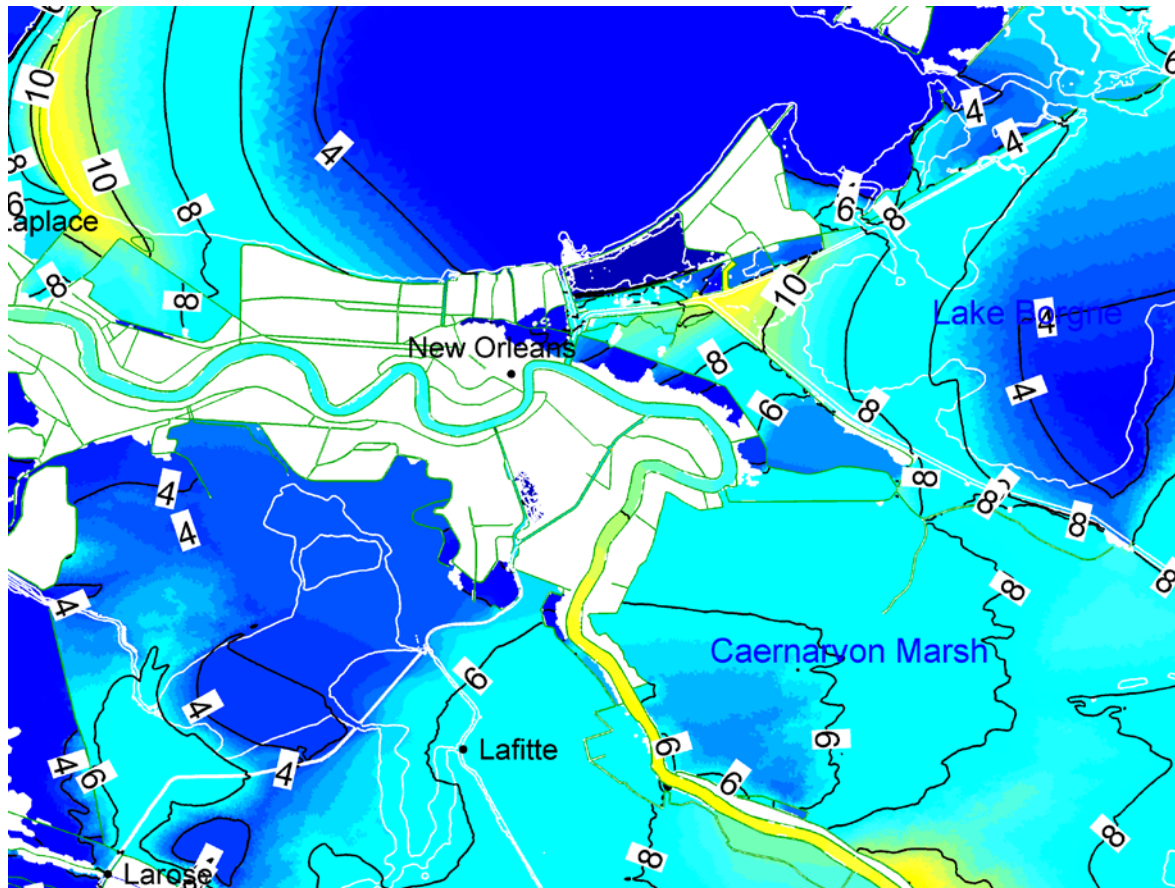


**APPENDIX T – HYDRAULIC REPORTS**

---

---

# An Evaluation of Storm Surge in Areas Outside the Greater New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS)



New Orleans District (MVN) Authors:  
Maxwell Agnew, MVN Hydraulics and Hydrologic (H&H) Branch  
Julie Z. LeBlanc, P.E., MVN H&H Branch  
Stacey Frost, P.E., MVN H&H Branch

Technical Reviewers:  
Ty Wamsley, ERDC (Engineering Research and Development Center) Coastal  
Hydraulics Lab (CHL)  
Hasan Pourtaheri, MVN H&H Branch

Table of Contents

1. Executive Summary..... 4

2. Storm Surge Modeling Methodology..... 9

    2.1 Introduction..... 9

    2.2 Synthetic Storms..... 9

    2.3 Historical Storms..... 10

    2.4 Grid Modifications ..... 13

    2.5 Wind Input ..... 20

    2.6 Limitations and Assumptions ..... 22

3. ADCIRC Simulations of Betsy, Camille, Katrina, Rita, Gustav, Ike, Isaac and 10 Synthetic Storms ..... 23

    3.1 Introduction..... 23

    3.2 Example Storm Surge Development for Hurricane Betsy ..... 23

    3.3 Validation for Betsy and Camille ..... 25

    3.4 Impacts to Surrounding Communities..... 28

4.0 Conclusions and Discussion ..... 44

References..... 45

List of Figures

Figure 1 Storm tracks of past and synthetic storms..... 11

Figure 2 Storm Windspeed vs. Distance from Landfall..... 11

Figure 3 Storm Central Pressure vs. Distance from Landfall..... 12

Figure 4 Storm Forward Speed vs. Distance from Landfall ..... 13

Figure 5 General Design Memorandum Map of New Orleans East – South Point to GIWW..... 15

Figure 6 Plan and Profile Plot Showing Existing Grade Levee Elevations in GDM ..... 16

Figure 7 Example of Trimmed Plan and Profile Plot..... 16

Figure 8 Plan and Profile Plot Showing Existing Grade Levee Elevations in GDM - IHNC ..... 16

Figure 9 1966 Existing Ground Profile of St Bernard Area – Prior to HPS Construction ..... 17

Figure 10 SL15-1965 Sub-grid Feature Elevations ..... 18

Figure 11 SL15-2005 Sub-grid Feature Elevations ..... 19

Figure 12 SL15-2012 Sub-grid Feature Elevations ..... 20

Figure 13 Hurricane Betsy Wind Field – NOAA H\*Wind..... 21

Figure 14 Hurricane Camille Wind Field at Landfall – NOAA H\*Wind ..... 22

Figure 15 Storm Surge Development for Hurricane Betsy on the SL15-1965 Grid. .... 24

Figure 16 Wave Height Development for Hurricane Betsy on the SL15-1965 Grid..... 25

Figure 17 Hurricane Betsy Observed High Water Marks..... 26

Figure 18 Hurricane Betsy High Water Mark Validation in SE Louisiana ..... 27

Figure 19 Hurricane Camille Observed High Water Profile along the MS, GA, FL Coast ..... 27

Figure 20 Hurricane Camille Validation of High Water Profile along the MS, GA, FL Coast..... 28

Figure 21 Hurricane Betsy Maximum Surge Elevation on SL15-1965 Grid..... 29

Figure 22 Hurricane Betsy Maximum Surge Elevation on SL15-2005 Grid..... 29

Figure 23 Hurricane Betsy Maximum Surge Elevation on SL15-2012 Grid..... 30

Figure 24	Peak Surge Difference Between SL15-2005 and SL15-2012 .....	32
Figure 25	Peak Surge Difference Between SL15-1965 and SL15-2012 .....	33
Figure 26	Time Series of Differences in Peak Surge between SL15-1965 and SL15-2012 .....	34
Figure 27	Selected Output Locations .....	35
Figure 28	Surge Frequency Regression Analysis at IHNC.....	41
Figure 29	Surge Frequency Regression Analysis at Venetian Isle.....	41
Figure 30	Surge Frequency Regression Analysis at Eden Isle .....	42

List of Tables

Table 1	Synthetic Storm Selection .....	10
Table 2	Historical Storm Selection .....	10
Table 3	Comparison of Peak Surge at Eden Isles, Chef Pass, and IHNC Surge Barrier for SL15-1965, SL15-2005, and SL15-2012.....	37
Table 4	Summary of Regression Analysis at all Output Locations .....	43

# 1. Executive Summary

In this analysis, a series of historical and synthetic storms of high impact to the Louisiana Gulf Coast were modeled. The purpose of this modeling is to assess the impacts to surge levels due to construction of the Greater New Orleans (GNO) Hurricane and Storm Damage Risk Reduction System (HSDRRS) on communities inside and outside the system. The Greater New Orleans HSDRRS consists of the Lake Pontchartrain and Vicinity (LPV) and West Bank and Vicinity (WBV) 100-year projects as constructed post-Katrina; hereinafter referred to as the GNO HSDRRS. The analysis evaluates the projected storm surge levels in areas outside the GNO HSDRRS as the levee system existed in the years 1965 (pre-Betsy, pre-federal levees), 2005 (pre-Katrina) and 2012 (post-GNO HSDRRS construction). The analysis describes and evaluates the past, present and potential cumulative storm surge impacts of the completed GNO HSDRRS on the surrounding areas.

The modeled historical storms include Hurricanes Betsy, Camille, Katrina, Rita, Gustav, Ike and Isaac. Ten (10) synthetic storms that are a subset of the suite of 152 storms processed for the hydraulic design of GNO HSDRRS were also evaluated. These storms are simulated on three different versions of the SL15 Advanced Circulation Model (ADCIRC) grid. The SL15 grid was originally developed at the Notre Dame Computational Hydraulics Laboratory. The SL15 grid was the primary ADCIRC grid used to model a suite of 152 synthetic storms to aid in the hydraulic design of the GNO HSDRRS. The SL15 has been utilized and validated for many storm surge studies throughout Southeast Louisiana, including hindcasts of Hurricanes Katrina and Rita.

One recent evaluation which used the SL15 ADCIRC grid was conducted immediately after Hurricane Isaac in 2012. The February 2013 published report titled "Hurricane Isaac With and Without 2012 100-Year HSDRRS Evaluation" provides a complete analysis of how the GNO HSDRRS changed storm surge development and impacted communities outside the system. When compared to 2005 conditions, the 2012 GNO HSDRRS includes canal closures along Lake Pontchartrain, the Inner Harbor Navigation Canal (IHNC) Surge Barrier and Seabrook Closure, the West Closure Complex, and many upgraded levee and floodwalls. During Hurricane Isaac, these features prevented interior flooding, forcing some additional piling of water on the exterior of the system. The purpose of modeling Hurricane Isaac with and without the GNO HSDRRS was to document the characteristics and impacts of the storm, including an assessment of any GNO HSDRRS-induced impacts to the communities located outside the risk reduction system. The analysis concluded that the impacts to the surrounding communities would have been similar for the with and without GNO HSDRRS conditions.

In this analysis, we expand the post-Isaac evaluation by processing 16 more storms, including a series of high impact historical storms and a series of high impact synthetic storms. A total of 17 storms were run on three different versions of the SL15 grid. Each version of the grid represents a different year with different levee heights and alignments (1965, 2005, and 2012). The following describes the three versions of the SL15 grid used in this analysis:

**SL15-2012.** This version of the SL15 grid includes all of the updated features of the GNO HSDRRS, including the IHNC Surge Barrier, the West Closure Complex, the Lake Pontchartrain canal closures (at London Avenue, Orleans Ave and 17<sup>th</sup> Street), the IHNC Seabrook Closure, and upgraded levee and floodwalls throughout the system.

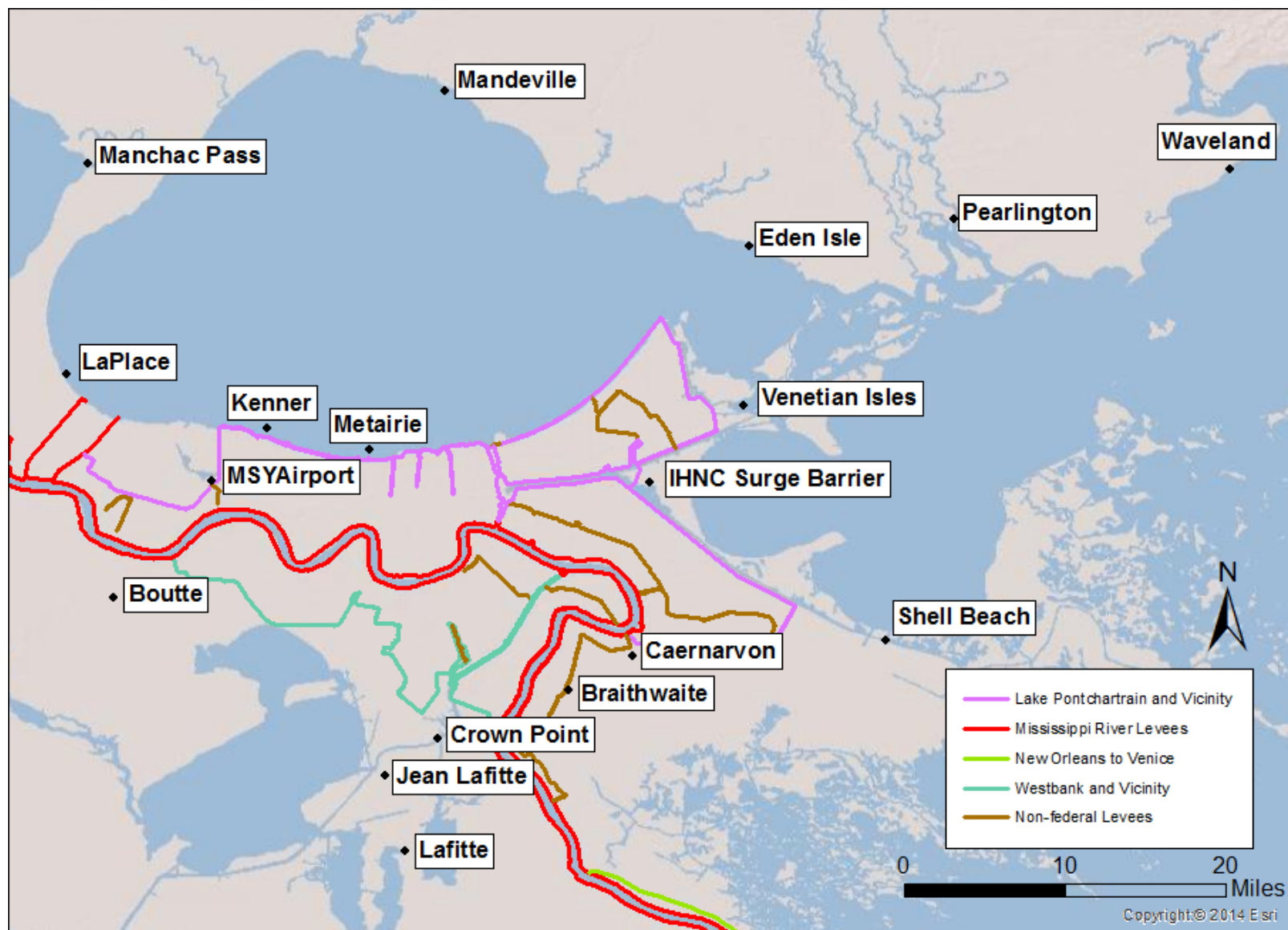
**SL15-2005.** This version of the grid represents conditions immediately prior to Hurricane Katrina. The grid includes various features of the 1960s-era system. This grid was used extensively to hindcast Hurricanes Katrina and Rita of the 2005 season.

**SL15-1965.** In this version of the SL15 grid, levee heights are reduced for the New Orleans East, St. Bernard, and portions of the New Orleans metropolitan area to project construction grades present in 1965 (pre-Betsy conditions). In these areas, this grid represents a condition without federal levees in place. Prior to federal participation, local levees existed at many of these locations. In other areas, including a large portion of the WBV project area, no levees existed prior to federal involvement. The 1965 grid is set up to evaluate the impact to communities outside the GNO HSDRRS due to federal levee construction after Hurricane Betsy.

When comparing the storm surge model output from the SL15-1965 grid to SL15-2012 grid, the results show a larger impact to peak water levels at areas immediately adjacent to the GNO HSDRRS. For example, at the present location of the IHNC Surge Barrier, the peak water level produced on the SL15-2012 grid is 4.56 ft higher than the water level produced on the SL15-1965 grid for one synthetic storm S023. At Venetian Isles, New Orleans, LA, which is located immediately outside of the New Orleans East area, the peak water level produced on the SL15-2012 grid is 2.17 ft higher than the water level produced on the SL15-1965 grid for storm 023. At Eden Isle, Slidell, LA, which is located about 7 miles from the eastern most portion of GNO HSDRRS, the peak water level is 0.23 ft higher than the peak water level produced on the SL15-1965 grid for storm S023. The impacts to peak water levels due to the levee system that existed in 1965 pre-Betsy and the GNO HSDRRS vary by storm and location. The impacts are greatest in the immediate vicinity of the GNO HSDRRS; impacts diminish as the distance from the GNO HSDRRS increases.

In the group of storms modeled for this analysis, the storm which produces the greatest impact at Eden Isle is synthetic storm S094. At this location, for this storm, a 0.48 ft rise in water level (an increase of 4.6%) can be attributed to construction of the 1965 pre-Betsy levees around New Orleans East and St. Bernard and construction of the GNO HSDRRS. Storm S094 is an extreme storm which produces approximately 500-year surge values at portions of GNO HSDRRS. In the 1965 and 2005 conditions, the St. Bernard, New Orleans East, and Orleans Metro areas are inundated for storm S094. In the 2012 condition, no overtopping is modeled. The displaced water causes an increase in surge on the GNO HSDRRS exterior.

With additional post processing of peak surge results, we compare peak water levels produced on the SL15-1965 and SL15-2012 grids and conduct a regression analysis to estimate changes to surge-frequency for the 50-year, 100-year, 200-year and 500-year return periods at various locations of interest, pictured in the map below. When assessing the impacts to surrounding communities, it is useful to compare surge statistics, rather than focusing on effects on a storm-by-storm basis. The regression analysis shows the 100-year surge produced on the SL15-1965 grid at the present location of the IHNC Surge Barrier is estimated to be 14.7 ft NAVD88 2004.65. At this location, the 100-year surge produced on the SL15-2012 grid is 17.5 ft. NAVD88. At the IHNC Surge Barrier, a 2.8 ft increase to 100-year surge levels can be attributed to the combined effects of 1965 pre-Betsy levee system and the GNO HSDRRS. The regression analysis shows a 1.2 ft increase to the 100-year water level at Venetian Isles, New Orleans, LA, and a 0.2 ft increase to the 100-year water level at Eden Isle, Slidell, LA. At Mandeville, LA, 100-year water levels decrease -0.1 ft because the levees constructed around New Orleans east reduce flow into Lake Pontchartrain. The impacts to surge frequency vary by location, with the largest impacts in immediate vicinity of the GNO HSDRRS. The following table provides detailed output at Metairie, Kenner, Caernarvon, IHNC Surge Barrier, Shell Beach, Venetian Isles, Eden Isle, Pearlington, Manchac Pass, Mandeville, LaPlace, New Orleans International (MSY) Airport, Braithwaite, Jean Lafitte, Lafitte, Crown Point, Waveland, and Boutte (the following figure and table are also provided in the main body of the report).



Map of selected model output locations in SE Louisiana

Location	Long	Lat	SI15-2012 Stage-frequency (ft. NAVD88 2004.65)				SI15-1965 Est. Stage-frequency (ft. NAVD88 2004.65)				Difference (ft) and Percent Difference for various return periods							
			50 YR	100 YR	200 YR	500 YR	50 YR	100 YR	200 YR	500 YR	50 Yr Dif	50 Yr %Dif	100 Yr Dif	100 Yr %Dif	200 Yr Dif	200 Yr %Dif	500 Yr Dif	500 Yr %Dif
Metairie	-90.144	30.028	7.8	9.1	10.2	11.5	7.9	9.3	10.5	12.0	-0.1	-1%	-0.2	-2%	-0.3	-3%	-0.5	-4%
Kenner	-90.236	30.047	7.9	9.1	10.2	11.3	7.9	9.0	10.1	11.1	0.0	0%	0.1	1%	0.1	1%	0.2	2%
Caernarvon	-89.906	29.842	14.6	17.7	19.8	21.9	14.0	16.9	18.8	20.8	0.6	4%	0.8	5%	1.0	5%	1.1	5%
IHNC Surge Barrier	-89.891	29.999	14.6	17.5	19.5	21.5	12.6	14.7	16.2	17.5	2.0	16%	2.8	19%	3.3	20%	4.0	23%
Shell Beach	-89.678	29.856	10.7	12.5	14.1	16.0	10.0	11.6	13.0	14.6	0.7	7%	0.9	8%	1.1	8%	1.4	10%
Venetian Isles	-89.807	30.069	11.7	13.7	15.3	16.9	10.7	12.5	13.9	15.3	1.0	9%	1.2	10%	1.4	10%	1.6	10%
Eden Isle	-89.801	30.212	8.6	10.5	12.2	13.9	8.5	10.3	12.0	13.7	0.1	1%	0.2	2%	0.2	2%	0.2	1%
Pearlington, MS	-89.616	30.236	11.6	13.9	16.0	18.4	11.2	13.4	15.4	17.6	0.4	4%	0.5	4%	0.6	4%	0.8	5%
Manchac Pass	-90.397	30.286	7.1	8.3	9.3	10.3	7.1	8.4	9.5	10.5	0.0	0%	-0.1	-1%	-0.2	-2%	-0.2	-2%
Mandeville	-90.075	30.351	8.2	9.6	10.7	11.8	8.2	9.7	10.9	12.2	0.0	0%	-0.1	-1%	-0.2	-2%	-0.4	-3%
LaPlace	-90.416	30.096	7.3	9.6	11.3	13.0	7.3	9.6	11.3	12.9	0.0	0%	0.0	0%	0.0	0%	0.1	1%
MSYAirport	-90.285	30.001	9.3	11.0	12.3	13.8	9.1	10.6	11.7	13.0	0.2	2%	0.4	4%	0.6	5%	0.8	6%
Braithwaite	-89.963	29.811	14.4	17.7	20.0	22.1	13.8	17.0	19.2	21.2	0.6	4%	0.7	4%	0.8	4%	0.9	4%
Jean Lafitte	-90.129	29.734	5.3	7.0	8.4	9.9	5.2	6.8	8.1	9.5	0.1	2%	0.2	3%	0.3	4%	0.4	4%
Lafitte	-90.112	29.667	6.0	7.8	9.3	11.0	6.0	7.7	9.1	10.7	0.0	0%	0.1	1%	0.2	2%	0.3	3%
Crown Point	-90.081	29.769	5.7	7.5	9.1	10.9	5.3	6.9	8.3	9.9	0.4	8%	0.6	9%	0.8	10%	1.0	10%
Waveland	-89.368	30.280	13.1	15.6	17.8	20.2	12.9	15.4	17.6	20.0	0.2	2%	0.2	1%	0.2	1%	0.2	1%
Boutte	-90.374	29.895	3.2	3.6	4.0	4.3	3.2	3.6	4.0	4.2	0.0	0%	0.0	0%	0.0	0%	0.1	2%

Summary of changes to stage-frequency at various output locations

## **2. Storm Surge Modeling Methodology**

### **2.1 Introduction**

This section describes the methodology used to model the 7 historical storms (Betsy, Camille, Katrina, Rita, Gustav, Ike and Isaac) and 10 synthetic storms. First we describe how the 10 synthetic storms were picked from the full suite of 152. Storms were selected to cover a parameter space representative of the historical record. We then describe and compare the individual storm characteristics for all 17 storms.

The next section describes the methodology used to create the SL15-1965 grid using data from 1960s-era General Design Memorandums (GDM) for the LPV construction that was authorized after Hurricane Betsy in 1965. These documents contain pre-construction ground elevations and elevations of the levees that were in place before the corps began construction of the federal levees after Betsy in New Orleans East and St. Bernard.

The next section describes sources of wind and pressure fields for the different historical storms. Prior to presenting results, the final section in the methodology chapter describes some assumptions and limitations of the overall analysis.

### **2.2 Synthetic Storms**

The left portion of Table 1 displays stage-frequency data developed for the design of GNO HSDRRS at Lake Pontchartrain, Lake Borgne and the West Bank for 50-year, 100-year and 500-year return periods. This data is based on the suite of 152 ADCIRC runs completed for the IHNC Surge Barrier project, referred to as the "IHNC 152". At each location, storms were selected to match as closely as possible the 50-year, 100-year and 500-year surge values. The right portion of Table 1 displays the selected synthetic storms and the associated storm surge value. For example, at Lake Borgne, storm 014 produces a 50-year surge, storm 077 produces a 100-year surge, and storm 094 produces a 500-year surge. One extra storm was modeled (storm 008). Storm 008 was selected at random from the suite of 152. Storm 008 produces less than 50-year water levels at Lake Pontchartrain, Lake Borgne, and the West Bank.

**Table 1 Synthetic Storm Selection**

Stage-Frequency					Selected Synthetic Storms					
Location	Qpt	50yr (ft. NAVD88)	100yr (ft. NAVD88)	500yr (ft. NAVD88)	~50yr	surge elevation (ft. NAVD88)	~100yr	surge elevation (ft. NAVD88)	~500yr	surge elevation (ft. NAVD88)
Lake Pontchartrain	Q-149	7.6	8.8	11.4	S023	7.4	S146	8.7	S085	11.1
Lake Borgne	Q-305	14.6	17.5	21.5	S014	14.0	S077	16.4	S094	20.6
West Bank	Q-466	5.7	7.5	11.0	S012	5.5	S126	7.3	S069	10.4

### 2.3 Historical Storms

Table 2 summarizes the dates of the historical storms evaluated in this analysis. These storms were selected based on their relatively high impact to Southeast Louisiana and the Gulf Coast. Figure 1 displays the tracks of the historical storms, including Ike (blue), Rita (magenta), Gustav (green), Betsy (light blue), Isaac (black), Katrina (red), and Camille (orange). The 10 synthetic storms are plotted as light grey lines.

**Table 2 Historical Storm Selection**

Storm Name	Date
Betsy	9/8/1965 to 9/11/1965
Camille	8/16/1969 to 8/19/1969
Katrina	8/25/2005 to 8/31/2005
Rita	9/18/2005 to 9/24/2005
Gustav	8/26/2008 to 9/4/2008
Ike	9/5/2008 to 9/14/2008
Isaac	8/24/2012 to 9/1/2012

Figure 2 displays the windspeed versus distance from landfall. In this case, landfall is defined as the location where the track intersects the coastline which is drawn as a white line in Figure 1. The windspeeds of the past historical storms vary from category 1 to category 5 on the Saffir-Simpson scale. The synthetic storms vary from a category 1 to category 5. Intensification and decay rates of the synthetic storms are consistent with that of the historical storms. Figure 3 displays the storm central pressures versus distance from landfall location. The central pressures of some of the more intense synthetic storms are 900mb, which is lower than any of the selected historical storms. The central pressure and windspeeds of the synthetic storms are consistent with the historical storms.

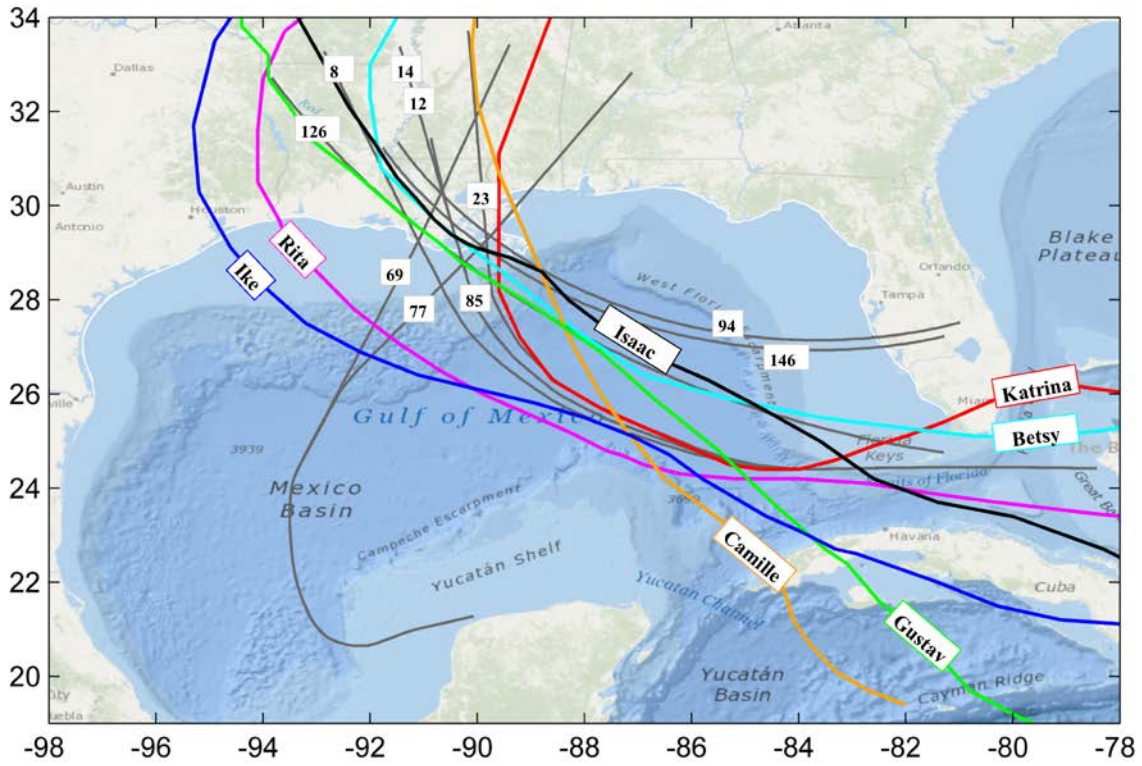


Figure 1 Storm tracks of past and synthetic storms.

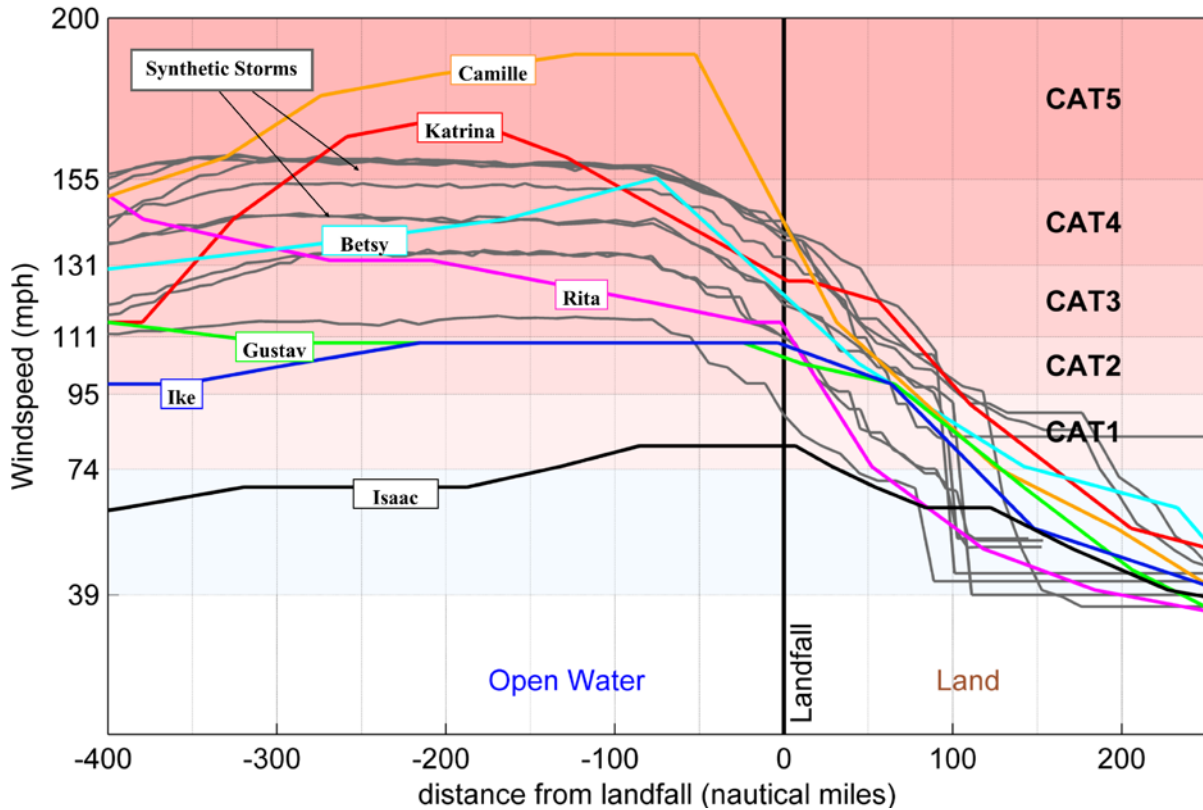


Figure 2 Storm Windspeed vs. Distance from Landfall

Figure 4 displays the storm forward speed versus distance from landfall for the historical and synthetic storms. The 10 selected synthetic storms have two forward speed values at approximately 7 or 12.5 mph. There is more variation within the historical records, however the synthetic storm forward speeds are representative of the historical record. Slower storm forward speeds can produce higher surge values, particularly in deltaic and inland regions. Isaac has the slowest storm forward speed in the selected historical storms. The slow forward speed is one characteristic of Hurricane Isaac which facilitated some of the highest ever observed inland flooding, despite being a category 1 storm on the Saffir-Simpson scale.

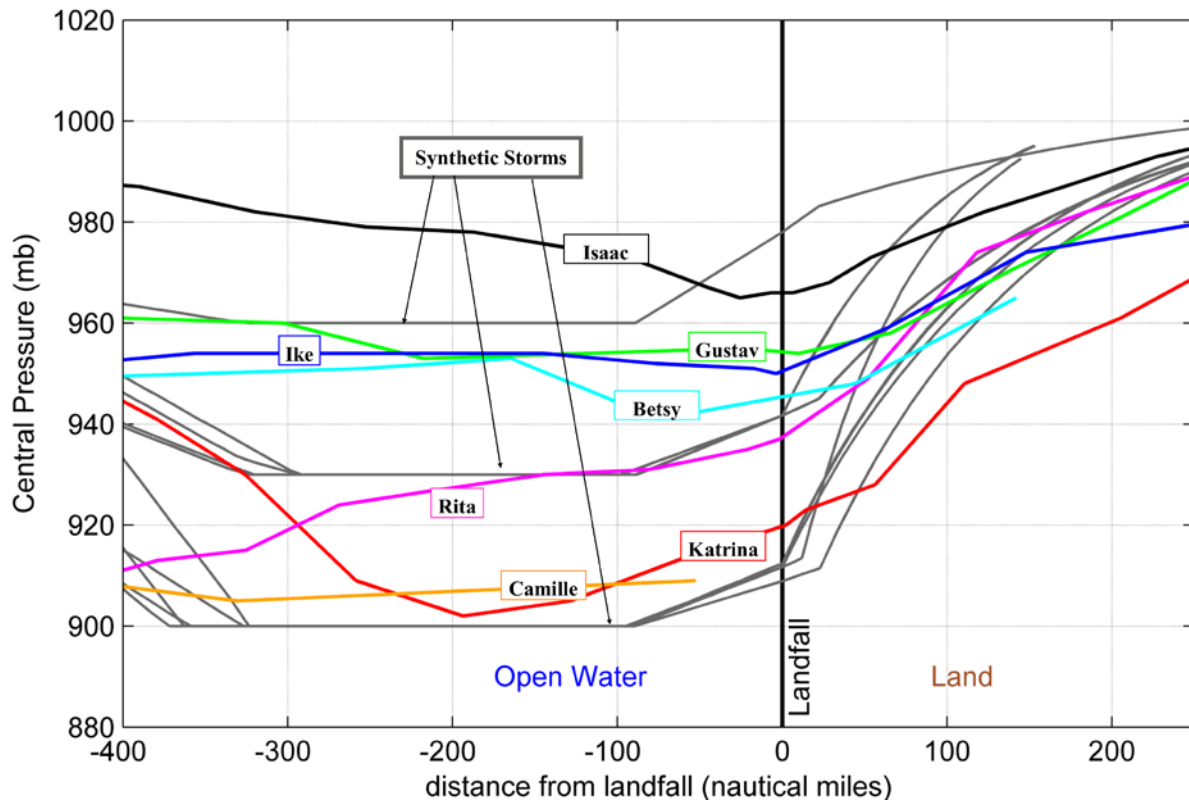
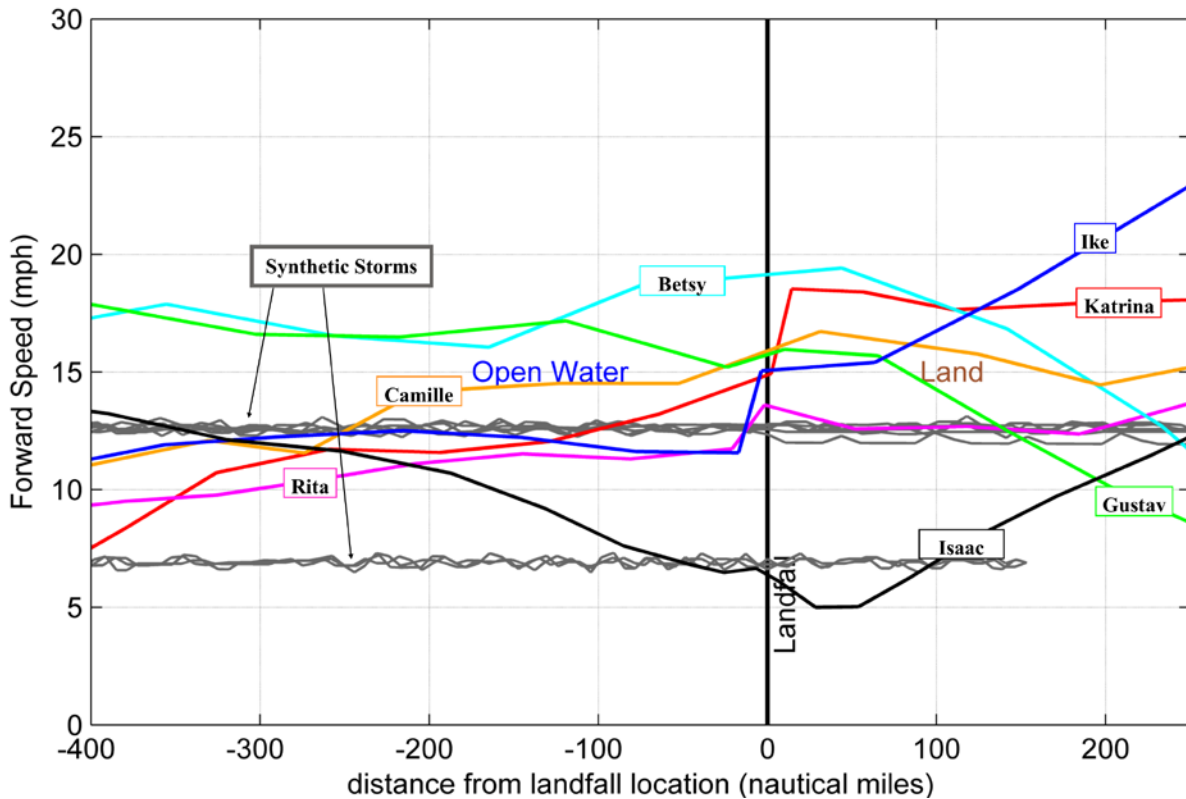


Figure 3 Storm Central Pressure vs. Distance from Landfall



**Figure 4 Storm Forward Speed vs. Distance from Landfall**

In conclusion, the characteristics of the selected storms are consistent with the historical record. The selected group of storms covers a plausible parameters space of storm characteristics. It is important to note that the selected storms are only a sample, and do not completely encompass the full range of possibilities.

## 2.4 Grid Modifications

In the 2013 Isaac analysis, two versions of the grid were developed. The first one contained levee and floodwall elevations as they existed at the timing of Hurricane Katrina, or roughly 2005. In this analysis we will call this grid SL15-2005. This grid was developed for hindcasting Hurricanes Katrina and Rita.

The second version of the SL15 grid developed contains all of the GNO HSDRRS features including the IHNC Surge Barrier, the IHNC Seabrook Closure, and the West Closure Complex. Levee and floodwall elevations are set to 2013 as-built surveys. In this analysis, we will call this grid the SL15-2012.

For this analysis, the SL15 grid was modified to remove portions of the levee alignment, effectively lowering elevations around St. Bernard, New Orleans East, and portions of the New Orleans metropolitan area. This grid represents the levees that existed prior to federal levee construction (pre-Betsy). The purpose of this modification is to determine changes in surge patterns and development at Lake Borgne and Lake Pontchartrain,

comparing 1965 pre-Betsy levees to the GNO HSDRRS levees. The analysis will show whether or not levees that existed in 1965 pre-Betsy and the GNO HSDRRS changed to way water flows into Lake Pontchartrain. This version of the grid is called the SL15-1965. To develop this grid, pre-project existing grade surveys were extracted from the 1960s-era General Design Memorandums (GDM) and applied to the SL15 grid.

Figure 5 displays a map from one GDM for New Orleans East. The map is taken from the report titled "Lake Pontchartrain High Level Plan: Design Memorandum No. 16 General Design: New Orleans East Levee South Point to GIWW, September 1987". The map shows the location of different plan and profile plots. For example purposes, one profile plot at the location immediately south of I-10 is selected and displayed in Figure 6. Although difficult to read, the profile plot shows the authorized design grade and the existing levee crown elevations plotted for the levee segment. The existing grade profiles show the local levees around New Orleans East prior to corps federal levee construction.

The elevations of pre-Betsy pre-federal levees were extracted from the GDMs using a specialized procedure and MATLAB code. Each of the GDM plan and profile plots were converted to digital format (.png) and cropped and straightened. The plan and profile plots were manually cropped at the beginning and end of the x and y axes. Next, a red line was manually drawn along the existing grade profile. A MATLAB code was written to extract the elevations along the drawn red. Figure 7 displays an example of a cropped profile plot, with the red line drawn at the existing grade. The program works by reading in the image, finding the location of the red pixels, and relating the location of the red pixels to the stationing and elevation. The method provides reasonable estimates of topographic elevations based on available data. The elevations were converted to NAVD88 using an assumed and uniform -0.6 ft conversion factor. It is very difficult to properly convert NGVD to NAVD88 in southern Louisiana, especially surveyed elevations from over 20 years ago. Although there are many assumptions in the levee elevation extraction and assignment procedure, the resulting grid is a reasonable estimate of what existed prior to the corps federal levee construction.

Figure 8 displays a plan and profile plot for a portion of the IHNC. This profile plot shows an existing levee elevation of approximately 15.0 ft NGVD. The plot reads "Existing Levee Crown El. 15 ft Constructed by Orleans Levee District". These profile plots show that levees did exist around New Orleans East prior to the corps effort to construct federal levees post-Betsy. It is important to note that the SL15-1965 grid is only modified at New Orleans East, St. Bernard and the portion of the New Orleans metropolitan area from Seabrook to the Mississippi River. The WBV project area levee elevations are the same in the SL16-1965 grids and the SL15-2005 grids.

Figure 9 displays the existing ground taken from the GDM for the Chalmette Area Plan. The profile shows that no levees existed prior to federal levee construction post-Betsy in this location. The SL15-1965 grid, elevations are lowered substantially in order to match the pre-Betsy existing ground profile. Dredging of the MRGO created a spoil bank in this area, and those elevations are plotted on the profile plot.

Figure 10 displays the final SL15-1965 sub-grid feature elevations. The plot shows relatively low elevations around New Orleans East, St. Bernard, and the eastern portions the New Orleans metropolitan area. Prior to construction of the federal levees post-Betsy, the relatively low levee and floodwall elevations allowed surge to overflow between separate areas during modest storm surge events. Figure 11 displays the SL15-2005 sub-grid feature elevations. With construction of the federal levees post-Betsy, levee elevations were significantly raised around New Orleans East, St. Bernard, and the eastern portions the New Orleans metropolitan areas; essentially forming separate areas and reducing the surge overflow between these separate areas which was previously experienced in modest storm surge events

Figure 12 displays the SL15-2012 sub-grid feature elevations. This version of the grid includes the new features of the GNO HSDRRS, including the IHNC Surge Barrier, the IHNC Seabrook Closure and the West Closure Complex. These features, along with raised levees and floodwalls, prevent water from flowing into the interior canals of the city during significant surge events. In the St. Bernard area, a roughly 30' floodwall now exists where a spoil bank with low elevations of approximately 4-6 ft existed prior to construction of federal levees post-Betsy. This is a major modification to the landscape. The goal of this analysis is to determine the cumulative effect of these major modifications on storm surge patterns in Lake Borgne and Lake Pontchartrain for a group of possible events.

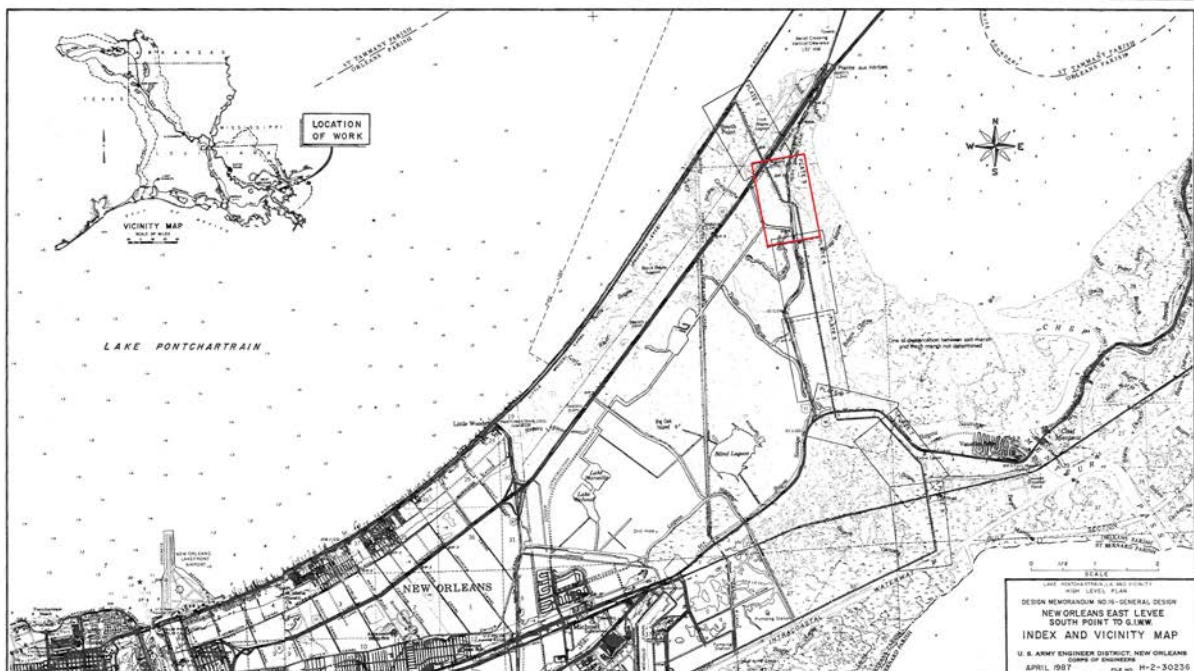


Figure 5 General Design Memorandum Map of New Orleans East – South Point to GIWW.



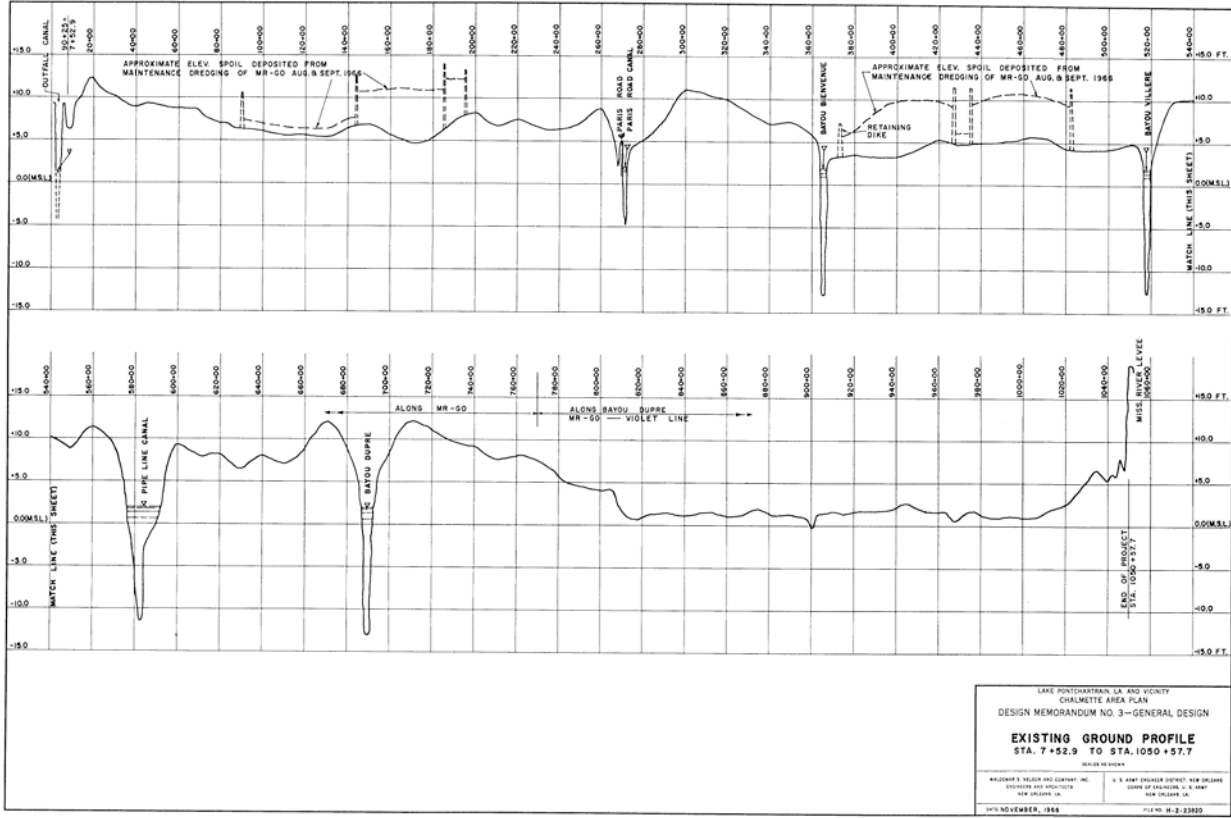


Figure 9 1966 Existing Ground Profile of St Bernard Area – Prior to HPS Construction

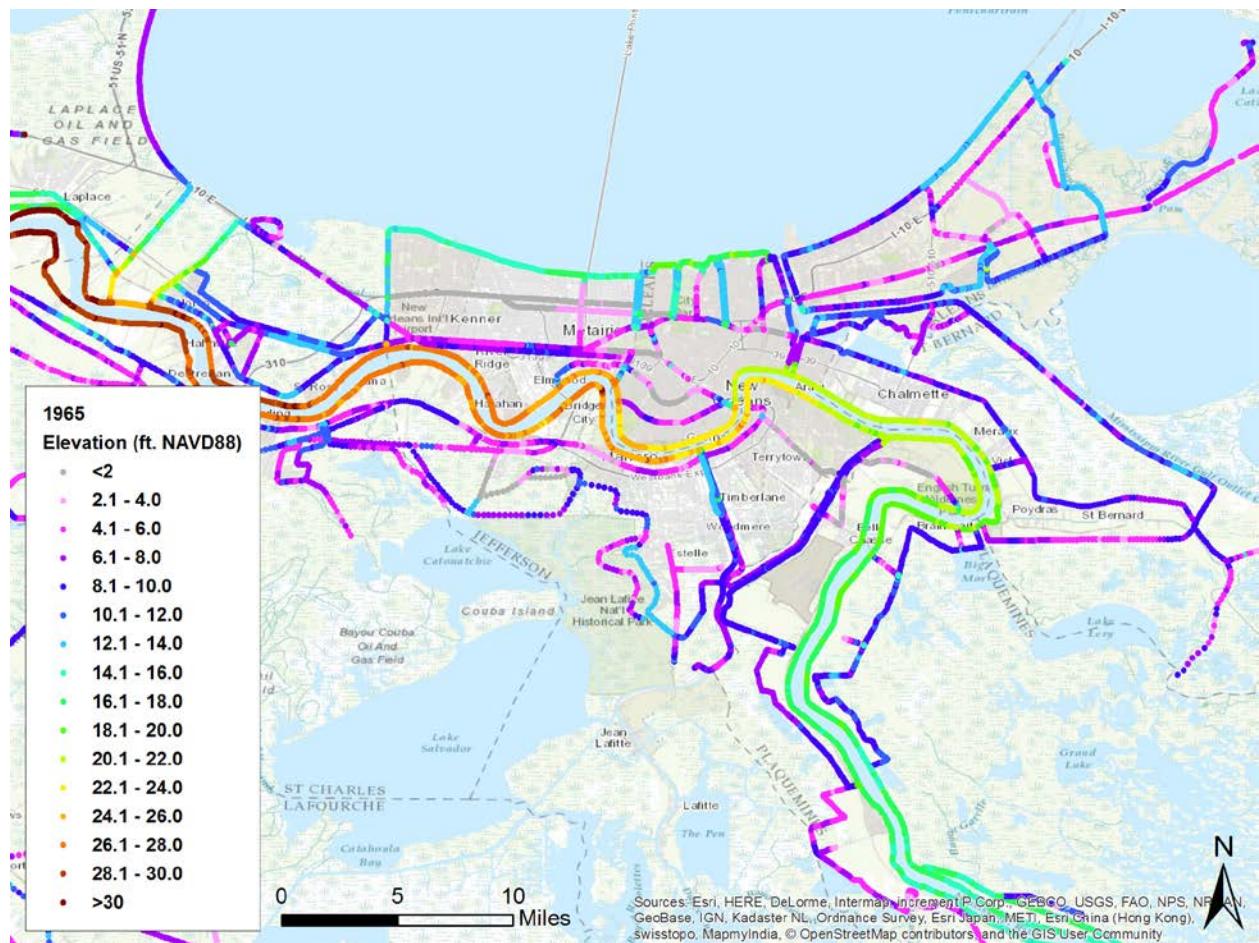


Figure 10 SL15-1965 Sub-grid Feature Elevations

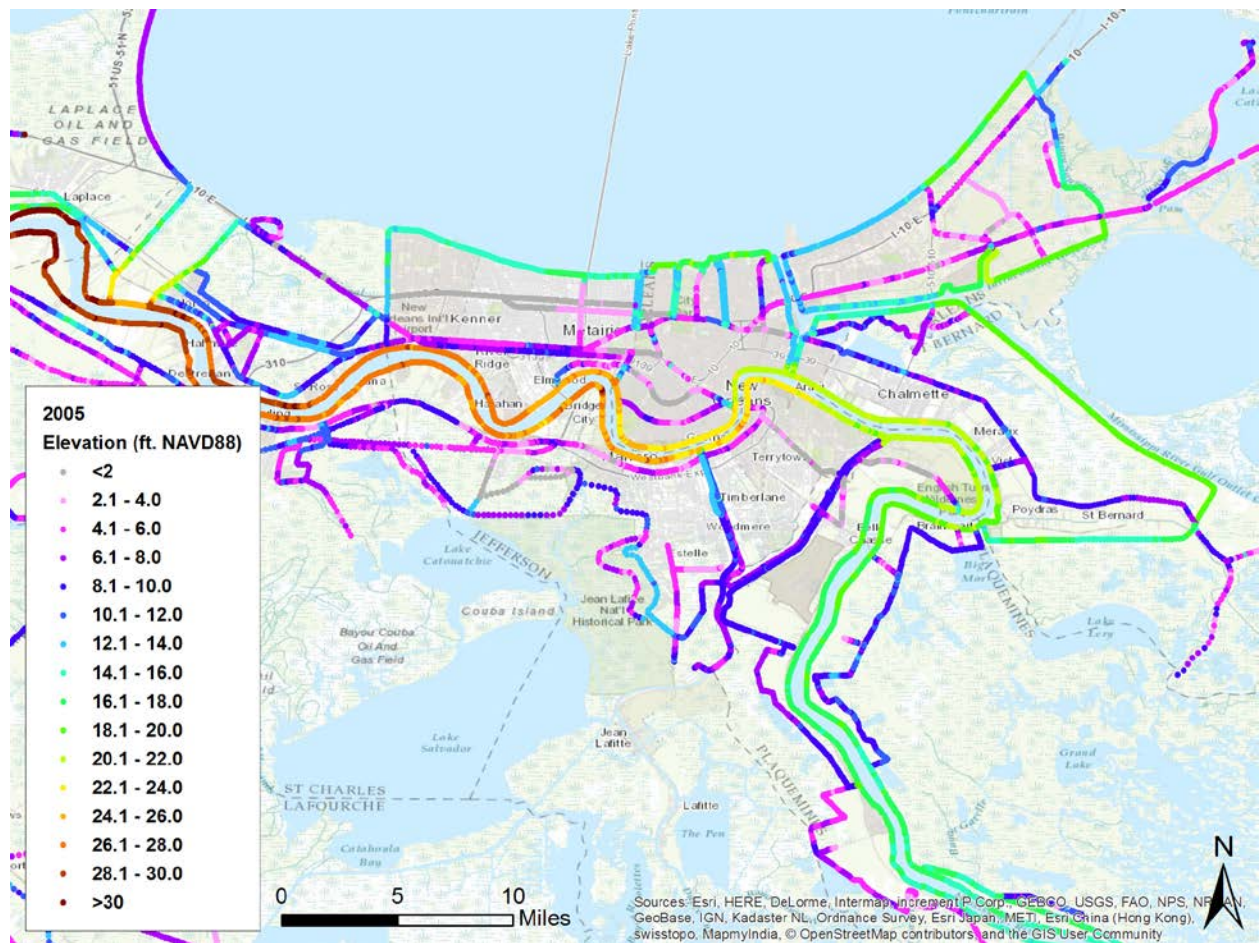


Figure 11 SL15-2005 Sub-grid Feature Elevations

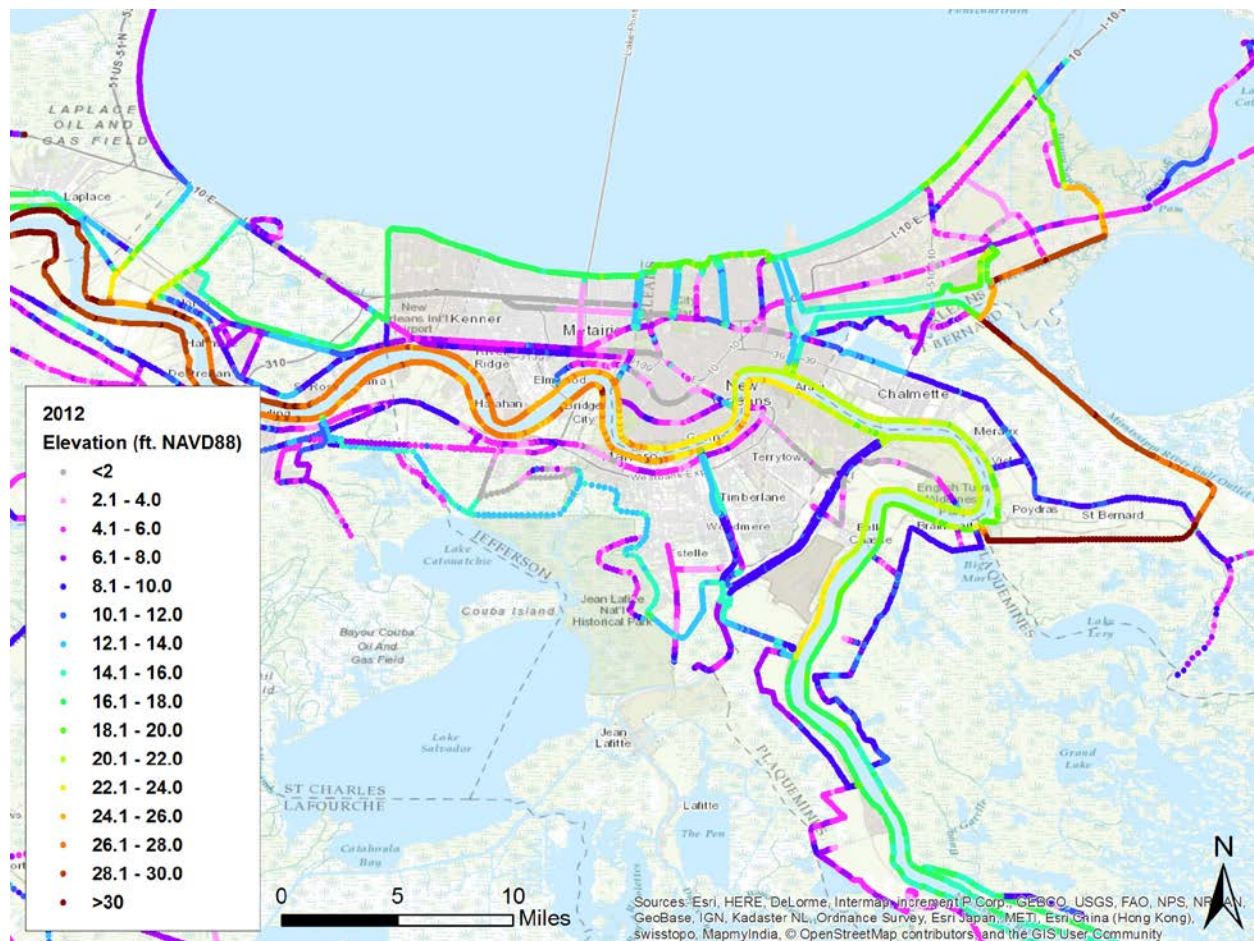


Figure 12 SL15-2012 Sub-grid Feature Elevations

## 2.5 Wind Input

One of the major inputs needed to model storms using ADCIRC is wind data. The wind drives the storm surge. For Hurricane Betsy, the wind input was taken from NOAA's H\*Wind Project ([http://www.aoml.noaa.gov/hrd/data\\_sub/wind.html](http://www.aoml.noaa.gov/hrd/data_sub/wind.html)). The H\*Wind project uses measurements from a variety of observation platforms to develop a realistic distribution of wind speeds for major hurricane events. Figure 13 displays some of the snapshots of Hurricane Betsy's winds as the storm progressed across the Gulf of Mexico. H\*Wind data provides a realistic approximation of what occurred because it is primarily based on recorded observations.

H\*Wind data is only available for the timing of landfall for Hurricane Camille, as shown in Figure 14. Therefore H\*Wind cannot be used to model the entire storm. However, NOAA records important track data for all hurricanes in the HURRDAT database. ([http://www.aoml.noaa.gov/hrd/hurdat/Data\\_Storm.html](http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html)).

This track data, which include lat/long coordinates, central pressure and wind speed data, can be used to produce wind input for the ADCIRC model. Using the ADCIRC utility program called ASWIP, the NOAA Camille track file was converted to a special format, which provides the pertinent hurricane parameters to ADCIRC's internal

parametric vortex model, producing a wind field for the storm. For Camille, we have selected the NWS=19 internal vortex model within ADCIRC.

For Hurricanes Katrina, Rita, Gustav, Ike and Isaac, “best winds” in the OWI format have been applied in the modeling. “Best winds” were developed as part of previous analyses for accurate hindcasting of Hurricanes Katrina, Rita, Gustav, Ike and Isaac. The “best winds” are also data-assimilated, meaning that they incorporate observations from many wind and pressure gages throughout the region.

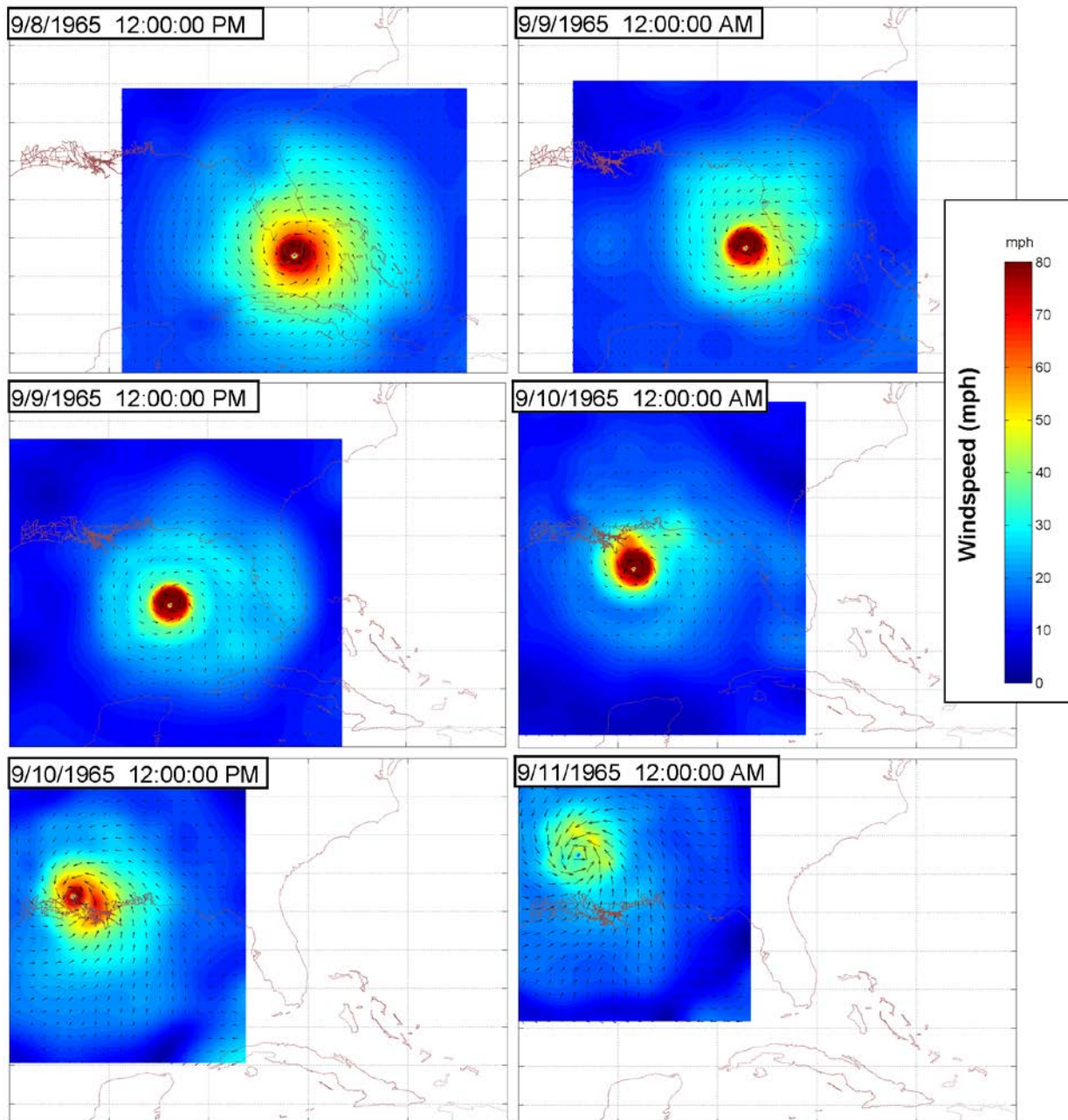


Figure 13 Hurricane Betsy Wind Field – NOAA H\*Wind

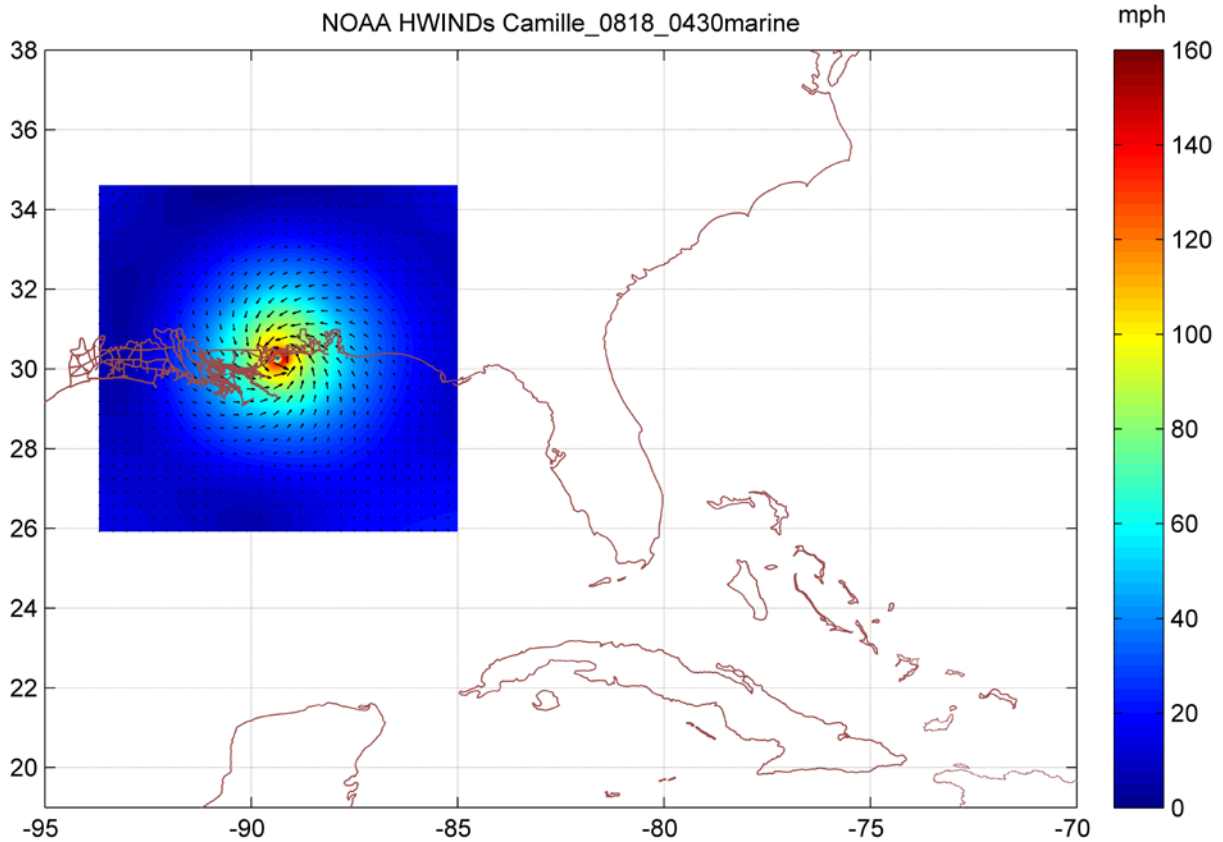


Figure 14 Hurricane Camille Wind Field at Landfall – NOAA H\*Wind

## 2.6 Limitations and Assumptions

One of the limitations of the analysis is the limited sample size of the selected synthetic and historical storms. The sample of storms does not cover the full range of possibilities, but rather provides a few examples of storms which have occurred, and a few examples of storms which could occur. However, this analysis builds on the 2013 Isaac analysis as only one storm was modeled as part of that analysis.

### **3. ADCIRC Simulations of Betsy, Camille, Katrina, Rita, Gustav, Ike, Isaac and 10 Synthetic Storms**

#### ***3.1 Introduction***

In this chapter we present storm surge model results for the SL15-1965, SL15-2005, and SL15-2012 grids. Some validation data for Hurricanes Betsy and Camille are also presented. It is important to validate the simulations of Camille and Betsy on the SL15-1965 grid to show that the model reasonably reproduces measured peak water levels. Betsy flooded large portions of the Greater New Orleans area and it is important to quantify how well the ADCIRC modeling replicates this flooding.

#### ***3.2 Example Storm Surge Development for Hurricane Betsy***

Figure 15 displays the simulated surge elevation time-series as Betsy makes landfall using the SL15-1965 ADCIRC grid. At midnight on 9/10/1965, strong winds begin to develop from the northeast, forcing water into Lake Borgne. By 6:00AM, a considerable surge of about 12.5 ft has developed in Lake Borgne causing the New Orleans East and St. Bernard existing levees to overtop and begin to flood. By 3:00PM, the eye of the storm has passed southeast Louisiana and New Orleans East and St. Bernard areas have substantial flooding. The modeled storm surge for Betsy is similar to what occurred in reality, although some interior flooding patterns are different. In reality, Betsy flooded New Orleans East, St. Bernard and portions of the New Orleans Metro areas. The model does not show all of these areas flooding exactly the way it happened in reality. However, the general pattern of modeled inundation is consistent with observations. The interior flooding is difficult to predict without more detailed model of the interior.

Figure 16 displays the wave height time series from the simulation of Hurricane Betsy using the SL15-1965 grid. The highest waves, with significant wave heights of roughly 7 to 9 ft, occur in Lake Pontchartrain. The wave development appears reasonable, although wave validation data is not available.

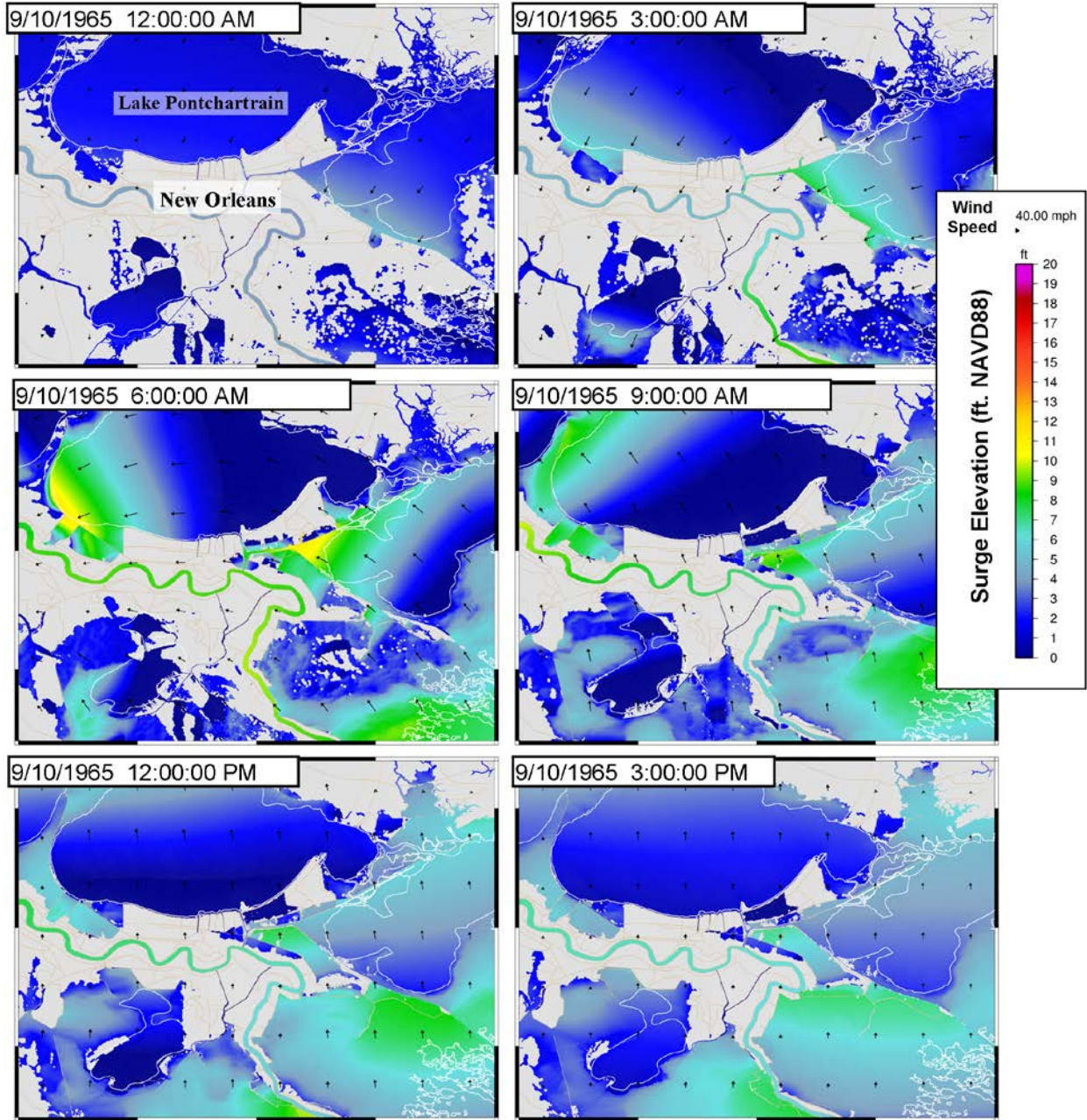


Figure 15 Storm Surge Development for Hurricane Betsy on the SL15-1965 Grid.

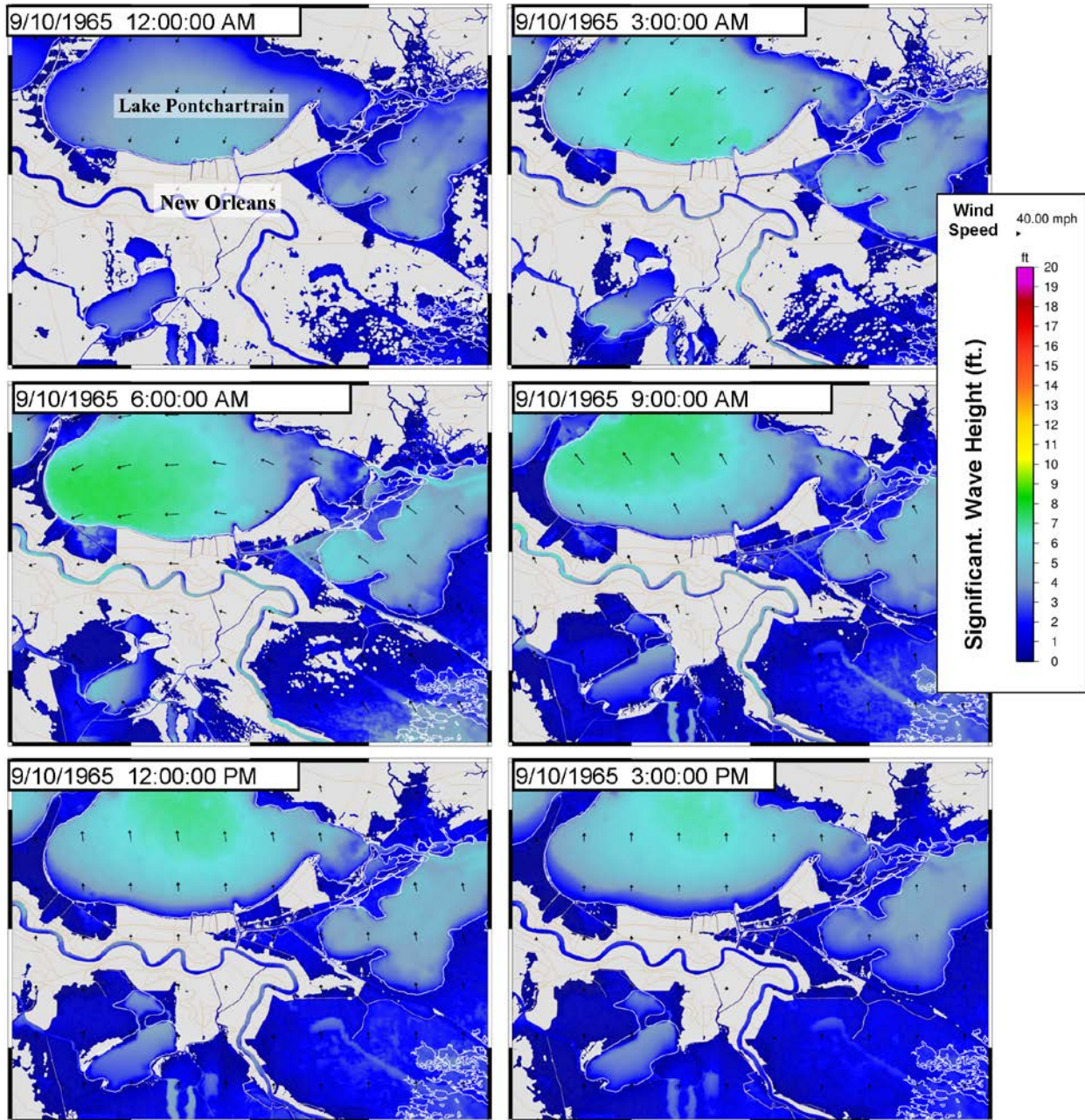
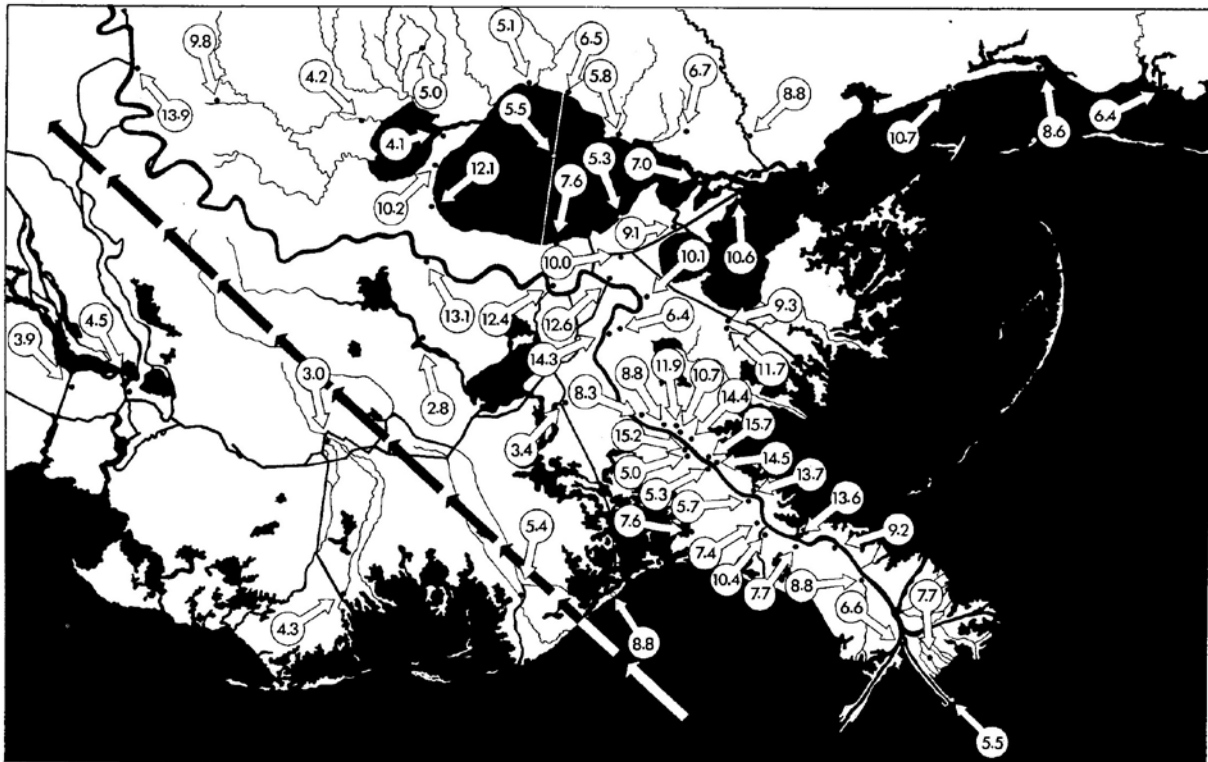


Figure 16 Wave Height Development for Hurricane Betsy on the SL15-1965 Grid.

### 3.3 Validation for Betsy and Camille

Figure 17 displays the observed high water mark data collected after the storm by USACE. A very dense network of high water mark data is useful for validation purposes. The data from the figure was extracted and converted to shapefile format. Figure 18 displays a validation plot, comparing modeled data to observed data. The plot presents scatter data of the difference between modeled and observed peak water surface elevation. The color of each scatter point corresponds to the error between the modeled high water mark and the observed high water marks. Warmer colors suggest model over prediction, while cooler colors suggest under-prediction. Overall ADCIRC seems to

under-predict the peak surge and also interior flooding, however in the location of interest (Lake Borgne, IHNC and Lake Pontchartrain), the model predicts peak surge to within 1 to 2 ft at most high water mark locations.



**Figure 17 Hurricane Betsy Observed High Water Marks**

Figure 19 displays a high water mark profile plot for Hurricane Camille taken from a May 1970 corps report, produced by the USACE Mobile District, entitled “Hurricane Camille 14 – 22 August 1969”. The profile is plotted along the Gulf Coast from the Rigolets pass in Louisiana to Perdido Pass, FL. The observed data shows a peak surge near Pass Christian, MS of approximately 22.5 ft. M.S.L. The data from this plot is extracted using a similar technique as used to extract the levee elevation data from the GDMs. The surge is adjusted to the NAVD88 datum. Figure 20 is a validation plot for Hurricane Camille. The top portion of Figure 20 shows the maximum surge elevation for Camille using the SL15-1965 grid. The black line represents a transect where peak surge is extracted from the simulation. The bottom portion of the figure compares the modeled peak surge to the observed peak surge. The model provides a reasonable reproduction of surge for the area of impact, although modeled peak surge is under-predicted by approximately 2-3 ft west of Bay St. Louis. The quality of wind data applied in the simulation of Camille might explain some of the differences between modeled and observed. H\*Wind or other data-assimilated wind products are not available for Camille.

The high water mark data used for validation of Hurricanes Betsy and Camille is from the 1960s and it is difficult to know whether or the surveyed marks include the effects of

wave run-up. The data is taken as-is because very little documentation is available to verify these high water marks.

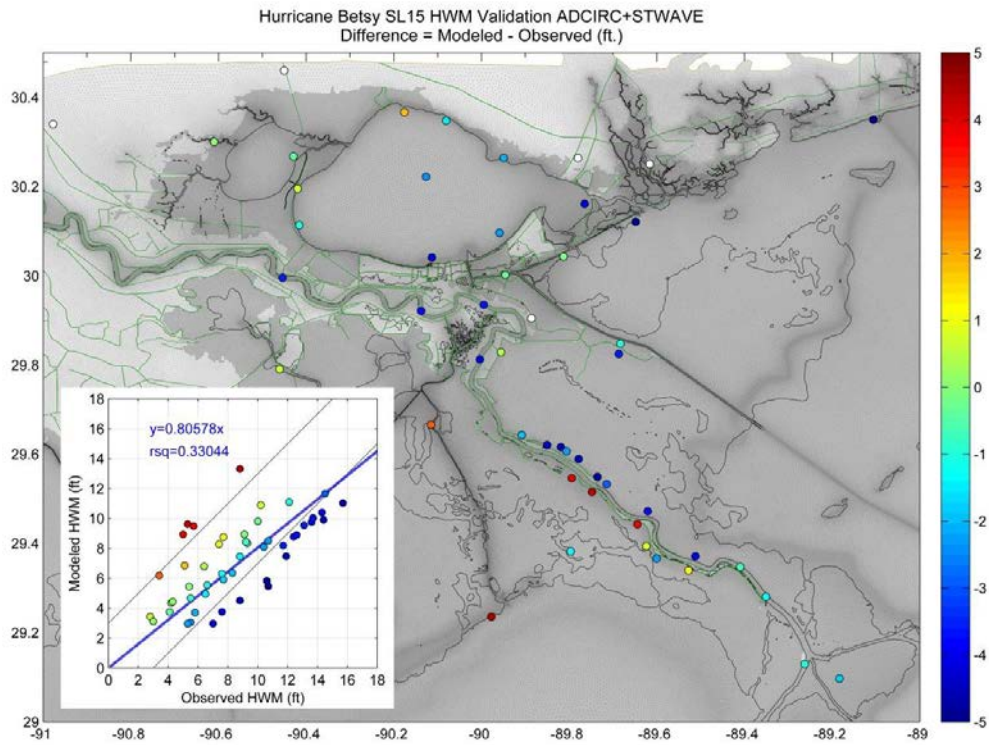


Figure 18 Hurricane Betsy High Water Mark Validation in SE Louisiana

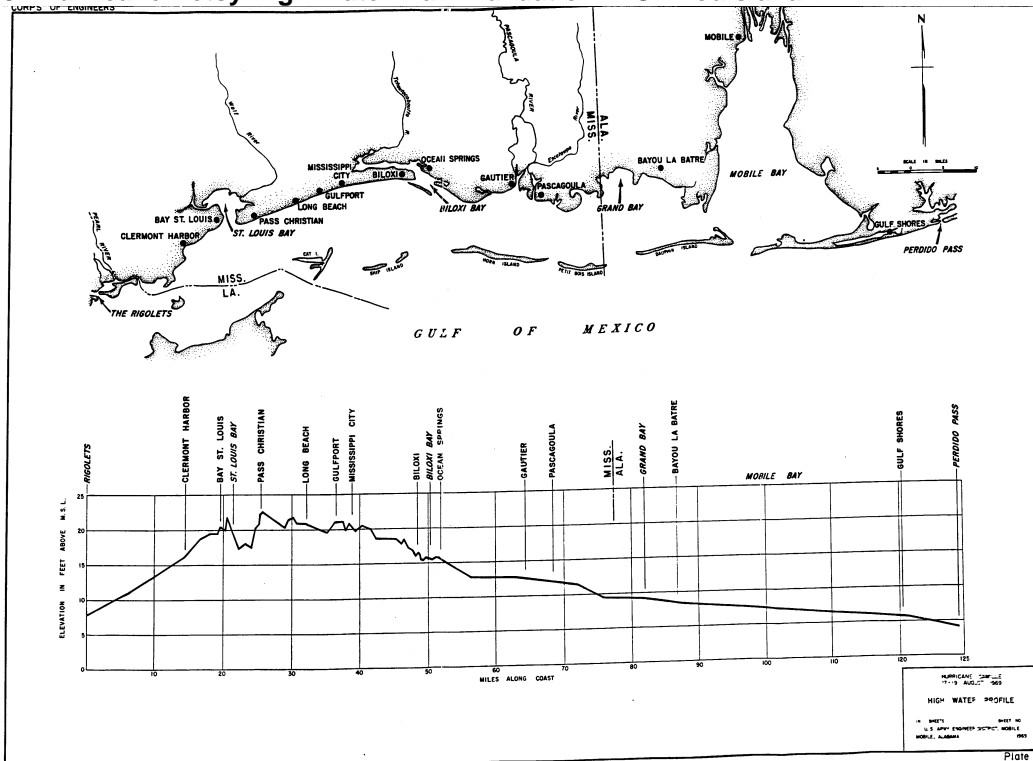


Figure 19 Hurricane Camille Observed High Water Profile along the MS, GA, FL Coast

ADCIRC SL15 pre-HPS 1969 Hurricane Camille  
max. surge elevation (ft. NAVD88)

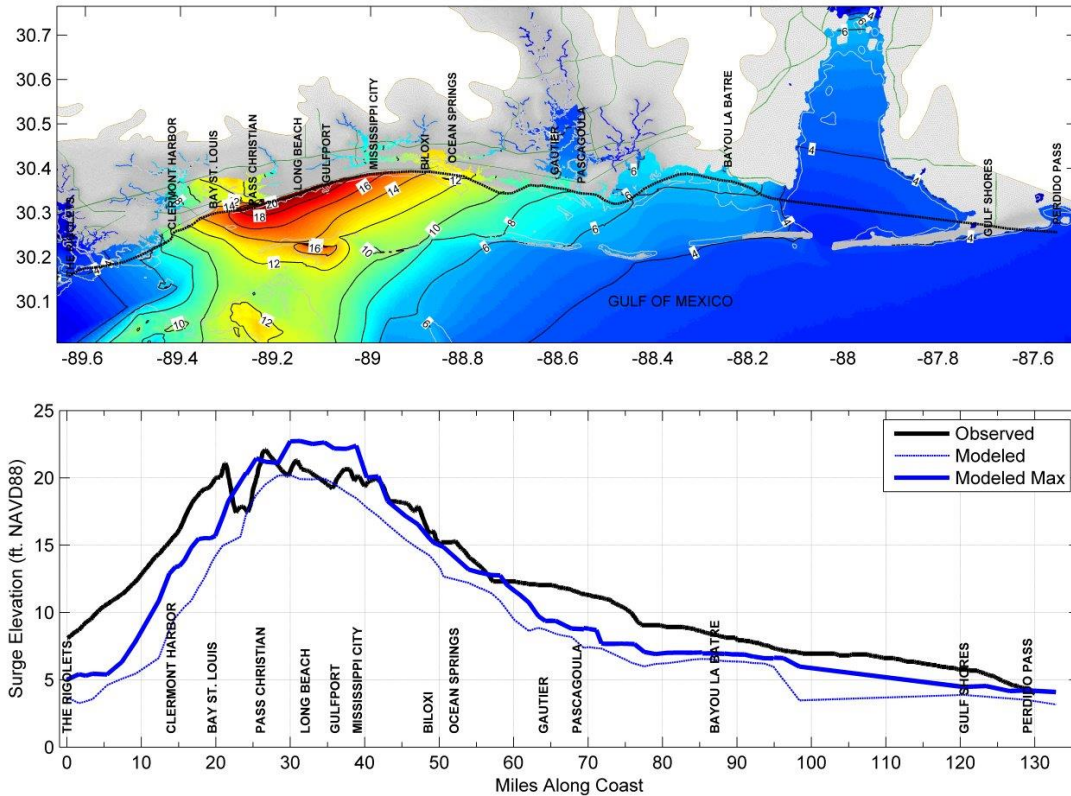
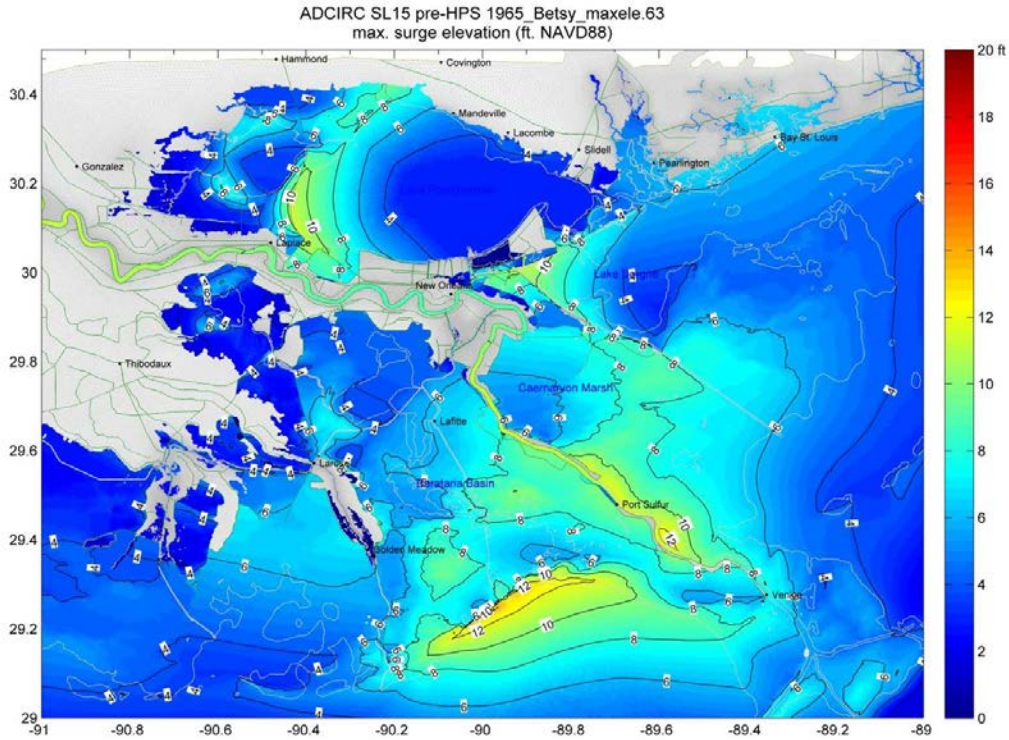


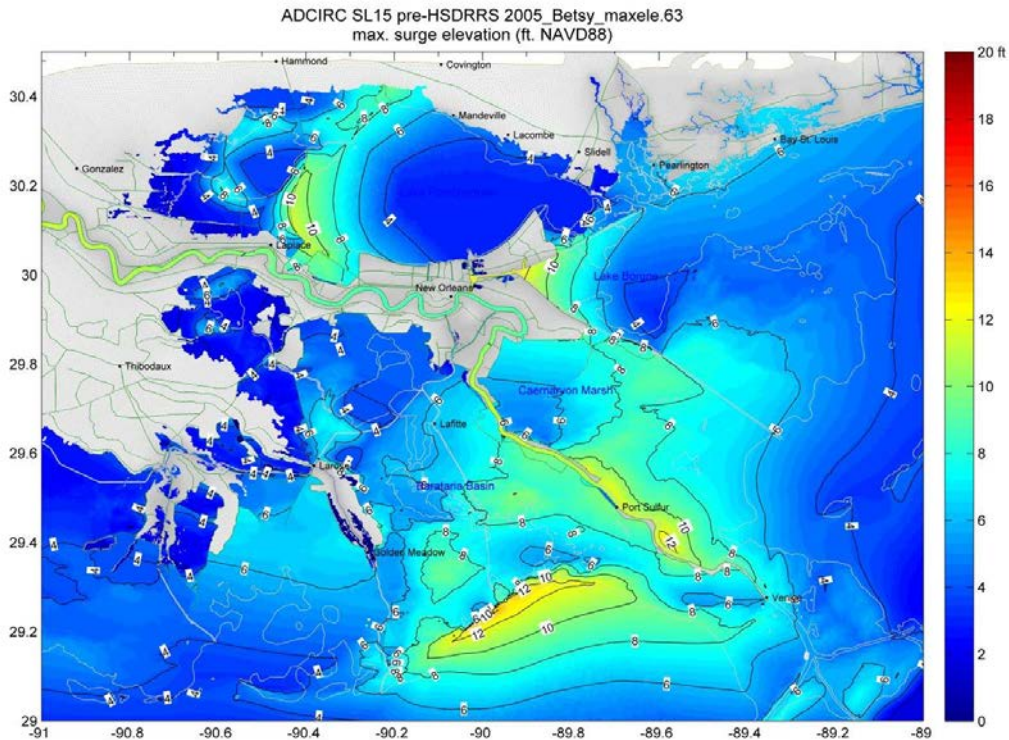
Figure 20 Hurricane Camille Validation of High Water Profile along the MS, GA, FL Coast

### 3.4 Impacts to Surrounding Communities

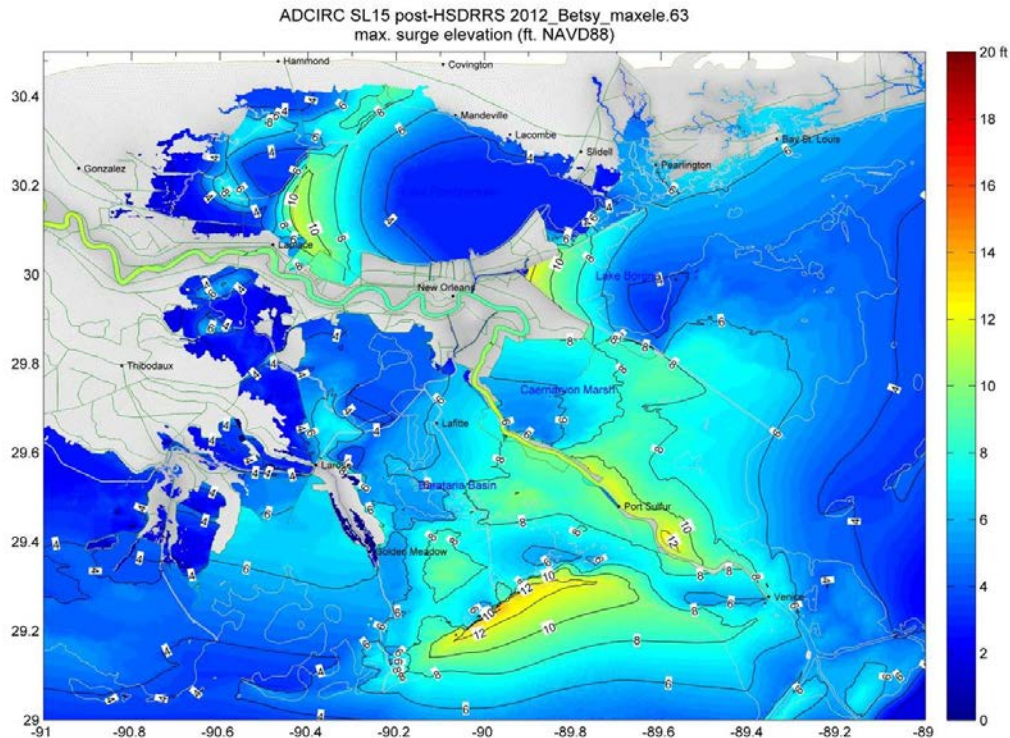
Figure 21 displays the maximum surge elevation for the Hurricane Betsy simulation on the SL15-1965 grid. Without post-Betsy federal levees in place around St. Bernard and New Orleans East, substantial flooding occurs in these areas. This result is similar to what occurred in reality during Betsy. Figure 22 displays the maximum surge plot for Hurricane Betsy on the SL15-2005 grid. With the federal levees post-Betsy in place, the St. Bernard and New Orleans East areas do not flood for the Betsy simulation, although some minor overtopping seems to occur at isolated locations. Figure 23 displays the maximum surge of Hurricane Betsy using the SL15-2012 grid. With this grid, the features of GNO HSDRRS, including the IHNC Surge Barrier, IHNC Seabrook Closure and West Closure Complex prevent major interior flooding in the Betsy simulation. Maximum surge elevation plots for all 17 storms are presented in Appendix A.



**Figure 21 Hurricane Betsy Maximum Surge Elevation on SL15-1965 Grid**



**Figure 22 Hurricane Betsy Maximum Surge Elevation on SL15-2005 Grid**



**Figure 23 Hurricane Betsy Maximum Surge Elevation on SL15-2012 Grid**

To help visualize the impact on surge patterns due to the post-Betsy federal levees and the GNO HSDRRS, difference plots for each storm have been created. Figure 24 displays the difference in maximum surge produced for Betsy between the SL15-2005 and SL15-2012 grids. The difference surface is color coded, with warmer color representing an increase in water level due to the GNO HSDRRS project features. The figure suggests that the project features of GNO HSDRRS increase water level very modestly between the 2005 and 2012 conditions. A roughly 1.0 inch increase in water level is observed near Eden Isle, Slidell, LA, while a reduction of approximately 1.0 inch is observed in Lake Pontchartrain near Mandeville, LA. The reduction in peak water surface can be attributed to the closure of the IHNC corridor, which prevents some flow into Lake Pontchartrain through Seabrook. With the IHNC Surge Barrier in place, the hydraulic conductivity between the source of the surge (the Gulf of Mexico / Lake Borgne) and Lake Pontchartrain is reduced, reducing the overall volume entering Lake Pontchartrain. This behavior is not unique to Betsy, and similar results are produced for Isaac and other storms. The WBV levees, including the West Closure Complex, reduce interior flooding, and increase exterior water levels immediately outside the system. As distance from the WCC increases, the increase in water level is diminished. Difference plots for the SL15-2005 and SL15-2012 grids for all 17 modeled storms are presented in Appendix B.

Figure 25 is a difference plot for Hurricane Betsy comparing the peak surge produced on the SL15-1965 grid and peak surge produced on the SL15-2012 grid. This comparison shows the impact on surge patterns due to construction of the post-Betsy federal levees and GNO HSDRRS, or the changes to the system between 1965 and

2012. As expected, the changes to surge patterns are more intense, although still a modest increase in water level is observed. Simulation of Betsy on the SL15-1965 grid shows a tremendous amount of water volume entering St. Bernard, New Orleans East and the eastern side of the New Orleans metropolitan area. With the GNO HSDRRS in place, the volume no longer enters the areas, but it causes a minor increase in surge levels on the exterior of the system. Most of this increase in water level is immediately adjacent to the GNO HSDRRS (in Lake Borgne and to the east of New Orleans within the levee system). An approximate 2.0 inch increase in water level is observed near the Rigolets, while water levels are unchanged near Mandeville, LA and Eden Isle, Slidell, LA. Lake Pontchartrain generally shows a reduction in water level since the hydraulic connectivity to the Gulf is reduced with the New Orleans East levees in place. In the Betsy simulations, construction of the GNO HSDRRS on the westbank prevents the interior flooding and raises exterior water levels about 7 inches in the immediate vicinity of the West Closure Complex. The increase in water level is diminished with increased distance from the system. At Lafitte, the increase is less than 1 inch.

To demonstrate how the differences in water level evolve throughout time, a time series difference plot has been created and presented in Figure 26. The plot shows that as water surface elevation is reduced in the interior, the exterior is increased. The largest increase in water level occurs in Lake Borgne, immediately east of the IHNC Surge Barrier. Near Slidell and more specifically Eden Isle, the increase is nearly zero, but further east near Pearlinton, MS the increase is roughly 2.0 inches or less.

2005 HPS vs 2012 100YR HSDRRS: Historical and Synthetic Storms  
Difference in maximum water surface elevation (in) 2012\_Betsy\_maxele.63

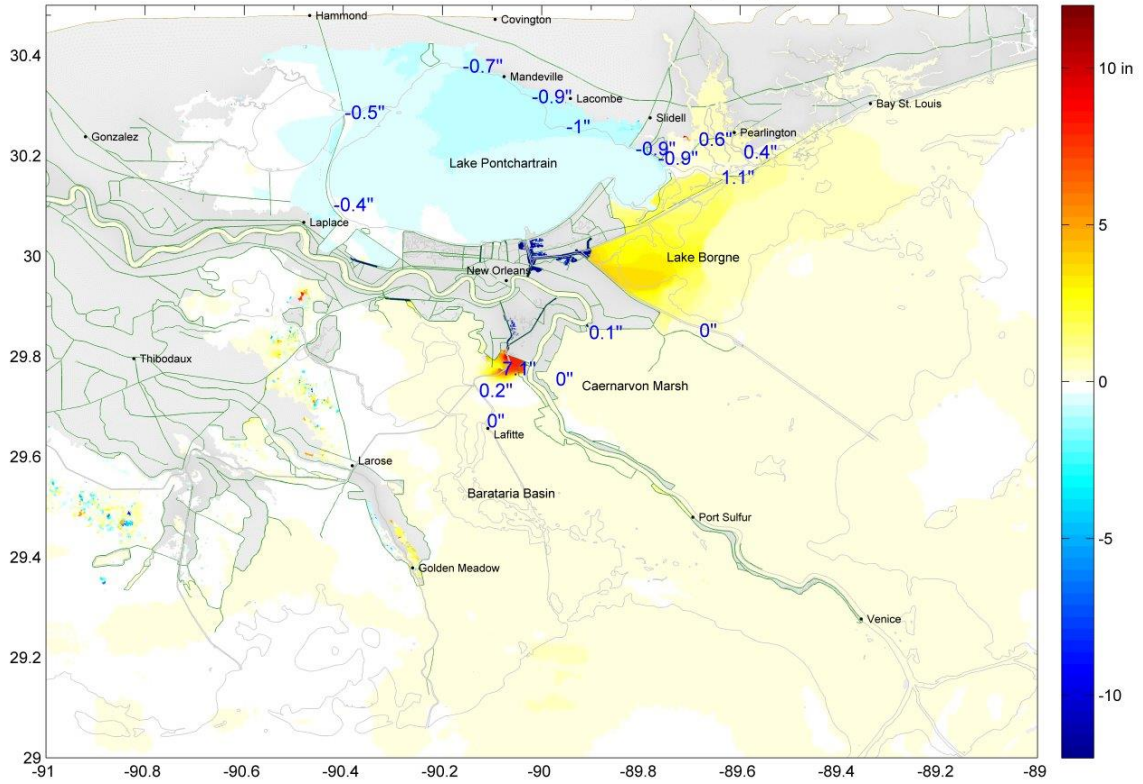


Figure 24 Peak Surge Difference Between SL15-2005 and SL15-2012

PRE-1965 HPS vs 2012 100YR HSDRRS: Historical and Synthetic Storms  
Difference in maximum water surface elevation (in) 2012\_Betsy\_maxele.63

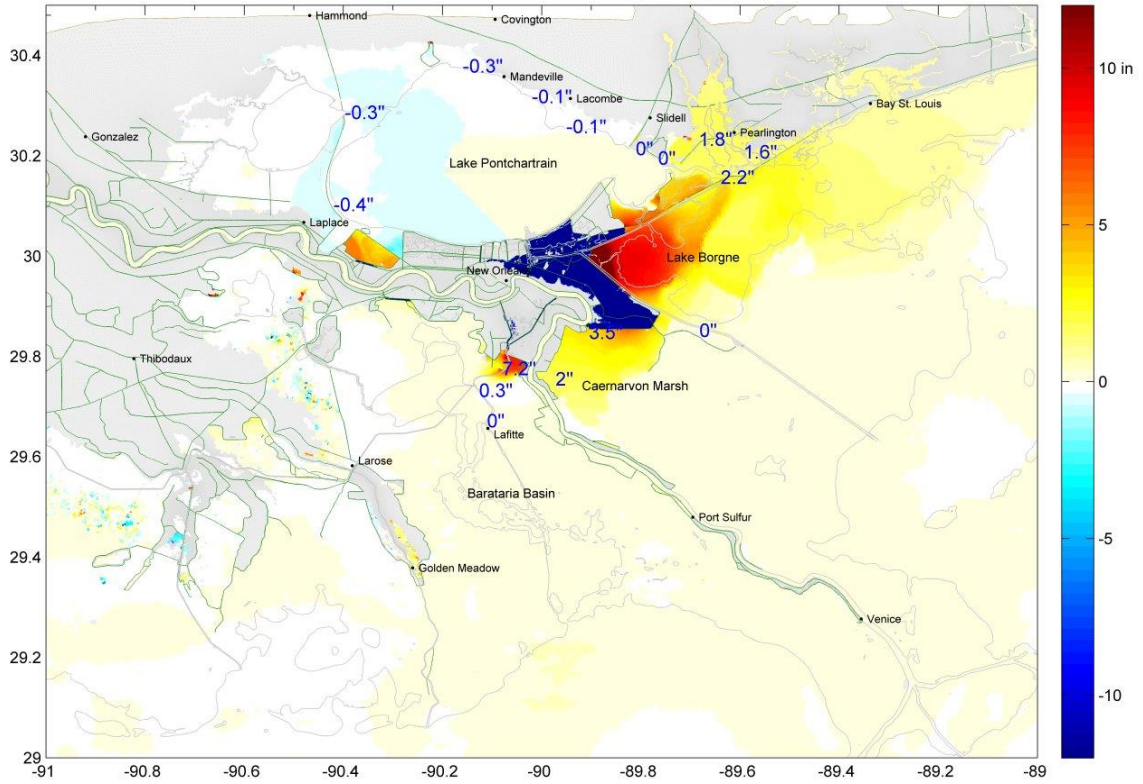


Figure 25 Peak Surge Difference Between SL15-1965 and SL15-2012

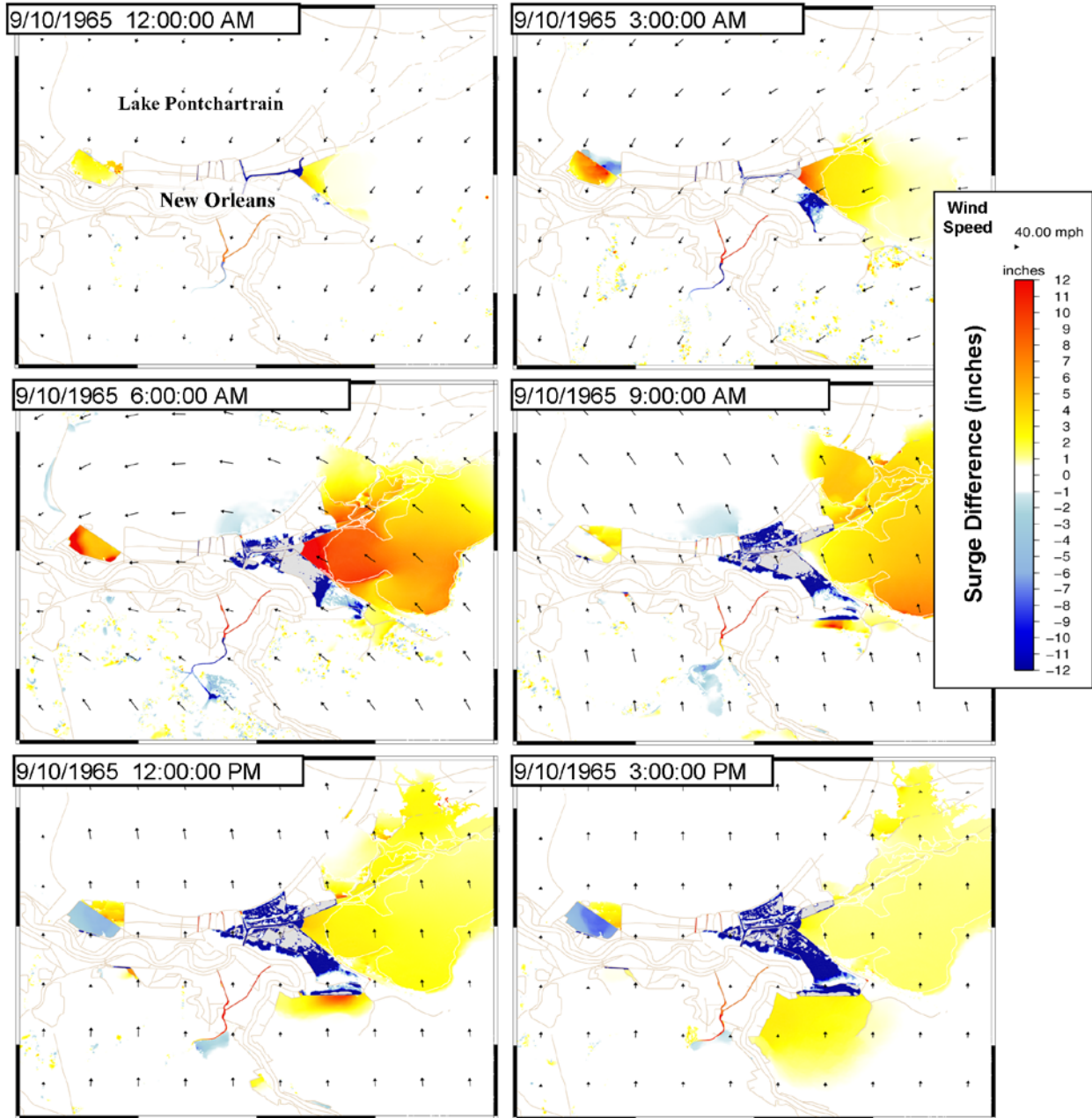
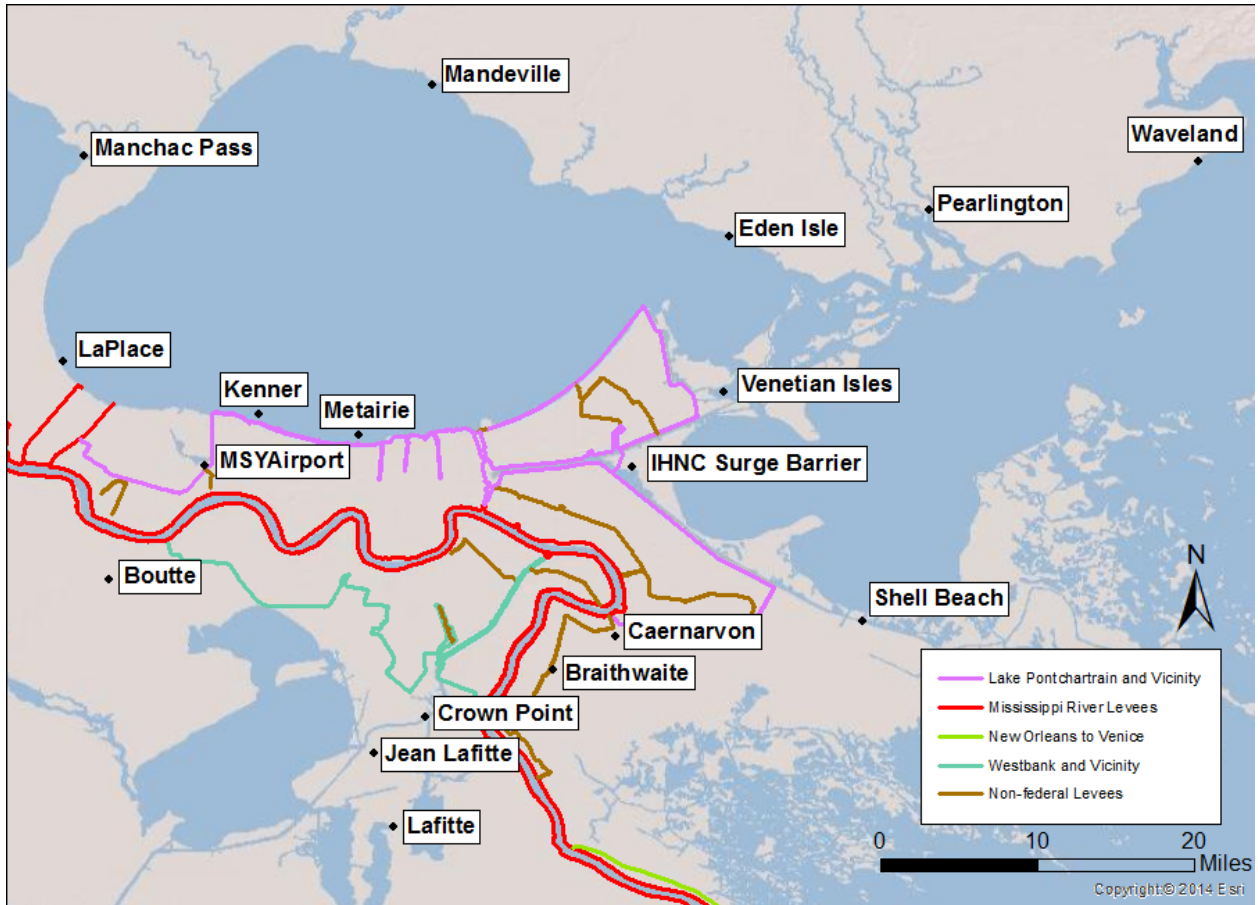


Figure 26 Time Series of Differences in Peak Surge between SL15-1965 and SL15-2012

Figure 27 displays the selected output locations where peak surge values for all simulations have been extracted.



**Figure 27 Selected Output Locations**

Table 3 displays the maximum surge values at the selected output points for all storms for the SL15-1965, SL15-2005 and SL15-2012 grids. The table also displays the difference in peak surge elevation between the SL15-2005 and SL15-2012 grids, and the SL15-1965 and SL15-2012 grids. Positive difference values represent an increase in water level due to the federal project. A percentage change has also been calculated. For example, at Eden Isle, Slidell, LA, storm S094 produced a 10.4 ft NAVD88 storm surge on the SL15-1965 grid, a 10.4 ft NAVD storm surge on the SL16-2005 grid, and a 10.9 ft NAVD88 storm surge on the SL15-2012 grid. The difference between the peak water level produced on the SL15-1965 grid and SL15-2012 grid is 0.48 ft, which is a 4.6% increase. Table 3 shows that the maximum increase at Eden Isle between peak water levels produced on the SL15-1965 and SL15-2012 is 0.48 ft and occurs with storm S094, a storm which floods major portions of New Orleans in the SL15-1965 grid and SL15-2005 grid, but does not flood New Orleans in the SL15-2012 grid.

At Crown Point, which is located in the Barataria Basin, the maximum increase in surge between the SL15-1965 grid and the SL15-2012 grid occurs for storm S146. For this specific storm, the peak surge level increases 1.35 ft, which is a 13.3% increase. With increased distance from the West Closure Complex, the increase in peak surge is reduced. At Lafitte, the increase in peak surge is reduced to 0.41 ft, or a 4.6% increase.

At the IHNC Surge Barrier location, the differences between maximum surge produced on the SL15-1965 and SL15-2012 grids are much greater. At this location, the peak surge increases by about 4.56 ft for storm S023, an approximate 33% increase. The results in Table 3 show that the impact to peak surge values depends heavily on storm characteristics and location. In general, larger impacts occur at locations that are immediately adjacent to the GNO HSDRRS, such as the area immediately adjacent to the IHNC Surge Barrier or the West Closure Complex.

**Table 3 Comparison of Peak Surge at Eden Isles, Chef Pass, and IHNC Surge Barrier for SL15-1965, SL15-2005, and SL15-2012**

Metairie	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	4.7	2.3	4.8	4.8	6.8	8.4	5.2	6.3	6.2	6.4	8.4	4.9	8.3	8.4	9.1	7.3	8.4																	
2005 Peak Surge (ft. NAVD88)	4.7	2.3	4.9	4.8	6.8	8.5	5.3	6.4	6.3	6.6	8.4	5.0	8.4	7.7	8.7	7.3	8.1																	
2012 Peak Surge (ft. NAVD88)	4.6	2.3	4.8	4.7	6.8	8.4	5.2	6.4	6.2	6.6	8.4	4.9	8.3	7.7	8.8	7.3	8.2																	
Difference 1965 to 2012 (ft.)	-0.04	-0.9%	0.01	0.4%	0.00	0.0%	-0.06	-1.3%	0.01	0.1%	-0.03	-0.6%	0.09	1.4%	0.05	0.8%	0.15	2.3%	-0.05	-0.6%	0.03	0.6%	0.01	0.1%	-0.68	-8.1%	-0.26	-2.9%	-0.03	-0.4%	-0.24	-2.9%		
Difference 2005 to 2012 (ft.)	-0.03	-0.6%	0.01	0.4%	-0.07	-1.5%	-0.08	-1.7%	-0.06	-0.9%	-0.07	-0.8%	-0.05	-1.0%	-0.08	-1.3%	-0.08	-1.3%	-0.05	-0.8%	-0.09	-1.1%	-0.05	-1.0%	-0.04	-0.5%	0.03	0.4%	0.13	1.4%	-0.03	-0.4%	0.04	0.5%

Kenner	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	6.1	1.8	4.9	4.9	6.8	7.7	5.2	6.3	6.2	7.3	9.5	4.9	8.6	9.8	9.1	7.5	8.5																	
2005 Peak Surge (ft. NAVD88)	6.1	1.8	4.9	5.0	6.9	7.8	5.2	6.5	6.3	7.3	9.6	5.0	8.7	10.0	9.3	7.6	8.5																	
2012 Peak Surge (ft. NAVD88)	6.1	1.8	4.9	4.9	6.8	7.7	5.2	6.4	6.2	7.2	9.5	5.0	8.6	10.0	9.3	7.5	8.4																	
Difference 1965 to 2012 (ft.)	-0.04	-0.7%	0.01	0.5%	0.00	0.0%	-0.05	-1.0%	0.01	0.1%	-0.02	-0.3%	-0.03	-0.6%	0.08	1.3%	0.04	0.6%	-0.07	-1.0%	-0.02	-0.2%	0.03	0.6%	-0.04	-0.5%	0.22	2.2%	0.17	1.9%	-0.04	-0.5%	-0.02	-0.2%
Difference 2005 to 2012 (ft.)	-0.03	-0.5%	0.01	0.5%	-0.08	-1.6%	-0.07	-1.4%	-0.07	-1.0%	-0.08	-1.0%	-0.05	-1.0%	-0.08	-1.3%	-0.08	-1.3%	-0.09	-1.2%	-0.07	-0.7%	-0.04	-0.8%	-0.06	-0.7%	0.02	0.2%	0.00	0.0%	-0.08	-1.1%	-0.05	-0.6%

Caernarvon	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	7.1	3.0	8.3	8.2	15.1	10.7	9.5	15.0	13.9	16.8	11.7	13.6	10.0	21.9	20.9	18.3	20.6																	
2005 Peak Surge (ft. NAVD88)	7.3	3.0	8.6	8.4	15.8	10.8	9.7	15.8	14.7	17.7	12.5	14.5	10.0	22.0	21.0	18.9	20.9																	
2012 Peak Surge (ft. NAVD88)	7.4	3.0	8.6	8.4	15.9	10.8	9.7	15.8	14.8	17.9	12.5	14.5	10.0	23.2	21.9	19.2	21.6																	
Difference 1965 to 2012 (ft.)	0.29	4.1%	0.00	0.0%	0.25	3.0%	0.14	1.7%	0.81	5.4%	0.11	1.0%	0.20	2.1%	0.82	5.5%	0.82	5.9%	1.06	6.3%	0.82	7.0%	0.94	6.9%	0.09	0.9%	1.27	5.8%	0.97	4.6%	0.91	5.0%	0.98	4.7%
Difference 2005 to 2012 (ft.)	0.01	0.1%	0.00	0.0%	0.01	0.1%	0.01	0.1%	0.04	0.3%	0.04	0.3%	0.20	1.2%	0.04	0.3%	0.02	0.1%	0.06	0.6%	1.17	5.3%	0.92	4.4%	0.32	1.7%	0.76	3.7%						

IHNC Surge Barrier	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	10.6	2.0	9.3	7.1	11.8	12.5	7.9	11.4	10.9	12.4	14.0	10.6	12.8	17.8	18.1	13.6	16.1																	
2005 Peak Surge (ft. NAVD88)	11.7	2.0	9.7	7.1	12.6	15.5	8.0	12.8	11.9	14.6	17.9	11.6	15.9	19.2	19.9	15.7	17.9																	
2012 Peak Surge (ft. NAVD88)	11.9	1.9	9.8	7.2	12.7	15.8	8.1	13.0	12.0	14.9	18.6	11.9	16.3	20.5	21.4	16.2	18.5																	
Difference 1965 to 2012 (ft.)	1.36	12.9%	-0.09	-4.4%	0.54	5.8%	0.11	1.6%	0.94	8.0%	3.32	26.6%	0.21	2.7%	1.64	14.4%	1.16	10.7%	2.53	20.4%	4.56	32.5%	1.28	12.1%	3.53	27.6%	2.62	14.7%	3.27	18.0%	2.58	19.0%	2.45	15.2%
Difference 2005 to 2012 (ft.)	0.29	2.7%	-0.09	-4.4%	0.16	1.7%	0.07	1.0%	0.14	1.2%	0.34	2.7%	0.09	1.1%	0.23	2.0%	0.17	1.6%	0.37	3.0%	0.72	5.1%	0.28	2.6%	0.42	3.3%	1.21	6.8%	1.48	8.2%	0.41	3.0%	0.60	3.7%

Shell Beach	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	5.8	7.7	7.7	5.9	9.1	14.1	6.3	8.4	7.8	8.4	10.5	5.7	13.2	13.8	14.6	11.4	13.2																	
2005 Peak Surge (ft. NAVD88)	5.8	7.7	7.9	5.9	9.6	14.9	6.4	8.8	8.3	9.0	11.3	6.0	14.1	14.5	15.6	12.1	14.1																	
2012 Peak Surge (ft. NAVD88)	5.9	7.7	7.9	6.0	9.7	15.0	6.4	8.9	8.4	9.1	11.5	6.1	14.2	15.2	16.2	12.3	14.4																	
Difference 1965 to 2012 (ft.)	0.04	0.7%	0.00	0.0%	0.24	3.1%	0.08	1.4%	0.65	7.2%	0.94	6.7%	0.14	2.2%	0.53	6.3%	0.57	7.3%	0.70	8.3%	1.02	9.7%	0.40	7.1%	1.05	8.0%	1.37	9.9%	1.54	10.5%	0.88	7.7%	1.21	9.2%
Difference 2005 to 2012 (ft.)	0.03	0.5%	0.00	0.0%	0.08	1.0%	0.04	0.7%	0.09	1.0%	0.11	0.8%	0.05	0.8%	0.09	1.1%	0.08	1.0%	0.14	1.7%	0.19	1.8%	0.02	0.4%	0.16	1.2%	0.71	5.1%	0.52	3.6%	0.22	1.9%	0.35	2.7%

Venetian Isles	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	6.7	2.8	7.5	5.5	9.3	12.3	6.1	8.7	8.6	9.5	11.0	7.9	9.2	15.1	15.3	11.2	13.2																	
2005 Peak Surge (ft. NAVD88)	7.1	2.8	7.7	5.5	9.8	12.5	6.2	9.3	9.1	10.6	12.8	8.4	10.4	15.6	16.2	12.1	14.1																	
2012 Peak Surge (ft. NAVD88)	7.3	2.7	7.8	5.5	9.8	12.6	6.2	9.5	9.2	10.8	13.1	8.5	10.7	16.3	16.9	12.3	14.5																	
Difference 1965 to 2012 (ft.)	0.59	8.8%	-0.08	-2.9%	0.28	3.7%	0.07	1.3%	0.54	5.8%	0.28	2.3%	0.14	2.3%	0.75	8.6%	0.61	7.1%	1.25	13.1%	2.17	19.8%	0.58	7.3%	1.49	16.2%	1.21	8.0%	1.62	10.6%	1.11	9.9%	1.28	9.7%
Difference 2005 to 2012 (ft.)	0.16	2.4%	-0.05	-1.8%	0.07	0.9%	0.01	0.2%	0.07	0.8%	0.06	0.5%	0.03	0.5%	0.13	1.5%	0.10	1.2%	0.20	2.1%	0.36	3.3%	0.15	1.9%	0.27	2.9%	0.68	4.5%	0.75	4.9%	0.22	2.0%	0.35	2.7%

Eden Isle	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146																	
1965 Peak Surge (ft. NAVD88)	3.1	6.1	4.9	4.7	7.3	12.1	5.2	6.5	7.2	7.4	11.7	7.6	6.9	11.5	10.4	7.4	8.6																	
2005 Peak Surge (ft. NAVD88)	3.1	6.1	4.9	4.7	7.4	12.4	5.2	6.7	7.4	7.7	12.0	7.7	7.2	11.0	10.4	7.5	8.6																	
2012 Peak Surge (ft. NAVD88)	3.1	6.1	4.9	4.7	7.3	12.3	5.2	6.6	7.3	7.7	12.0	7.7	7.2	11.2	10.9	7.6	8.8																	
Difference 1965 to 2012 (ft.)	0.00	0.0%	0.01	0.2%	0.01	0.2%	-0.04	-0.8%	0.01	0.1%	0.19	1.6%	-0.04	-0.8%	0.11	1.7%	0.11	1.5%	0.24	3.2%	0.26	2.2%	0.07	0.9%	0.30	4.4%	-0.30	-2.6%	0.48	4.6%	0.22	3.0%	0.19	2.2%
Difference 2005 to 2012 (ft.)	-0.07	-2.3%	0.01	0.2%	-0.05	-1.0%	-0.06	-1.3%	-0.07	-1.0%	-0.03	-0.2%	-0.07	-1.3%	-0.08	-1.2%	-0.07	-1.0%	-0.03	-0.4%	0.02	0.2%	-0.06	-0.8%	0.01	0.1%	0.24	2.1%	0.51	4.9%	0.08	1.1%	0.23	2.7%

Table 3 Continued

Pearlington, MS	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	5.8	2.4	8.0	5.6	9.5	16.3	6.2	10.1	10.2	11.6	15.9	11.4	8.6	15.0	14.4	11.5	12.5	
2005 Peak Surge (ft. NAVD88)	5.9	2.4	8.2	5.6	9.7	16.6	6.3	10.4	10.4	12.0	16.2	11.6	8.9	15.4	14.9	12.0	13.0	
2012 Peak Surge (ft. NAVD88)	5.9	2.4	8.2	5.6	9.8	16.6	6.3	10.5	10.4	12.1	16.3	11.6	8.9	15.8	15.3	12.2	13.2	
Difference 1965 to 2012 (ft.)	0.14	2.4%	0.00	0.0%	0.19	2.4%	0.04	0.7%	0.25	2.6%	0.37	2.3%	0.09	1.5%	0.43	4.3%	0.26	2.6%
Difference 2005 to 2012 (ft.)	0.04	0.7%	0.00	0.0%	0.07	0.9%	0.01	0.2%	0.05	0.5%	0.03	0.2%	0.03	0.5%	0.08	0.8%	0.04	0.4%

Manchac Pass	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	4.3	2.2	3.8	4.4	6.7	4.0	4.7	6.4	5.2	7.5	4.6	8.6	3.2	11.6	9.1	6.8	9.0	
2005 Peak Surge (ft. NAVD88)	4.4	2.2	3.9	4.4	6.9	4.1	4.7	6.5	5.2	7.5	4.7	8.6	3.3	11.2	8.7	6.9	8.8	
2012 Peak Surge (ft. NAVD88)	4.3	2.2	3.8	4.4	6.8	4.1	4.6	6.4	5.2	7.5	4.7	8.5	3.3	11.3	8.9	6.8	8.8	
Difference 1965 to 2012 (ft.)	-0.02	-0.5%	0.01	0.5%	-0.01	-0.3%	-0.04	-0.9%	0.06	0.9%	0.10	2.5%	-0.04	-0.9%	-0.01	-0.2%	-0.02	-0.4%
Difference 2005 to 2012 (ft.)	-0.04	-0.9%	0.01	0.5%	-0.04	-1.0%	-0.05	-1.1%	-0.12	-1.8%	-0.02	-0.5%	-0.06	-1.3%	-0.11	-1.7%	-0.08	-1.5%

Mandeville	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	5.0	2.0	5.2	5.3	8.5	6.5	5.8	7.0	8.0	8.6	7.6	9.9	4.8	13.2	11.2	7.9	9.7	
2005 Peak Surge (ft. NAVD88)	5.1	2.0	5.3	5.3	8.6	6.8	5.9	7.2	8.1	8.8	7.8	10.0	5.0	12.4	10.7	7.9	9.4	
2012 Peak Surge (ft. NAVD88)	5.0	2.0	5.3	5.3	8.5	6.8	5.8	7.1	8.0	8.7	7.8	9.9	5.0	12.6	10.9	7.9	9.4	
Difference 1965 to 2012 (ft.)	-0.02	-0.4%	0.02	1.0%	0.01	0.2%	-0.05	-0.9%	0.04	0.5%	0.24	3.7%	-0.05	-0.9%	0.12	1.7%	0.06	0.8%
Difference 2005 to 2012 (ft.)	-0.07	-1.4%	0.02	1.0%	-0.06	-1.1%	-0.07	-1.3%	-0.08	-0.9%	-0.06	-0.9%	-0.09	-1.5%	-0.11	-1.6%	-0.11	-1.4%

LaPlace	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	11.5	1.4	5.9	5.4	8.4	6.4	5.8	10.8	8.4	12.9	10.5	11.2	9.6	14.9	12.1	12.6	12.0	
2005 Peak Surge (ft. NAVD88)	11.5	1.4	5.9	5.4	8.6	6.5	5.9	10.8	8.4	13.0	10.6	11.2	9.6	15.0	12.4	12.6	12.3	
2012 Peak Surge (ft. NAVD88)	11.5	1.4	5.8	5.3	8.5	6.5	5.8	10.7	8.3	12.9	10.6	11.1	9.5	15.1	12.4	12.6	12.3	
Difference 1965 to 2012 (ft.)	-0.03	-0.3%	0.00	0.0%	-0.07	-1.2%	-0.06	-1.1%	0.06	0.7%	0.03	0.5%	-0.05	-0.9%	-0.04	-0.4%	-0.05	-0.6%
Difference 2005 to 2012 (ft.)	-0.03	-0.3%	0.00	0.0%	-0.06	-1.0%	-0.08	-1.5%	-0.09	-1.1%	-0.05	-0.8%	-0.09	-1.5%	-0.07	-0.6%	-0.09	-1.1%

MSY Airport	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	7.6	1.4	4.8	4.8	6.5	9.5	5.1	6.4	6.4	8.4	11.8	5.0	11.2	11.7	11.4	9.5	10.4	
2005 Peak Surge (ft. NAVD88)	7.5	2.1	4.9	4.9	6.7	9.7	5.2	6.4	6.6	8.7	11.9	5.0	11.2	11.8	11.5	9.5	10.4	
2012 Peak Surge (ft. NAVD88)	7.5	2.1	4.8	4.8	6.6	9.7	5.1	6.3	6.5	8.6	12.5	5.0	11.6	12.5	12.0	9.8	10.7	
Difference 1965 to 2012 (ft.)	-0.13	-1.7%	0.70	49.3%	0.02	0.4%	-0.06	-1.2%	0.09	1.4%	0.19	2.0%	-0.04	-0.8%	-0.08	-1.3%	0.03	0.5%
Difference 2005 to 2012 (ft.)	-0.02	-0.3%	0.01	0.7%	-0.08	-1.7%	-0.09	-1.9%	-0.12	-1.9%	-0.06	-0.6%	-0.06	-1.2%	-0.09	-1.4%	-0.11	-1.7%

Braithwaite	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	6.5	2.0	8.3	8.4	15.5	9.4	9.7	15.3	13.6	16.6	10.8	12.5	10.9	23.0	21.1	18.9	21.7	
2005 Peak Surge (ft. NAVD88)	6.7	2.0	8.6	8.5	16.2	9.5	9.9	16.1	14.4	17.4	11.3	13.4	11.0	23.2	21.2	19.6	21.9	
2012 Peak Surge (ft. NAVD88)	6.7	2.0	8.6	8.5	16.3	9.6	9.9	16.1	14.4	17.5	11.4	13.4	10.9	23.9	21.7	19.8	22.4	
Difference 1965 to 2012 (ft.)	0.21	3.2%	0.00	0.0%	0.24	2.9%	0.14	1.7%	0.77	5.0%	0.18	1.9%	0.17	1.7%	0.76	5.0%	0.81	6.0%
Difference 2005 to 2012 (ft.)	0.01	0.2%	0.00	0.0%	0.00	0.0%	0.01	0.1%	0.05	0.3%	0.07	0.7%	0.00	0.0%	0.04	0.3%	0.03	0.2%

Jean Lafitte	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	5.1	2.2	3.0	3.6	4.9	1.3	3.9	5.5	4.3	6.7	2.4	8.3	2.3	13.9	4.1	5.9	8.5	
2005 Peak Surge (ft. NAVD88)	5.1	2.2	3.0	3.6	4.9	1.3	3.9	5.5	4.3	6.7	2.4	8.3	2.3	14.0	4.2	5.9	8.6	
2012 Peak Surge (ft. NAVD88)	5.2	2.2	3.1	3.6	5.1	1.3	3.9	5.6	4.3	6.7	2.5	8.5	2.3	14.8	4.5	5.9	9.1	
Difference 1965 to 2012 (ft.)	0.03	0.6%	0.01	0.5%	0.02	0.7%	0.02	0.6%	0.11	2.2%	0.00	0.0%	0.02	0.5%	0.03	0.5%	0.02	0.5%
Difference 2005 to 2012 (ft.)	0.02	0.4%	0.01	0.5%	0.02	0.7%	0.02	0.6%	0.11	2.2%	0.00	0.0%	0.02	0.5%	0.02	0.4%	0.01	0.2%

Table 3 Continued

Lafitte	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	6.2	1.5	3.5	3.8	5.5	1.3	4.2	6.6	5.0	7.8	2.8	8.7	2.6	14.9	5.0	7.4	8.9	
2005 Peak Surge (ft. NAVD88)	6.2	1.5	3.5	3.8	5.5	1.3	4.2	6.6	5.0	7.8	2.7	8.7	2.6	15.0	5.0	7.4	9.0	
2012 Peak Surge (ft. NAVD88)	6.2	1.5	3.5	3.8	5.5	1.3	4.2	6.6	5.0	7.8	2.8	8.7	2.6	15.7	5.2	7.4	9.3	
Difference 1965 to 2012 (ft.)	0.01	0.2%	-0.01	-0.7%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.82	5.5%	0.20	4.0%
Difference 2005 to 2012 (ft.)	0.01	0.2%	-0.01	-0.7%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-0.01	-0.2%	0.00	0.0%	0.66	4.4%	0.15	3.0%

Crown Point	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	5.4	1.8	3.0	3.8	5.7	1.3	3.9	5.7	4.4	7.2	2.2	9.2	2.0	15.5	5.8	5.9	10.2	
2005 Peak Surge (ft. NAVD88)	5.4	1.8	3.0	3.8	5.7	1.3	3.9	5.7	4.4	7.2	2.2	9.2	2.0	15.7	5.9	5.9	10.3	
2012 Peak Surge (ft. NAVD88)	6.0	2.4	3.2	3.9	6.2	1.3	4.2	6.1	4.9	7.5	2.4	9.6	2.0	17.0	6.7	6.4	11.5	
Difference 1965 to 2012 (ft.)	0.57	10.6%	0.57	31.0%	0.21	6.9%	0.05	1.3%	0.53	9.3%	0.00	0.0%	0.25	6.4%	0.39	6.9%	0.50	11.4%
Difference 2005 to 2012 (ft.)	0.57	10.6%	0.57	31.0%	0.21	6.9%	0.05	1.3%	0.53	9.3%	0.00	0.0%	0.25	6.4%	0.38	6.7%	0.49	11.2%

Waveland	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	6.2	13.1	9.4	5.4	8.4	24.5	6.0	10.2	9.5	11.6	18.3	11.4	15.7	13.5	13.6	11.6	11.5	
2005 Peak Surge (ft. NAVD88)	6.3	13.1	9.5	5.4	8.6	24.7	6.0	10.3	9.6	11.8	18.5	11.4	15.8	13.7	13.9	11.8	11.8	
2012 Peak Surge (ft. NAVD88)	6.3	13.1	9.5	5.4	8.6	24.7	6.0	10.3	9.6	11.8	18.6	11.5	15.8	13.9	14.0	11.9	11.9	
Difference 1965 to 2012 (ft.)	0.08	1.3%	0.00	0.0%	0.03	0.3%	0.01	0.2%	0.21	2.5%	0.22	0.9%	0.02	0.3%	0.13	1.3%	0.12	1.3%
Difference 2005 to 2012 (ft.)	0.03	0.5%	0.00	0.0%	0.01	0.1%	0.01	0.2%	0.03	0.4%	0.02	0.1%	0.01	0.2%	0.04	0.4%	0.03	0.3%

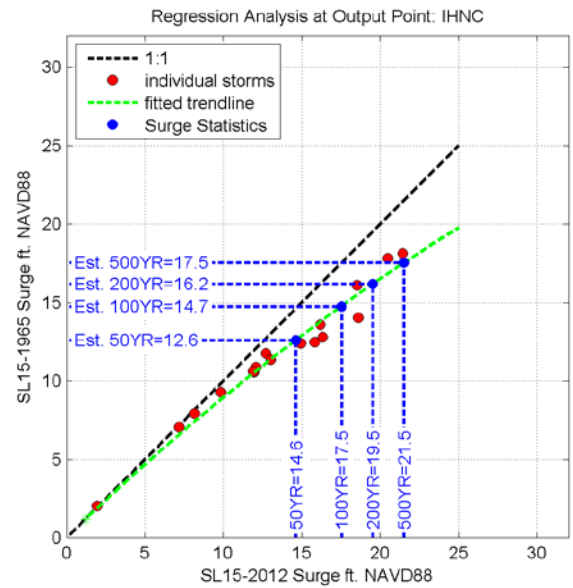
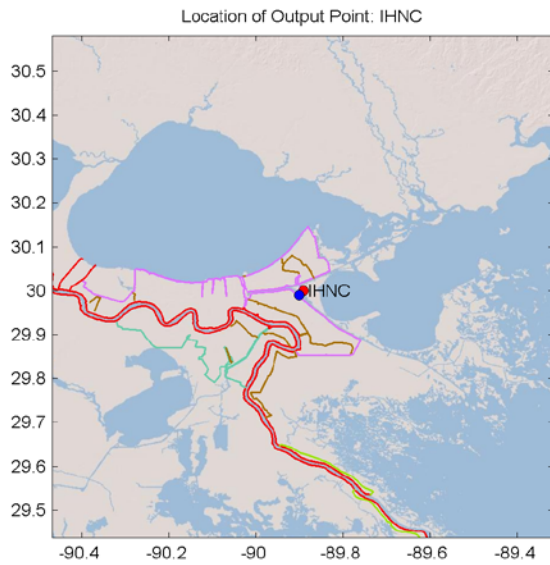
Boutte	Betsy	Camille	Gustav	Ike	Isaac	Katrina	Rita	S008	S012	S014	S023	S069	S077	S085	S094	S126	S146	
1965 Peak Surge (ft. NAVD88)	3.7	1.9	2.9	3.6	4.0	1.9	3.8	5.4	3.2	5.0	1.9	7.2	2.2	1.9	2.1	5.0	4.9	
2005 Peak Surge (ft. NAVD88)	3.7	1.9	2.9	3.6	4.0	1.9	3.8	5.4	3.2	5.0	1.9	7.2	2.2	1.9	2.1	5.0	5.0	
2012 Peak Surge (ft. NAVD88)	3.7	1.9	2.9	3.7	4.1	1.9	3.8	5.4	3.3	5.0	1.9	7.5	2.2	1.9	2.2	5.0	5.2	
Difference 1965 to 2012 (ft.)	0.00	0.0%	0.00	0.0%	0.01	0.3%	0.02	0.6%	0.05	1.2%	0.00	0.0%	0.02	0.5%	0.00	0.0%	0.06	2.8%
Difference 2005 to 2012 (ft.)	-0.01	-0.3%	0.00	0.0%	0.00	0.0%	0.01	0.3%	0.05	1.2%	0.00	0.0%	0.01	0.5%	0.00	0.0%	0.06	2.8%

Figure 30 displays a regression plot comparing individual peak storm surge values from the SL15-2012 grid against the SL15-1965 grid at the IHNC Surge Barrier location. The small red dots represent the peak surge values. A 2<sup>nd</sup> order polynomial trendline, which is plotted as a green line, has been fitted to the data. Fifty (50)-year, 100-year, 200-year and 500-year statistics from the IHNC Surge Barrier frequency analysis are plugged into the trendline to estimate the corresponding statistics that would be produced on the SL15-1965 grid. The IHNC Surge Barrier frequency analysis was conducted to determine with-project design water levels for the IHNC Surge Barrier and surrounding GNO HSDRRS components. Figure 28 shows the 100-year from the SL15-2012 condition is roughly 17.5 ft NAVD88, while the estimated 100-year surge from the SL15-1965 grid is 14.7 ft NAVD88. Using this approach, one can estimate that the post-Betsy federal levees and GNO HSDRRS have increased the 50-year surge by 2.0 ft, increased the 100-year by 2.8 ft, increased the 200-year by 3.3ft, and increased the 500-year by 4.0 ft at the immediate location of the IHNC Surge Barrier. These estimates are based on a simple trend between surge values produced on the SL15-1965 and SL15-2012 grids.

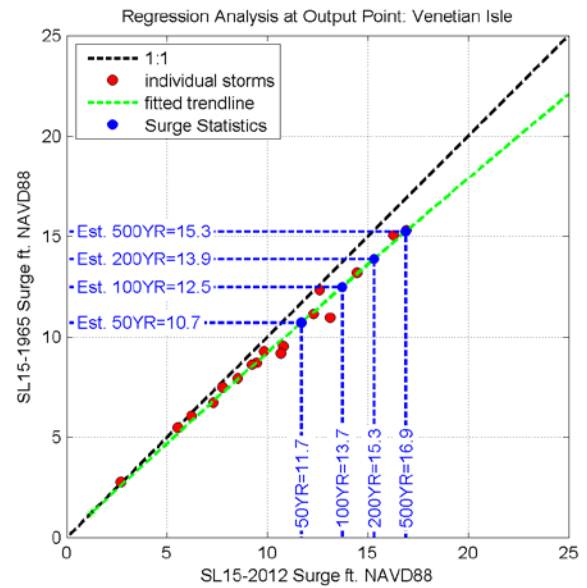
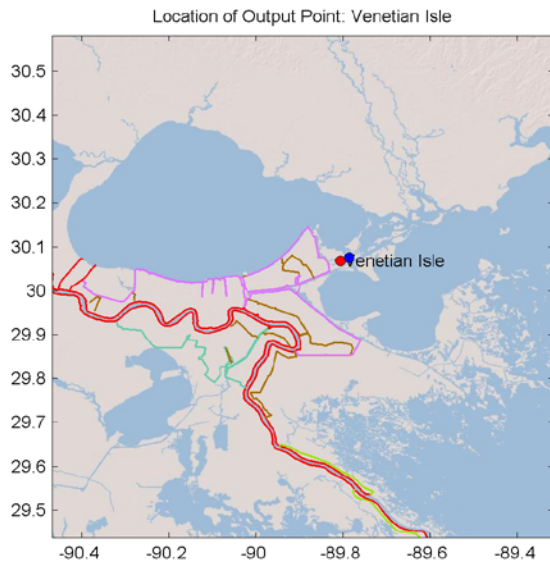
Figure 29 displays the same regression analysis, but at the Venetian Isles, New Orleans, LA location. The estimates show that the 50-year surge is increased 1.0 ft, the 100-year is increased by 1.2 ft, the 200-year is increased 1.4 ft, and the 500-year is increased 1.6 ft at the immediate location of Venetian Isles. These increases can be attributed to the combined effects of construction of the post-Betsy federal levees and the GNO HSDRRS.

Figure 30 displays the same regression analysis, but at the Eden Isle, Slidell, LA location. Here regression analysis estimates a smaller increase between the SL15-1965 and SL15-2012 statistical surge estimates. The estimates show that the 50-year surge is increased 0.1 ft, the 100-year is increased by 0.2 ft, the 200-year is increased 0.2 ft, and the 500-year is increased 0.2 ft.

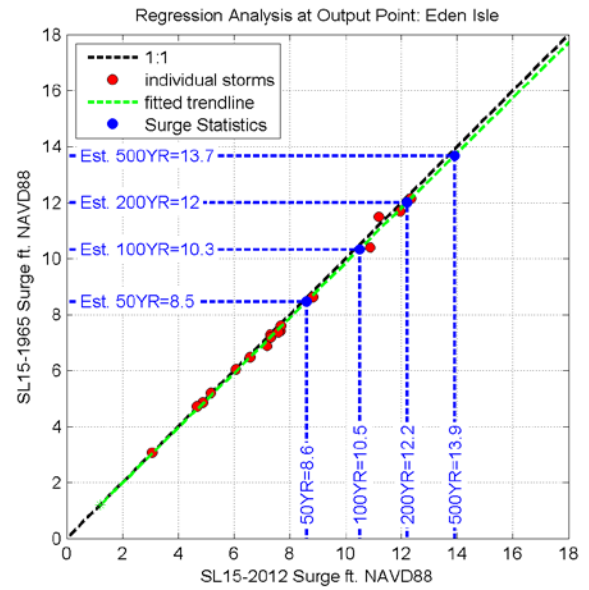
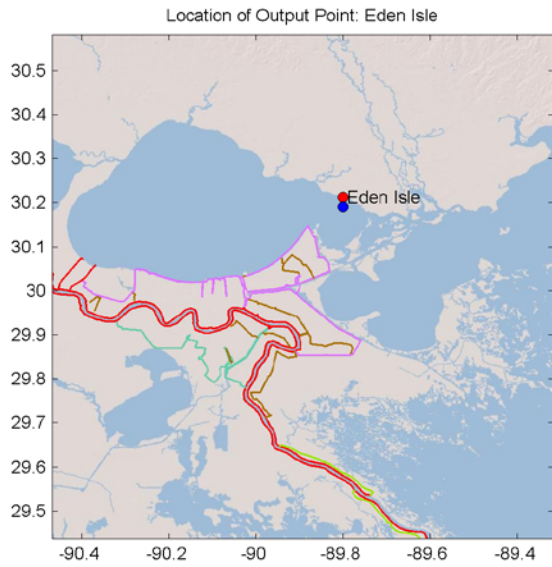
Table 4 contains the results of the regression analysis at all locations of interest. The results in Table 4 show that the impact to peak surge values depends heavily on location and proximity to the GNO HSDRRS. In general, the impacts are greatest in the areas immediate adjacent to the GNO HSDRRS; impacts diminish as the distance from the GNO HSDRRS increases. Table 4 shows that the absolute change in water level depends also on the return period, although the percent change is similar across all return periods.



**Figure 28 Surge Frequency Regression Analysis at IHNC**



**Figure 29 Surge Frequency Regression Analysis at Venetian Isle**



**Figure 30 Surge Frequency Regression Analysis at Eden Isle**

**Table 4 Summary of Regression Analysis at all Output Locations**

Location	Long	Lat	SI15-2012 Stage-frequency (ft. NAVD88 2004.65)				SI15-1965 Est. Stage-frequency (ft. NAVD88 2004.65)				Difference (ft) and Percent Difference for various return periods							
			50 YR	100 YR	200 YR	500 YR	50 YR	100 YR	200 YR	500 YR	50 Yr Dif	50 Yr %Dif	100 Yr Dif	100 Yr %Dif	200 Yr Dif	200 Yr %Dif	500 Yr Dif	500 Yr %Dif
Metairie	-90.144	30.028	7.8	9.1	10.2	11.5	7.9	9.3	10.5	12.0	-0.1	-1%	-0.2	-2%	-0.3	-3%	-0.5	-4%
Kenner	-90.236	30.047	7.9	9.1	10.2	11.3	7.9	9.0	10.1	11.1	0.0	0%	0.1	1%	0.1	1%	0.2	2%
Caernarvon	-89.906	29.842	14.6	17.7	19.8	21.9	14.0	16.9	18.8	20.8	0.6	4%	0.8	5%	1.0	5%	1.1	5%
IHNC Surge Barrier	-89.891	29.999	14.6	17.5	19.5	21.5	12.6	14.7	16.2	17.5	2.0	16%	2.8	19%	3.3	20%	4.0	23%
Shell Beach	-89.678	29.856	10.7	12.5	14.1	16.0	10.0	11.6	13.0	14.6	0.7	7%	0.9	8%	1.1	8%	1.4	10%
Venetian Isles	-89.807	30.069	11.7	13.7	15.3	16.9	10.7	12.5	13.9	15.3	1.0	9%	1.2	10%	1.4	10%	1.6	10%
Eden Isle	-89.801	30.212	8.6	10.5	12.2	13.9	8.5	10.3	12.0	13.7	0.1	1%	0.2	2%	0.2	2%	0.2	1%
Pearlington, MS	-89.616	30.236	11.6	13.9	16.0	18.4	11.2	13.4	15.4	17.6	0.4	4%	0.5	4%	0.6	4%	0.8	5%
Manchac Pass	-90.397	30.286	7.1	8.3	9.3	10.3	7.1	8.4	9.5	10.5	0.0	0%	-0.1	-1%	-0.2	-2%	-0.2	-2%
Mandeville	-90.075	30.351	8.2	9.6	10.7	11.8	8.2	9.7	10.9	12.2	0.0	0%	-0.1	-1%	-0.2	-2%	-0.4	-3%
LaPlace	-90.416	30.096	7.3	9.6	11.3	13.0	7.3	9.6	11.3	12.9	0.0	0%	0.0	0%	0.0	0%	0.1	1%
MSYAirport	-90.285	30.001	9.3	11.0	12.3	13.8	9.1	10.6	11.7	13.0	0.2	2%	0.4	4%	0.6	5%	0.8	6%
Braithwaite	-89.963	29.811	14.4	17.7	20.0	22.1	13.8	17.0	19.2	21.2	0.6	4%	0.7	4%	0.8	4%	0.9	4%
Jean Lafitte	-90.129	29.734	5.3	7.0	8.4	9.9	5.2	6.8	8.1	9.5	0.1	2%	0.2	3%	0.3	4%	0.4	4%
Lafitte	-90.112	29.667	6.0	7.8	9.3	11.0	6.0	7.7	9.1	10.7	0.0	0%	0.1	1%	0.2	2%	0.3	3%
Crown Point	-90.081	29.769	5.7	7.5	9.1	10.9	5.3	6.9	8.3	9.9	0.4	8%	0.6	9%	0.8	10%	1.0	10%
Waveland	-89.368	30.280	13.1	15.6	17.8	20.2	12.9	15.4	17.6	20.0	0.2	2%	0.2	1%	0.2	1%	0.2	1%
Boutte	-90.374	29.895	3.2	3.6	4.0	4.3	3.2	3.6	4.0	4.2	0.0	0%	0.0	0%	0.0	0%	0.1	2%

## 4.0 Conclusions and Discussion

The purpose of this modeling is to assess the impacts to surge levels due to construction of the GNO HSDRRS on communities inside and outside the system. The analysis evaluates the projected storm surge levels in areas outside the GNO HSDRRS as the levee system existed in the years 1965 (pre-Betsy, pre-federal levees), 2005 (pre-Katrina) and 2012 (post-GNO HSDRRS construction). The analysis describes and evaluates the past, present and potential cumulative storm surge impacts of the completed GNO HSDRRS on the surrounding areas. Prior to construction of the post-Betsy federal levees, local levees existed in many areas including New Orleans East and the New Orleans metropolitan area. Prior to construction of the post-Betsy federal levees, the St. Bernard area had no levees along the MRGO, although surveys show a spoil bank with modest elevation. The SL15-1965 grid is simply a version of the SL15-2005 grid with elevations lowered to match pre-Betsy surveys of St. Bernard, New Orleans East and the east side of the New Orleans metropolitan area. The SL15-1965 and SL15-2005 grids are the same in the WBV project area, as very little levee construction occurred on the west bank during this time period.

Flood risk reduction features, including levees, floodwalls, floodgates and surge barriers reduce the risk of flooding in the Greater New Orleans area. When these features prevent water from flowing into the interior, the surrounding surge levels are amplified. This effect is most pronounced in the immediate vicinity of major modifications to the existing levee elevations such as the IHNC Surge Barrier and West Closure Complex. The effect is less pronounced with increased distance from the major modifications. This analysis provides estimates of these impacts for a variety of past and synthetic storms. The storms which have the most impact are the intense synthetic storms which follow critical tracks for the New Orleans area.

The analysis provides some examples of past storms, and a small sample of synthetic storms. From this small subset of 17 storms, we can estimate the changes to surge frequency at the surrounding communities using a regression analysis. The surge frequency regression analysis, presented in Figures 29 through Figure 30 and summarized in Table 4, shows that the changes to the stage-frequency depend heavily on location. In general, the impacts are greatest in the areas immediate adjacent to the GNO HSDRRS; impacts diminish as the distance from the GNO HSDRRS increases.

## References

Bunya, S., J.C. Dietrich, J.J. Westerink, B.A. Ebersole, J.M. Smith, J.H. Atkinson, R. Jensen, D.T. Resio, R.A. Luettich, C. Dawson, V.J. Cardone, A.T. Cox, M.D. Powell, H.J. Westerink, and H.J. Roberts, 2010: A High Resolution Coupled Riverine Flow, Tide, Wind, Wind Wave and Storm Surge Model for Southern Louisiana and Mississippi: Part I - Model Development and Validation. *Monthly Weather Review*, 138(2), 345-377.

Dietrich, J.C., J.J. Westerink, A.B. Kennedy, J.M. Smith, R. Jensen, M. Zijlema, L.H. Holthuijsen, C.N. Dawson, R.A. Luettich, M.D. Powell, V.J. Cardone, A.T. Cox, G.W. Stone, H. Pourtaheri, M.E. Hope, S. Tanaka, L. Westerink, H. Westerink, and Z. Cobell, 2010c: Hurricane Gustav (2008) Waves, Storm Surge and Currents: Hindcast and Synoptic Analysis in Southern Louisiana. *Monthly Weather Review*.

National Hurricane Center (NHC), 2011: Best Track Data. <ftp://ftp.nhc.noaa.gov/atcf/btk>

## APPENDIX A

Maximum Elevation Plots SL15-1965, SL15-2005, SL15-2012

APPENDIX B  
Difference Plots SL15-1965 vs SL15-2012

APPENDIX C  
Difference Plots SL15-2005 vs SL15-2012

# An Evaluation of Storm Surge in Areas Outside the Greater New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) using the Coastal Protection and Restoration Authority (CPRA) 2017 ADCIRC + Simulating Waves Nearshore Model (SWAN)

The following data is informed by hydraulic modeling conducted after the completion of Appendix T. This additional modeling was performed in response to public comments submitted during the review period of the *Comprehensive Environmental Document Phase I Greater New Orleans Hurricane and Storm Damage Risk Reduction System Report*.

## **CED – PHASE I COMMENT AND RESPONSES**

## Public Comments and CEMVN Responses

### **Question #1**

Do the model simulations show surge elevations for the full path/duration of these scenarios passing over Lake Pontchartrain? Will the study be revised to show the southeast Lake Pontchartrain surge tilt as the surge leaves the Lake Basin?

The only reference to surge flow is on Page 14 paragraph 1, of the Corps' evaluation states: the comparison between the SL15-2012, grid and the SL15-1965, grid was modeled to show only surge flows "into" Lake Pontchartrain. In addition all simulation Figures only show wind and surge elevations as the Lake Pontchartrain is tilted to the northwest. The highest surge levels within the Lake Pontchartrain Basin are created when storm winds rotate to the southeast funneling the surge out of the lake (outflow surge). Therefore, official confirmation is needed to confirm that the study model simulations show the full cycle of Lake Pontchartrain Basin's wind and surge tilt, both to the northwest and the southeast.

### **Question #1 Response**

The modeling includes storms that cause the "outflow funnel surge" described above. Noted in the original question, the "outflow funnel surge" destroyed the I-10 bridge in 2005 during Katrina. This outflow is included in the ADCIRC simulation of Katrina, and other storms. ADCIRC simulates the entire duration of each storm and captures the complete surge development and subsequent draining of the floodplain.

The ADCIRC modeling of these storms includes the full time-series of surge development and subsequent draining. The model includes inflow and outflow of Lake Pontchartrain. A surge animation of Katrina or Storm 023 would show winds and surge approaching Eden Isle from the west after the storm crossed the lake. However, the corps approach is not to evaluate such a specific storm when evaluating overall impacts to surge patterns. Storm specific impacts can vary considerably depending of track, size, forward speed, intensity etc. The purpose of the Corps modeling is to determine overall impacts of a wide range of storm parameters.

8/29 10:00 CDT

KATRINA Surge (ft)

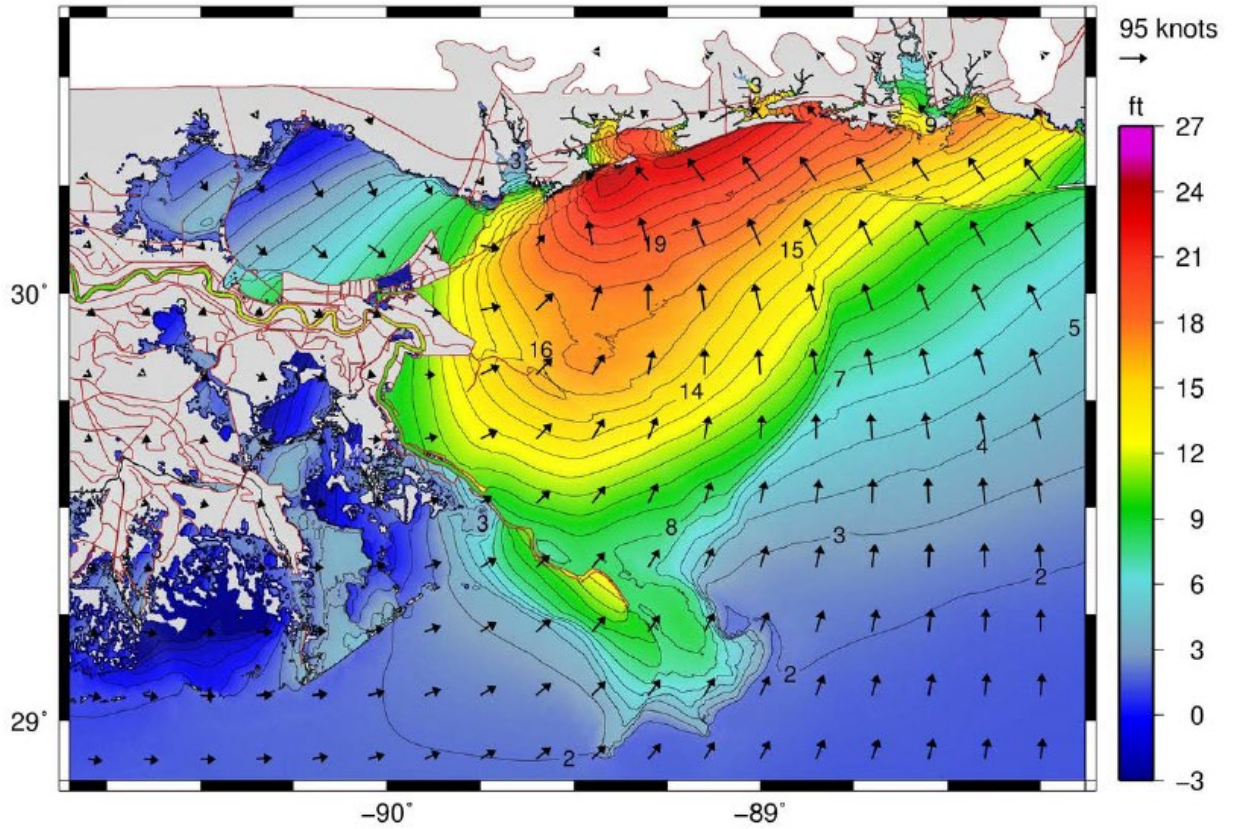


Figure 1 Snapshot of simulated ADCIRC water levels of Hurricane Katrina showing outflow surge from Lake Pontchartrain. Simulation time is 8/29 10:00 CDT.

**Question #2** –Why is there a discrepancy between the Corps’ study surge elevations and other independent studies? Will the Corps address these discrepancies?

Table 3, page 37, of the Corps’ study shows a peak elevation of 12.4 feet at Eden Isles. However, The Lake Pontchartrain Basin Foundation Study Dynamics of Storm Surge in the Pontchartrain and Maurepas Region, has the Hurricane Katrina Slidell surge elevation at 16feet (Table 3, page 26 of the study).

**Table 3:** Record water levels in feet at various locations around Lake Pontchartrain, based on a SURGEDAT dataset covering 1900 - 2013. The highest water levels in the lake are expected in Slidell (northeast shoreline) and Frenier (southwest shoreline.)

Location	Storm	Year	Water Level (ft)	Calculated Recurrence Interval (yr)	Datum
Slidell	Katrina	2005	15.7	114	NAVD88
Frenier	Betsy	1965	13.1	115	Unknown
New Orleans Lakefront	Katrina	2005	11.9	98	NAVD88
Mandeville	Katrina	2005	10	78	NAVD88

**Question #2 response**

High water marks surveyed after the storm by FEMA show coastal flooding elevations of 10.5 to 13.5 feet NAVD88 were recorded in the Slidell vicinity. These values tend to agree with the Corps’ Katrina simulation. Typically, ADCIRC matches HWM data to within 1.5ft, but higher discrepancies between observed and modeled high water marks can occur.

[https://www.fema.gov/pdf/hazard/flood/recoverydata/katrina/katrina\\_la\\_hwm\\_public.pdf](https://www.fema.gov/pdf/hazard/flood/recoverydata/katrina/katrina_la_hwm_public.pdf)

From page x:

*Northern Shore: St. Tammany and Tangipahoa Parishes*

*The increased volume of water was forced into Lake Pontchartrain by hurricane winds.*

*This caused water to pile up on the north shore of the lake and resulted in storm surge extending north as far as US Highway 190 in Slidell and to Interstate 12 north of*

*Mandeville. HWMs recorded flooding elevations ranging from 7 to 16 feet, with the*

*general trend of the highest values on the east end of the north shore working westward to lower surge values. Coastal flooding elevations of 10.5 to 13.5 feet were recorded in the Slidell vicinity.*



### **Question # 3 –Will the Corps address questions raised about how the 1965 vs. current HSDRRS impacts were determined?**

See attached comments by Bob Jacobsen:

The Report Section 2.4, says that the Figure 10 1965 (pre-Betsy) linear feature elevations are taken from information showing “existing conditions” on the original (mid-60s, post-Betsy) Hurricane Protection System Design Memos. For example, see the Report Figure 5 copy of 1967 Design Memo. This Figure 5 shows that there is a substantial “existing” levee at the time of the 1967 design. The Report states that the elevation of this “existing” levee is what is used as the 1965 “pre-Betsy” elevation in Figure 10. HOWEVER, an initial perusal of historical topography (<http://historicalmaps.arcgis.com/usgs/>) indicates that this substantial “existing” levee shown in Figure 5 may not have been present in 1965 for Betsy. It is important to consider that there likely was significant post-Betsy emergency levee work” done in the immediate aftermath of Betsy in 1965-66 (maybe with federal funds).HOWEVER, if the Report is meant to evaluate the impact of full post-Betsy improvements, then perhaps the real 1965 topography should be used. In this latter case, there may be many reaches of 1965 linear feature elevations that need to be substantially reduced.

### **Question #3 Response:**

The Corps is aware that the historical U.S. Geological Survey topographic maps produced at the time of Hurricane Betsy do not indicate levees around New Orleans East. However, our experience is that these maps do not always provide the best source of information regarding levee alignments and elevations. With this understanding, we sought and consulted additional resources to gain better insight into what levees existed during this time period. We identified the U.S. Army Corps of Engineers’ “Interim Survey Report-Lake Pontchartrain and Vicinity, 21 NOV 1962” during our research for the project. In addition to the attached map, the below is an excerpt from this report that describes the levee system as it existed in 1962:

*"Citrus and New Orleans East. The New Orleans Airport is fronted by a vertical seawall with an average elevation of 11.5 feet and a length of 2.3 miles. The embankment of the Southern Railway extends along the remainder of the south shore for approximately 11.5 miles with an average elevation of about 9.3 feet. The area is protected on the west by a levee along the Inner Harbor Navigation Canal having a grade of 9.6 feet, on the east by a levee that extends from South Point to the Gulf Intracoastal Waterway with an elevation of 11.6 feet, and on south by a levee along the Gulf Intracoastal Waterway with elevation 9.6 to 14."*

We attempted to develop each scenario based on the best information accessible when preparing to undertake this modeling effort. Based on our research, the 1962 survey report provides the most accurate information regarding the existing levee details when establishing the 1965 baseline.

### Interim Survey Report-Lake Pontchartrain and Vicinity, 21 NOV 1962

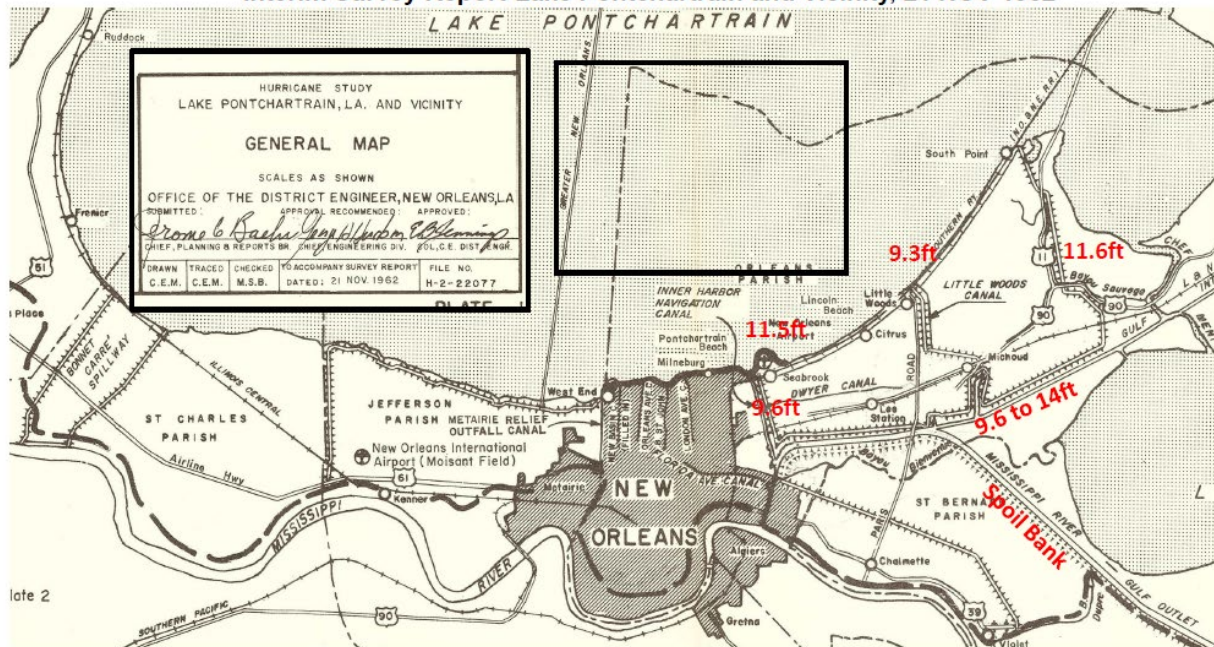


Figure 3 Elevations from “Interim Survey Report-Lake Pontchartrain and Vicinity, 21 NOV 1962”

Subsequent review revealed a discrepancy between the levee heights described in “Interim Survey Report-Lake Pontchartrain and Vicinity, 21 NOV 1962” and the elevations assigned in the SL15-1965 ADCIRC grid. Specifically, the elevation assigned in the SL15-1965 grid for the Southern Railway was approximately 14 ft NAVD88 based on a report from the 1980s. This elevation conflicts with the 1962 report which states the elevation is approximately 9.3ft NGVD. A lower levee elevation assigned in the SL15-1965 ADCIRC grid will result in more inundation within the polder for certain storms. This effect has potential to increase the estimates of induced flooding, since a greater volume of water will be displaced to the polder exterior for “with-project” conditions.

To remedy this error in the assumed levee elevations, a series of ADCIRC simulations were conducted with most up-to-date understanding of the levee system as it existed in 1965. An ADCIRC grid developed by CPRA in 2017 was utilized for this re-analysis. Figure 4 displays the updated elevations assumed in the 1965 ADCIRC grid. In the latest simulations, the elevations along the Southern Railway were set to natural ground elevations (< 2 ft NAVD88), which is less than the 9.3 ft NGVD elevation described in the 1962 report. Since the railway embankment was composed on substandard material, it could not be included in the analysis because it was assumed it would have failed completely during a storm surge event. Figure 5 displays the elevations assumed in the 2017 “With Project” ADCIRC grid. From 1965 to 2017, there has been a significant increase in the perimeter levee and floodwall elevations, and also creation of new barriers, such as the Inner Harbor Navigation Channel Surge Barrier. These changes to HSDRRS have potential to displace volume during surge events and increase water levels on the exterior. The ADCIRC simulations comparing 1965 to 2017 give a general idea of the magnitude of increase due to levee and floodwall construction.

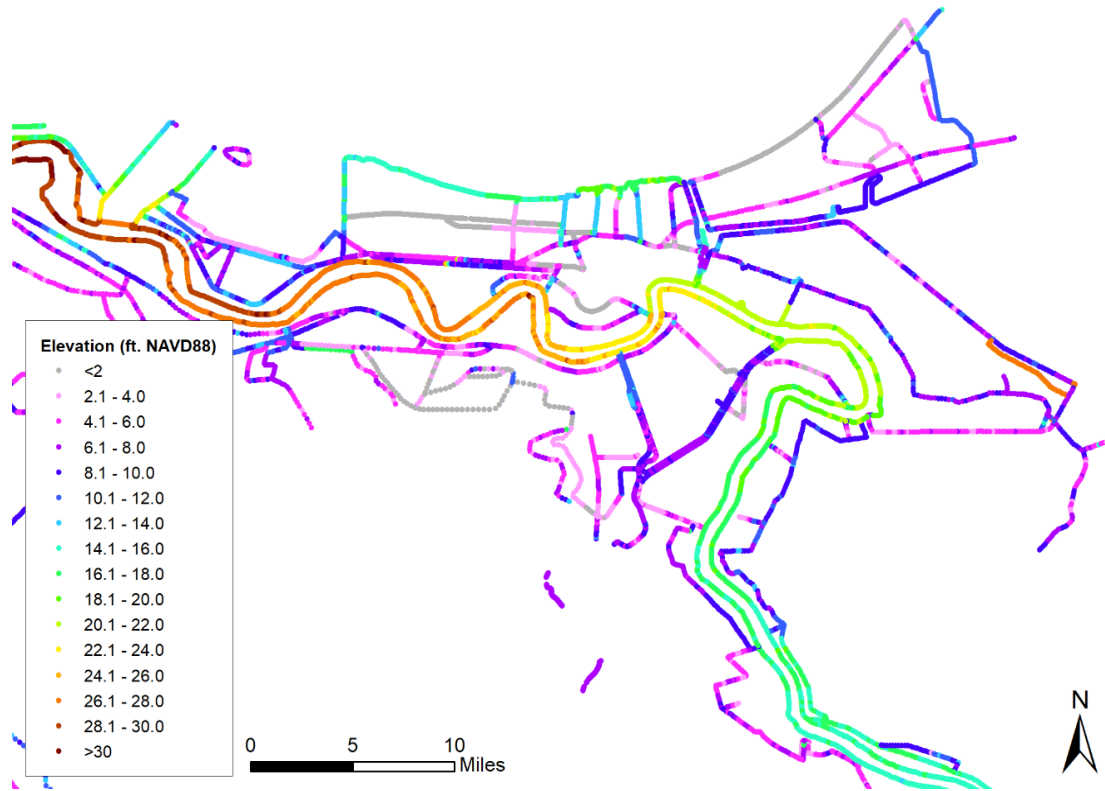


Figure 4 Elevations assumed in the updated CPRA-1965 ADCIRC grid

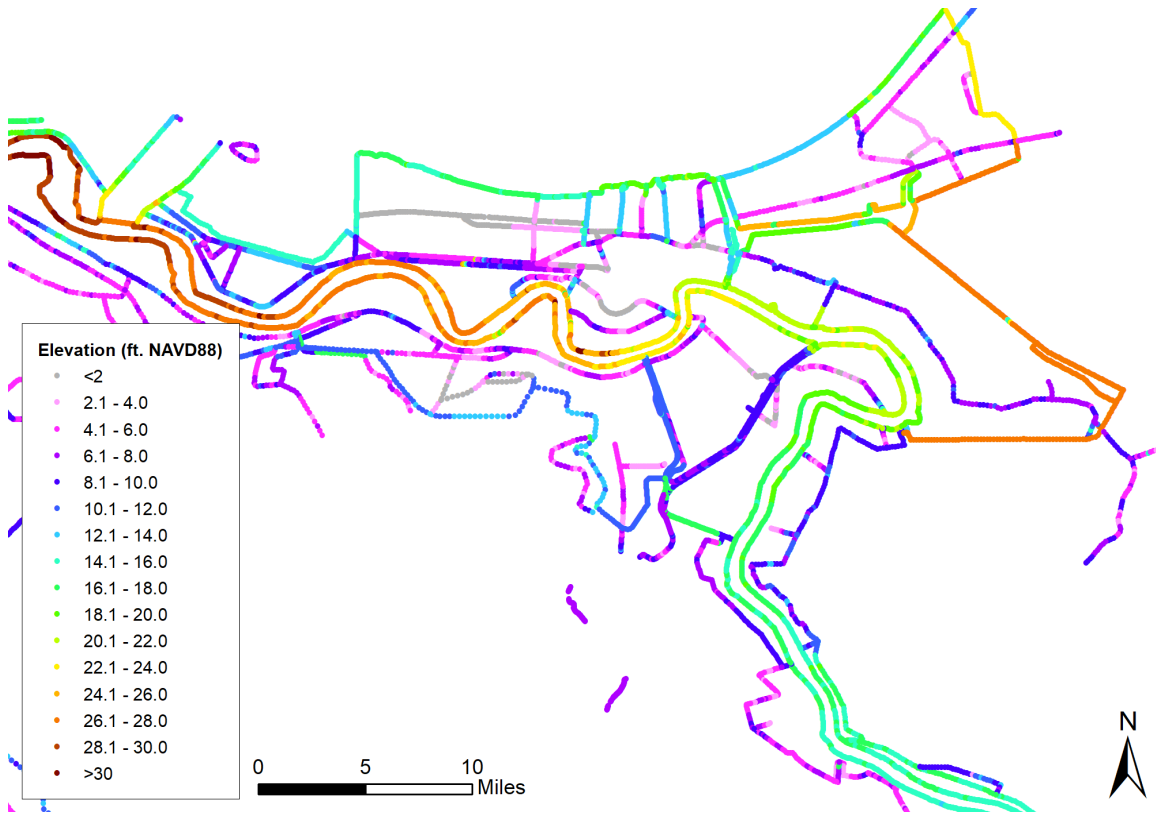


Figure 5 Elevations assumed in the updated CPRA-2017 ADCIRC grid

Figure 6 displays the maximum water surface elevations produced during the ADCIRC simulation of Hurricane Katrina assuming the 1965 levee elevations. The lower elevations assigned in the grid result in a tremendous amount of volume entering the Saint Bernard, New Orleans East, and New Orleans Metro Polders. In the 1965 simulation, the levee elevations of the Saint Bernard and New Orleans East polders are completely overwhelmed, resulting in complete inundation within the polder. Figure 7 displays the maximum water surface elevation produced by Katrina assuming the 2017 levee elevations. The simulation shows very little overtopping into the HSDRRS polders. Figure 8 displays the difference in maximum water surface elevation between the 2017 and 1965 simulations of hurricane Katrina. The difference plot shows the increase in water surface elevation that can be attributed to the raising of levees from 1965 to present day. At Eden Isles, the maximum surge produced by Katrina on the 1965 grid was 15.4 ft NAVD88 while the maximum surge produced by the 2017 grid was 15.8 ft NAVD88. This means an increase of approximately 5" (or roughly 3%) can be attributed to construction of the HSDRRS at Eden Isle. When looking at a broader area, the maximum increase in water surface elevation along the Northshore communities of Slidell and Pearlinton is shown to be roughly 8 to 10". The earlier simulations showed a maximum surge at Eden Isles of 12.1 ft NAVD88 for the SL15-1965 grid and a maximum surge of 12.4 ft NAVD88 for the SL15-2012 grid. This results in a 4" increase in peak surge level with is a roughly 2% increase in peak surge elevation. The percentage increase in surge elevation is slightly higher (3% vs 2%) using the most up-to-date assumptions.

An additional suite of ADCIRC simulations was conducted to compare results on from the updated 1965 ADCIRC grid to the 2017 ADCIRC grid. Synthetic storms S008, S012, S014, S015, S023, S026, S069, S077, S085, S094, S126, S146 were simulated. These are the same synthetic storms as simulated in the earlier analysis. Table 1 contains the peak surge results for each of the synthetic storm for 1965 and 2017 conditions as well as the difference and percentage difference. Figure 9 displays a map of the selected output locations. The estimates of induced flooding varies by storm and location. Comparison to the earlier estimates of induced flooding show roughly the same order of magnitude of the percent increase. For example, the previous results for all storms show increase in peak surge elevation at Eden Isle to Pearlinton on the order of 3 to 6%. The latest simulations show an increase on the order of 3 to 7%. The overall conclusions derived from the latest simulations show that a slightly higher estimate of induced flooding, when compared to previous estimates, can be attributed to the construction of HSDRRS levees from 1965 to present day.

ADCIRC CPRA2017 D1965\_Katrina\_maxele.63.nc  
max. surge elevation (ft. NAVD88)

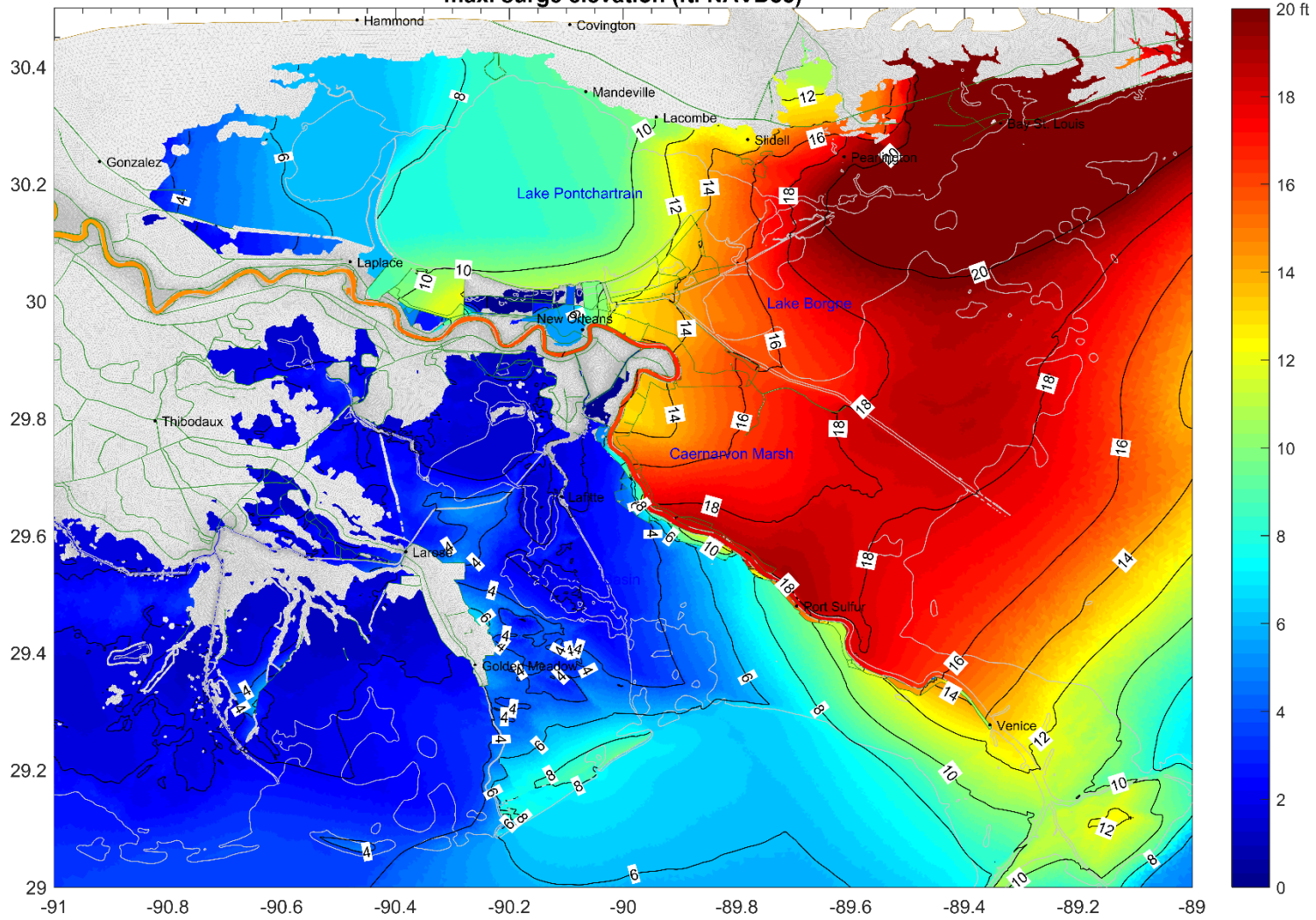


Figure 6 Maximum Water Surface Elevation from Hurricane Katrina Simulation for 1965 Conditions

ADCIRC CPRA2017 CPRA\_Katrina\_maxele.63.nc  
max. surge elevation (ft. NAVD88)

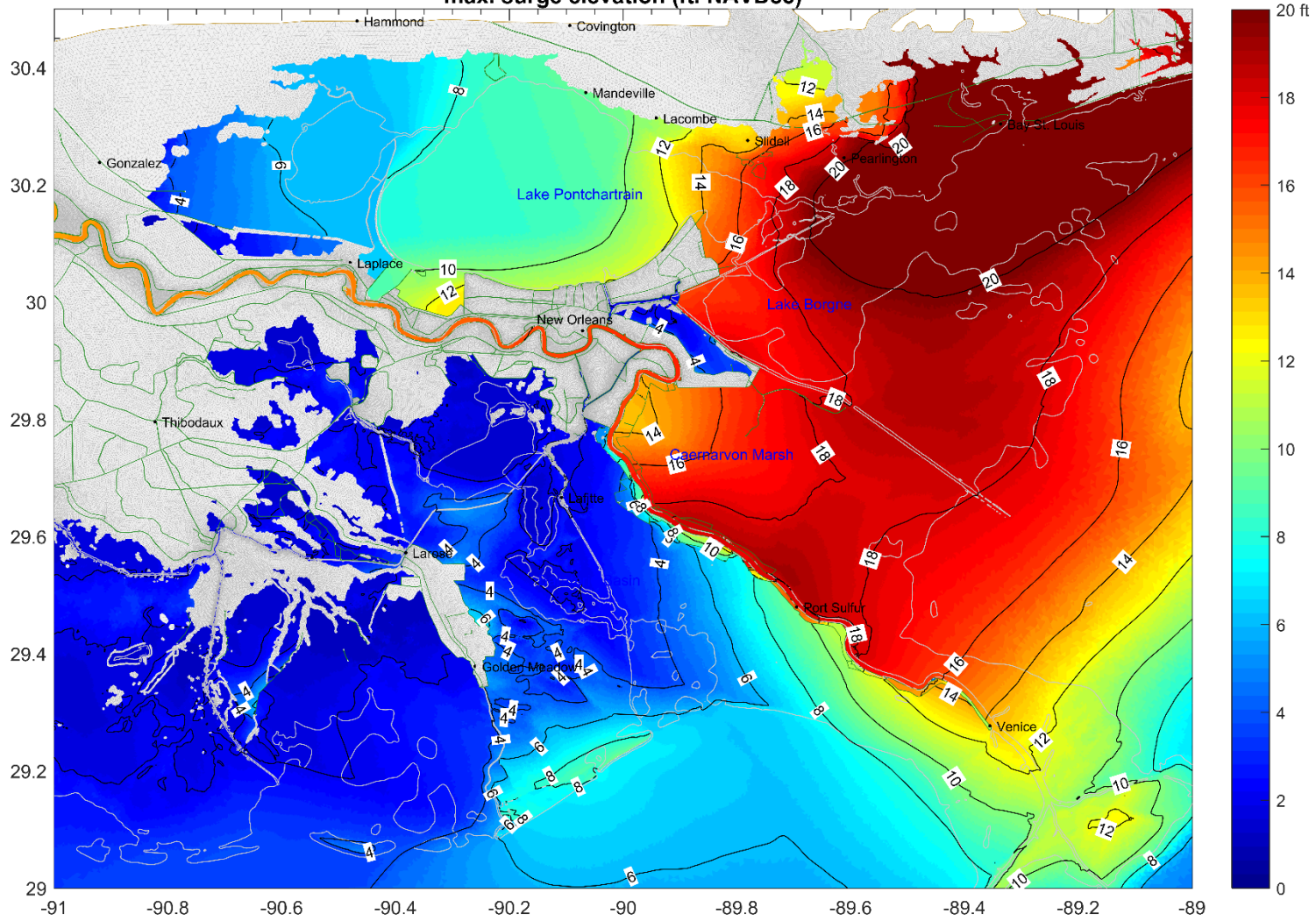


Figure 7 Maximum Water Surface Elevation from Hurricane Katrina Simulation for 1965 Conditions

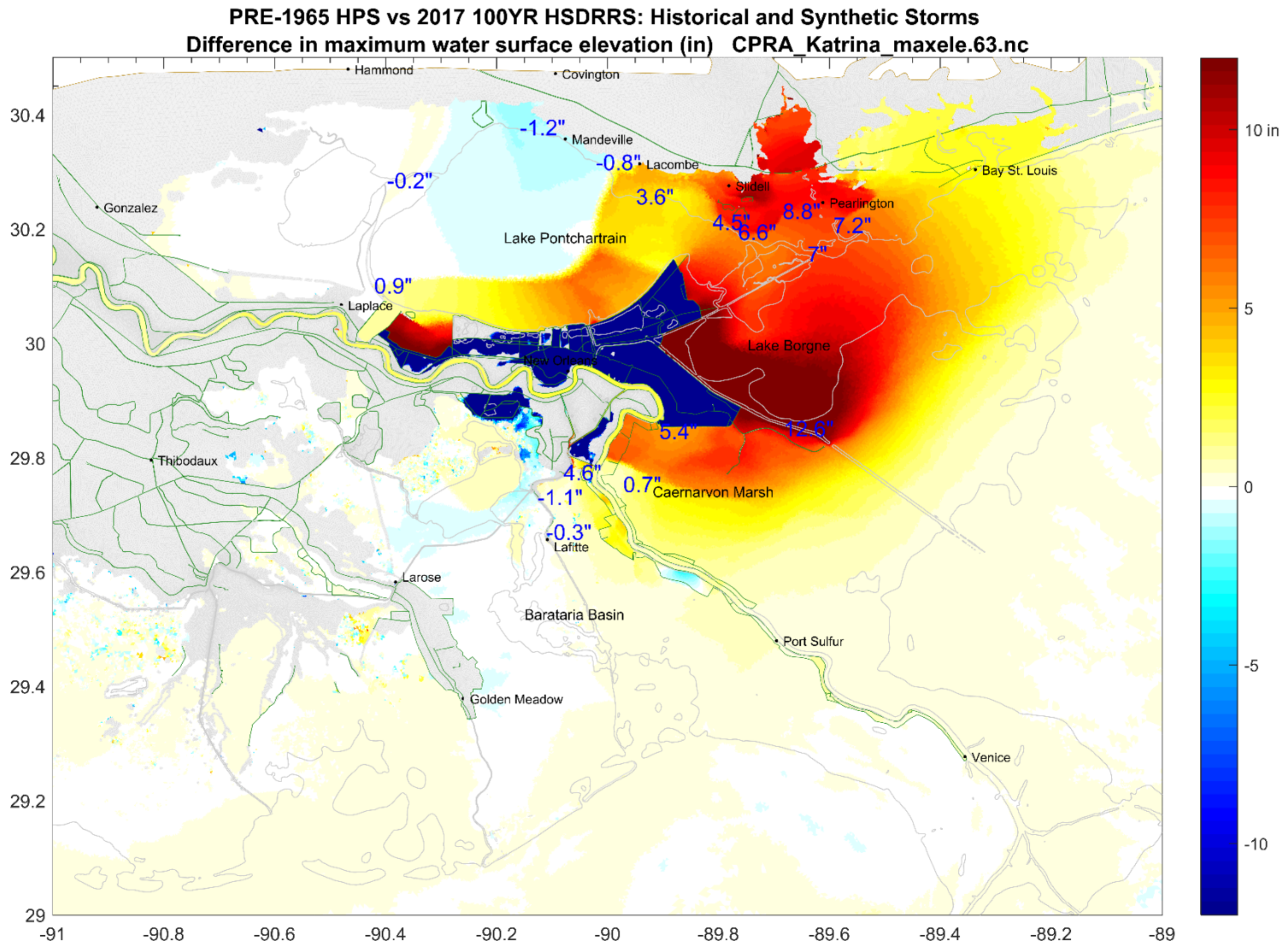


Figure 8 Difference in Maximum Water Surface Elevation between 1965 and 2017 ADCIRC simulations of Hurricane Katrina.

Table 1 Comparison of Peak Surge at Selected Output Locations for the updated 1965 and 2017 ADCIRC Grids

<b>Metairie</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	10.7		7.2		7.0		7.4		8.5		8.7		9.8		3.2		8.1		11.0		9.4		8.3		8.9	
2012 Peak Surge (ft. NAVD88)	11.0		7.2		7.1		7.4		8.4		8.7		9.9		3.0		8.1		10.6		9.0		8.0		8.1	
Difference 1965 to 2012 (ft.)	0.28	2.6%	0.01	0.2%	0.06	0.9%	0.00	0.0%	-0.18	-2.1%	0.03	0.4%	0.12	1.2%	-0.18	-5.7%	0.02	0.2%	-0.40	-3.6%	-0.34	-3.6%	-0.32	-3.8%	-0.76	-8.6%
<b>Kenner</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	10.0		7.3		7.0		7.3		8.5		9.8		9.9		5.3		8.9		11.0		10.8		8.4		9.3	
2012 Peak Surge (ft. NAVD88)	10.2		7.3		7.0		7.3		8.4		9.9		10.1		5.1		8.9		10.6		10.8		8.1		9.4	
Difference 1965 to 2012 (ft.)	0.19	1.9%	0.02	0.2%	0.07	1.0%	0.00	-0.1%	-0.17	-2.0%	0.04	0.4%	0.15	1.5%	-0.14	-2.7%	0.02	0.3%	-0.43	-3.9%	-0.01	-0.1%	-0.32	-3.9%	0.08	0.8%
<b>Caernarvon</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	14.1		13.5		13.3		14.8		17.4		12.8		16.4		8.1		5.2		20.5		19.7		17.0		19.3	
2012 Peak Surge (ft. NAVD88)	14.6		14.2		14.0		15.7		18.4		13.6		17.5		8.3		4.9		21.4		20.5		17.8		20.1	
Difference 1965 to 2012 (ft.)	0.45	3.2%	0.73	5.4%	0.71	5.3%	0.85	5.7%	0.97	5.5%	0.80	6.3%	1.13	6.9%	0.21	2.6%	-0.38	-7.3%	0.90	4.4%	0.75	3.8%	0.84	5.0%	0.74	3.9%
<b>IHNC Surge Barrier</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	14.3		10.0		10.0		10.6		12.4		12.3		14.9		8.2		10.4		15.5		17.0		12.8		14.6	
2012 Peak Surge (ft. NAVD88)	16.3		11.7		11.5		13.1		14.9		16.4		21.0		9.7		13.1		18.2		20.1		15.1		17.4	
Difference 1965 to 2012 (ft.)	2.07	14.5%	1.72	17.2%	1.55	15.6%	2.49	23.4%	2.53	20.4%	4.10	33.4%	6.18	41.5%	1.48	18.1%	2.62	25.1%	2.67	17.2%	3.09	18.1%	2.27	17.7%	2.73	18.6%
<b>Shell Beach</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	16.3		8.4		8.3		8.6		10.4		10.8		13.3		4.6		10.1		13.0		14.9		11.4		13.0	
2012 Peak Surge (ft. NAVD88)	17.6		9.2		9.1		9.5		11.6		12.3		15.3		4.9		11.3		14.4		16.4		12.5		14.3	
Difference 1965 to 2012 (ft.)	1.23	7.5%	0.75	8.9%	0.74	8.9%	0.94	11.0%	1.15	11.1%	1.54	14.3%	2.05	15.5%	0.36	7.9%	1.14	11.2%	1.36	10.4%	1.48	9.9%	1.14	10.0%	1.29	9.9%
<b>Venetian Isles</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	15.6		9.0		9.0		9.6		11.4		10.9		14.2		5.8		7.7		13.7		14.8		11.5		12.8	
2012 Peak Surge (ft. NAVD88)	16.5		9.9		9.8		10.8		12.5		12.8		16.8		6.3		9.2		15.0		16.6		12.7		14.0	
Difference 1965 to 2012 (ft.)	0.88	5.7%	0.85	9.4%	0.79	8.7%	1.12	11.7%	1.17	10.3%	1.90	17.3%	2.59	18.2%	0.43	7.3%	1.47	19.0%	1.28	9.4%	1.85	12.6%	1.18	10.2%	1.23	9.6%
<b>Eden Isle</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	15.4		7.4		8.1		8.4		9.9		11.9		15.0		2.3		2.3		11.6		10.6		8.7		9.4	
2012 Peak Surge (ft. NAVD88)	15.8		7.6		8.2		8.6		10.1		12.2		15.4		2.3		2.3		11.2		11.1		9.0		9.7	
Difference 1965 to 2012 (ft.)	0.40	2.6%	0.15	2.0%	0.12	1.5%	0.26	3.0%	0.15	1.5%	0.25	2.1%	0.40	2.6%	-0.01	-0.3%	0.00	-0.1%	-0.41	-3.6%	0.57	5.4%	0.33	3.8%	0.29	3.1%
<b>Pearlington, MS</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	19.3		10.2		10.3		11.4		12.9		15.3		19.8		4.8		3.3		13.7		13.6		11.8		12.1	
2012 Peak Surge (ft. NAVD88)	20.0		10.7		10.6		11.9		13.5		15.9		20.6		4.9		3.3		14.5		14.6		12.5		12.8	
Difference 1965 to 2012 (ft.)	0.65	3.4%	0.48	4.7%	0.37	3.6%	0.55	4.8%	0.64	5.0%	0.62	4.1%	0.82	4.1%	0.11	2.2%	0.05	1.4%	0.82	6.0%	1.01	7.4%	0.76	6.5%	0.74	6.1%
<b>Manchac Pass</b>	<b>Katrina</b>	<b>S008</b>		<b>S012</b>		<b>S014</b>		<b>S015</b>		<b>S023</b>		<b>S026</b>		<b>S069</b>		<b>S077</b>		<b>S085</b>		<b>S094</b>		<b>S126</b>		<b>S146</b>		
1965 Peak Surge (ft. NAVD88)	6.3		8.2		7.3		8.5		9.1		6.4		7.4		4.9		3.4		13.1		10.9		9.2		10.8	
2012 Peak Surge (ft. NAVD88)	6.3		8.1		7.3		8.4		8.8		6.4		7.5		4.9		3.3		12.4		10.3		8.8		10.2	
Difference 1965 to 2012 (ft.)	-0.01	-0.2%	-0.07	-0.8%	0.01	0.2%	-0.08	-0.9%	-0.22	-2.5%	0.06	1.0%	0.10	1.3%	-0.07	-1.5%	-0.07	-2.1%	-0.65	-4.9%	-0.63	-5.8%	-0.37	-4.0%	-0.62	-5.8%

<b>Mandeville</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	9.3	8.2	8.6	8.9	10.6	8.8	10.7	3.1	2.9	13.6	11.8	9.1	10.6																	
2012 Peak Surge (ft. NAVD88)	9.2	8.2	8.6	8.8	10.2	8.9	10.8	3.0	2.9	13.0	11.0	8.7	9.8																	
Difference 1965 to 2012 (ft.)	-0.08	-0.8%	-0.01	-0.1%	0.01	0.1%	-0.12	-1.4%	-0.37	-3.5%	0.14	1.6%	0.09	0.8%	-0.05	-1.5%	-0.03	-1.0%	-0.65	-4.8%	-0.80	-6.8%	-0.41	-4.5%	-0.84	-7.9%				
<b>LaPlace</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	8.2	9.5	8.6	11.3	11.6	11.6	11.6	9.9	11.2	14.3	13.5	11.0	11.8																	
2012 Peak Surge (ft. NAVD88)	8.3	9.4	8.6	11.3	11.5	11.7	11.6	9.9	11.2	14.0	13.5	11.0	11.9																	
Difference 1965 to 2012 (ft.)	0.08	1.0%	-0.08	-0.8%	-0.01	-0.1%	-0.08	-0.7%	-0.03	-0.3%	0.02	0.2%	0.01	0.0%	0.00	0.0%	-0.05	-0.4%	-0.25	-1.8%	-0.02	-0.2%	-0.03	-0.3%	0.08	0.7%				
<b>MSY Airport</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	11.8	7.1	6.9	8.7	9.6	12.6	12.7	5.7	11.8	11.6	12.4	8.8	11.3																	
2012 Peak Surge (ft. NAVD88)	12.7	7.2	7.0	9.1	10.0	13.2	13.5	5.6	12.3	12.2	13.2	8.9	11.8																	
Difference 1965 to 2012 (ft.)	0.94	8.0%	0.05	0.6%	0.08	1.2%	0.36	4.1%	0.35	3.6%	0.54	4.3%	0.78	6.1%	-0.14	-2.4%	0.51	4.3%	0.58	5.0%	0.72	5.8%	0.13	1.5%	0.50	4.4%				
<b>Braithwaite</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	13.2	13.8	13.2	14.9	17.7	12.1	15.5	9.8	9.3	21.5	20.3	17.6	20.4																	
2012 Peak Surge (ft. NAVD88)	13.8	14.4	13.9	15.6	18.6	12.8	16.5	9.8	9.3	22.2	20.9	18.3	21.0																	
Difference 1965 to 2012 (ft.)	0.55	4.2%	0.65	4.7%	0.68	5.2%	0.78	5.3%	0.88	4.9%	0.66	5.4%	1.02	6.6%	0.08	0.8%	-0.03	-0.3%	0.67	3.1%	0.57	2.8%	0.77	4.4%	0.59	2.9%				
<b>Jean Lafitte</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	2.3	6.3	4.7	6.6	6.8	2.4	3.1	2.6	2.2	11.5	3.3	6.0	6.6																	
2012 Peak Surge (ft. NAVD88)	2.2	6.5	4.9	6.7	6.9	2.5	3.0	2.6	2.2	12.1	3.8	6.1	7.0																	
Difference 1965 to 2012 (ft.)	-0.09	-4.2%	0.18	2.9%	0.12	2.6%	0.11	1.7%	0.11	1.7%	0.06	2.3%	-0.07	-2.4%	0.01	0.5%	0.05	2.5%	0.51	4.5%	0.57	17.5%	0.08	1.3%	0.41	6.2%				
<b>Lafitte</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	1.9	7.2	5.7	7.9	8.2	2.8	3.4	4.3	2.8	13.1	4.6	7.6	7.9																	
2012 Peak Surge (ft. NAVD88)	1.9	7.2	5.7	7.9	8.2	2.8	3.3	4.3	2.8	13.5	4.9	7.6	8.1																	
Difference 1965 to 2012 (ft.)	-0.03	-1.4%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-0.01	-0.3%	-0.02	-0.7%	0.01	0.1%	0.02	0.7%	0.35	2.7%	0.23	4.9%	0.00	0.0%	0.13	1.7%				
<b>Crown Point</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	1.5	6.1	4.9	6.6	6.9	2.6	3.1	2.6	2.3	12.0	4.8	5.8	7.2																	
2012 Peak Surge (ft. NAVD88)	1.8	6.9	5.6	7.7	8.0	2.9	3.5	2.9	2.5	13.3	6.4	6.6	8.8																	
Difference 1965 to 2012 (ft.)	0.36	24.9%	0.87	14.4%	0.78	16.0%	1.10	16.8%	1.12	16.2%	0.23	8.7%	0.39	12.6%	0.33	12.6%	0.18	7.6%	1.32	11.1%	1.58	33.0%	0.82	14.1%	1.66	23.1%				
<b>Waveland</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	25.6	10.1	9.6	11.3	12.5	17.0	21.5	8.4	11.5	12.7	13.0	11.9	11.2																	
2012 Peak Surge (ft. NAVD88)	25.8	10.3	9.7	11.5	12.8	17.3	22.0	8.4	11.6	13.0	13.4	12.0	11.5																	
Difference 1965 to 2012 (ft.)	0.25	1.0%	0.12	1.2%	0.13	1.3%	0.16	1.4%	0.25	2.0%	0.35	2.0%	0.46	2.2%	0.02	0.2%	0.02	0.2%	0.38	3.0%	0.34	2.6%	0.19	1.6%	0.31	2.7%				
<b>Boutte</b>	<b>Katrina</b>	<b>S008</b>	<b>S012</b>	<b>S014</b>	<b>S015</b>	<b>S023</b>	<b>S026</b>	<b>S069</b>	<b>S077</b>	<b>S085</b>	<b>S094</b>	<b>S126</b>	<b>S146</b>																	
1965 Peak Surge (ft. NAVD88)	NaN	5.9	2.9	5.0	4.7	NaN	NaN	2.4	2.3	8.9	NaN	5.1	NaN																	
2012 Peak Surge (ft. NAVD88)	NaN	6.2	3.2	5.4	5.2	NaN	NaN	2.5	2.3	9.7	NaN	5.4	NaN																	
Difference 1965 to 2012 (ft.)	NaN	NaN	0.33	5.5%	0.26	8.7%	0.36	7.1%	0.46	9.7%	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.09	3.8%	0.05	2.2%	0.87	9.8%	NaN	NaN	0.27	5.2%	NaN	NaN

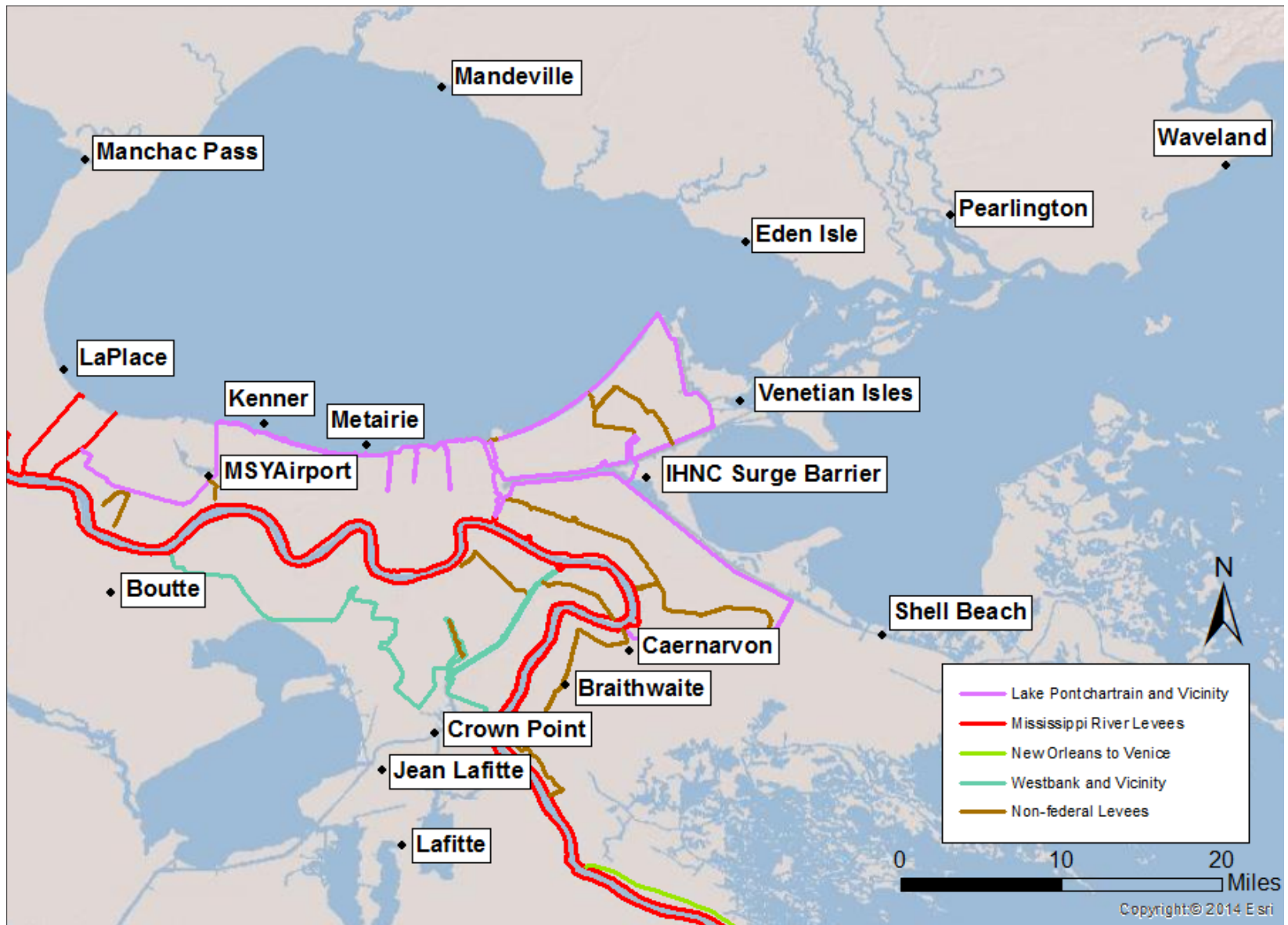


Figure 9 Selected Output Locations

Sensitivity Analysis of Relative Sea Level Rise on Gate Closure  
Frequency for Lake Pontchartrain and Vicinity (LPV)/  
West Bank and Vicinity (WBV) 1% Hurricane and Storm Damage  
Risk Reduction System (HSDRRS)

February 2016

New Orleans District (MVN) Authors:

Maxwell Agnew, MVN Hydraulics and Hydrologic (H&H) Branch

Julie Z. LeBlanc, P.E., MVN H&H Branch

Stacey Frost P.E., MVN H&H Branch

Technical Reviewers:

Ty Wamsley, ERDC (Engineering Research and Development Center) Coastal  
Hydraulics Lab (CHL)

Will Veatch, PH, MVN H&H Branch

Table of Contents

1. Executive Summary..... 3  
2. Introduction and Background..... 4  
3. Methodology ..... 7  
    3.1 ER 8162 and Relative Sea Level Rise Scenarios ..... 7  
    3.2 Water Level & Closure Analysis ..... 7  
    3.3 Limitations and Assumptions..... 11  
4. Results..... 12  
    4.1 Closure Frequency and Percentage of Year Closed for Low, Intermediate and High RSLR..... 12  
5. Conclusions and Discussion..... 17

List of Figures

Figure 1 LPV/WBV 1% HSDRRS Flood Gates ..... 6  
Figure 2 Low, intermediate and high RSLR projections for 2007 to 2057 at Grand Isle, LA (9.24 mm/yr) based on data available at <http://corpsclimate.us/ccaceslcurves.cfm>... 7  
Figure 3 Location of Shell Beach, New Canal, and Grande Isle gages ..... 8  
Figure 4 Historical observed water levels at Shell Beach, Grand Isle, and New Canal Station..... 10  
Figure 5 Predicted hourly water levels for the high RSLR scenario using random sampling and adjustment of historical water level data at Grand Isle, LA..... 10  
Figure 6 Predicted water levels and closure statistics at Shell Beach gage for a trigger elevation of 2.0 ft NAVD88 for low, intermediate and high RSLR..... 14

List of Tables

Table 1 Subset of Navigable Gates Closure Triggers and Top of Interior Wall Elevations. N/A means not available..... 5  
Table 2 Summary of number of closure per year and % of year closed for low RSLR 15  
Table 3 Summary of number of closure per year and % of year closed for intermediate RSLR..... 16  
Table 4 Summary of number of closures per year and % of year closed for high RSLR ..... 17

# 1. Executive Summary

This document presents the findings of a sensitivity analysis of gate closure frequency due to Relative Sea Level Rise (RSLR) for the Lake Pontchartrain and Vicinity and West Bank and Vicinity 1% Hurricane and Storm Damage Risk Reduction System (LPV/WBV 1% HSDRRS). Relative sea level rise includes the effects of eustatic sea level rise and land subsidence. Both of these hazards will have an increasing effect on LPV/WBV 1% HSDRRS over the 50-year project life.

The LPV/WBV 1% HSDRRS has a total of 501 openings that can be closed during tropical and riverine flood events. As sea level rises and land subsides, the frequency of gate closure will continue to increase to alleviate internal flooding. The purpose of this analysis is to estimate how the frequency of closure will change throughout the project life for three different RSLR scenarios. The analysis includes the effects of tides, high wind events, sea level rise, subsidence, seasonal water level variation, and storm surge events.

As sea level rises, some gates will be forced to close more often to reduce the risk of interior flooding. In some cases, the gate might be forced to remain closed indefinitely unless interior top of wall elevations are raised. In these scenarios, interior drainage modifications including pump stations might be necessary to remove rainfall and seepage inflows.

This analysis assumes each gate is closed when the water level (stage) reaches a given trigger height relative to the structure or its controlling gage, and opened when the water level recedes past the same trigger. In reality, each gate is operated according to a more complex set of opening and closing criteria. This analysis also assumes that stages will exceed their triggers more often in the future due to both the eustatic rise of the sea itself plus subsidence of the structure/gage (together known as RSLR). Water control manuals for some structures dictate that gates can close only when a tropical event is forecast or occurring. In this analysis, gates are assumed to close during any condition that produces a stage exceeding the trigger. As a result, this analysis may be conservative in the sense that future gate closures may not be as frequent as this analysis indicates.

The analysis provides estimates of gate closure frequency and percent of year closed for a range of hypothetical RSLR scenarios and gate closure triggers. In this analysis, the metrics are defined here:

**Gate closure frequency** = the number of closures per year. A closure is triggered when the exterior water elevation reaches the trigger elevation.

**Percent of year closed** = the total amount of time in hours the exterior water level is greater than the trigger elevation divided by the total number of hours in one year.

As expected, the results show that gates with lower trigger elevations will be affected earlier than gates with higher trigger elevations. The analysis provides estimates of the

year in which a gate will require chronic operation or permanent closure. These estimates are important, because they demonstrate the possible future need for permanent gate closure along with modified interior drainage with additional pumping capacity, or other modifications. For example, the Bayou Segnette complex on the WBV 1% HSDRRS requires a 2.0 ft NAVD88 closure elevation with a maximum interior water surface elevation of 2.4 ft NAVD88. For the low RSLR scenario, this gate is estimated to have chronic operation or closure by 2027. For gates facing similar conditions, some possible modifications to alleviate the interior flooding include:

- Permanent closure and installation of permanent pump station
- Raising internal line of risk reduction elevations to allow gates to remain open
- Buy out/retreat (areas that become subject to flooding during non-tropical events could be abandoned)
- Raising of flood-prone structures and infrastructure
- Modification of operating procedures to reduce the risk of internal flooding.

## **2. Introduction and Background**

The LPV/WBV 1% HSDRRS has a total of 501 openings that can be operated during high surge and riverine flood events to reduce interior flooding risk. There are 10 navigable openings, 144 roadway openings, 45 railroad openings, 136 access openings, and 160 drainage openings. Figure 1 displays the location and gate type for these LPV/WBV 1% HSDRRS gates. Additionally, there are 6 openings currently under construction as part of the WBV-Mississippi River Levee (MRL) co-located levees which extend from River Mile 70-85.5 on the west bank (these openings are not shown in Figure 1. The gates under construction along the WBV-MRL will only close during storm or riverine flood events even with the effects of RSLR considered, as the gate sills are above the MR&T flowline elevation. A subset of major navigable openings and drainage structures is labeled in Figure 1. The major navigation openings/drainage structures are the subset of openings that the Emergency Operations Center (EOC) primarily focus on during storm events. Table 1 displays pertinent information for a sub-set of major openings including the closure triggers for storm conditions and the top of interior wall elevations. The information in Table 1 was developed by the district's EOC, since the EOC is most familiar with the intricacies and constraints of the gates concerning closure of the system during tropical and riverine flood events. In Table 1, green cells are components of the WBV, while purple cells are part of the LPV.

During extreme surge events, many openings must be closed in a complex and coordinated effort involving Federal and local authorities. Some gates must be closed during high tide or high wind events, because the interior top of wall elevation is relatively low. For example, flooding will begin when the interior water level reached 2.4 ft NAVD88 at the Bayou Segnette Complex. On the east bank, interior flooding will begin at 2.9 ft NAVD88 at the Caernarvon Sector gate. As sea level rises, these gates will be forced to close more often to reduce the risk of interior flooding. In some cases, the gate might be forced to remain closed indefinitely unless interior top of wall elevations are raised or other measures are taken to reduce the interior water levels. In

these scenarios, interior drainage modifications including pump stations might be necessary to remove rainfall and seepage inflows.

The purpose of this analysis is to determine the impacts to gate operations due to RSLR. The analysis predicts future condition water levels using a random sampling of historical water level data and then determines the number of closures per year and the percent of year closed for a range of different closure elevations.

Structure	Closing Elevation (ft. NAVD88)	Structure Elevation (ft. NAVD88)	Top of Interior Wall Elevation (ft. NAVD88)	Maximum Operating Elevation (ft. NAVD88)	Top of Interior Wall Elevation Note
Harvey Sector Gate	2.0 ft and rising	10.7 ft	N/A	2.3 ft	Limited storage capacity.
Bayou Segnette Complex	2.0 ft	16 ft	4 ft	2.4 ft	Wave action will splash at ~EI+2.4.
Sellers Canal Complex	2.0 ft	16 ft	N/A	5 ft	Hwy 90 floods when prot side is EI+5. No pumps.
West Closure Complex	No later than 4 ft - See WCM	16 ft	8.5 ft	4.0 ft / 5.8 ft	Max on Harvey is EI+4.
Hero Canal Stoplogs	2.0 ft	14 ft	N/A	3.5 ft	Pump turns on at EI+2, off at EI 0.
Caernarvon Sector Gate	2.5 ft	26.0 ft	2.9 ft	5.0 ft – 6.5 ft	The point where water would begin to flow over Hwy 39 into the populated areas of St. Bernard
Bayou Bienvenue Sector Gate	2.0 ft	N/A	10.0 ft	5.0 ft – 6.5 ft	The local operator closes at approximately 2.0ft to reduce flooding at Paris road
Bayou Dupre Sector Gate	2.0 ft	31.0 ft	10.0 ft	5.0 ft – 6.5 ft	The elevation of the non-Federal back levee
Lake Borgne Surge Barrier	Between 1.5 and 4.0 ft	25.0 ft – 26.0 ft	11.0 ft	5.0 ft – 10.0 ft	The elevation of the lowest floodwall in the IHNC corridor
Seabrook Structure	Close after Surge Barrier when water equalizes	16.0 ft	11.0 ft	6.0 ft – 7.0 ft	The elevation of the lowest floodwall in the IHNC corridor
17th St Canal ICS	3.0 ft and rising	16.0 ft	8.7 ft	6.0 ft	West road ramp located just south of the interim control structure
Orleans Ave Canal ICS	5.0 ft and rising	16.0 ft	9.5 ft	8.0 ft	East levee section without wall at south end near OP#7 pump station
London Ave Canal ICS	2.5 ft and rising	16.0 ft	7.8 ft	5.0 ft	East floodwall at Robert E. Lee Blvd crossing
* All elevations are referenced to NAVD88 2004.65 datum					

**Table 1 Subset of Navigable Gates Closure Triggers and Top of Interior Wall Elevations. N/A means not available.**



### 3. Methodology

#### 3.1 ER 8162 and Relative Sea Level Rise Scenarios

Engineering Regulation (ER) 8162, *Incorporating Sea Level Change in Civil Works Programs*, dated December 31, 2013 is a policy document concerning incorporation of sea level change in civil works programs. The policy describes how projects must consider three possible RSLR projections including a low, intermediate and high RSLR. For this analysis, the Corps climate change website, which automatically calculates sea level change estimates based on the methodology outlined in ER 8162, was used to determine the three rates at the Grand Isle, LA gage.

<http://corpsclimate.us/ccaceslcurves.cfm>

Figure 2 displays the low, intermediate and high RSLR projections based historical water level gage records at Grand Isle, LA. The gage records indicate a long term RSLR rate of 9.24 mm/yr, which is one of the highest observed rates for the region. The project start year is 2007 and the project end year is 2057. The highest estimate of projected RSLR is 3.0ft NAVD88 in 2057. In this analysis, the Grand Isle RSLR projections were used as a representative curve for the entire region. Since Grand Isle has one of the higher RSLR projects, the decision to use the gage for the entire region is slightly conservative.

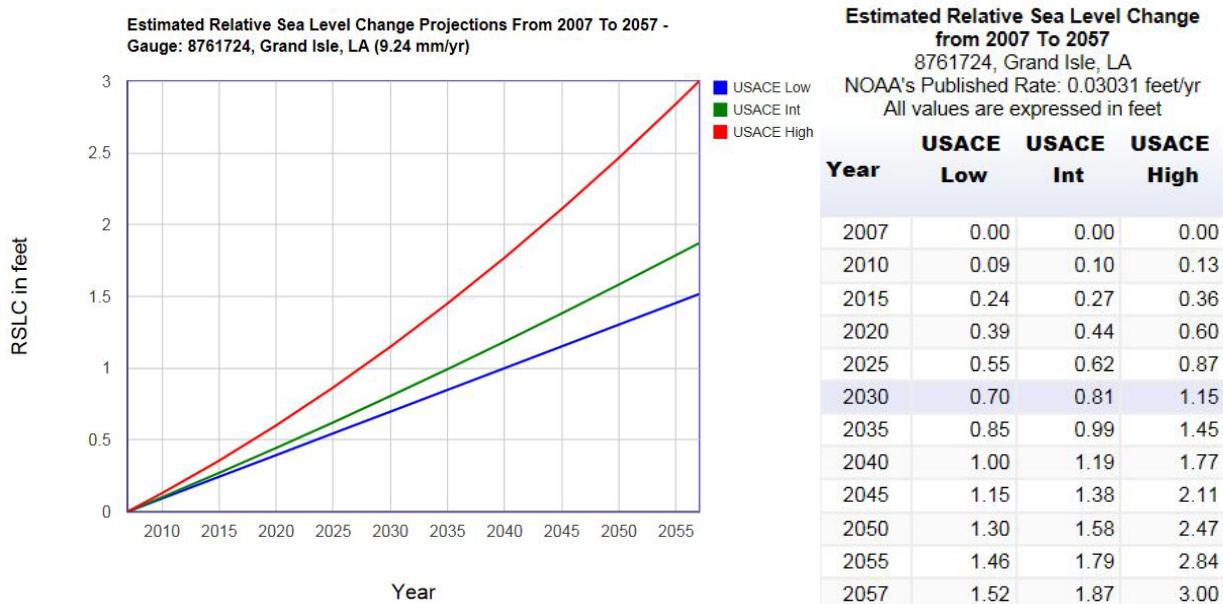
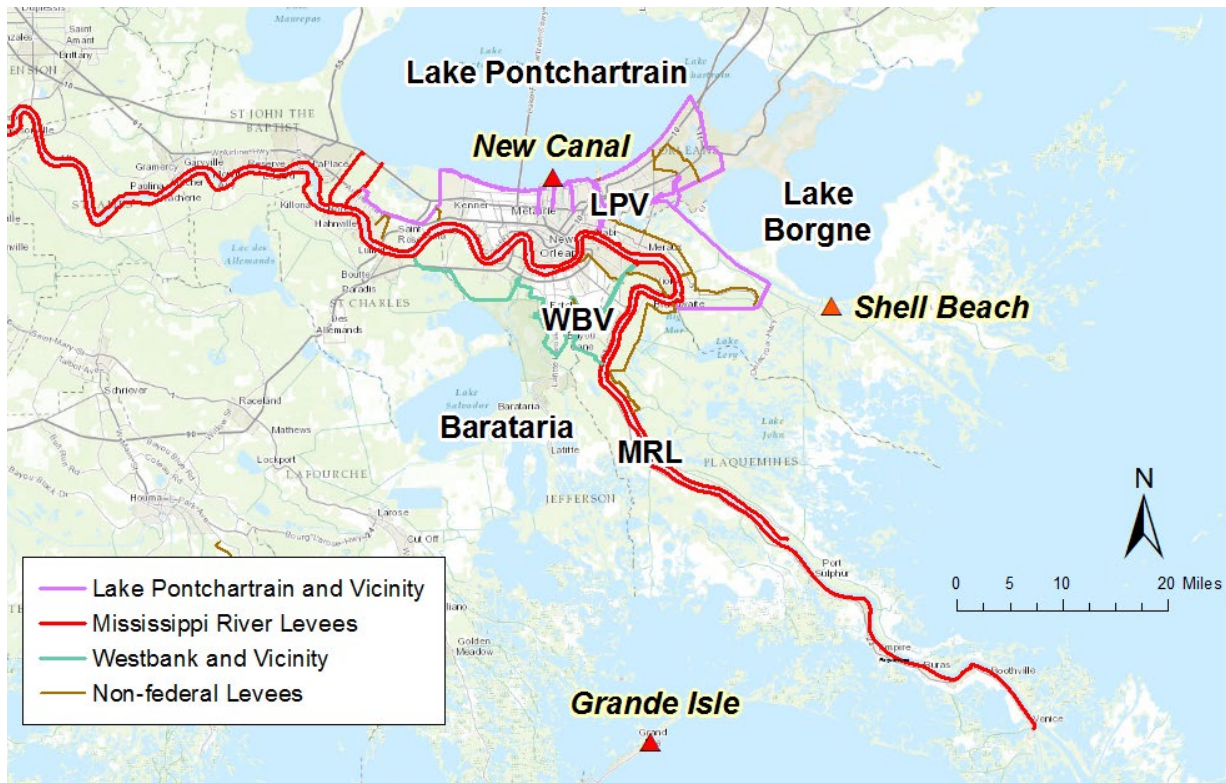


Figure 2 Low, intermediate and high RSLR projections for 2007 to 2057 at Grand Isle, LA (9.24 mm/yr) based on data available at <http://corpsclimate.us/ccaceslcurves.cfm>

#### 3.2 Water Level & Closure Analysis

Historical water level time-series are analyzed at three locations including Shell Beach, Grand Isle, and New Canal. The Shell Beach gage is in the open water of Lake Borgne.

The Grand Isle gage is located at the coast at the entrance to the Barataria Basin. The New Canal gage is located on the south shore of Lake Pontchartrain. These three gages were selected because each is representative of a distinct basin surrounding the HDSRRS. With RSLR and the loss of frictional resistance associated with wetlands, the connectivity between the Gulf of Mexico and the interior basins is expected to increase. Therefore, using the Grand Isle gage to represent the Barataria Basin in the future condition is a reasonable assumption, in the absence of more refined data. Figure 3 displays the location of the Shell Beach, New Canal, and Grande Isle gages.



**Figure 3** Location of Shell Beach, New Canal, and Grande Isle gages

Figure 4 displays the historical water levels at Shell Beach, Grand Isle and New Canal. All three time series include the highly active 2008 hurricane season which included Hurricanes Gustav and Ike, and the 2012 season, which included Hurricane Isaac.

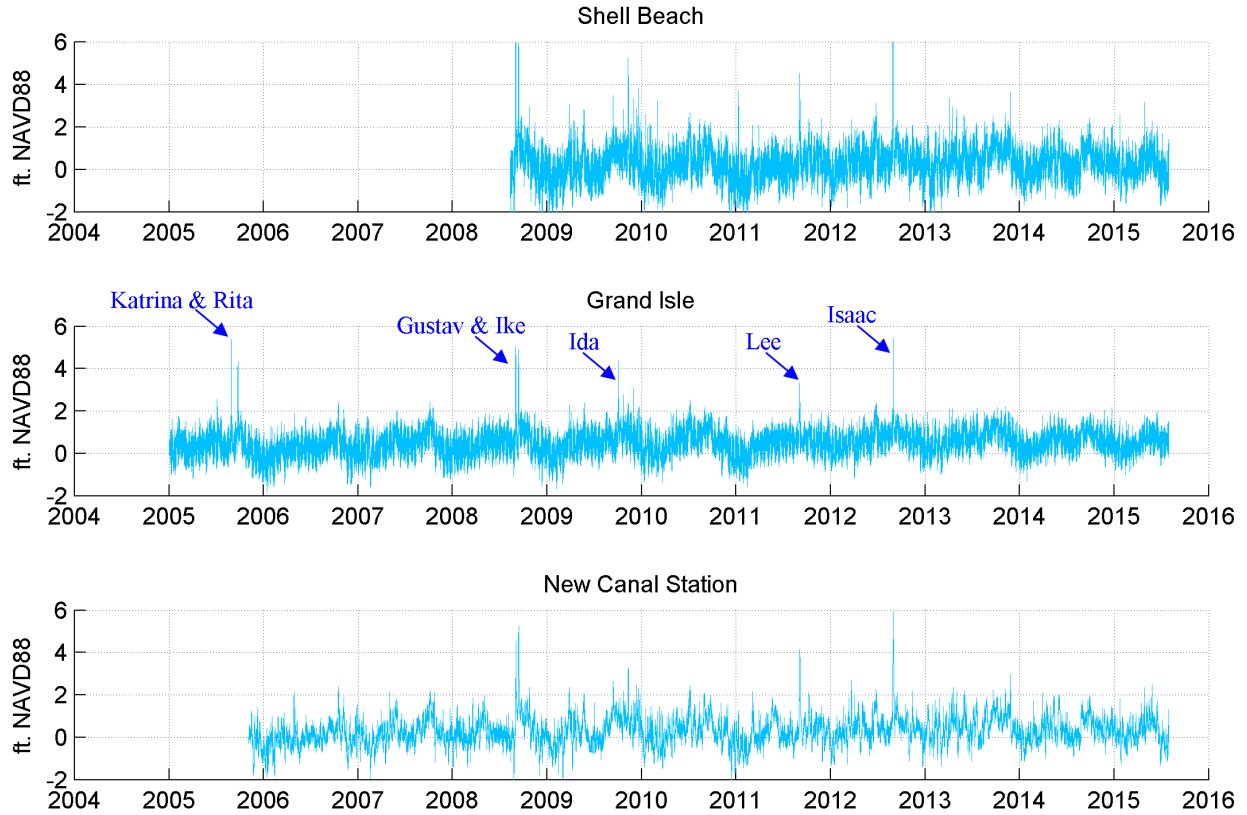
At any given time, the water level elevation is a function of tides, wind, rainfall, and seasonal steric adjustments. Steric adjustments to water level result from seasonal differences in temperature and salinity. The variation in water level can be seen in Figure 4. In the recent past, water levels typically range from around -1.5 to 2.0 ft NAVD88, although some extreme tides and surge events can push water levels lower or higher. The time-series includes the surges produced by major storms as labeled in Figure 4.

To develop future condition time-series, the historical water levels were randomly sampled on a month by month basis and adjusted to include the effects of RSLR. A

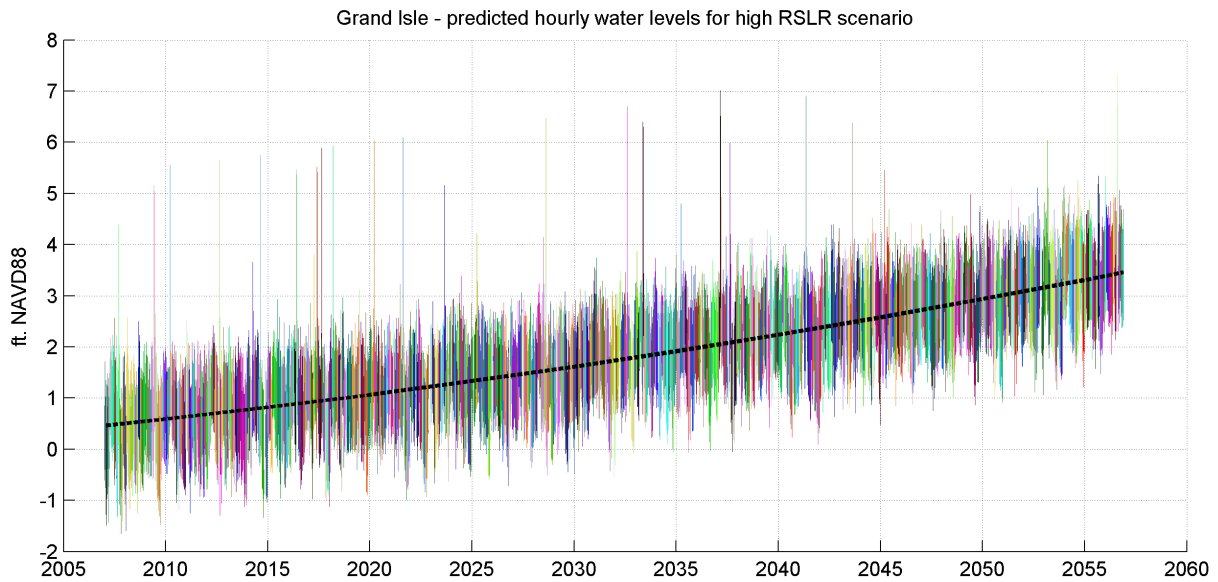
Matlab script was developed to randomly sample and process the historical water level data. For example, the script begins with the month of January in 2007. The script first needs to populate hourly water level time-series from 1/1/2007 00:00 to 1/31/2007 23:00. Instead of using the actual data from January 2007, the program randomly samples another month of January, possibly from a different year, and then adjusts this sampled data based on the 2007 RSLR projection (the 2007 RSLR is zero, so no adjustment is made). The program loops through month to month and populates the needed water level values. As the program gets to the final block of data need (12/1/2057 00:00 to 12/31/2057 23:00) the script will randomly sample an entire block of December data from the observed datasets and adjust the data based on the 2057 RSLR projection (the 2057 high estimate of RSLR is 3.0 ft, so 3.0 ft will be added to the sampled data). To estimate future condition time-series, the RSLR amount is added linearly to the sampled water levels. The script does not make any adjustments to the observed data to baseline it back to 2007 conditions before projecting it to the future condition, since a very small amount of RSLR can be measured from 2005 to 2015.

Figure 5 displays the predicted hourly water levels from 2007 to 2057 at the Grand Isle gage for the high RSLR scenario. Each distinct color represents a different month of sampled data. Similar time-series were developed for the low and intermediate RSLR scenarios for all three gages employed for the analysis.

Once the future condition time-series were developed, a separate Matlab script processes the data to determine the number of closures per year and the percent of the year closed. The closure trigger level varies from 1.0 to 5.0 ft NAVD88, a range which is reflective of actual structures presented in Table 1.



**Figure 4 Historical observed water levels at Shell Beach, Grand Isle, and New Canal Station.**



**Figure 5 Predicted hourly water levels for the high RSLR scenario using random sampling and adjustment of historical water level data at Grand Isle, LA**

### **3.3 Limitations and Assumptions**

The predicted water levels assume the tidal amplitude at the three gages will not change in the future condition. In reality, the loss of wetlands and other changes in the hydrodynamics of the Gulf of Mexico might change the tidal amplitude. In an attempt to address this issue, gages were selected in open water, where the effects of the marshes are minimal. Additional tidal modeling of the Gulf for future conditions can provide better estimates of future scenario water levels. However, using exposed gages and linearly adding the RSLR amount to the sampled water levels gives a reasonable first estimate of a possible future condition, in the absence of more refined data.

The analysis provides future condition water level time-series at only three locations. Each location is assumed to represent a unique area of the LPV/WBV 1% HSDRRS. More gages could be added to the analysis to better estimate gate closure frequency to specific areas. However, the water levels at the three gages do an adequate job of representing each basin around HSDRRS since each gage is located in an exposed area, subject to the full tidal range of the Gulf. The gages were selected in open water since the analysis focuses on the future conditions (+50 years) when the effects of the marsh on tides will be diminished if land-loss and subsidence continue.

The analysis considers simplified gates with closure triggers based on water level only. In reality, the closure trigger for many gates is not based solely on water level. The closure is also based on wind speed, navigation interests, and other factors.

This analysis only considers a small subset of LPV/WBV 1% HSDRRS gates, with some gates more vulnerable than others to the effects of RSLR. Specifically 6 gates listed in Table 1 have closing elevations around 2 ft NGVD88. There is a possibility that more gates (out of approximately 500 total) will be impacted by the effects of RSLR. However, the results of this analysis can be applied to other gates, as long as the trigger elevation, which is usually lower than maximum allowable interior water level, can be determined.

The analysis uses RSLR trends at Grand Isle to represent RSLR for all of LPV/WBV 1% HSDRRS. In reality, each location experiences a different amount of RSLR. Although the RSLR experienced at Grand Isle is high relative to most locations, therefore making the results conservative.

Another limitation is the fact that only one future with a low, medium and high RSLR rate was considered. A single future time series was created for each gage and each RSLR scenario, which of course is highly uncertain. A more rigorous approach would be to look at multiple (up to hundreds or thousands) of plausible future water level time series. However the future condition considered was a reasonable average of several predicted future conditions or was a worst case scenario or add some language justifying why we used just one scenario. Trying to not get hammered with comments from agencies that review the CED Phase II when they ask why we didn't do more analysis/future scenarios. Max, do you remember the specific comment from NMFS on the CED Phase I that spurred this analysis and maybe we should insert that comment here.

## 4. Results

### 4.1 Closure Frequency and Percentage of Year Closed for Low, Intermediate and High RSLR

The analysis provides estimates of gate closure frequency and percent of year closed for a range of hypothetical RSLR scenarios and gate closure triggers. In this analysis, the metrics are defined below:

**Gate closure frequency** = the number of closures per year. A closure is triggered when the exterior water elevation reaches the trigger elevation.

**Percent of year closed** = the total amount of time in hours the exterior water level is greater than the trigger elevation divided by the total number of hours in one year.

The results presented in this section are estimates based on a single future condition time-series which is developed using predicted low, medium, and high RSLR and observed water level time-series. There is considerable uncertainty in the results provided. The analysis is only meant to provide a general idea of what can possibly occur in the future. (Please see Limitations and Assumptions section).

Figure 6 displays some results of the closure frequency analysis for the Lake Borgne region for a trigger elevation of 2.0 ft NAVD88. The results from this plot represent any gate within the Lake Borgne Basin, with a trigger elevation of 2.0 ft NAVD88. The Bayou Bienvenue gate would be an example of a gate that is currently operated with a 2.0ft trigger elevation. The top portion of Figure 6 shows the predicted water levels for the low, intermediate and high RSLR trends. The data from the high RSLR water is visually covering the data from the low and intermediate RSLR time series. The middle plot of Figure 6 contains the calculated number of closures per year considering the 2.0 ft NAVD88 trigger elevation for all three RSLR scenarios. The bottom portion of the plot shows the percent of year closed for all three RSLR scenarios. As expected, both the number of closures per year and percent of year closed increase as the project ages. For the high RSLR projection, the number of closures actually starts to decrease around the year 2040, because by this time, the mean exterior water level is higher than 2ft, and the structure remains closed for a large percentage of the year.

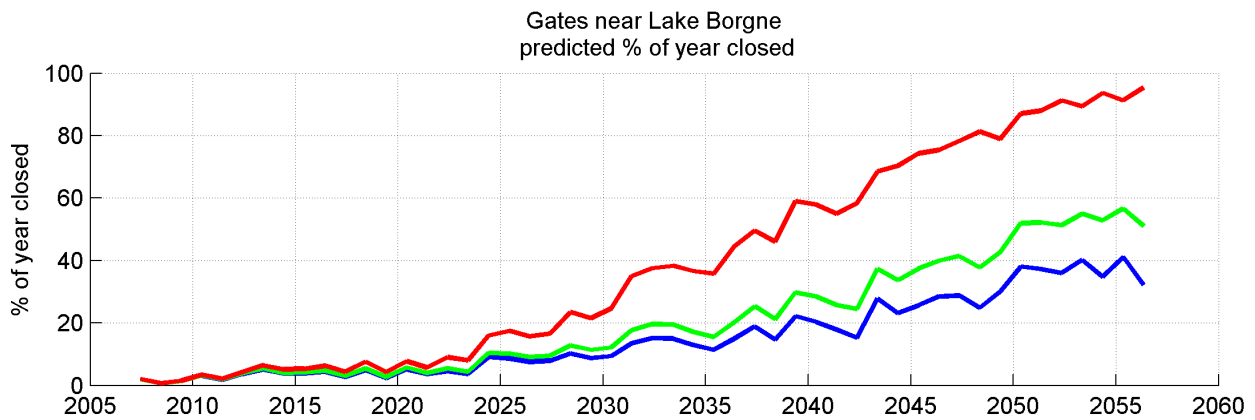
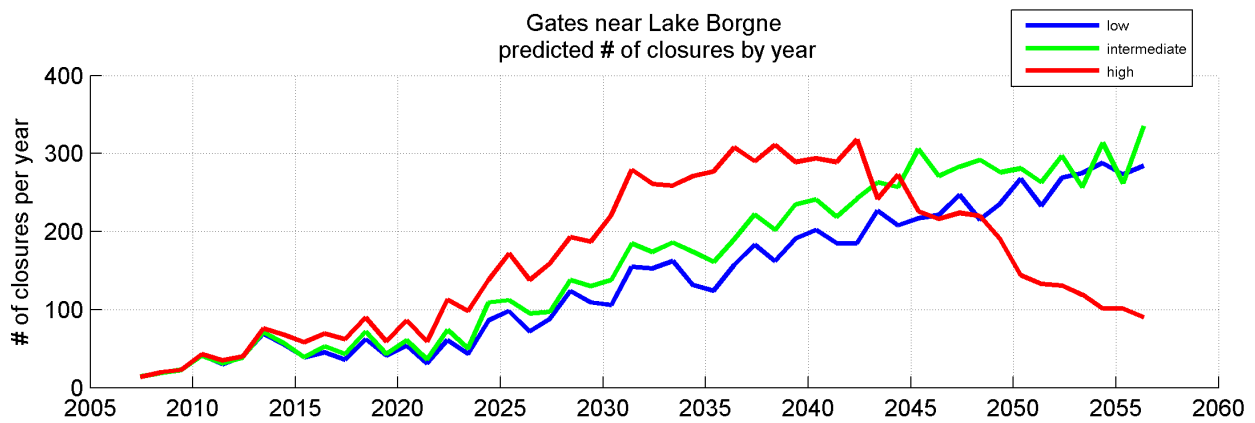
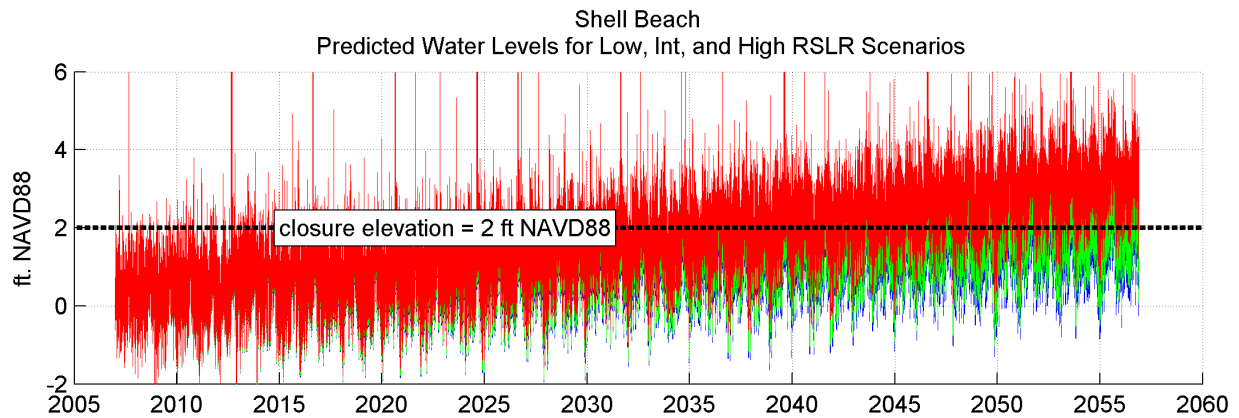
For the sake of consistency, the tables in the results section have been color coded to represent the metrics in the following way. Blue numbers represent less than 10 closures per year with the gate closed 0 to 1% of the entire year. This classification more or less represents gate operations in the existing 2007 to 2015 timeframe, where gates are typically closed for low-frequency surge or high tide events only. Green numbers represent between 10 and 20 closures per year with the gate closed between 1 and 2% of the year. This number of closures represents a condition where the gate is operated frequently due to high tide events and the occasional surge event. Green numbers more or less represent a tipping point of when the gate will be operated from frequently to chronically. Red numbers represent greater than 20 closures per year with

the gate closed between 2 and 100% of the year. In this scenario, the gate will be operated chronically to reduce the risk of interior flooding. For some specific locations, it might make more sense to seal the gate permanently and modify the internal drainage with additional pumping capacity.

Table 2 contains results for the low RSLR scenario for Lake Borgne, Lake Pontchartrain and the Barataria Basin for years 2007 to 2057 for 1.0 ft to 5.0 ft NAVD88 trigger elevations. The table shows that any gate with a 1.0 ft NAVD88 trigger elevation (although there are no LPV/WBV 1% HSDRRS gates with this operating criteria) requires chronic operation or permanent closure. Although there were no LPV/WBV 1% HSDRRS gates with a criteria of 1.0 ft NAVD88 (the lowest trigger is 2.0 ft NAVD88), this was analyzed to show closure impacts at 1 ft intervals. For example, in the year 2007, a gate with a 1.0 ft NAVD88 trigger elevation in the Lake Borgne basin (if there were any with this trigger elevation), would be required to close 191 times per year, and remained closed for 18% of the year. Gates with a trigger elevation of 2.0 ft NAVD88 are operated frequently in 2007 to 2027, however by the year 2037, gates with this operating criteria require chronic operation or permanent closure. Gates with a 3.0 ft NAVD88 trigger elevation require infrequent to frequent operation for most of the project life, depending on location. In the latter half of the project life, gates with a 3.0 ft NAVD88 trigger elevation will require chronic operation or permanent closure. For the low RSLR estimate, gates with a 4.0 to 5.0 trigger elevation will only require infrequent operation to reduce interior flooding.

Table 3 contains results for the intermediate RSLR scenario for Lake Borgne, Lake Pontchartrain and the Barataria Basin for years 2007 to 2057 for 1.0 ft to 5.0 ft NAVD88 trigger elevations. The results for the intermediate RSLR conditions are similar to the low RSLR results, although frequent and chronic operation are required a few years sooner than the low RSLR scenario. This is expected since the RSLR trends for the low and intermediate scenario are very similar (see Figure 2)

Table 4 contains results for the high RSLR scenario for Lake Borgne, Lake Pontchartrain and the Barataria Basin for years 2007 to 2057 for 1.0 ft to 5.0 ft NAVD88 trigger elevations. The results show that gates with a 3.0 ft NAVD88 trigger elevation will require chronic operation or permanent closure by year 2037. Gates with a 4.0 ft NAVD88 trigger elevation require chronic operation or permanent closure near year 2047. Gates with a 5.0 ft NAVD88 trigger elevation are infrequently operated at the end of the project life.



**Figure 6 Predicted water levels and closure statistics at Shell Beach gage for a trigger elevation of 2.0 ft NAVD88 for low, intermediate and high RSLR**

location	year	Trigger Elevation (ft NAVD88)				
		1.0	2.0	3.0	4.0	5.0
Lake Borgne	2007	191 (18%)	14 (2%)	8 (1%)	2 (0%)	0 (0%)
	2017	267 (29%)	36 (3%)	6 (0%)	3 (0%)	0 (0%)
	2027	296 (43%)	88 (8%)	6 (1%)	1 (0%)	1 (0%)
	2037	265 (65%)	183 (19%)	30 (2%)	3 (0%)	0 (0%)
	2047	230 (76%)	247 (29%)	26 (2%)	2 (0%)	0 (0%)
	2057	210 (83%)	284 (32%)	46 (4%)	5 (1%)	2 (0%)
Barataria Basin	2007	172 (14%)	11 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	243 (29%)	15 (1%)	0 (0%)	0 (0%)	0 (0%)
	2027	300 (61%)	81 (5%)	1 (0%)	0 (0%)	0 (0%)
	2037	192 (81%)	212 (21%)	2 (0%)	0 (0%)	0 (0%)
	2047	120 (90%)	291 (37%)	20 (1%)	0 (0%)	0 (0%)
	2057	70 (95%)	272 (53%)	65 (4%)	0 (0%)	0 (0%)
Lake Pontchartrain	2007	91 (9%)	9 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	136 (22%)	11 (1%)	2 (0%)	0 (0%)	0 (0%)
	2027	210 (39%)	43 (3%)	0 (0%)	0 (0%)	0 (0%)
	2037	175 (59%)	55 (9%)	4 (1%)	2 (1%)	1 (0%)
	2047	146 (78%)	89 (12%)	7 (1%)	1 (0%)	0 (0%)
	2057	68 (92%)	160 (31%)	33 (2%)	2 (0%)	0 (0%)

Table 2 Summary of number of closure per year and % of year closed for low RSLR

location	year	Trigger Elevation (ft NAVD88)				
		1.0	2.0	3.0	4.0	5.0
Lake Borgne	2007	192 (18%)	14 (2%)	8 (1%)	2 (0%)	0 (0%)
	2017	286 (31%)	43 (3%)	6 (0%)	3 (0%)	0 (0%)
	2027	293 (47%)	97 (9%)	8 (1%)	1 (0%)	1 (0%)
	2037	251 (72%)	222 (25%)	40 (3%)	3 (0%)	0 (0%)
	2047	175 (85%)	283 (41%)	62 (4%)	4 (0%)	1 (0%)
	2057	116 (93%)	335 (51%)	88 (9%)	6 (1%)	3 (0%)
Barataria Basin	2007	173 (14%)	11 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	248 (31%)	18 (1%)	0 (0%)	0 (0%)	0 (0%)
	2027	279 (67%)	101 (8%)	1 (0%)	0 (0%)	0 (0%)
	2037	147 (87%)	272 (31%)	6 (0%)	0 (0%)	0 (0%)
	2047	67 (95%)	279 (54%)	63 (4%)	0 (0%)	0 (0%)
	2057	25 (99%)	225 (73%)	147 (13%)	1 (0%)	0 (0%)
Lake Pontchartrain	2007	90 (9%)	9 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	149 (24%)	16 (1%)	1 (0%)	0 (0%)	0 (0%)
	2027	220 (46%)	42 (5%)	0 (0%)	0 (0%)	0 (0%)
	2037	174 (70%)	85 (13%)	11 (1%)	2 (1%)	3 (0%)
	2047	74 (91%)	156 (23%)	13 (2%)	2 (0%)	0 (0%)
	2057	17 (98%)	187 (56%)	62 (7%)	2 (0%)	1 (0%)

Table 3 Summary of number of closure per year and % of year closed for intermediate RSLR

		Trigger Elevation (ft NAVD88)				
location	year	1.0	2.0	3.0	4.0	5.0
Lake Borgne	2007	193 (18%)	14 (2%)	8 (1%)	2 (0%)	0 (0%)
	2017	307 (38%)	62 (4%)	6 (1%)	2 (0%)	1 (0%)
	2027	292 (61%)	159 (17%)	22 (2%)	5 (1%)	1 (0%)
	2037	138 (89%)	290 (50%)	102 (10%)	12 (1%)	1 (0%)
	2047	21 (99%)	224 (78%)	255 (32%)	36 (2%)	2 (0%)
	2057	2 (100%)	90 (95%)	328 (57%)	115 (11%)	8 (1%)
Barataria Basin	2007	175 (15%)	11 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	268 (38%)	28 (1%)	1 (0%)	0 (0%)	0 (0%)
	2027	200 (83%)	201 (19%)	2 (0%)	0 (0%)	0 (0%)
	2037	29 (99%)	266 (65%)	105 (7%)	0 (0%)	0 (0%)
	2047	10 (100%)	102 (91%)	280 (42%)	27 (2%)	0 (0%)
	2057	0 (100%)	19 (99%)	192 (80%)	186 (19%)	2 (0%)
Lake Pontchartrain	2007	91 (10%)	8 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	176 (31%)	22 (2%)	2 (0%)	0 (0%)	0 (0%)
	2027	209 (69%)	75 (10%)	2 (0%)	0 (0%)	0 (0%)
	2037	64 (90%)	173 (37%)	35 (4%)	1 (1%)	4 (0%)
	2047	1 (100%)	131 (81%)	107 (15%)	8 (1%)	1 (0%)
	2057	1 (100%)	7 (99%)	200 (64%)	76 (9%)	4 (0%)

Table 4 Summary of number of closures per year and % of year closed for high RSLR

## 5. Conclusions and Discussion

The analysis provides estimates of gate closure frequency and percentage of year closed for a range of hypothetical RSLR scenarios, five different trigger elevations, and three different regions. As expected, the results show that gates with lower trigger elevations will be affected earlier than gates with higher trigger elevations. The analysis provides estimates of the year in which a gate will require chronic operation or permanent closure. These estimates are important, because they demonstrate the possible future need for permanent gate closure along with modified interior drainage with additional pumping capacity, or other modifications. For example, the Bayou Segnette complex on the WBV 1% HSDRRS requires a 2.0 ft NAVD88 closure elevation with a maximum interior water surface elevation of 2.4 ft NAVD88. For the low RSLR scenario, this gate is estimated to have chronic operation or closure by 2027. For gates facing similar conditions, some possible modifications to alleviate the interior flooding include:

- Permanent closure and installation of permanent pump station

- Raising internal line of risk reduction elevations to allow gates to remain open
- Buy out/retreat (areas that become subject to flooding during non-tropical events could be abandoned)
- Raising of flood-prone structures and infrastructure
- Modification of operating procedures to reduce the risk of internal flooding.

This analysis assumes each gate is closed when the water level (stage) reaches a given trigger height relative to the structure or its controlling gage, and opened when the water level recedes past the same trigger. In reality, each gate is operated according to a more complex set of opening and closing criteria. This analysis also assumes that stages will exceed their triggers more often in the future due to both the eustatic rise of the sea itself plus subsidence of the structure/gage (together known as RSLR). Water control manuals for some structures dictate that gates can close only when a tropical event is forecast or occurring. In this analysis, gates are assumed to close during any condition that produces a stage exceeding the trigger. As a result, this analysis may be conservative in the sense that future gate closures may not be as frequent as this analysis indicates.