water in the areas of the Maurepas swamp took much longer to recede than water levels in other parts of the system.

During Isaac, the rivers mentioned above were observed to be categorized as major flooding for more than one day. Also at this time, water elevation in Lake Maurepas crested and remained very high for the next two to three days. Based on the observed stages in Manchac Pass, it is believed that initial storm surge from Hurricane Isaac pushed water into Lake Maurepas, over the land bridge between Lake Pontchartrain and itself. Heavy amounts of rainfall runoff restricted the rivers in this area from receding at the same rate as other open water areas.

There are two drivers of stage in the Hope Canal, stage at Pass Manchac and runoff into Lake Maurepas. Investigation into the differences in the recession limbs between the three lake gage stage hydrographs show a linear recession on the Pass Manchac gage rather than a logarithmic decay consistent with a free-draining system. This change is due to inflows into the system from the upstream river basins. The only inflows are the runoff and thus we can estimate their magnitude by estimating the logarithmic decay form based on the other two gages. Estimates based on this seem to indicate that about 0.2 feet of peak stage at LaPlace (next to Hope Canal) is due to runoff.

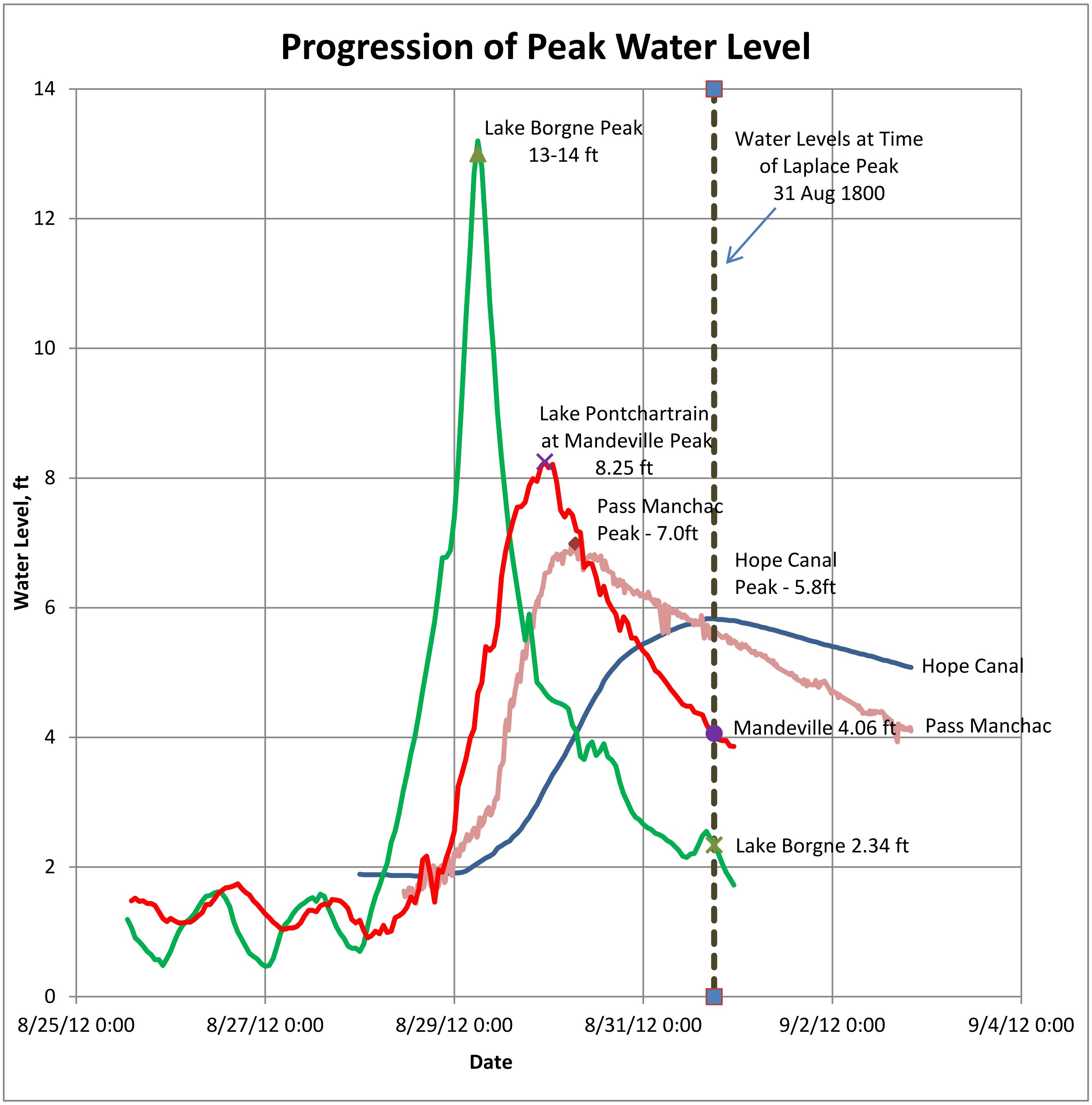

Figure 7.3.17. Progression of Surge Plots. Datum: Lake Borgne: NAVD88 2004.65; Mandeville: NAVD88 2004.65; Pass Manchac: NAVD88; Hope Canal: NAVD88.

Lower Jefferson & Plaquemine Parishes

7.1.10 Hydrodynamic Model Results

Figure 7.4.1 plots the difference in peak water level in lower Jefferson Parish along the eastern extent of West Bank and Vicinity storm damage risk reduction project and the west bank of Plaquemines. Levees in the without 2012 100-year HSDRRS simulation for this area overtop for the Hurricane Isaac simulation. The raising of these levees and the construction of the Western Closure Complex eliminate any water from entering the West Bank polder. Water levels on the outside of the system increase by as much as 0.8 feet in the immediate vicinity of the Western Closure Complex. At the community of Crown Point south of the complex, water levels are estimated to be about 0.4 feet higher with the HSDRRS in place and 0.2 feet at Jean Lafitte. Elsewhere along the West Bank and further south west of the Plaquemines levees, peak water elevations are predicted to increase by 0.2 feet or less.

The model predicts over topping in the Plaquemines polder levee south of Oakville for both the with and without 2012 100-year HSDRRS simulations, but that did not occur during Hurricane Isaac. Actual conditions for this levee reach included the use of HESCO baskets to increase levee height. Local observations indicate that overtopping may have occurred without these additional features. The modeled water level inside this polder increased approximately 1 foot in the simulations with the HSDRRS in place. The increase results from increased overtopping at the non-federal levee. The water levels just outside the levee are predicted to increase approximately 0.5 feet. This increase results in additional overtopping in the model. However, as previously stated, flooding of this polder did not actually occur. The overtopping in the model is caused by the model over predicting water levels in this area by 1.5 to 2 feet, as documented in the Chapter 5 model assessment. Further south of the Oakville area, modeled differences for the with and without HSDRRS conditions are 0.2 feet or less.

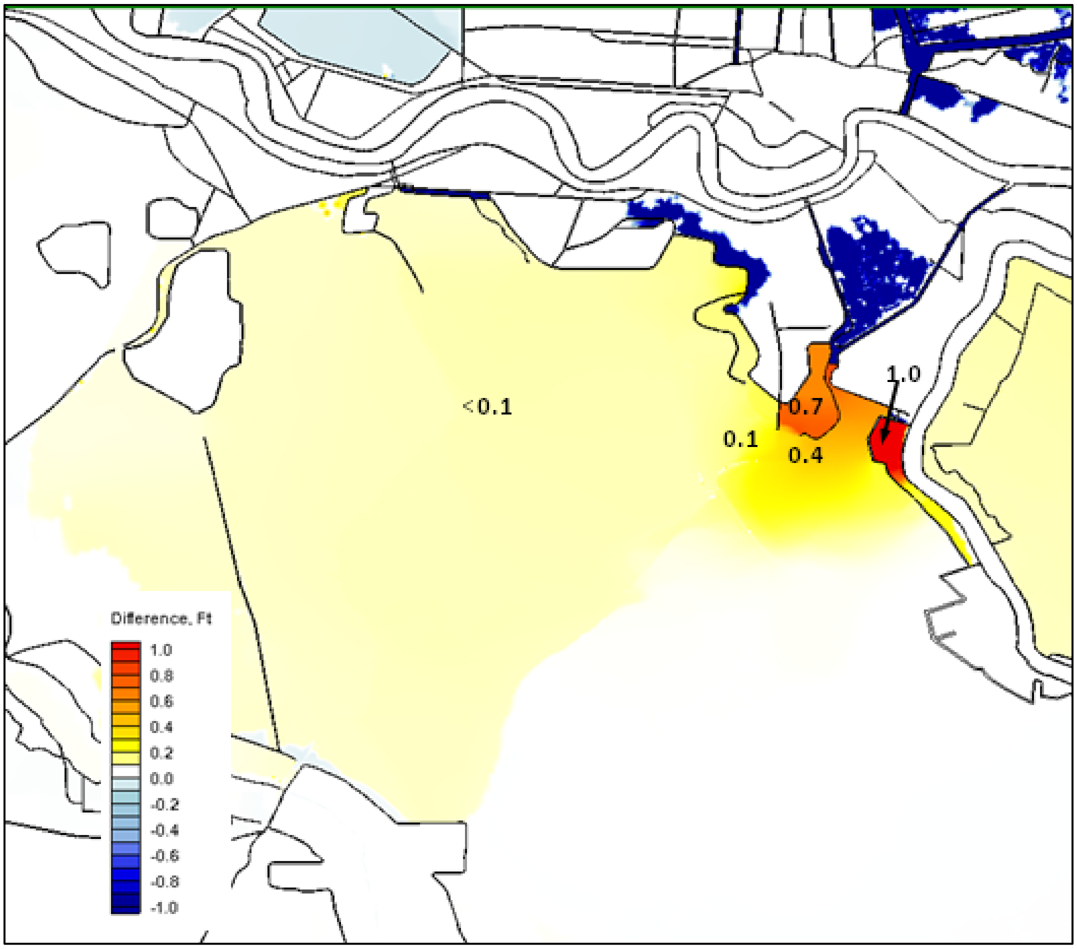

Figure 7.4.1 Difference in ADCIRC predicted maximum water level for Hurricane Isaac in lower Jefferson Parish (With & Without 2012 100-Year HSDRRS).

7.1.11 Rainfall and Runoff Analysis

This section addresses precipitation and observed stages in the Barataria Basin with an emphasis on the operation of the Western Closure Complex during hurricane Isaac.

Figure 7.4.2 displays the locations of a subset of USGS gages (black triangles) and synthetic precipitation gages (blue circles) in the Barataria basin. In this assessment, rain data has been extracted from the National Mosaic & Multi-Sensor QPE dataset produced by NOAA for Hurricane Isaac available at http://nmq.ou.edu/. This precipitation dataset is developed by adjusting radar data to actual precipitation gage data, giving high resolution precipitation information at areas where gages do not exist.

Figure 7.4.3 displays the precipitation at the 4 synthetic gages. The total amount of precipitation at each gage was on the order of 10 to 11 inches. The timing and magnitude of precipitation was similar for all four gages. The peak precipitation rate was nearly 0.96 inches/hour in the morning of 29 August.

Table 7.4.1 displays the ID number and name of the stage gages presented in this assessment. The gage hydrographs at 3 USGS gages and the USACE readings at the WCC are presented in Figure 7.4.4.

Table 7.5 Barataria Basin Gage IDs

ID	Name
USGS 2951190901217	Lake Cataouatche at Whiskey Canal
USGS 073802375	Lake Salvador near Lafitte, LA
USGS 07380335	Little Lake Near Cutoff, LA
USACE WCC	Western Closure Complex gage

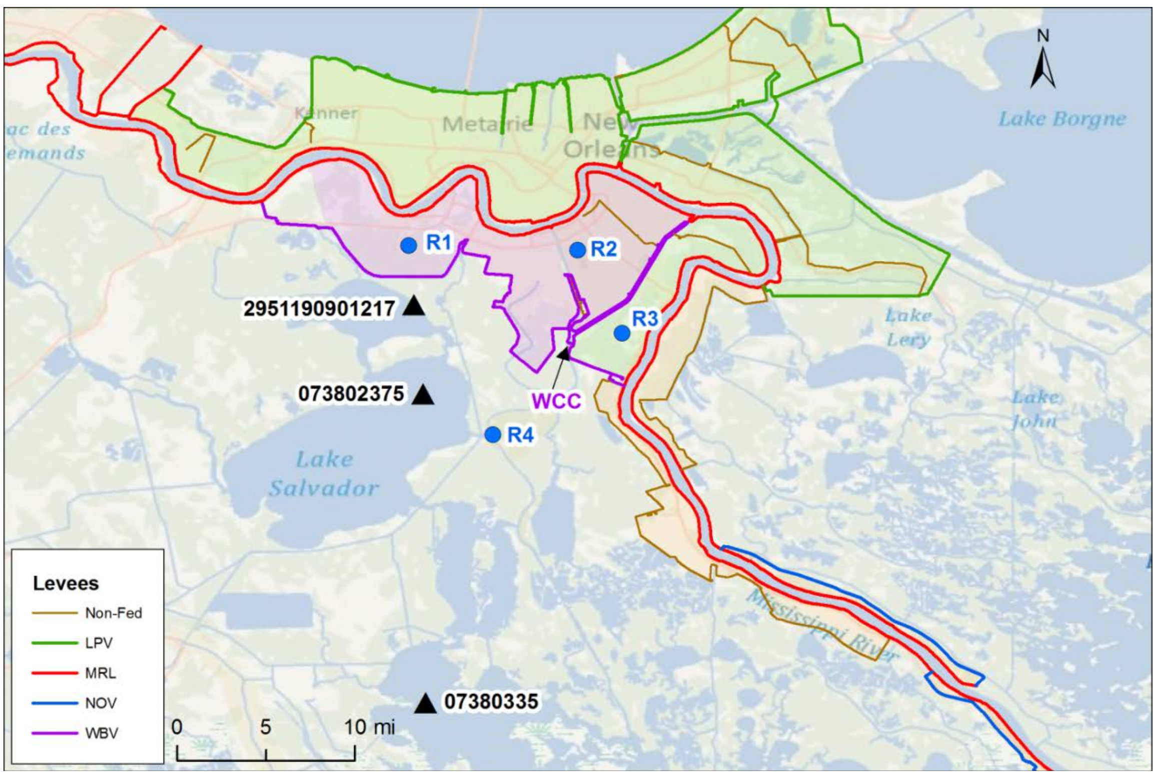

Figure 7.4.2 Map of the USGS/USACE stage gages and the Synthetic precipitation output points in Barataria Basin. Black triangle points represent locations of stage gages and Blue dots represent synthetic precipitation estimate points

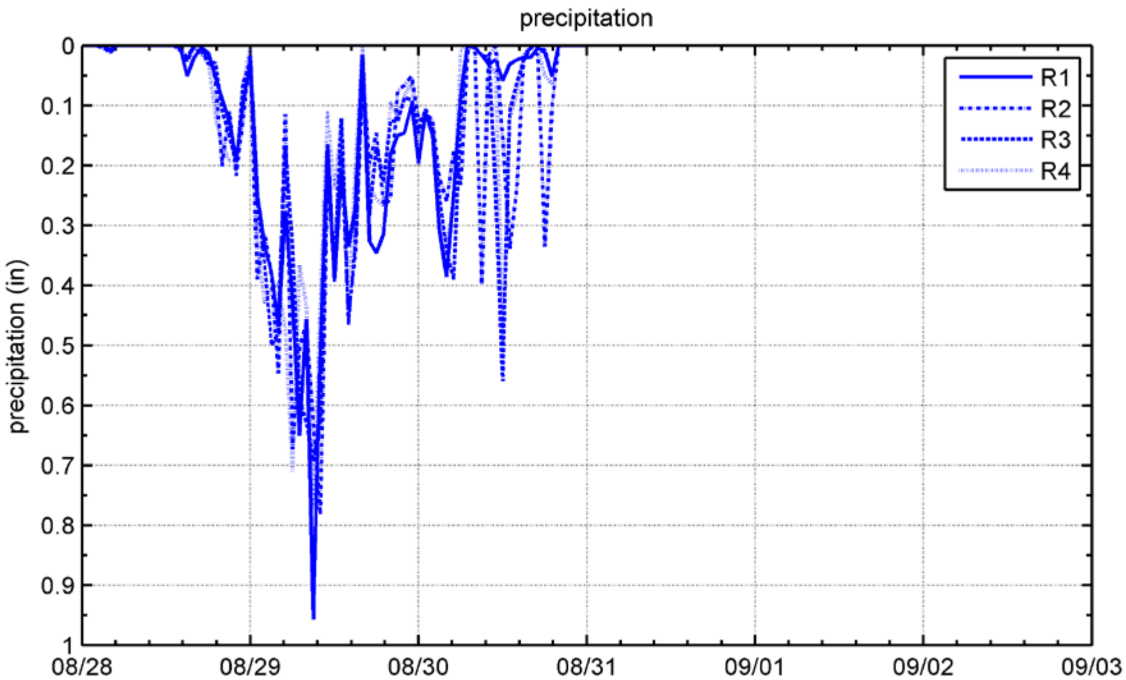

Figure 7.4.3 Precipitation data at synthetic gages

As Isaac made its initial landfall, an initial drawdown of water levels was observed at the four gages in the basin. The drawdown occurred because Isaac's winds were initially blowing from the north as the storm made landfall. The drawdown at the Lake Cataouatche gage was nearly -4.0 feet, while at the Little Lake gage, the drawdown was approximately -1.0 feet. As the storm passed, winds reversed direction and the inner Barataria Basin (near WCC and WBV levee) was inundated on the morning of 29 August. Peak stage observations at the four selected gages were in the 4.5 to 5.5 foot range. No significant overtopping was reported along the WBV levees and floodwalls.

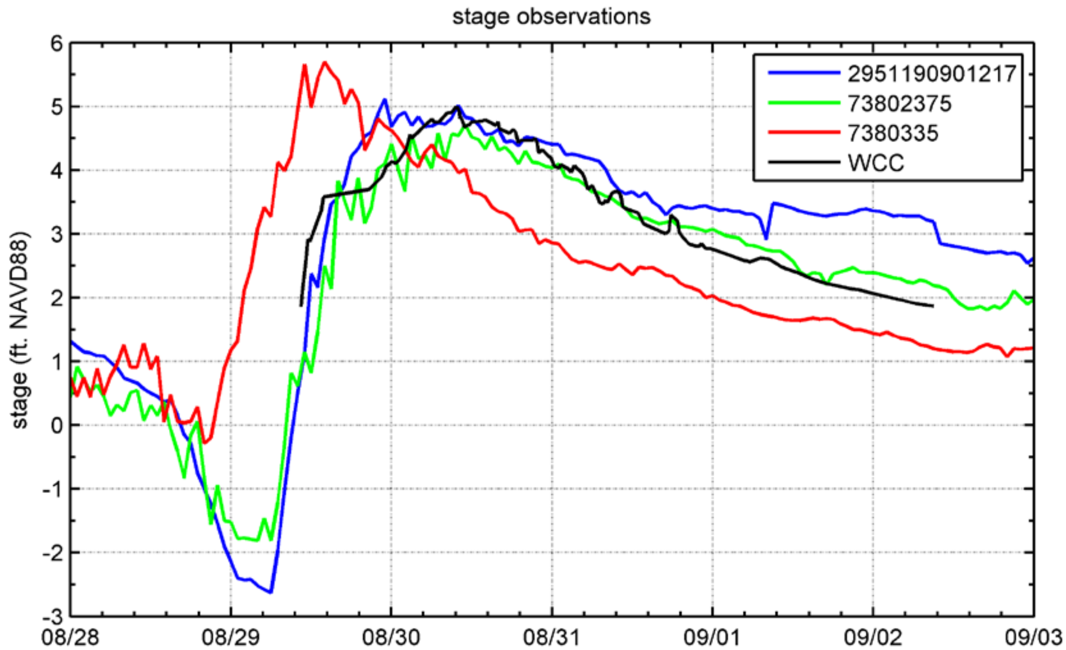

Figure 7.4.4 Stage observations at gages near the WCC. All datum NAVD88 except WCC which is NAVD88 2004.65.

The WCC structure was closed on the morning of 29 August and pumping operations drained the Harvey and Algiers canals to the required interior levels. Figure 7.4.5 displays the discharge at the Western Closure Complex. Peak stages at the WCC sector gate reached approximately 5.0 feet in the morning of 30 August. The pumps were operated intermittently throughout the storm, but peak pump discharge occurred in the evening of 29 August, directly after peak precipitation, and about 12 hours before peak observed stages.

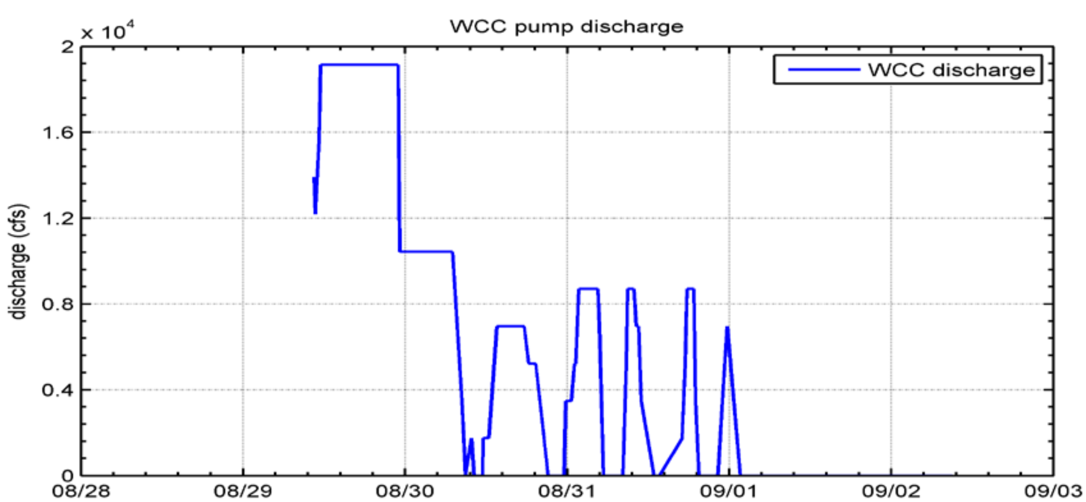

Figure 7.4.5 Discharge observations at the WCC

7.1.12 Summary of Effects

Model results for both with and without 2012 100-year HSDRRS conditions estimated stages of approximately 5 to 7 feet in this area. Model sensitivity analysis indicates water levels on the outside of the system increase by as much as 0.8 feet in the immediate vicinity of the Western Closure Complex between with and without 2012 100-year HSDRRS conditions. At the community of Crown Point south of the complex, water levels are estimated to be about 0.4 feet higher with the HSDRRS in place and 0.2 feet at Jean Lafitte. Elsewhere along the West Bank and further south west of the Plaquemines levees, peak water elevations are predicted to increase by 0.2 feet or less. Overtopping of non-federal levees predicted by the model that did not occur in reality could be the result of model over prediction or the actual use of non-permanent features not represented in the model.

Rainfall likely played a minor role in the flooding of the Barataria basin. As a conservative estimate, rainfall runoff could have increased peak observed stages by 0.5 feet in the basin. In the area immediately adjacent to the WCC, peak stages may have been increased by pump discharge. However, discharge from the WCC complex had been reduced to less than fifty percent of capacity in advance of the peak stage at that location. Without ADCIRC modeling that includes pump discharge forcing at the WCC, it is difficult to assess the actual impact of the rainfall runoff in the area of interest. Previous modeling has shown that peak stage levels are increased by less than 0.5 feet in the area immediately downstream from the WCC for 100-year discharge levels, and are increased by less than 0.5 feet at the communities of Crown Point and Jean Lafitte. More information on the impacts of WCC operations is presented in Chapter 4.

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8.0 SUMMARY OF FINDINGS

Introduction

During Hurricane Isaac, the greater New Orleans area 100-year hurricane and storm damage risk reduction system (100-year HSDRRS) performed to expectations in preventing the storm surge from inundating the areas within the system. However, substantial flooding did occur in areas without federal levee systems, including, but not limited to Slidell, Mandeville, Madisonville, LaPlace, Braithwaite, Lafitte, and others.

This assessment was developed and conducted to answer one primary question:

Did construction of the 100-year HSDRRS have a measurable effect on areas outside the system flooded by Hurricane Isaac?

To answer this question, the following were examined:

- Hurricane Isaac's meteorological statistics and surge propagation, and how they contributed to flooding outside the 100-year HSDRRS

- Previous Corps of Engineers analyses regarding effects from the 100-year HSDRRS

- What, if any, differences in surge conditions are identifiable between the with and without 100-year HSDRRS (2012 conditions) specifically for Isaac?

The general answers to these questions provided by the evaluations documented in this report are:

- Although Isaac was a Category 1 hurricane, it's nearly 45 hour duration of tropical force winds, track, size and slow forward motion, and considerable rainfall resulted in significant volume of water delivered onshore. In many locations, water levels exceeded those from storms such as Hurricanes Katrina and Gustav.

- Prior evaluations of the potential effect of the HSDRRS on surge outside that system were compared with the hindcast effects based on Hurricane Isaac. The comparison indicates that, for Isaac, the modeled effects of the HSDRRS are consistent with those previously reported.

- Sensitivity analsis of the Hurricane Issac hindcast for both with and without 2012 100-year HSDRRS conditions calculates only one area, in the vicinity of the West Closure Complex, where estimated stages differences exceed 0.3 feet. For the significant majority of modeled area the estimated differences range from plus to minus 0.1 feet.

Evaluation Background

This assessment considered the “2012 100-year HSDRRS” as it existed at the time of Hurricane Isaac. In addition to increases in levee and floodwall heights and improved tie-ins throughout the 100-year HSDRRS, numerous structural components have been incorporated into the system, including the Inner Harbor Navigation Canal Surge Barrier, the Seabrook Gate Complex, and the West Closure Complex. Although the 100-year level of risk reduction has been achieved, the HSDRRS is not complete. Any features as yet incomplete were not incorporated into the assessment.

The evaluation includes: Assessment of conditions resulting from Hurricane Isaac with and without 2012 100-year HSDRRS features, compilation and analysis of available Hurricane Isaac storm information, meteorological, stage, and high water mark data, comparison of with and without 2012 100-year HSDRRS characteristics and performance, qualitative analysis and review of previous modeling and analyses, ADCIRC Isaac model simulations for with and without-HSDRRS conditions, and evaluation of specific areas outside the 100-year HSDRRS where flooding occurred. Specific areas were selected as representative areas to assess the impact of the 100-year HSDRRS; it is not an exhaustive investigation of all areas that were subject to inundation.

Because the purpose of the Hurricane Isaac modeling investigation was to assess possible differences in surge elevations related to the 100-year HSDRRS, and resulting specifically from Hurricane Isaac, the “without 100-year HSDRRS” condition was applied only to features of the 100-year HSDRR System. Other landscape features represented in the model were identical for the with and without 2012 100-year HSDRRS simulations.

Evaluation of Collected Data and Qualitative Assessment of System

According to the Saffir-Simpson scale, Isaac was a Category 1 hurricane. However, the storm's nearly 45 hour duration of tropical force winds, storm track and slow forward motion, storm size, high tide conditions, and considerable rainfall occurring at the same time as the maximum storm surge, resulted in large amounts of water being pushed into the coastal areas of the northern Gulf. In many locations, water levels exceeded those from storms such as Hurricanes Katrina and Gustav.

The review of water surface elevation gage data revealed a clear progression of this combined surge effect within the Pontchartrain Basin. Figure 7.3.17 presented on page 7-35 displays the timing of the surge peak from Lake Borgne in the lower basin to Hope Canal in upper Lake Maurepas. The time between these peaks is approximately 60 hours. In addition this data provides some insight regarding the possible compounding effects of delayed surge and rainfall runoff revealing that the recession of surge inundation was much slower for the upper extent of this basin.

A qualitative assessment of the potential hydraulic performance for conditions prior to the construction of the 100-year HSDRRS levees and floodwalls was made based on the gage and high water mark data collected for Hurricane Isaac. Only three areas were identified that would, or may, have over topped during this storm prior to the 2012 100-year HSDRRS being in place. On the east bank, those areas included the St. Bernard levee from Caernarvon to Highway 46, the IHNC-GIWW floodwall corridor, and the St. Charles Parish levee. On the west bank, areas of probable overtopping included the Western and Eastern Tie-In reaches, where the pre-100-year HSDRRS had no levees, and portions of the Harvey Canal banks south of Harvey Lock.

No collected or observed data identified any wave overtopping or surge overflow of the 2012 100-year HSDRRS, or the portion of the Mississippi River levees, river mile 80 through 130, integral to the 2012 100-year HSDRRS. Overtopping was evident on the Mississippi River levees, but it was downstream of river mile 80 and therefore outside the 2012 100-year HSDRRS area.

Numerical Modeling of Hurricane Isaac

8.1.1 General

Numerical model hind casts of Hurricane Isaac performed with the 2012 100-year HSDRRS grid were compared with actual measured data hydrograph plots for the storm at various locations throughout Southeast Louisiana and Mississippi. The conformance of model result to the measured data varied from site to site. Generally, the model predictions showed a high correlation with the measured data. A model with an uncertainty characterized by a standard deviation of 1.5 feet is considered well validated (see Bunya et al.

2010).For many of the gaged data locations, in both Louisiana and Mississippi, used for this model values correlated well within 1.5 feet of measured values. The upper end of Caernarvon marsh in Breton Sound was an area in which model predictions were up to 3 feet higher than measured peak values.

The comparison of high water mark and peak gage data with ADCIRC model results for Hurricane Isaac with the 2012 100-year HSDRRS in place indicate the model is over estimating peak water levels in some locations and under estimating peak water levels in other locations. When the National Hurricane Center completes a post storm assessment of the winds and hurricane characteristics, better wind fields will be available, which in turn may improve model results.

Numerical model hind casts of Hurricane Isaac were also performed with the without 100-year HSDRRS grid. Sensitivity analysis comparing output from the with and without 2012 100-year HSDRRS numerical model runs was performed to characterize possible effects related to the 100-year HSDRRS improvements.

In general, comparison of the with and without 2012 100-year HSDRRS model results produced water levels for Hurricane Isaac that were higher in Breton Sound and lower in Lake Pontchartrain with the 100-year HSDRRS in place, and produced differences on the order of plus or minus 0.2 feet or less. Model estimated water level increases in the Barataria Basin are generally negligible with the 100-year HSDRRS in place, with the majority of the basin indicating no difference. However, a few exceptions were identified; Eastbank Plaquemines Parish in the Braithwaite area, and the vicinity of the WCC.

8.1.2 Detailed Evaluations

8.1.2.1 Eastbank Plaquemines Parish

In the immediate vicinity of the Caernarvon floodwall, the sensitivity analysis estimated that peak water levels increased on the order of 0.3 feet from the without 100-year HSDRRS condition. In general, water levels increased by about 0.1 feet or less throughout the area. The evaluation of the model against high water data collected at this location indicates that the model is over predicting surge results in this area. The over prediction of surge by the model in the area results in the levees in the without 100-year HSDRRS simulations to overtop, potentially producing an over estimate of the increase in water level attributed to the 100-year HSDRRS.

The findings are consistent with results of earlier investigations that were conducted during the design of the HSDRRS. Prior evaluations had estimated potential increases on the order of 0.5 feet in the Caernarvon floodwall area. Environmental documentation reported changes on the order of one foot at the Plaquemines Parish back levee for the 1% annual exceedence probability.

8.1.2.2 Lake Pontchartrain Northshore and West Shore

Sensitivity analysis estimated that peak water levels on the north and south shores of Lake Pontchartrain, as well as in LaPlace and throughout the West Shore Lake Pontchartrain area, were reduced for Hurricane Isaac due to the presence of the 100-year HSDRRS. This is the result of the IHNC barrier eliminating conveyance from Breton Sound to Lake Pontchartrain through the IHNC, resulting in a reduced surge volume in the lake. Evaluation of the model against measured data indicates that the model is slightly over predicting surge results within Lake Pontchartain. The model results show very good correlation with the data for Lake Maurepas.

These results are consistent with earlier investigations. Prior evaluations had indicated no change to reductions of 0.1 foot within Lake Pontchartrain resulting from the 100-year HSDRRS. The results of the prior LACPR evaluation presented in Chapter 5 do show potential for increases in the Westshore area in locations removed from the southwestern shoreline of the lake. However, this was the result of the inclusion of a non-overtopping levee feature at the time of that evaluation to aid design for the Westshore Lake Ponchartrain damage risk reduction study. With the absence of this not constructed feature the numerical modeling of Isaac does not identify any increase in this area.

Analysis of surge propagation and rainfall runoff performed for the Westshore and Northshore areas of Lake Pontchartrain indicated that rainfall runoff made minor contributions to peak surge elevations. The Northshore did experience severe river flooding, exacerbated by elevated lake stages. However, the total estimated volume of runoff would not have substantially increased lake stage.

Similarly for Lake Maurepas, the total estimated volume of rainfall runoff would not measurably add to peak surge elevations. However, investigation of surge propagation in this area indicates that surge continued to push into areas surrounding Lake Maurepas for 24 to 36 hours after peaking at Pass Manchac. High water levels in Lake Maurepas continued to push out in all possible directions, exacerbated by continuing rainfall runoff, even as Lake Pontchartrain had receded and surge drained through Pass Manchac.

Measured data from several gages reveal that surge receded from Lake Maurepas and the surrounding area at a significantly slower rate than Lakes Pontchartrain and Borgne.

8.1.2.3 West Closure Complex / Eastern Tie-In Area

In the immediate vicinity of the WCC, the sensitivity analysis indicated an increase in water level of approximately 0.8 feet for Hurricane Isaac. Increases in water level outside the immediate vicinity of the WCC are lower, from 0.4 feet near Crown Point, 0.2 feet at Jean Lafitte and zero to less than 0.1 foot in the majority of the Barataria basin.

These results are consistent with earlier investigations. The earlier investigations concluded that there was potential for a 0.5 foot or less change in the immediate vicinity of the WCC and Eastern Tie-In with the potential difference diminishing in the surrounding communities as a result of construction of the 100-year HSDRRS.

8.1.2.4 Areas of Orleans and St Bernard Parishes Immediately Outside the HSDRRS

Areas in both Orleans and St. Bernard parishes lay outside the HSDRRS, and were impacted by surge from Hurricane Isaac. The model sensitivity analysis calculates differences of no more than 0.1 feet in any of these areas. Based on the models relative accuracy in forecasting surge elevations, potential change in the sensitivity results is unlikely. As a result no further detailed evaluation was performed in these areas.

8.1.2.5 Mississippi Coast

The sensitivity analysis of modeled peak water levels along the Mississippi coast for Hurricane Isaac estimated increases of less than 0.1 foot. Because of the models relative accuracy in forecasting surge elevations, as well as its close correlation to the actual storm data collected at Bay St. Louis, MS, no further detailed evaluation was performed.