2023 DRAFT COASTAL MASTER PLAN

ICM-HIGH TIDE FLOODING APPROACH

ATTACHMENT H2

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COASTAL PROTECTION AND RESTORATION AUTHORITY

This document was developed in support of the 2023 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties, and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every six years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

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EXECUTIVE SUMMARY

The 2023 Coastal Master Plan defines “high tide flooding” as a localized coastal flooding event due to meteorological conditions and tides that increase water levels (i.e., not due solely to fluvial, pluvial, or tropical storm surge-based flooding). The analysis described in this report focuses on the prediction of future high tide flooding in coastal Louisiana communities and a preliminary evaluation of its effects. The direct effects of tropical storm surge-based flooding are examined in depth in other components of the 2023 Coastal Master Plan and are therefore not included in this discussion.

Many factors influence water levels and their variability in coastal Louisiana. These factors include the underlying topography, natural processes (such as river discharge, tidal fluctuations, winds and storms, and changes in sea level), and human activities (such as dredging, subsurface fluid extraction, diversions, and flood control features) (Hiatt et al., 2019). High tide flooding events in coastal Louisiana are largely driven by synoptic scale weather events (on the order of 1,000 km), possibly located some distance away, and mesoscale weather events (Kurian et al., 2009) producing conditions that lead to sustained onshore winds for a prolonged time period.

In order to understand how the incidence and effects of high tide flooding may change in the future, this analysis established a baseline of high tide flooding and its effects for a number of key coastal Louisiana communities. This baseline describes present-day high tide flooding events and their associated impacts. The analysis then evaluated the ability of master plan predictive modeling tools to estimate future conditions related to high tide flooding. Both applicability and appropriateness were evaluated. The Integrated Compartment Model (ICM) and ADvanced CIRCulation (ADCIRC) models were tested for their ability to accurately simulate selected historic events for the selected communities. Two scales of analysis were considered: a coastwide analysis and a community-based analysis.

A coastwide analysis would allow for evaluation over multiple spatial scales and at any location within the model domain. However, it would require models that accurately simulate localized high tide flooding events over the entire coastal zone. The results of model performance tests indicated that the existing modeling tools would need improvements to operate at a larger scale to better match observed high tide flooding events before being used to predict future events with confidence.

An alternative community-based analysis would not require significant changes to existing modeling tools. A community-based analysis involves predicting high tide flooding events, defining thresholds, and evaluating outcomes relative to specific coastal communities. Selecting specific communities also enables the definition of particular thresholds and metrics that are meaningful to those specific locations. This can support the clear communication of current and future high tide flooding risks and impacts to stakeholders.

The master plan team selected the community-based approach to evaluate the risks and of high tide flooding. This approach required the development of a method that used adjusted water level output data from the ICM to reflect high tide events. This method was implemented as a proof-of-concept using hydrodynamic data from the 2017 Coastal Master Plan. The initial implementation on five communities. However, the methods can be applied to any coastal community. Developing the approach also required identifying and defining the consequence evaluation metrics.

For the 2023 Coastal Master Plan, CPRA will pursue a community-based analyses to determine vulnerability and consequences for communities in coastal Louisiana. This approach, while not comprehensive in a coastwide evaluation of current and future high tide flooding risk and impacts, does allow for the development of methodologies for subsequent master plans. Focus communities chosen to illustrate a variety of current and future conditions may not be representative of the full spectrum of conditions present in coastal Louisiana. However, future work will be aimed to bridge the divide between the illustrative approach of the 2023 master plan and a more comprehensive, coastwide analysis of the vulnerability of coastal communities to high tide flooding.

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LIST OF ABBREVIATIONS

ADCIRC .... ADVANCED CIRCULATION
CLARA .... COASTAL LOUISIANA RISK ASSESSMENT MODEL
CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY
CRMS .... COASTWIDE REFERENCE MONITORING SYSTEM
DEM .... DIGITAL ELEVATION MODELS
EAD .... EXPECTED ANNUAL DAMAGE
ESRI .... ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE
FWOA .... FUTURE WITHOUT ACTION
GIS .... ARCGIS
ICM .... INTEGRATED COMPARTMENT MODEL
LERN .... LOUISIANA EMERGENCY RESPONSE NETWORK
MCS .... MESOSCALE CONVECTIVE SYSTEMS
MWL .... MEAN WATER LEVEL
NAM .... NORTH AMERICAN MESOSCALE
NCDC .... NATIONAL CLIMATE DATA CENTER
NOAA .... NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
USGS .... UNITED STATES GEOLOGICAL SURVEY
WSE .... WATER SURFACE ELEVATION

1.0 INTRODUCTION

1.1 BACKGROUND

The term high tide flooding has been used interchangeably with other terms such as, “tidal flooding”, “sunny day flooding”, “chronic flooding”, and “nuisance flooding” (e.g., Spanger-Siegfried et al., 2014; Sweet et al., 2018; Moftakhari et al., 2018; Union of Concerned Scientists, 2018). Each of these terms, however, have specific definitions and varying usages within the scientific community and colloquially. The 2023 Coastal Master Plan defines the term high tide flooding as localized coastal flooding events that occur as a result of meteorological conditions and tides leading to increased water levels not due solely to fluvial, pluvial, or tropical storm surge-based flood conditions.

This exploratory analysis evaluates and recommends methodologies for predicting future high tide flooding in coastal Louisiana communities and a preliminary evaluation of its effects on those communities. Impacts of tropical storm surge-based flooding are examined in depth in other components of the master plan and are therefore not included in this discussion.

Water levels and water level variability are influenced by many factors in coastal Louisiana. These include the underlying topography, natural processes (such as river discharge, tidal fluctuations, winds and storms), changes in sea level, and human activities (such as dredging, subsurface fluid extraction, diversions, and flood control features) (Hiatt et al., 2019). High tide flooding events in coastal Louisiana are largely driven by synoptic scale and mesoscale meteorological events (Kurian et al., 2009). These scales are large enough to produce conditions that lead to sustained onshore winds. Some event types that may setup these conditions are tropical cyclones (tropical storms and hurricanes) with a far-field landfall, extratropical cyclones, cold fronts, and mesoscale convective systems (MCS).

Climate and landscape changes also affect coastal flooding in Louisiana. Louisiana’s coastline is made of soft-sediments that are prone to erosion and subsidence. Over time, Louisiana will continue to lose land due to natural and manmade processes. Louisiana is eroding and sinking, and as a result of climate change, seas are also rising, meaning that future water elevations associated with low tides and high tides, will be higher than those experienced today.

An exploratory analysis conducted to inform the 2017 Coastal Master Plan focused on 80 communities without levee protection. The changes in both land area and the amount of land inundated at mean water surface elevation (WSE) were analyzed on a community-by-community basis using daily mean water levels extracted from Integrated Compartment Model (ICM) outputs to evaluate impacts to strategic assets and increases in community vulnerability to flooding. Some results are summarized in the 2017 Coastal Master Plan Appendix B (Clipp et al., 2017), and there was general interest in expanding the analysis to examine similar questions in more depth for the 2023 Coastal

Master Plan.

In order to provide an assessment of future high tide flooding risk for coastal Louisiana, it is necessary to understand present-day vulnerability to high tide flooding first, and then to define community specific impact thresholds. This also provides a baseline to compare the effects of future events with and without the implementation of projects included in the 2023 Coastal Master Plan. This includes the effects of structural protection projects (e.g., levees, floodwalls), nonstructural risk reduction projects (e.g., floodproofing, elevating structures, voluntary acquisition), and large-scale ecosystem restoration projects.

Identifying an effective approach to predicting future high tide flooding frequency and magnitude requires the examination of the capabilities of current modeling tools as well as evaluation of limitations. This report describes work done to inform the 2023 Coastal Master Plan high tide flooding analysis. This analysis was exploratory in nature and the approach and questions of interests were modified as new information and insights were made available. The analysis was done in two phases.

Phase one tested approaches to high tide flooding analysis with existing modeling tools, including identification of water level thresholds and events. This phase investigated the ability of master plan models to characterize the physical phenomena driving high tide flooding and to evaluate predicted water surface elevations against impact thresholds to characterize how magnitude and frequency of such flood events may change over time.

Phase two provided a simplified, alternative approach for generating high tide flood depths and uses these flood depths to analyze flood effects on community accessibility to critical and essential facilities through a drive time analysis of accessible roads during flood conditions.

1.2 GLOSSARY OF TERMS

Critical facilities: facilities that are considered important for short-term response operations, including those used for public safety purposes, medical services, and infrastructure maintenance.

Disruption: a reduction of physical, social, or administrative functioning within an affected area where normal routines will no longer be supported or maintained.

Essential facilities: facilities that are considered important for long-term recovery, including those that provide basic necessities for residents (e.g., banks and credit unions, gas stations, and grocery stores) or serve government functions.

Focus Communities: communities with nearby water surface elevation data and the potential for future land loss and inundation as predicted in the 2017 Coastal Master Plan, and that together represent spatial distribution areas across coastal areas currently experiencing high tide flooding.

High Tide Flooding: localized coastal flooding that occurs as a result of meteorological conditions and tides leading to increased water levels not due solely to fluvial, pluvial, or tropical storm surge-based flood conditions.

Impact Threshold: the critical water surface elevation at which a community will begin to be negatively impacted due to high tide flooding (e.g., defined by the top of a levee or the elevation of the main access road).

Mesoscale convective systems (MCS): large and organized complex of thunderstorms.

Mean Water Level (MWL): average background water surface elevation before an event (i.e., local sea level).

Metrics: qualitative and/or quantitative measures of disruption and damage resulting from high tide flooding events (i.e., consequences).

Water Surface Elevation (WSE): water level relative to a reference elevation (such as NAVD88).

Water Surface Elevation (WSE) Threshold: water elevation from observed WSE data that is noticeably higher than the average tidal waters yet below extremes during a tropical storm surge event; used as a proxy for potential high tide flooding for initial evaluation of current high tide flooding.

2.0 PHASE 1: ANALYSIS OF MODEL PERFORMANCE

To understand how high tide flooding occurrence may change in the future requires predictive modeling that reflects the behavior of current and expected natural processes and conditions. Phase 1 of this analysis considered observational data to identify potential high tide flood events and then evaluated the currently available models, ICM and ADCIRC, for their ability to predict SWE relative to observed SWE.

2.1 COMMUNITY SELECTION

A number of coastal Louisiana focus community locations were initially selected for assessment of present-day high tide flooding occurrence and associated impacts. These initial five locations were selected based on available flooding information and several other factors, including:

- Spatial distribution – represent as much of coastal Louisiana as possible,
- Location in relation to major structural protection systems to represent various levels of protection;
- Evaluation in other studies (e.g., 2017 Coastal Master Plan analysis,[1] Resilience Index work by the Water Institute,[2] etc.),
- Confirmed high tide flooding events (e.g., from analysis of coastal flood advisories, examination of feasibility and engineering design studies at CPRA, and internet searches of news and social media outlets),
- Availability of nearby WSE data from continuous observation stations, which is necessary to quantitatively examine high tide flooding events and impact thresholds, and
- The potential for future land loss and future inundation within communities, based on predictive model output from the 2017 Coastal Master Plan

Table 1 lists the community locations chosen for analysis and Figure 1 shows their geographic locations. An initial analysis of each location used Coastwide Reference Monitoring System (CRMS) data to identify possible high tide flood events and their associated meteorological conditions. The results of this analysis are in Appendix A which shows when high tide flood events may have occurred, the magnitude of those events, meteorological and hydrological (if available) data associated with those events for each community.

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[1] Clipp et al., 2016; Hemmerling & Hijuelos, 2016; Louisiana Coastal Protection and Restoration Authority, 2017

[2] Hemmerling et al., 2020

Table 1. Initial Focus Communities Selected for Phase 1 of High Tide Flooding Analysis

COMMUNITY NAME	CENSUS DATA AND RESULTS FROM 2017 COASTAL MASTER PLAN ANALYSIS*	WSE DATA AVAILABILITY
AMELIA, LA	U.S. CENSUS BUREAU (2018): POPULATION SIZE IS 1,876; MEDIAN HOUSEHOLD INCOME IS $29,638; POVERTY RATE IS 27.5% 2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 45	CRMS5035; USGS FLOW IN ATCHAFALAYA RIVER AT MORGAN CITY
CAMERON, LA	U.S. CENSUS BUREAU (2018): POPULATION SIZE IS 222; MEDIAN HOUSEHOLD INCOME IS NOT REPORTED; POVERTY RATE IS $25.5% 2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 30; LESS THAN 25% REMAINING BY MODEL YEAR 45	USGS 08017118 (CALCASIEU RIVER AT CAMERON); NOAA 8768094 (CALCASIEU PASS); CS-65 MIKE MODELING EFFORT; NOTE THAT NEARBY CRMS SITES ARE IN IMPOUNDED MARSH AREAS FAR FROM THE TOWN; WANG, 2019; WHEAT, 2016
COCODRIE, LA/LUMCON	2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 20	CRMS 0369; USGS 07381349 (CAILLOU LAKE SW OF DULAC, LA);
ISLE DE JEAN CHARLES, LA	2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 15; LESS THAN 25% REMAINING BY MODEL YEAR 20	CRMS3296
MANDEVILLE, LA	U.S. CENSUS BUREAU (2018): POPULATION SIZE IS 12,215; MEDIAN HOUSEHOLD INCOME IS $70,609; POVERTY RATE IS 7.58%	CRMS0006 LOCATED IN BIG BRANCH MARSH NWR; CRMS4094 - AT MOUTH OF TCHEFUNCTE RIVER; USGS 07375230 - TCHEFUNCTE RIVER AT HWY 2
*LAND CHANGE RESULTS FROM THE 2017 COASTAL MASTER PLAN ANALYSIS ARE BASED ON THE HIGH SCENARIO, FUTURE WITHOUT ACTION (FWOA).		

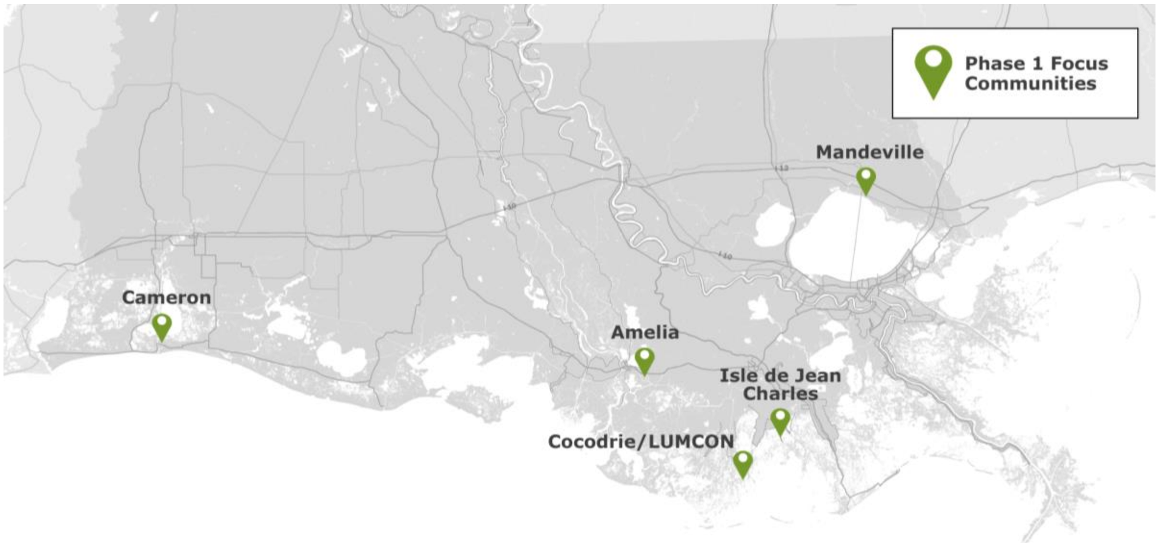


Figure 1. Locations of High Tide Flooding Analysis Phase 1. Five communities (green marker) were selected across Phase 1 of analysis.

2.2 MODEL PERFORMANCE TESTS

The analysis then evaluated the ability of existing predictive models (ADCIRC and ICM) to adequately characterize potential high tide flooding events. Evaluating the performance of these models with respect to high tide flooding first required identification of historic flooding events and impacted communities associated with smaller storms.

ADCIRC outputs were compared to observed data for selected storm events. Performance of the 2017 Coastal Master Plan ICM was evaluated by comparison with field observations and through comparison to ADCIRC output for the same events. Coupling of the ICM and ADCIRC models was tested by imposing ADCIRC output at offshore and near-shore ICM compartments.

For the ICM tests, performance was determined mainly by comparison of water level patterns for specific historical events at each location rather than evaluation based on the more general water level thresholds used to identify potential present-day high tide flooding events. Two different sets of tests were conducted. The first test used the model's predicted WSEs from the calibration/validation period at selected locations and compared them against field observations. The second test imposed predicted WSEs from the ADCIRC model at offshore and near-shore ICM compartments to explore the possibility of coupling ADCIRC and the ICM to predict future high tide flooding events. Detailed descriptions of these two analyses are provided in the following sections.

ANALYSIS OF ADCIRC PERFORMANCE

The ADCIRC model developed for the 2017 Coastal Master Plan has primarily been validated against large, tropical cyclone events. This is because the model was designed to evaluate storm surge and waves for relatively infrequent events (i.e., events necessary to define annual exceedance probabilities ranging from approximately 10% to 0.2%). By contrast, the events that are specified for this work are less intense, more frequent events typically consisting of frontal passages from west to east. Though the 2017 Coastal Master Plan ADCIRC model can simulate these types of events, additional model validation would likely be required to support the required model performance needed to effectively evaluate high tide flooding risk.

The ADCIRC model is developed using an unstructured mesh and a domain that consists of the Western North Atlantic, Gulf of Mexico, and coastal Louisiana. To simulate frontal passages, the model uses tidal harmonic constituents on the eastern boundary and wind and pressure fields throughout the Gulf of Mexico to simulate WSEs. The ADCIRC model domain is shown in Figure 2 and comprises computational elements ranging in size from 100 km down to 30 m.

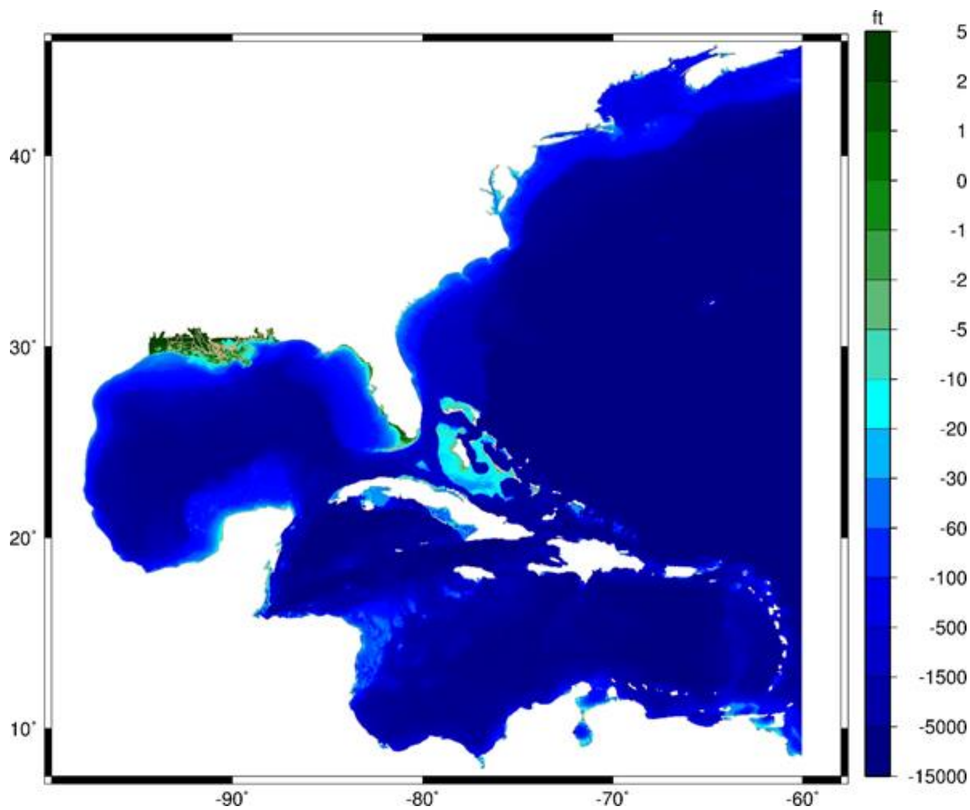


Figure 2. ADCIRC Model Domain for Louisiana. Typical ADCIRC modeling domain for Louisiana.

For these analyses, the ADCIRC model used wind and pressure fields from the North American Mesoscale (NAM) model operated by National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC). Data are supplied every three hours using Grid 218 shown as the area within the heavy black line in the left image in Figure 3. Grid 218 uses a 12 km curvilinear grid which can be interpolated to the unstructured ADCIRC mesh. Figure 3 also shows an example of the wind and pressure fields used in ADCIRC during a frontal passage which created a high tide flooding event in the observation data.

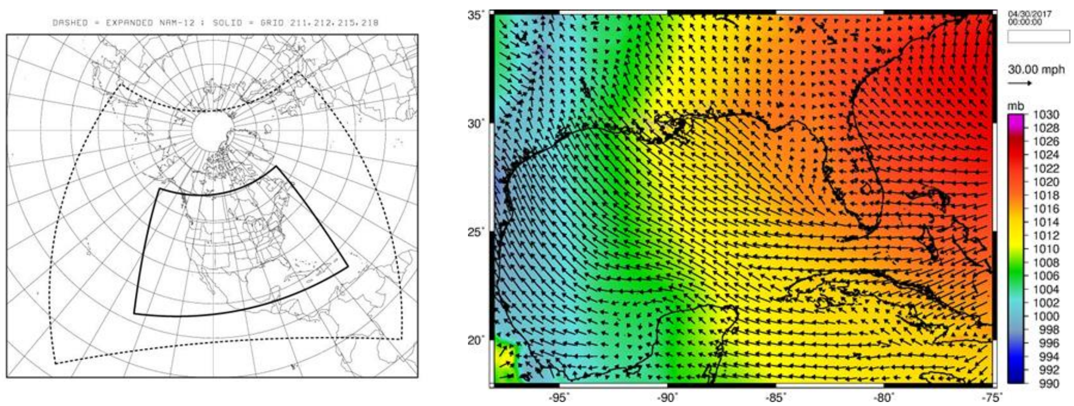


Figure 3. NAM Grid and Wind and Pressure Fields. NAM Model Grid 218 shown by the solid black line (left) NAM generated wind and pressure field during high tide flooding event in southern Louisiana. Contours represent barometric pressure and vectors represent wind velocities (right).

The generated wind fields were compared to available wind speed gages in the area, as shown in Figure 4, to understand how the NAM model might differ from observed winds. The NAM model predicts overall trends in the data. However, certain peaks are not captured. This is likely due to the coarse temporal and spatial resolution of the model and/or localized wind effects observed at the gage.

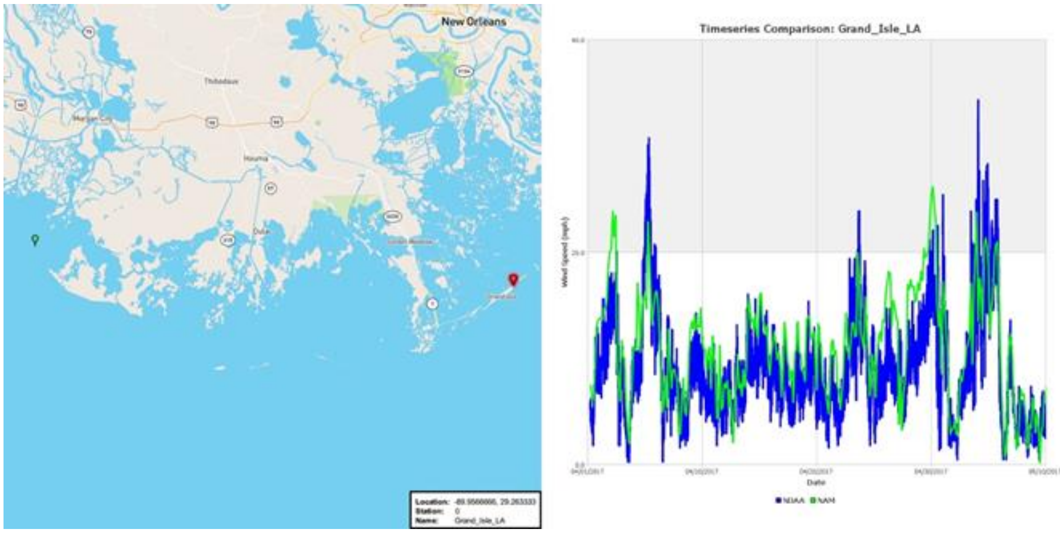


Figure 4. Modeled vs. Observed Wind Speed at Grand Isle. Comparison of NAM model wind speed and observed data at NOAA Grand Isle gage.

To evaluate ADCIRC model performance, modeled water levels were compared with observations at both the NOAA and CRMS stations. The results are shown in Figure 5, Figure 6, and Figure 7. Each green line shows the ADCIRC modeled SWE and the blue shows the observed CRMS SWE.

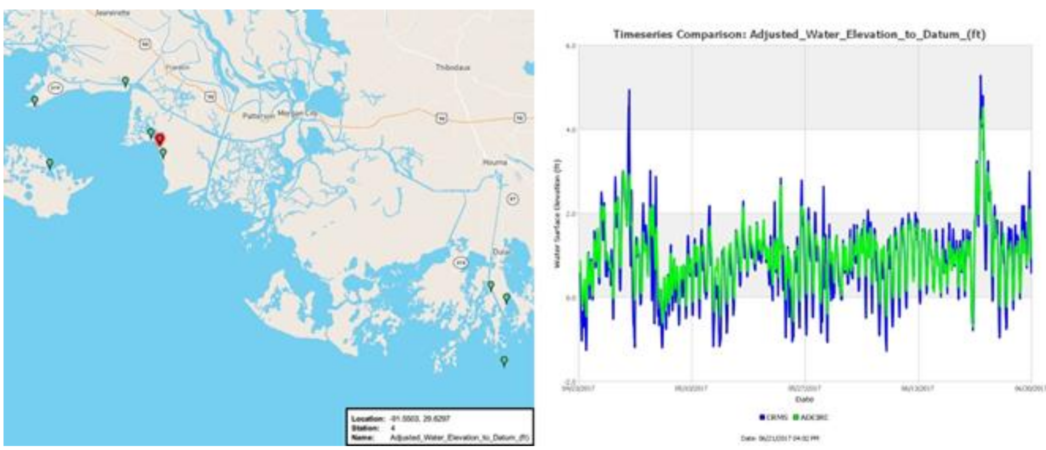


Figure 5. Modeled vs. Observed WSE near Cypremort Point. Comparison of modeled and observed water levels near Cypremort Point.

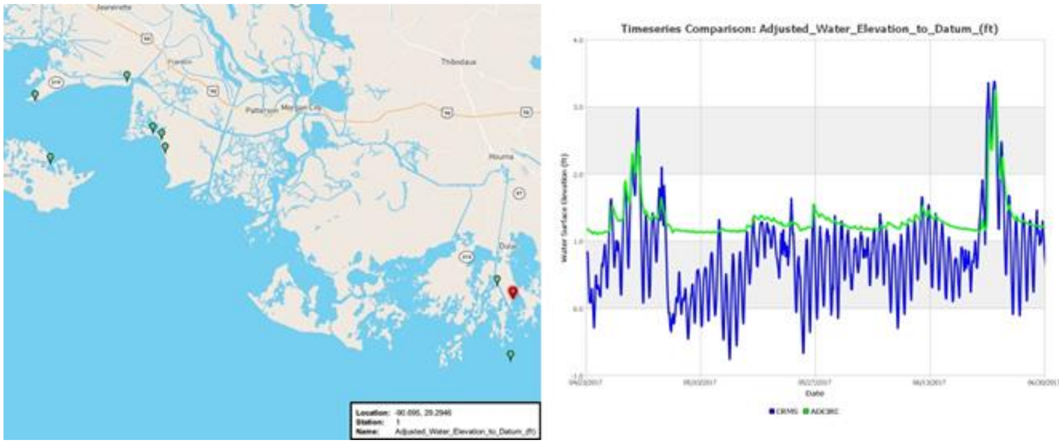


Figure 6. Modeled vs. Observed WSE near Dulac. Comparison of modeled and observed water levels near Dulac.

The ADCIRC model can predict tide phasing and amplitude well but does not replicate certain peaks in the historic simulation period as well as extended events where water is drawn down with offshore winds. The peak elevation near April 30, 2017 is underrepresented in the wind field and likely the cause of lower water levels in the model. Additionally, Figure 6 shows an area that does not have a tidal connection represented within the ADCIRC model, though peak water levels are replicated when the marsh is inundated from offshore. It appears that ADCIRC does not adequately reflect tidal penetration within the interior coastal areas as these are not necessary to simulate the larger storm surges.

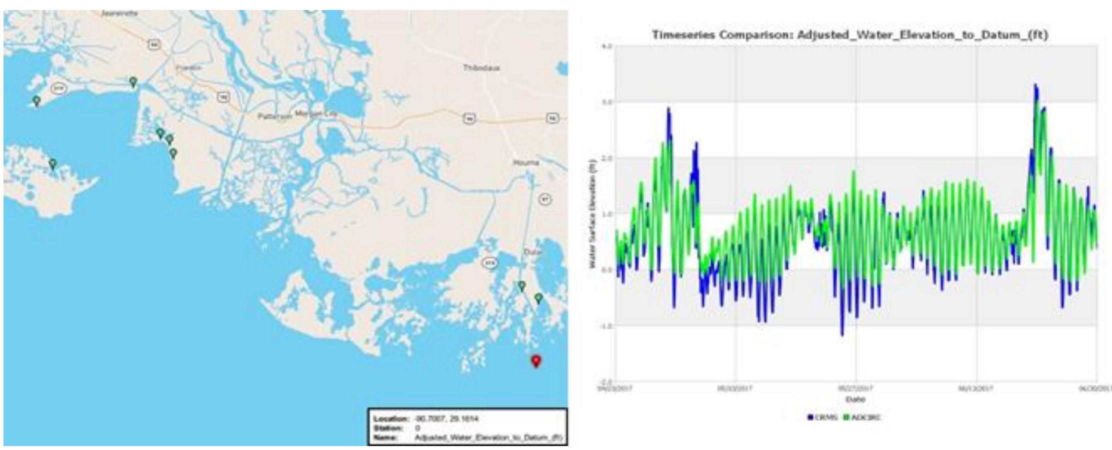


Figure 7. Modeled vs. Observed WSE Offshore of Dulac. Comparison of modeled and observed water levels offshore of Dulac.

To effectively use the ADCIRC model to predict high tide flooding would require modification so that it can capture smaller scale hydraulic features to resolve the water levels of interest during these events. Since the master plan ADCIRC model is designed with the purpose of simulating storm surge, many small-scale features, which do not contribute significantly to total water levels during these events, are not included to ensure the model is computationally efficient.

ANALYSIS OF ICM PERFORMANCE

This analysis evaluated the ability of the ICM developed for the 2017 Coastal Master Plan to capture high tide flooding events in the Louisiana coastal zone. As shown in Table 2, two locations were initially selected for ICM model performance tests. Figure 8 shows when coastal flood advisories were initiated for the two locations between September 2007 and June 2019.

Table 2. Focus Locations Selected for Model Performance Tests.

COMMUNITY NAME	CENSUS DATA AND RESULTS FROM 2017 COASTAL MASTER PLAN ANALYSIS*	WSE DATA AVAILABILITY
COCODRIE, LA/LUMCON	2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 20	CRMS 0369; USGS 07381349 (CAILLOU LAKE SW OF DULAC, LA);
CYPREMORT POINT, LA (AND STATE PARK)	2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 30; LESS THAN 25% BY MODEL YEAR 45	CRMS0527; USGS 07387040 (VERMILION BAY NEAR CYPREMORT POINT, LA)
*LAND CHANGE RESULTS FROM THE 2017 COASTAL MASTER PLAN ANALYSIS ARE BASED ON THE HIGH SCENARIO, FUTURE WITHOUT ACTION (FWOA).		

LUMCON is located in Cocodrie, Louisiana and is subjected to frequent high tide flooding. Recent work by Kolker et al. (2019) indicates that the LUMCON parking lot is expected to flood when the Caillou Lake gage (United States Geological Survey (USGS) #07381349) exceeds 0.76 m, and the building becomes inaccessible when WSE at the same gage exceeds 0.82 m. Additionally, high tide flood events have been recorded on social media at LUMCON, providing useful information to validate model outcomes.

Cypremort Point State Park is a low-lying area known for its man-made beach and boat access for recreational activities and is frequently exposed to high tide flooding. High tide flooding events at Cypremort State Park have been recorded on social media and in local storm reports. To determine potential high tide flooding events at or near LUMCON and Cypremort Point, historic coastal flood advisories issued from the Lake Charles and the New Orleans/Baton Rouge National Weather Service offices were examined.

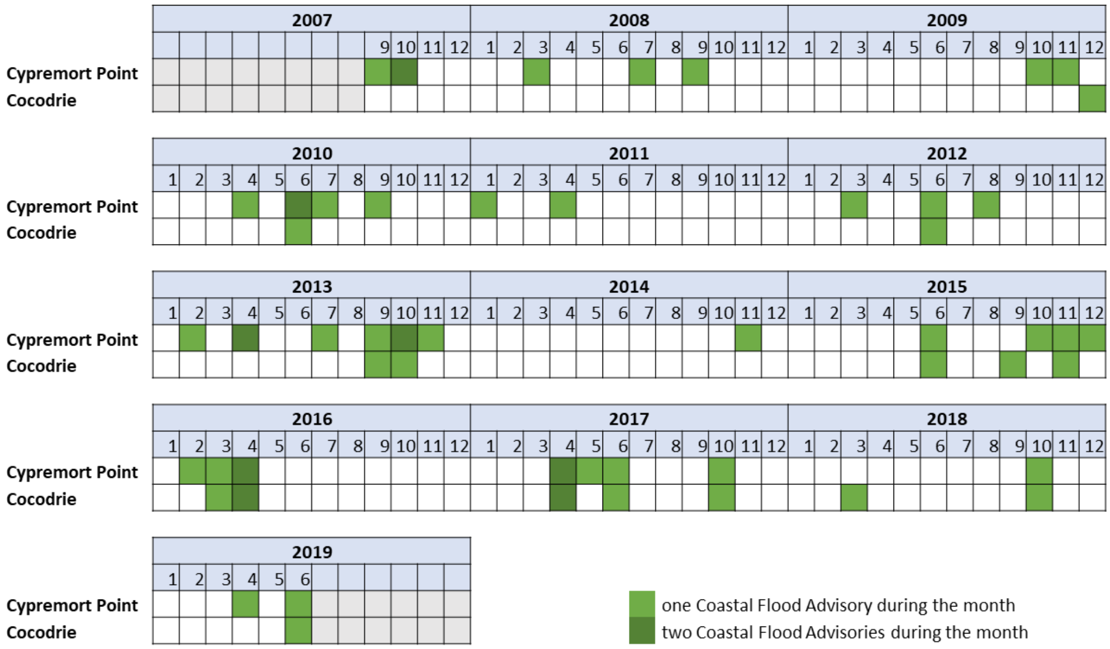


Figure 8. Coastal Flood Advisories. Coastal flood advisories issued for Cypremort Point and Cocodrie, LA are indicated in light green. Instances where two coastal flood advisories were issued in the same month are indicated in dark green.

As discussed above, WSE observations at gages near Cypremort Point and LUMCON were used as indicators for potential high tide flooding events in those locations. ICM results from the calibration/validation period (2006–2013) were extracted to evaluate the model performance in predicting high tide flooding events. Model output time series were extracted at ICM compartments where CRMS observations were also available. These are shown in Figure 9. For Cypremort Point, compartment 724 was selected to correspond with CRMS station 0527. For LUMCON, compartments 494 and 439 were selected to correspond with CRMS stations 0355 and 0369, respectively.

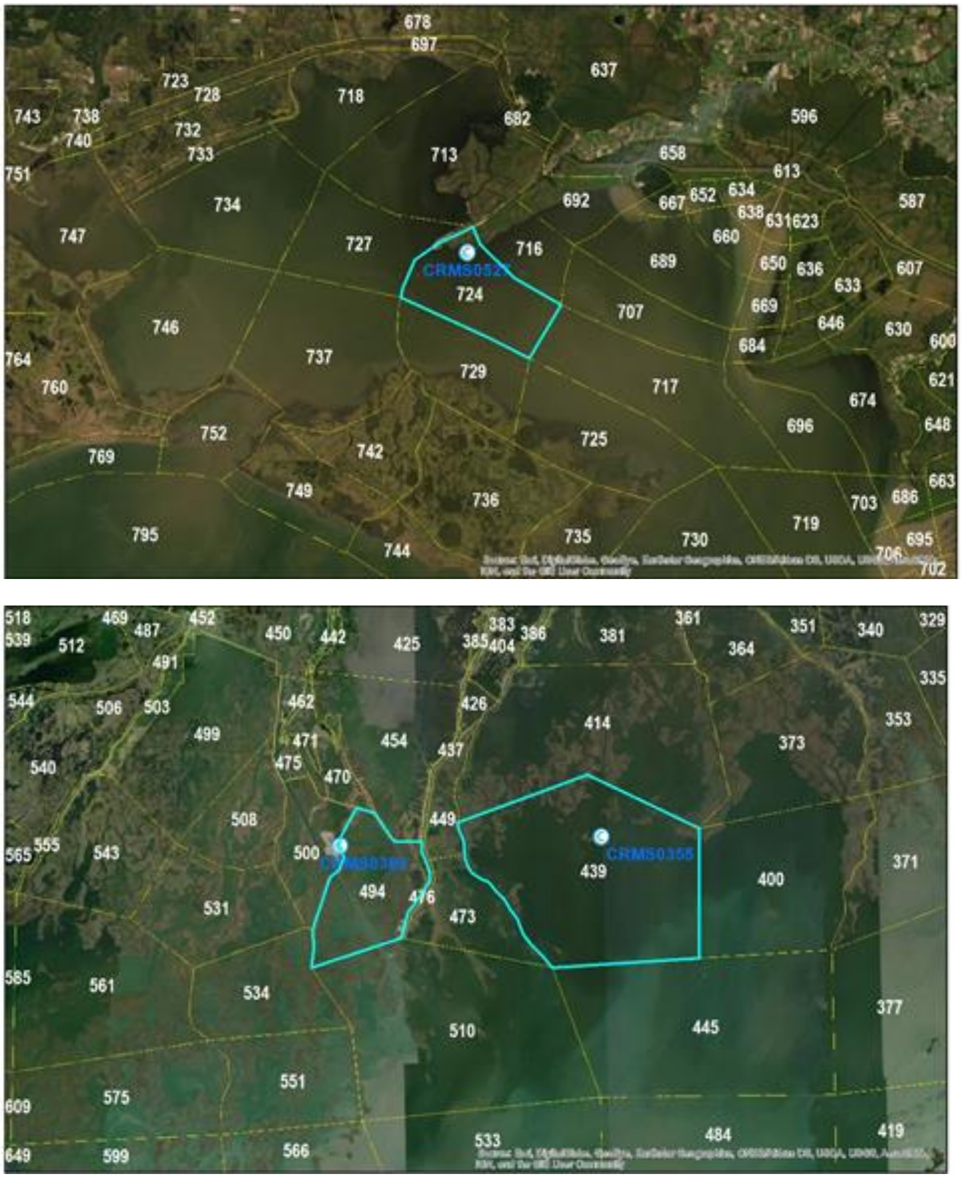


Figure 9. ICM Compartments with Available CRMS Observations. ICM compartments (outlined in blue) and CRMS stations (light blue dot) for Cypremort Point (top panel) and LUMCON near Cocodrie (bottom panel).

Figure 10 and Figure 11 display the predicted daily mean WSEs compared against observations on the specified date ranges at Cypremort Point and LUMCON, respectively. As shown, it is evident that in most cases the 2017 Coastal Master Plan ICM could capture WSE trends for observed high tide flooding events. However, in general, the ICM tended to under predict the maximum stages for these events.

Additionally, some events shown in Figure 8 could not be identified in the CRMS data. This indicates that some discrepancies may exist between the coastal flood advisories and field observations. Additional figures for each of the events shown in Figure 8 are available in Appendix B to this report.

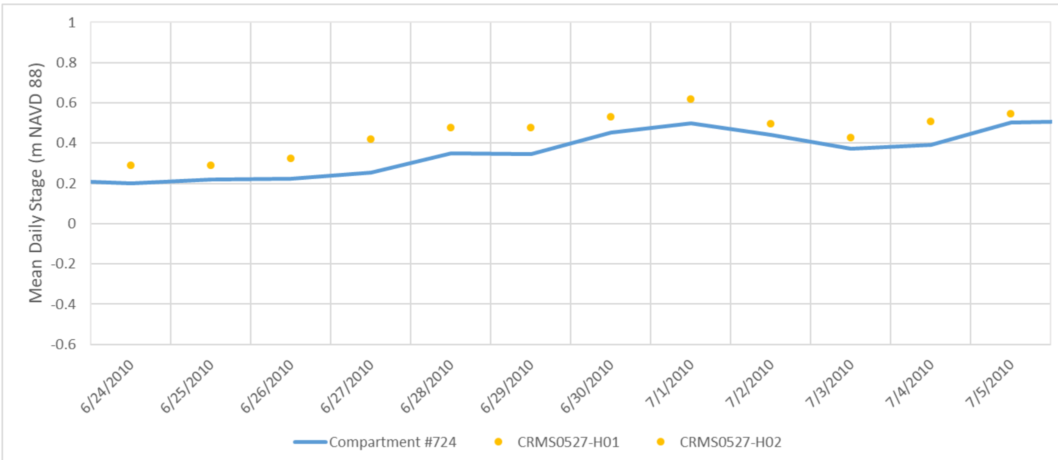
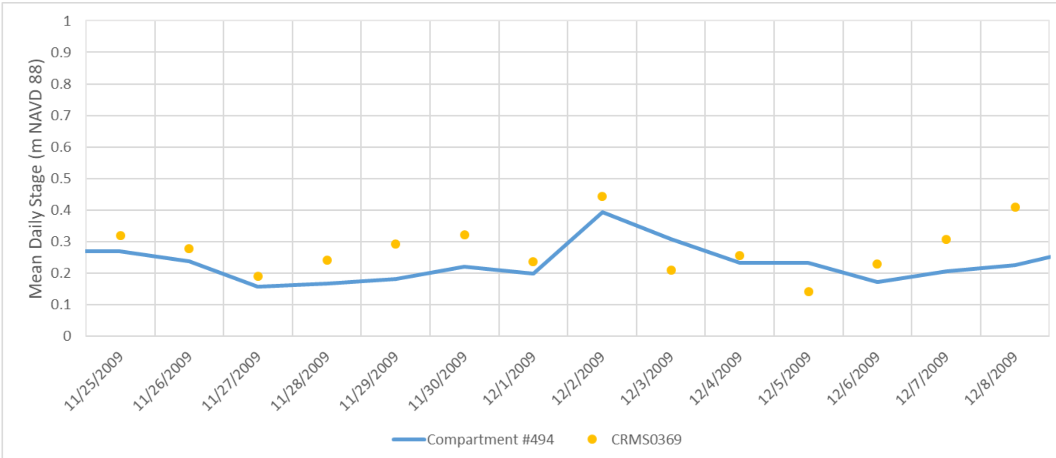


Figure 10. Predicted vs. Observed Daily Mean Stage at Cypremort Point. Comparison of ICM predicted and observed daily mean stage at Cypremort Point during the days before and after the June 29-30, 2010 high tide flooding period.



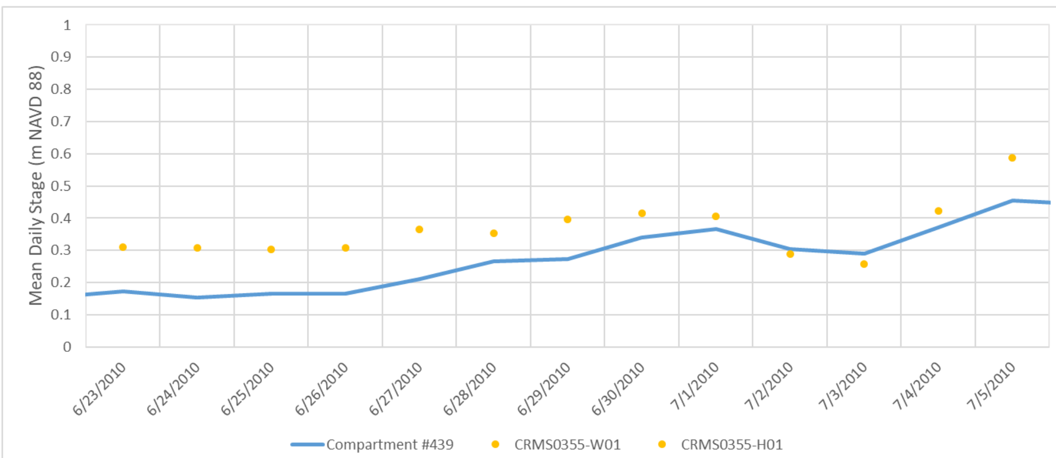


Figure 11. Predicted vs. Observed Daily Mean Stage at LUMCON. Comparison of ICM predicted and observed daily mean stage at LUMCON during the days before and after the December 1-3, 2009 high tide flooding period (top) and after the Jun 29-30, 2010 high tide flooding period (bottom).

In addition to comparing model predicted WSE against observed WSE in the marsh at a CRMS station near LUMCON, a comparison was also made at a USGS station in the open water area of Caillou Lake (Figure 12). The daily mean water level comparison between ICM outputs and mean daily observations at the USGS Caillou Lake station are shown in Figure 13. Note that the horizontal grey line on this figure represents the elevation 0.75 m NAVD88. Water levels higher than this threshold are identified as flooding events by LUMCON (Kolker, 2019).

Figure 13 shows a consistent bias in the model predictions relative to the associated field observations. The predicted WSEs are generally lower than the observed WSEs. The 2017 Coastal Master Plan ICM was not able to predict the number of days when WSE exceeded the 0.75 m threshold.

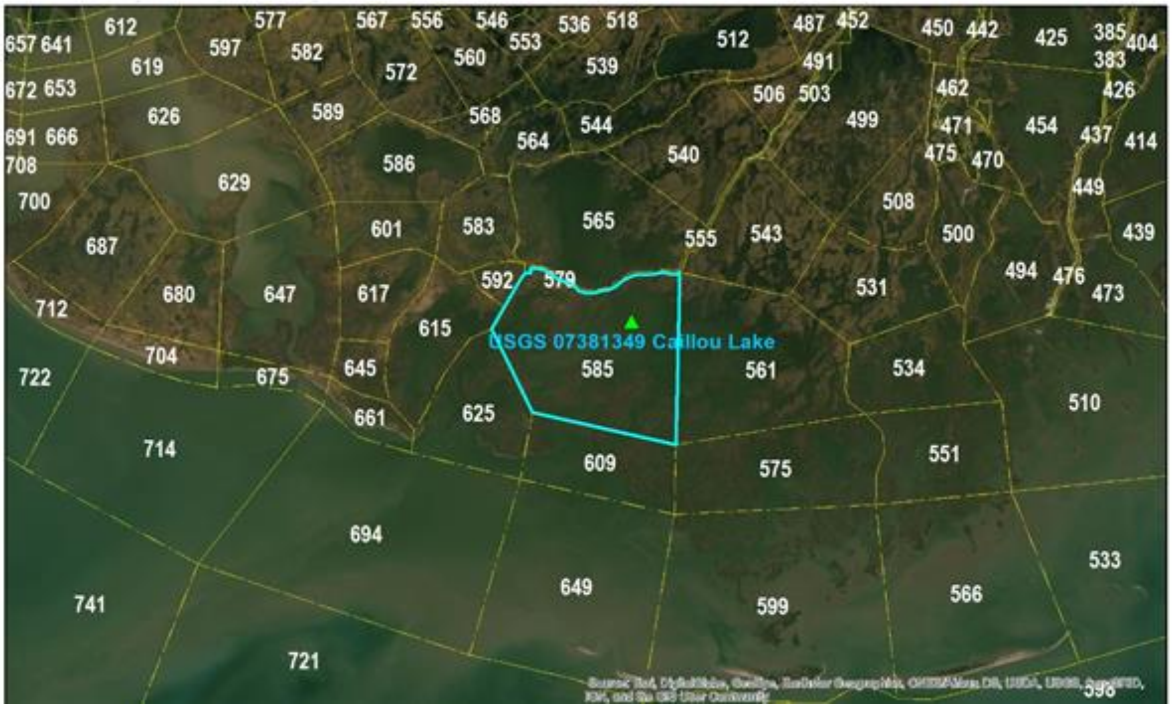


Figure 12. ICM Compartment with CRMS Observations for Caillou Lake. Selected ICM compartment (outlined in blue) and USGS station (green triangle) for Caillou Lake near LUMCON.

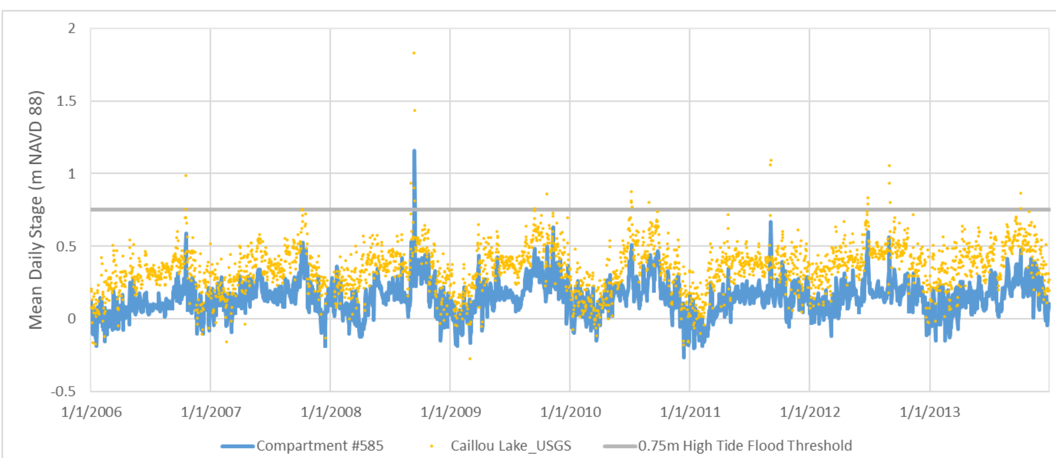


Figure 13. Uncorrected Observed Daily Mean Stage at Caillou Lake. Comparison of ICM predicted and observed daily mean stage at Caillou Lake for 2006-2013. The horizontal grey line represents the 0.75 m high tide flooding threshold.

Note that this consistent bias can be significantly reduced with further calibration in the ICM at this location. For the sake of this analysis, the bias was assumed to be corrected by matching the long-term average from model outputs and field observations, and the resulting data were used to evaluate the model's capability in predicting these flooding events. As shown in Figure 14, with the corrected model outputs the ICM's ability to predict the 0.75 m threshold exceedance improved. The general trends for major flooding events were captured by the ICM at this location. However, the model still under predicted the maximum stage for these events. This is likely at least partially due to using mean water levels as the calibration target parameter, as opposed to calibrating specifically for maximum stage. Another potential reason for the lack of performance is that the 2017 Coastal Master Plan ICM does not include wind forcing and wave radiation stress, which causes an uplift in water surface when waves break as they move into more shallow water. As shown from this analysis, the 2017 Coastal Master Plan model can reproduce flooding events from most hurricanes but is not sensitive enough for high tide flooding events.

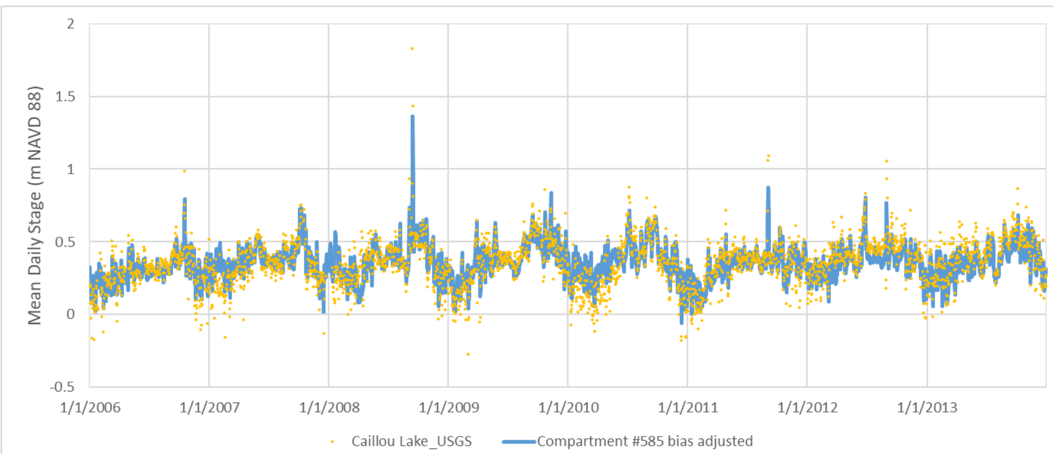


Figure 14. Corrected Observed Mean Daily Stage at Caillou Lake. Comparison of observed daily mean stage and corrected ICM prediction at Caillou Lake for 2006-2013. Dark green horizontal line represents the 0.75 m high tide flooding threshold.

COUPLING ADCIRC AND THE ICM

Since the 2017 Coastal Master Plan ICM could not adequately predict high tide flooding events in the coastal zone without further adjustments and/or calibration, a series of follow-up sensitivity tests and analyses were devised and conducted to explore the possibility of coupling ADCIRC and the ICM to better predict high tide flooding events. The intent was to overcome the lack of wind forcing on the ICM predicted water surface levels.

ADCIRC is the modeling tool used to predict storm surge behavior for master plan flood risk predictions (e.g., CPRA 2012, 2017). If possible, coupling ADCIRC and the ICM to generate high tide flooding events would allow the 2023 Coastal Master Plan team to conduct more long-term project evaluation simulations using the computationally efficient and less expensive ICM framework with the predicted tidal signal from ADCIRC (which includes the WSE response to wind forcing) imposed as a boundary condition.

The predicted WSE time series from eight pre-selected synthetic storms from the suite of synthetic storms used in the 2017 Coastal Master Plan was imposed both at the ICM offshore boundary and at near-shore compartments to test which approach would perform better within the ICM. The eight synthetic storms were chosen from ADCIRC to represent the highest frequencies in the synthetic tropical set; to produce WSE of the same order of magnitude of the high tide flooding events, tropical or non-tropical, that are being evaluated; and to span the entire Louisiana coast from east to west in terms of tracks and affected areas (storms 404, 426, 436, 457, 504, 526, 540, and 564). To illustrate, Figure 15 shows the storm track and maximum WSE (NAVD88) from storm 457; additional figures for the remaining storm tracks are available in Appendix B to this report.

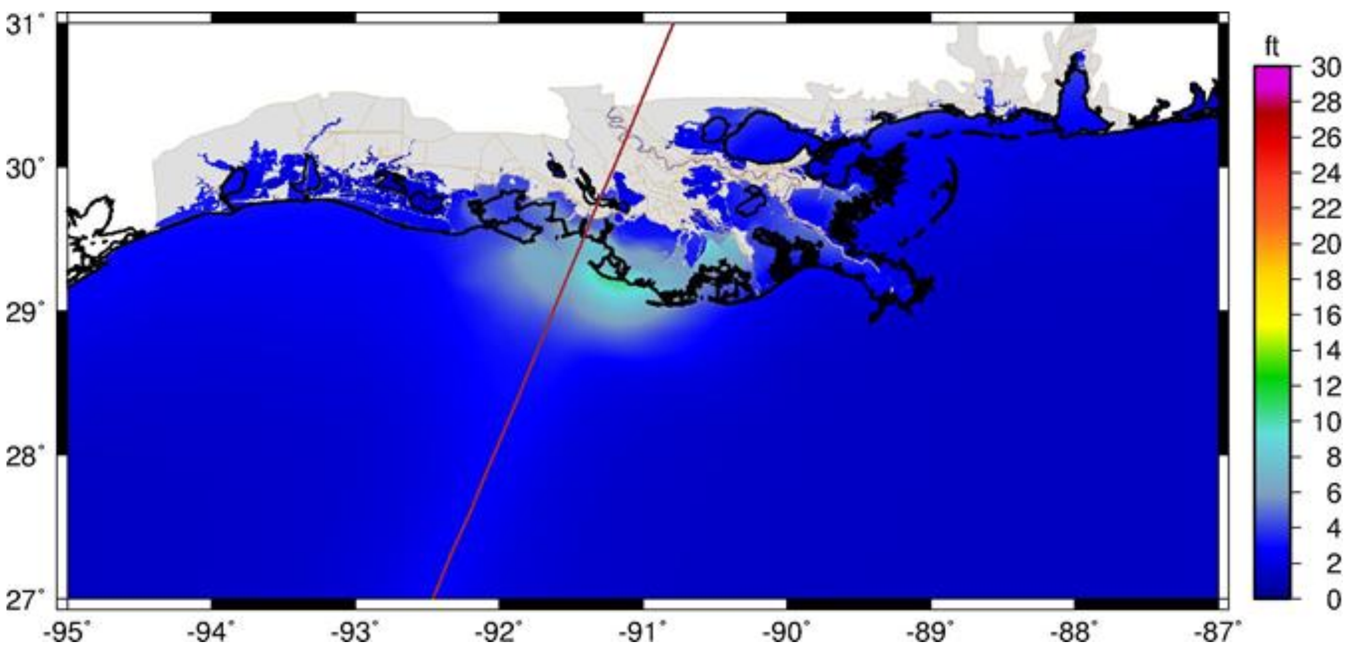


Figure 15. Synthetic Storm Track in ADCIRC. Storm 457 track and maximum WSE (NAVD88).

The first coupling test evaluated offshore coupling of ADCIRC and the ICM. The test involved imposing the ADCIRC time series stage data at the offshore boundary compartments of the ICM (Figure 16) for each of the synthetic storms. This test was designed to observe how well the ICM was able to propagate the surge signal generated by the synthetic storm events into the near-shore and inshore areas.

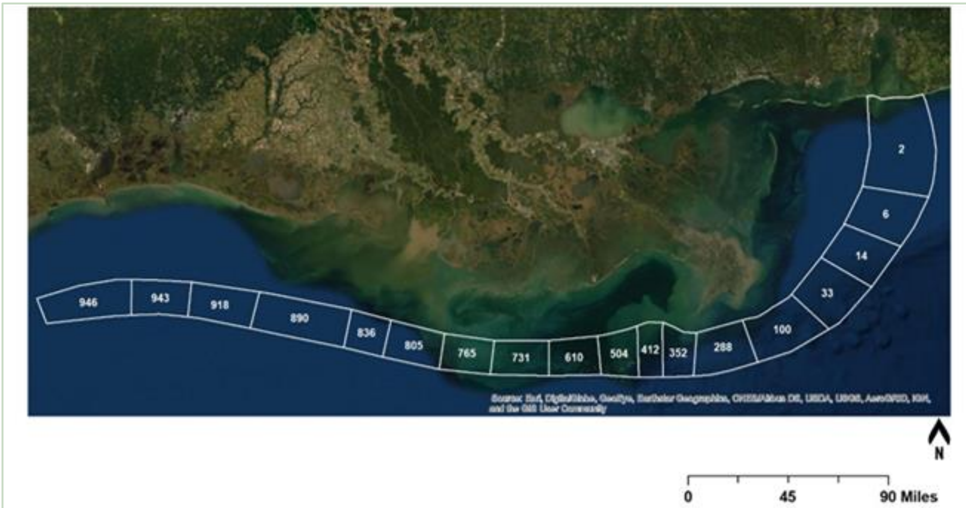


Figure 16. ICM Offshore Boundary Compartments. White boxes indicate the 18 coastal offshore boundary compartments in the ICM.

To measure the differences in WSE generated by the ICM and ADCIRC, a series of transects of ICM compartments extending from the offshore boundary to the inshore areas was generated and for each transect time series WSE data was extracted. An example transect can be found in Figure 17.

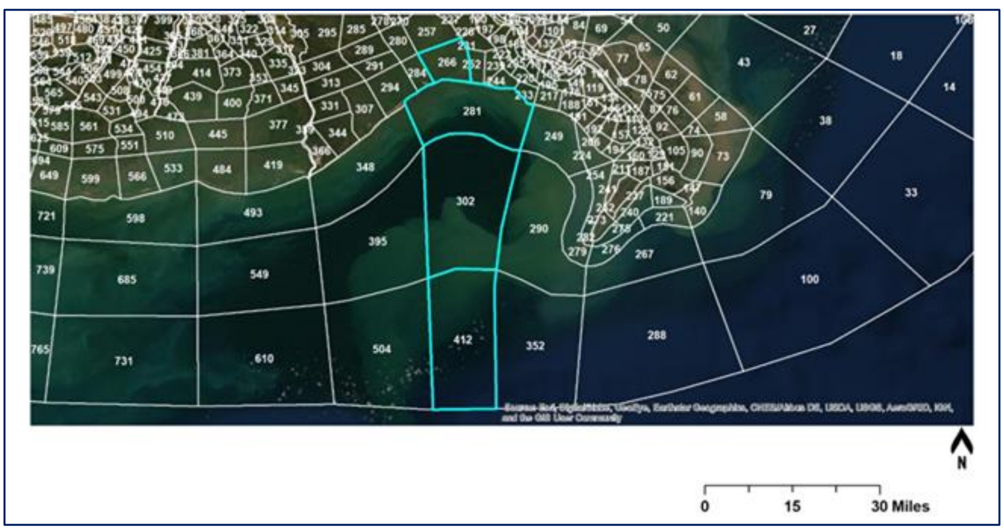


Figure 17. Example transect of offshore boundary to inshore ICM compartments.

Figure 18 displays example time series WSE data from the ICM simulation for the transect of ICM compartments shown in Figure 17 for a single storm. These results indicate the importance of overland flow links – where the offshore compartments quickly respond to the elevated WSEs, however interior zones (i.e., compartment #266 – the green line) respond much slower due to lower flow capacity in the interior links.

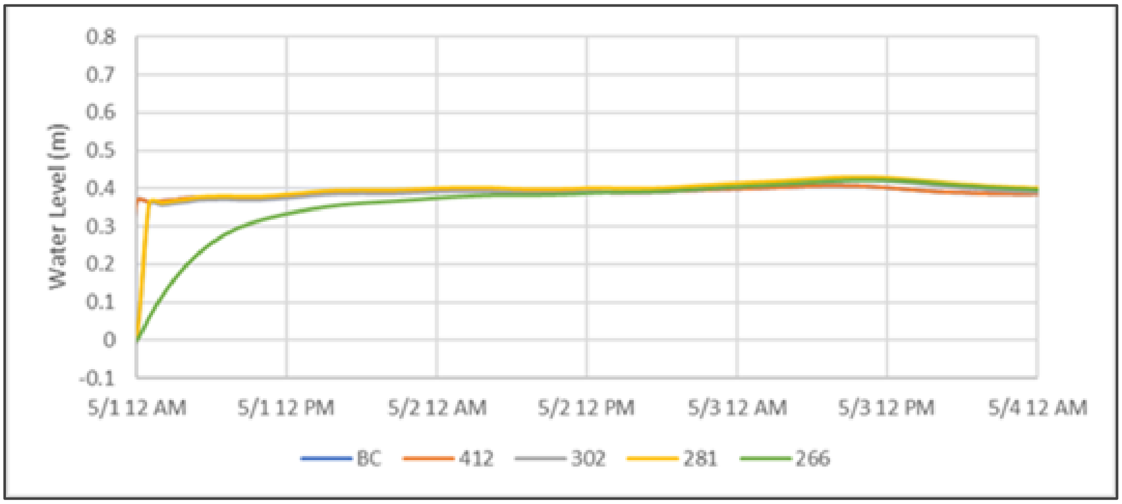


Figure 18. Comparison of WSE across ICM Transect. Comparison of WSE time series at ICM compartment transect shown in Figure 12.

Figure 19 shows the comparison of the ICM and ADCIRC WSE time series data at the near-shore/inshore area. As is evident in the figure, the ICM was unable to accurately mimic or reproduce the ADCIRC results for local WSE near the coastline, confirming its inability to handle wind forcing and wave radiation stress. Note that the ADCIRC simulations assumed a mean water level in the Gulf of 0.3 m NAVD88 as an initial condition.

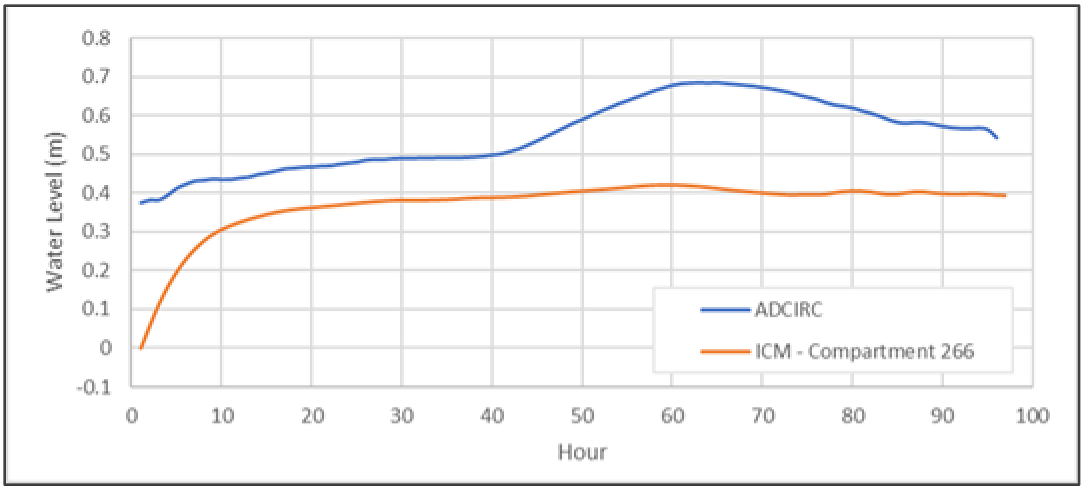


Figure 19. Comparison of near-shore ICM and ADCIRC WSE time series. Water level comparison of ADCIRC and ICM WSE at an inshore region (ICM 266).

The second test investigated the ability to effectively couple ADCIRC and the ICM at near inshore, open water areas. This involved imposing the ADCIRC-derived WSE time series data for a synthetic storm at near-shore or inshore ICM compartments rather than in the offshore compartments. ICM compartments interior to the shoreface but still within open water areas (e.g., bays and sounds), were chosen as locations to impose the ADCIRC WSE as internal boundary conditions in the ICM. Synthetic storm 457 was used for this test since its path is generally perpendicular to the coastal zone and aligned with the transect of ICM compartments used for comparison. Figure 20 displays the maximum ADCIRC-derived WSEs for this storm. The green points in the figure are the data extraction points used to take the data from ADCIRC and impose it within the labeled ICM compartments.

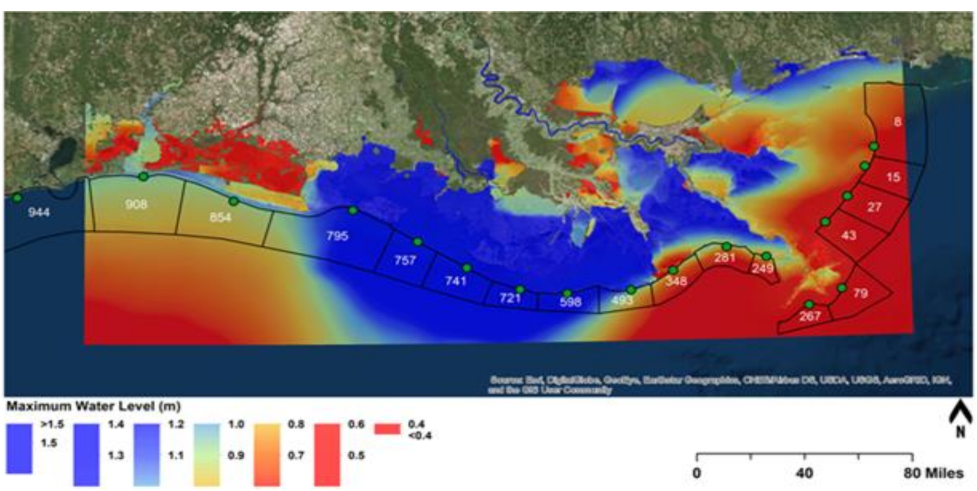


Figure 20. Maximum ADCIRC-Derived WSE for Synthetic Storm 457. ADCIRC

maximum WSEs for storm 457 with proposed ICM near-shore coupling locations/compartments superimposed.

Figure 21 displays the ICM's performance in predicting the same maximum WSEs where the ADCIRC time series data serves as an internal boundary in the near-shore of the ICM. As can be seen when comparing Figure 20 and Figure 21, there is a general agreement between the models in the distribution of maximum WSEs for this example storm. However, a notable difference in WSE magnitudes remains between the ICM and ADCIRC.

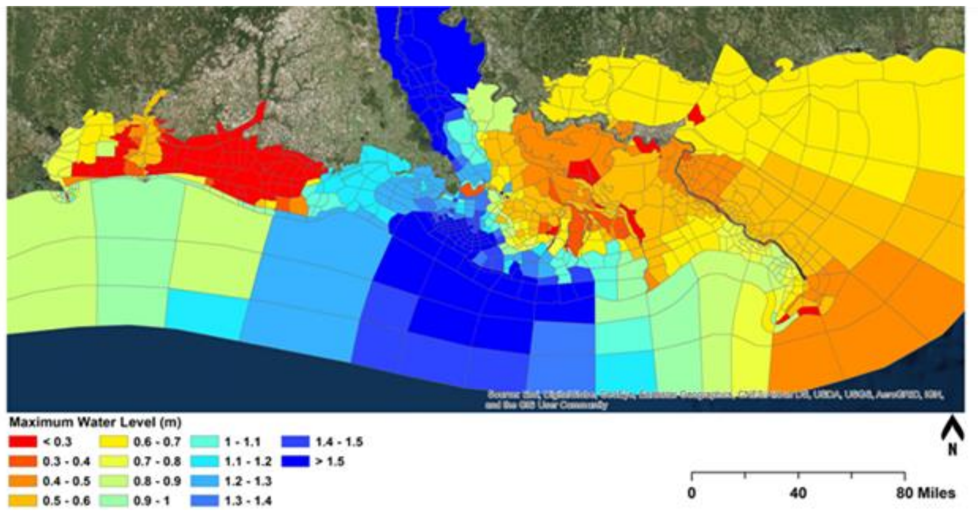


Figure 21. ICM-Derived WSE for Synthetic Storm 457. ICM test results showing maximum WSEs for storm 457 in the ICM when using the near-shore coupling locations to impose the ADCIRC-derived data as shown in Figure 15.

Although both approaches were imperfect, the test to couple ADCIRC to the ICM at the near-shore was more successful at producing water level patterns similar to observed time series than the attempt to couple ADCIRC and the ICM in the offshore area.

To further investigate the efficacy of the second method (imposing ADCIRC data at the coastline within the ICM), proof-of-concept testing was performed to determine the sensitivity of the ICM to overland flow linkage calibration. The ICM has several compartment linkage categories. Channel links and composite channel links represent channels, bayous, and other water area linkages between compartments whereas the overland links represent over-marsh flow when the WSE exceeds the bank elevation. The channel links were the focus of previous calibration/validation efforts whereas the overland links were not fully validated or calibrated. However, for considering high tide flooding events, the overland links are important since increased WSE, as seen in high tide flooding events, can lead to inundation of the landscape and create over-marsh type flow. Extensive calibration and validation would be required to enable the ICM to better match ADCIRC WSEs since there are hundreds of overland links over the entire coastal zone.

2.3 FUTURE PROJECTIONS AND MODELING TOOLS

To help determine the best path forward for an analysis using modeling tools to predict future conditions related to high tide flooding, the existing ICM and ADCIRC model were tested for their ability to capture selected historic events, whose selection was based upon the location and scale of their effects relative to focus communities. These tests indicated that either model would need adjustments to provide water levels to inform a coastwide high tide flooding analysis (or to provide outputs for a community-based analysis).

ICM IMPROVEMENTS

The WSE is affected by many natural processes in the coastal region. For example, the action of wind across the water surface results in the frictional transfer of momentum from wind to water in the form of stress applied at the free surface, generating waves and surface drift. Wind setup can occur if a steady wind pushes the surface water to a shore. Additionally, as a wave approaches the shore, its height increases due to wave shoaling as the water shallows. The effects of wind and waves were accounted for in the 2017 ICM when predicting sediment transport but not in hydrodynamic calculations. Due to the relatively large size of the offshore ICM compartments, an algorithm would be needed to include the effects of wind and waves at the sub-compartment scale in order to model these phenomena. In addition to adding new algorithms, detailed gridded wind data would be needed for all model simulations to account for wind effects on water flow. Tropical storm wind fields are generated for ADCIRC simulations, but “fair weather” wind fields are not provided – only observed wind data via the NAM data discussed in previous sections is available. To model wind effects in the ICM, additional effort is needed to identify appropriate wind fields to use as boundary conditions for future conditions.

In addition to capturing the displacement of water near the shoreline, a detailed calibration of the overland link network is needed. In previous ICM calibration/validation efforts, the focus was calibration of the primary channels and waterways to minimize the root mean square error for the calibration period. As discussed in the previous sections, the overland links become important for high water level events such as high tide flooding and hurricanes. In order to better capture water propagation for high tide flooding and other more extreme events, future efforts should be made to calibrate the secondary overland link network during periods of elevated stage using ADCIRC output from well-calibrated events.

ADCIRC SMALL EVENT VALIDATION

ADCIRC can adequately capture the effects wind on WSE but would require the development (or identification) of appropriate wind forcings assumptions to be applied to future periods. The storm surge modeling conducted in ADCIRC uses synthetic tropical cyclone events developed by the surge modeling community based on the probability of different storm characteristics in the historical record. No such statistical framework currently exists for extratropical or other meteorological events. This makes it difficult to consider any high tide flooding impacts that may reflect changes to the frequency and/or intensity of frontal events.

The ADCIRC model has been extensively applied for large tropical systems and can predict water levels during smaller, frontal events under some conditions for some parts of the coast. To understand how the model would perform for future conditions with sea level rise for the master plan analysis, smaller tropical events (or larger, bypassing events with far field effects) could be used to assess its performance for the inland portions of the model with low water depths. Previously only the portions of the model exposed to tropical storm surge-derived extreme water levels have been evaluated during large tropical cyclone validation events. In order to develop a series of representative validation events to use as proxies for “future high tide events,” several steps should be completed:

1. Estimate the extent of future high tide flooding further inland by combining sea level rise and the non-tidal component of presently occurring storms (or frontal passages) at locations further offshore;
2. Examine the historic record for storms and other meteorological events that generate the approximate inland water levels calculated in (1), and work with meteorologists to generate hindcast wind fields; and
3. Using hindcast wind fields, determine the model’s skill at predicting shallower depths for locations inland.

3.0 PHASE 2: ALTERNATIVE METHODOLOGIES FOR ANALYSIS

The approach to evaluate vulnerability and impacts for focus communities in coastal Louisiana described here, while not comprehensive in evaluating current and future risk of high tide flooding coastwide, serves as a proof-of-concept using 2017 Coastal Master Plan data to allow for the development of foundational analysis methodologies for master plan efforts. Focus communities were selected to illustrate a variety of current and future vulnerability and consequence conditions, although they may not be representative of the full spectrum of conditions present in coastal Louisiana. The approach tracks how changes in local ground elevation, basin morphology, and restoration and protection projects interact with meteorological and/or high tides to change patterns in the focus communities of high tide flooding, now or in the future.

The Phase 1 analysis revealed that existing modeling tools would require improvements to better capture observed high tide flooding events before they could be applied to predict future events with confidence. Further analysis could either be coastwide, which would require these improvements be made, or could focus on specific communities, which potentially would not. Both approaches require predicting future conditions, and both require consideration of impact thresholds and quantitative and/or qualitative metrics to evaluate impacts as well as the sensitivity to small variations in impact threshold and WSE.

A coastwide analysis requires tools for predictive modeling over the whole coast but allows for evaluation over multiple spatial scales and at any location. On the other hand, a community-based analysis involves predicting high tide flooding events, defining thresholds, and evaluating outcomes relative to specific coastal communities and allows for a simplified approach for predicting future events. Selecting focus communities also enables the definition of specific thresholds and metrics that are meaningful for those particular locations.

For Phase 2, CPRA chose to pursue evaluation of vulnerability and impacts for selected focus communities in coastal Louisiana. This approach, while not comprehensive in evaluating current and future risk of high tide flooding coastwide, serves as a proof-of-concept using 2017 Coastal Master Plan data, to allow for the development of foundational analysis methodologies for subsequent master plan efforts. Focus communities were selected for Phase 2 analysis to illustrate a variety of current and future vulnerability and consequence conditions and may not be representative of the full spectrum of conditions present in coastal Louisiana. The approach, described in more detail below, tracks how changes in local ground elevation, basin morphology, and restoration and protection projects interact with meteorological and/or high tides to change patterns of high tide flooding, now or in the future, in selected focus communities. In order to pursue a comprehensive, coastwide analysis in the future, additional work would be needed to bridge the divide between the illustrative approach described here and a fully integrated coastwide analysis.

3.1 FOCUS COMMUNITIES

Phase 2 concentrated on a revised set of focus communities as a test-case to analyze the effects of high tide flooding on the communities. These communities were selected based on the same criteria listed in Phase 1, as well as:

- Proximity to critical and essential facilities
- Presence of critical and essential facilities within the community
- Number and type of roadways connecting the community to the surrounding region

Although five focus communities were chosen for Phase 2 (Figure 22), in theory, the analysis can be performed anywhere within the ICM domain with reliable sources of WSE data nearby. Impact thresholds within these communities were either defined by stakeholders or obtained through analysis of local geography (e.g., limiting low elevations for critical access roads or protection berms, etc.). A summary of the focus communities is found below in Table 3.

Table 3. Focus Communities Selected for Community-Based Analysis.

COMMUNITY NAME	CENSUS DATA AND RESULTS FROM 2017 COASTAL MASTER PLAN ANALYSIS*	WSE DATA AVAILABILITY
AMELIA, LA	U.S. CENSUS BUREAU (2018): POPULATION SIZE IS 1,876; MEDIAN HOUSEHOLD INCOME IS $29,638; POVERTY RATE IS 27.5% 2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 45	CRMS5035; USGS FLOW IN ATCHAFALAYA RIVER AT MORGAN CITY/NOAA 8764044 (BERWICK); ICM (2017 COASTAL MASTER PLAN) HYDRO COMPARTMENT 498
CAMERON, LA	U.S. CENSUS BUREAU (2018): POPULATION SIZE IS 222; MEDIAN HOUSEHOLD INCOME IS NOT REPORTED; POVERTY RATE IS $25.5% 2017 COASTAL MASTER PLAN ANALYSIS: LESS THAN 50% LAND REMAINING BY MODEL YEAR 30; LESS THAN 25% REMAINING BY MODEL YEAR 45	USGS 08017118 (CALCASIEU RIVER AT CAMERON)/NOAA 8768094 (CALCASIEU PASS); ICM (2017 COASTAL MASTER PLAN) HYDRO COMPARTMENT 874
DELACROIX, LA	U.S. CENSUS BUREAU (2019): CENSUS TRACT POPULATION SIZE IS 296; PER CAPITA INCOME IS $20,190; POVERTY RATE IS 13.9%.	CRMS0146; NOAA 8761108 (BAY GARDENE); ICM (2017 COASTAL MASTER PLAN) HYDRO COMPARTMENT 081
DULAC, LA	U.S. CENSUS BUREAU (2019): DULAC POPULATION SIZE IS 1,154; MEDIAN HOUSEHOLD INCOME IS $35,977; POVERTY RATE IS 30.8%.	CRMS0434 – HYDRO STATION; USGS 07381349 (CAILLOU LAKE SW OF DULAC, LA); NOAA 8762075 (PORT FOURCHON); ICM (2017 COASTAL MASTER

COMMUNITY NAME	CENSUS DATA AND RESULTS FROM 2017 COASTAL MASTER PLAN ANALYSIS*	WSE DATA AVAILABILITY
		PLAN) HYDRO COMPARTMENT 425
SLIDELL/EDEN ISLE, LA	U.S. CENSUS BUREAU (2019): SLIDELL POPULATION SIZE IS 27,633; MEDIAN HOUSEHOLD INCOME IS $42,856; POVERTY RATE IS 11.8%. EDEN ISLE POPULATION SIZE IS 7,041; MEDIAN HOUSEHOLD INCOME IS $53,811; POVERTY RATE IS 9.8%.	CRMS4406; NOAA 8761402 (THE RIGOLETS); ICM (2017 COASTAL MASTER PLAN) HYDRO COMPARTMENT 037

Figure 22. Locations of High Tide Flooding Analysis Phase 2. Five focus communities (green marker) were selected for Phase 2 of the analysis.

PROJECTING FUTURE HIGH TIDE FLOODING AT SELECT LOCATIONS

As the community-based analysis was designed, it was important to keep in mind several caveats and limitations of the modeling tools currently available. The ICM is the best available tool for comprehensively assessing long-term changes in mean water levels and the physical make-up of the coastal wetland system. However, the ICM currently does not model wind-induced water surface setup, which is important for high tide flooding predictions.

Traditional flood risk analysis often makes use of impact thresholds (e.g., the top of a levee, dune, or critical landform protecting an area) and calculates the likelihood of overtopping of the threshold elevation at any point in time and the anticipated frequency of occurrence of overtopping over time to estimate statistics such as the annualized probability of exceedance. This threshold approach can be projected into the future by tracking how often thresholds are exceeded in future model runs and how the WSE percentile which they represent changes over time. For instance, the present-day 99th percentile WSE may be 6 inches below the assigned high tide flooding impact threshold, which may be at the 99.5th percentile. Over time as subsidence, land loss, and sea level rise affect water levels, the same impact threshold may be crossed more frequently. The increase in frequency over time could be quantified by calculating WSE percentiles for each year of the future model run and be compared to the threshold.

A potential shortcoming of this approach is that present-day events that often lead to thresholds being crossed are acute meteorological events. The ICM is currently capable of modeling hydrological response to tides, sea levels, precipitation, and river hydrographs, while the effects of strong winds on water surface are not captured. Since high tide flooding typically lasts hours rather than days, the resolution of the timestep used to track the frequency of threshold exceedance is also important. The ICM model operates on a 30 second timestep, but the ICM is calibrated to daily mean WSE values. Thus, the model improvement team determined that an approach for considering high tide flooding impacts that is less reliant on frequency analysis and instead focuses on the consequences of occurrence would be warranted.

DEFINITION OF IMPACT THRESHOLDS AND CONSEQUENCES

The analysis focused on capturing consequences that can be reasonably predicted when high tide flood events exceed impact thresholds into the future. Rather than focus on a single impact threshold per focus community (like a berm or bulkhead low spot), the model improvement team chose a network analysis approach, which characterizes the community’s ability to access critical and essential facilities (e.g., hospitals, emergency services, groceries, pharmacies, etc.) during high tide flooding events. In this way, all low areas of the transportation network are accounted for and essentially become impact thresholds. For this approach, digital elevation models (DEMs) and mean annual WSE data from the ICM (from the 2017 Coastal Master Plan Future Without Action (FWOA), Medium Scenario run) were adjusted using long-term seasonal high tide data from nearby observation stations, which were then used to generate flood depths over the roadway system with Environmental Systems Research Institute (ESRI) ArcGIS (GIS) software. Depths were generated for Years 10, 25, and 50 to predict disruption to access and drive times to critical and essential facilities. Further discussion of the approach to generate the WSE and depth information can be found in Section 3.3.

3.2 EVALUATING IMPACTS

IDENTIFYING AND DEFINING METRICS AND CONSEQUENCES

Another consideration for defining metrics is consistency with other modeling efforts (e.g., storm surge modeling and risk assessment) to help with clear communication of risks. Given their frequency and lack of consistent reporting methods, quantitative metrics and data on impacts of high tide flooding events are generally lacking. Developing risk metrics for high tide flooding is critical to understanding its impacts. The development of appropriate metrics could also allow the integration of economic damage from high tide flooding estimates with those from storm surge events within the Coastal Louisiana Risk Assessment model (CLARA).

Metrics can be quantitative or qualitative, but quantitative evaluation of flooding impacts is limited by the ability of modeling tools to make predictions and provide outputs. The outputs of this evaluation include a quantitative assessment of the degree of disruption high tide flooding may have on local residents' daily lives.

An integrated risk and resilience index for southeast Louisiana that adapts the traditional perspective of risk assessment to incorporate aspects of social vulnerability and resilience is currently under development (Hemmerling et al., 2020). This work includes an array of metrics to describe the impacts of flooding in quantitative ways that augment local knowledge and accounts of these events. It was used here to categorize potentially relevant variables by intensity of flooding in order to focus on those that might be most relevant to high tide flooding events. This current analysis focuses on the degree to which high tide flooding disrupts normal physical, social, and administrative routines within potentially affected areas (Paton, 2006). A working severity scale was developed to better understand the potential range of disruptive impacts on communities from high tide flooding. Three main categories of disruption were identified:

- **Minor:** Impacts range from minimal water on streets (less than 6 in) to disruption of essential facilities for minutes to hours.
- **Moderate:** Impacts range from water on streets/roads (more than 6 in) to disruption of critical facilities for minutes to hours.
- **Severe:** Impacts range from water on state highways and interstates to disruption of critical facilities for hours. It should be noted that events within this category are likely inappropriate to consider as high tide flooding events under present conditions.

For the purposes of this high tide flooding analysis, critical facilities are defined as those considered important for short-term response operations while essential facilities are defined as those considered important for long-term recovery of the community (Hemmerling et al., 2017). Critical facilities include those used for public safety purposes, medical services, and infrastructure maintenance while essential facilities include those that provide for basic necessities or serve government functions (Wood, 2007).

While the categories described above can be useful for communicating the potential extents and magnitudes of high tide flooding, the specific impact thresholds must be defined locally. For example, the analysis makes clarifying assumptions about the average height of the tailpipe or chassis of vehicles (approximately 6 inches) for the purpose of understanding at what point vehicles flood, but it is necessary to understand the ground elevation and elevation of infrastructure such as roads to fully understand impacts. These assumptions can be validated through additional community-based level analyses of natural and infrastructure thresholds.

Here impact is considered a function of the disruption of access to critical or essential facilities and residences from high tide flooding, concentrating on access and service coverage. These are the two aspects of facility location that are key to examining the local impacts of high tide flooding.

Access broadly refers to the ease of residents reaching a critical or essential facility or, in the case of emergency response, the ease of first responders reaching the place where an emergency occurs (Yao et al., 2019). The question of access becomes critical during flood events when key thoroughfares or streets may become impassable.

Service coverage is related to the maximum influence area of a facility defined by either spatial distance or travel time. Coverage models usually involve a service standard reflecting the spatial extent that demand sites can be reached by at least one facility.

Travel time between facilities and residents is a critical factor in calculating accessibility. Many indicators are used to represent travel distance, such as straight-line/Euclidian distance, shortest network distance, and travel time (Gao et al., 2016). In terms of coverage standard, previous studies have indicated that straight-line distance can be a satisfactory surrogate of network travel time and this has been commonly adopted in fire station siting (Yao et al., 2019). To assess the local impacts of high tide flooding, however, straight line distance is not an adequate measure for service coverage of a facility due in large part to the local, neighborhood-scale impacts of street flooding on accessibility. This analysis therefore utilized travel time to assess both access and service coverage. Travel time is dependent on road infrastructure, transport mode, and area topography.

The initial proof-of-concept analysis was split into two paths:

- The primary focus path of definition of disruptions to the community via a network drive time analysis and,
- The secondary path of investigation of threshold exceedance over time to help inform how the frequency of occurrence of such high tide flooding events may change over the 50-year planning horizon of the master plan.

3.3 METHODS: FLOOD DEPTH DEFINITION

The network analysis framework requires flood depths as a primary input but is generally agnostic to how those flood depths were derived. Since this effort was a proof-of-concept analysis to use readily available data from the 2017 Coastal Master Plan, the model improvement team chose to use mean annual WSE data from select ICM grid compartments adjusted to reflect a water level comparable to a high tide flooding event. Figure 23 and Figure 24 show example 2017 ICM compartments and WSE time series verification for Cameron, LA.

Figure 23. 2017 ICM Compartments in the Vicinity of Cameron, LA.

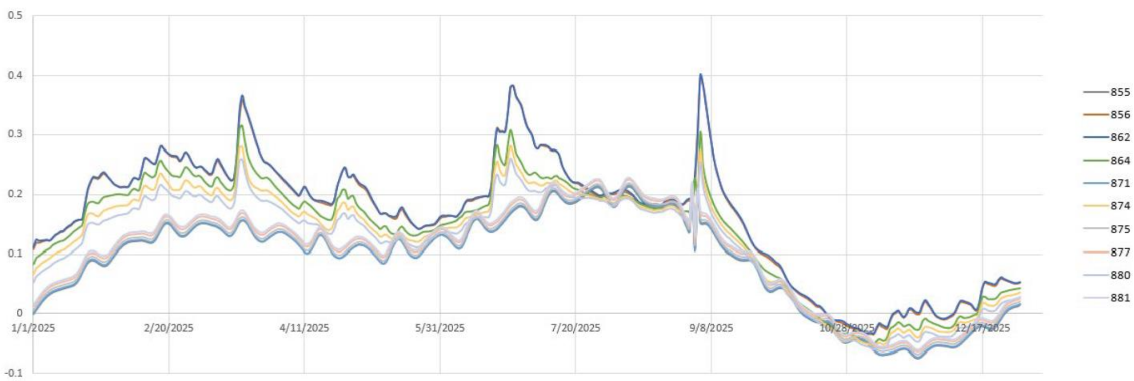


Figure 24. 2017 ICM Compartment WSE Time Series for Cameron, LA.

FLOOD DEPTH GENERATION IN SUPPORT OF NETWORK DRIVE TIME ANALYSIS

The model improvement team devised a simple method to modify available 2017 ICM data to be representative of a high tide flooding event possible in each of the three model years selected for the analysis. An adjustment factor was required to modify the mean annual time series data to reflect a high tide flooding event. This methodology was focused on supporting the drive time analysis proof-of-concept. Should the drive time analysis be pursued further, alternative, more rigorous WSE adjustment strategies may be appropriate.

For a simple adjustment, the model improvement team compared the seasonal and daily tidal ranges at 2017 ICM compartments corresponding to the focus communities (Table 4).

Table 4. ICM Compartments Corresponding to the Focus Communities.

Focus Community	ICM ID
Amelia	498
Cameron	874
Delacroix	81
Dulac	425
Slidell	37

For all high tide adjustment factors, seasonal tide range variation from the ICM generated WSEs was calculated at each focus community's ICM compartment. Half of the sum of the seasonal variation and daily variation ranges was added to the mean annual WSE data from the ICM for Years 10, 25, and 50 to generate WSEs exceeding most daily and seasonal tidal events but with magnitudes reflective of high tide events. Mean daily tidal ranges were obtained from proximal NOAA stations (Table 5).

Table 5. Tidal Stations and Adjustment Factors used for the Generation of High Tide Flood Depths.

Location	NOAA Station	Daily variation range (ft)	Seasonal variation range (ft)	Adjustment value (ft)
Amelia Yr. 10	8764044	0.45	2.13	1.29
Amelia Yr. 25	8764044	0.45	1.64	1.05
Amelia Yr. 50	8764044	0.45	0.49	0.47
Cameron	8768094	1.21	0.89	1.05
Delacroix	8761108	1.34	0.72	1.03
Dulac	8762075	1.17	0.77	0.97
Slidell	8761402	0.67	0.76	0.72

A simplifying assumption was made to hold the adjustment factor used to generate the high tide flooding water levels generally unchanged across the period of analysis. In reality, each community will likely experience varying extents of increases or even decreases in the magnitudes of high tide flood levels experienced based on coastal changes in the coming decades. Some communities may become exposed to increased fetch due to wetland loss, allowing frontal winds to drive larger amounts of setup into a community. Some communities may experience other tidal effects due to the implementation of diversions or other large-scale restoration features in a basin. Table 6 displays the adjustment factors used in the analysis.

Table 6. Adjusted High Tide WSE Compared to Year 10 ICM Mean Daily Data.

		Adjusted Local Impact Threshold (ft)	Year 10 ICM Mean Daily WSE (ft) and Percentiles				
ICM ID	Place	Year 10	50th	90th	95th	99th	max
498	Amelia	2.77	1.39	1.96	2.01	2.10	2.13
874	Cameron	1.58	0.53	0.72	0.76	0.89	0.93
81	Delacroix	1.55	0.52	0.75	0.78	0.86	1.18
425	Dulac	1.44	0.47	0.63	0.72	1.12	1.39
37	Slidell	1.17	0.46	0.71	0.74	0.77	1.32

Should this process be used to update the analysis using the 2023 ICM, the steps of analyzing multiple proximal ICM compartments to each community would need to be repeated to select the best time series for use in the drive time analysis.

Cameron, Delacroix, Dulac, and Slidell/Eden Isle are primarily coastal-dominated systems, where seasonal tidal variation is expected to be consistent over time. As sea level rises and the geography of the coast changes, it is assumed that these four communities will continue to experience current or relatively similar seasonal tidal variation. A single high tide adjustment factor was applied to each of these locations.

Amelia, in the present condition, is in a primarily riverine-dominated system and experiences larger seasonal variation in water levels compared to the other focus communities. As sea level rises and the coast retreats landward, Amelia is assumed to experience a progressive conversion to a more coastal-dominated system and decreasing seasonal tidal variation. Because of this, a variable high tide adjustment factor was applied that decreases from Year 10 to Year 50.

The variation in factors that influence seasonal WSE across the focus communities is important when considering how high tide flooding will occur coastwide over the coming decades: each focus community will likely experience different frequency and magnitude of impacts due to its unique geographic and hydrologic characteristics.

The next step in the high tide flood depth generation was to apply the adjustment factors to the WSE raster and to subtract the corresponding land surface elevation data from the same year (Year 10 (Table 6), 25 (Table 7), or 50 (Table 8)) from the high tide flood depth raster.

The adjustment was applied to the entire domain to ensure that all relevant facilities were considered. In some instances, the adjusted high tide WSE exceeded the maximum mean daily WSE from the ICM for the corresponding year. For example, in Dulac at Year 10, the adjusted high tide WSE used for the network drive time analysis was 1.44 ft (Table 6). The 99th percentile WSE from the ICM's daily time series for compartment 425 was 1.12 ft, and the maximum WSE in the daily time series was 1.39 ft.

However, the high tide WSE experienced in Year 10 would be below the 50th percentile WSE by Year 50 (Table 8). This means that changes could occur in the 40 years between Year 50 and Year 10 such that the elevation of flood waters from a high tide event in Year 10 would not even be the average daily WSE by Year 50 (e.g., high tide type water levels in Year 10 would be the daily norm and occur more than half the time by Year 50).

Table 7. Adjusted High Tide WSE Compared to Year 25 ICM Mean Daily Data.

		Adjusted Local Impact Threshold (ft)	**Year 25 ICM Mean Daily WSE (ft) and Percentiles**				
ICM ID	Focus Community	Year 25	50th	90th	95th	99th	max
498	Amelia	3.18	1.80	2.20	2.27	2.51	2.68
874	Cameron	2.09	1.03	1.25	1.28	1.47	1.76
81	Delacroix	2.03	1.00	1.25	1.28	1.32	1.38
425	Dulac	1.96	0.99	1.16	1.28	1.51	1.68
37	Slidell	1.71	1.00	1.25	1.30	1.33	1.35

Table 8. Adjusted High Tide WSE Compared to Year 50 ICM Mean Daily Data.

		Adjusted Local Impact Threshold (ft)	**Year 50 ICM Mean Daily WSE (ft) and Percentiles**				
ICM ID	Focus Community	Year 50	50th	90th	95th	99th	max
498	Amelia	3.65	2.28	2.40	2.44	2.53	2.57
874	Cameron	3.11	2.05	2.25	2.28	2.50	2.60
81	Delacroix	3.10	2.07	2.30	2.33	2.37	2.57
425	Dulac	3.03	2.06	2.16	2.24	2.39	2.49
37	Slidell	2.89	2.17	2.40	2.44	2.46	2.47

ASSIGNING WATER SURFACE ELEVATION TO ROADWAY NETWORK

The flood depth rasters created in previous steps were associated with an existing roadway features in ArcGIS. Because this base roadway network did not contain elevation information, and segments of roadways elevated above the base ground elevation would be inappropriately designated as flooded from ICE WSE outputs, an elevated roadway dataset was manually created. This was done separately from the base roadway network (to preserve important field attributes) via photogrammetric analysis. This static dataset for bridges, causeways, etc. was merged back into the year-specific roadway networks prior to running the network analysis geoprocessing tools.

Roadway features were assigned minimum, maximum, and mean flood depths (i.e., height of the water surface above ground level) corresponding to 10, 25, and 50 years in the future. A bilinear interpolation method was used to assign values from the continuous raster surface (flood depths) to the vector feature (roadway features) based on the nearest four cells in the raster.

Flooded roadways were isolated and removed from the base (i.e., unflooded) roadway network based on a depth criterion of 0.5 ft (0. 15 m) which indicated minor flooding likely to impact network connectivity. This depth criterion calculation, performed across the entire roadway network, essentially functions as a network of impact thresholds for each focus community for determining loss of accessibility. To ensure the approach was tested across communities, maximum flood depths were used for each ICM year. This process resulted in a unique roadway dataset for each timestep (Years 10, 25, and 50). Two unique impact variables were assigned to the output network datasets: a time-dependent cost (‘Minutes’) and a distance-dependent cost (‘Length_Miles’). A singular restriction was assigned that limited the flow based on real world transportation patterns along one-way highways and roads.

3.4 METHODS: POPULATION DISRUPTION IMPACTS ANALYSIS

POPULATION INTERPOLATION

To assess the local impacts of high tide flooding, it is necessary to have spatially accurate population location data. The decennial census and the American Community Survey provide the most accurate accounting of population currently available. Data at the census block level is only available in the decennial census, most recently released in 2010. Many census blocks contain broad areas of unpopulated land, particularly in rural locations, necessitating additional geospatial analysis of the census data. Utilizing dasymetric mapping techniques, this research interpolated and disaggregated the block group population counts to smaller areal units (e.g., CLARA grid cells) for each of the Phase 2 focus communities (Mitsova et al., 2012).

DRIVE TIME ANALYSIS

This analysis utilized the Closest Facility function from ESRI’s Network Analyst (Nicoară & Haidu, 2014). The Closest Facility analysis uses a multiple-origin, multiple-destination algorithm based on Dijkstra's algorithm. The algorithm searches for the distance from the starting point to every other vertex until it reaches the destination point and gives the shortest path possible. This makes the rapid calculation of the most appropriate route as well as other functions like closest facility possible. The object of this analysis was to determine the shortest paths along the street network from residential locations (represented by populated CLARA grid centroids) to essential facilities as well as from critical facilities to all locations within each focus community. The algorithm was first run using a network dataset with no anticipated flood impacts, which established baseline conditions. This was repeated with the flood depth datasets developed for Years 10, 25, and 50. The outputs of each of these analyses were further analyzed to estimate both the proportion of land area cut off by flooded streets and the number of residents impacted. By including both variables, this analysis can be used to assess both commercial and residential impacts. Details of the analysis can be found in Appendix C.

3.5 IMPACT THRESHOLD EXCEEDANCE FREQUENCY

Understanding the impacts of disruption to communities only paints a partial picture of the challenges they face. The network analysis described in Appendix C helps answer the questions concerning what could happen if high tide flooding occurs, but it looks at broad areas where the entire road network creates impact thresholds for a community. It does not answer the question of how often those thresholds will be exceeded in the future. A better understanding of how the frequency and likelihood of high tide flooding events may change in the future is also required to help community stakeholders plan and adapt.

Many communities across coastal Louisiana currently have some level of protection from more-or-less “normal” tidal waters and are generally not negatively impacted at these levels. Other communities may be susceptible to flooding and negatively impacted at lower WSEs than analyzed here, for example due to local conditions not reflected in the ICM model grid. Through stakeholder input, it was evident that some communities have informal impact thresholds that are widely known to the locals, such as the Dulac Community Center’s parking lot or the Cameron Ferry landing. Each of these places is a specific location where a distinct loss of function or use is affected by high tide flooding.

A more complete understanding of high tide flooding impacts would be gained with additional on-the-ground stakeholder input on local impact thresholds for high tide flooding disruption that could be used in future work to further define how flood frequencies may change with time. Based on initial stakeholder input and model improvement team research for the focus communities, 2017 ICM output was used to generate example impact thresholds and adjust them into the future to account for subsidence.[3] As noted previously, these impact thresholds are not intended to be a universal metric for predicting loss of function. Specific impact thresholds for each community and a summary of the time series data used in the analyses can be found in Table 9. It should be noted that due to uncertainty associated with the ground and WSE values used for calculations, exceedance frequency results should be used to inform anticipated trends rather than explicit counts of critical threshold exceedances in future years.

Table 9. Example Community Impact Thresholds.

[3] Please note, the 2023 Coastal Master Plan will release new spatially variable subsidence rates and thus, the rates, area of variation for the rates, and ultimate land surface elevation change over time is all subject to revision.

	ADJUSTED LOCAL IMPACT THRESHOLD (FT NAVD88 GEOID12A)				
COMMUNITY	LOCATION	YEAR 10	YEAR 25	YEAR 50	SOURCE FOR THRESHOLD VALUE
AMELIA	91.1223188°W 29.6652483°N	2.32	2.17	1.93	MODEL IMPROVEMENT TEAM SELECTION, LIDAR DATA
CAMERON	93.3445936°W 29.8035394°N	2.28	2.09	1.89	STAKEHOLDER INPUT CONCERNING ACCESS VIA ROAD AND FERRY, LIDAR DATA
DELACROIX	89.7645882°W 29.7894528°N	2.43	2.21	2.10	SOCIAL MEDIA AND MEDIA POSTS CONCERNING ACCESS TO LOWER ST. BERNARD COMMUNITIES, LIDAR DATA
DULAC	90.715169°W, 29.3728596°N	1.86	1.80	1.77	REPETITIVE HIGH TIDE FLOODING REGULARLY IMPACTS COMMUNITY CENTER ACCESS (STAKEHOLDER INPUT), LIDAR
SLIDELL	89.7479635°W 30.2229652°N	1.62	1.45	1.43	MODEL IMPROVEMENT TEAM SELECTION, LIDAR DATA

By Year 25, the impact thresholds typically are within 0.5-1.0 ft of the 50th percentile water level for a given year, which is within the typical normal tidal range for most of coastal Louisiana. By Year 50, the impact thresholds are all below the 50th percentile water levels indicating that high tide flooding will occur frequently and perhaps even the majority of the year.

4.0 IMPLEMENTATION DISCUSSION FOR THE 2023 COASTAL MASTER PLAN

The work presented in this document explores methodologies for incorporating high tide flooding into the broader analysis framework of the 2023 Coastal Master Plan. It coalesces around the idea of communicating the impacts of disruption to communities using methods tested by generating relationships between high tide flooding events and access to critical and essential facilities using existing 2017 Coastal Master Plan outputs. This section contains discussion and possible paths to incorporate this work into the 2023 Coastal Master Plan analysis.

There are a range of possible options for how this work, or ideas stemming from this work, could be incorporated into the 2023 Coastal Master Plan. The simplest option is to reproduce the Phase 2 drive time analysis using updated 2023 data, either for the same five focus communities in Section 3, or for an expanded set of communities. This would require some adjustment, such as researching the most relevant ICM compartment(s) to use for WSE data since many compartment boundaries have been refined since 2017. There are, however, multiple achievable improvements that can be incorporated in addition to a reproduction of the drive time analysis. These improvements can be categorized broadly into hydrodynamic and statistical improvements related to flood depths and socioeconomic and damage assessment improvements related to the monetization of disruptions caused by high tide flooding.

To reproduce the drive time analysis and community disruption metrics described in Section 3 and Appendix C, the following steps would need to occur:

- Consider the revised ICM compartment boundaries and re-run checks of the WSE time series data for appropriateness of use; select the new appropriate ICM compartment WSE data
- Update the input DEM, WSE rasters, and high tide flood depths with new 2023 data
- Update all block-level population data as 2020 decennial census products are released. These data will be released by the U.S. Census Bureau on a state-by-state basis throughout 2021 and 2022.
- Re-run the analysis and produce figures

From these inputs, a series of narrative community vignettes or storylines could incorporate community input to help local stakeholders understand what adaptations and hurdles lie ahead.

4.1 HYDRODYNAMIC AND STATISTICAL ANALYSIS NEXT STEPS

The proof-of-concept analysis described in Phase 2 selects a single WSE per year for Years 10, 25, and 50. However, future analyses are not limited to such a timestep. The network analysis processes could be automated via Python coding or similar so that the process uses a series of timesteps — for example, monthly or daily data across any series of selected years. This method would generate much larger quantities of data in terms of flood surfaces, flooded network data, and the resulting drive time data presented in Appendix C. From this larger amount of data, statistical analysis could be performed to report what percentage of days or months in a year may experience high tide flooding events. The steps would be similar to those listed in the bullets above, but with an added bullet at the end to perform statistical analysis within a given year and across all selected years for disruption frequency. This analysis could also replace or augment the simpler frequency analysis presented in Section 3.5 with a more robust method.

4.2 DEVELOPING HIGH TIDE FLOODING RISK/DAMAGE QUANTIFICATION METHODOLOGY NEXT STEPS

The proof-of-concept drive time analysis described in this report evaluated potential disruption to community function. Quantification or monetization of damages was not considered. Major damages usually begin with inundation depths greater than 2 ft. This analysis focused on interruptions caused by flood depths between 0.5 and 2 ft. Determination of monetized direct flood damage impacts would require appropriate depth-damage functions for short-duration events by asset type, which may not be available for all asset types of interest.

An initial proposal was to calculate event frequencies coastwide, incorporate monetized impacts into Expected Annual Damage (EAD) calculations, and estimate metrics related to disruption for both decision analysis and reporting. The major building blocks that would need to be generated to accomplish this strategy are:

- Further development of the modeling suite to fully capture high tide flood events in order to define event frequencies
- Generate depth-damage curves for short duration, low magnitude events like high tide flooding for a range of applicable assets
- Generate a strategy to incorporate and code EAD values into the broader CLARA framework

While not insurmountable, these steps would represent a significant investment in time of both the high tide flooding and broader risk reduction/CLARA teams not only to generate a working system of analysis, but also to generate the appropriate communication and reporting around the results.

Another, simplified approach would be to focus on measuring disruption versus monetized impacts (e.g., similar to how critical infrastructure vulnerabilities were assessed in the 2017 Coastal Master Plan). Since the output from the ICM and ADCIRC analysis is not able to support a coastwide probabilistic evaluation at this time, it makes sense for metrics to focus on disruption or other qualitative descriptors, without a corresponding EAD analysis.

Additionally, incorporating monetizable disruption impacts into estimates of EAD requires that impacts can be estimated coastwide along with a frequency of occurrence. This is requires that the statistical calculations can be simplified since the frequencies for high tide flooding impacts do not overlap with the frequencies covered for cyclonic storm surge events (i.e., analysis is restricted to roughly one year and more frequent events for high tide flooding). Even with this restriction, the joint probability of extreme high tide flooding and storm surge could be analyzed to assess whether existing methods for incorporating tidal variation into CLARA's statistical analysis are still sufficient when considering, for example, the coincidence of spring tides and frontal events. Additional exploratory analysis would be required to confidently assess the level of effort involved with this approach. Implementing this strategy would require conducting joint probability analysis of extreme high tide flooding and storm surge events to compare to tidal variation methods in CLARA.

Future efforts may build upon this work to also characterize damage (monetized). Qualitative evaluation could also be expanded to involve acquiring first-hand experience of high tide flooding, and this information could be used to:

1. Identify key facilities that affect community resilience
4. Validate WSE thresholds for community flooding, and
5. Provide a community-based understanding of the impacts of high tide flooding.

Additionally, uncertainty around future weather patterns (frequency and/or intensity of frontal events) could be incorporated into scenario development and handled within the CLARA framework in a manner consistent with changes to intensity and frequency for tropical cyclone events.

4.3 POSSIBILITIES FOR PROJECT SELECTION AND PLANNING TOOL APPLICATION

In previous planning cycles, CLARA has been used to estimate direct economic impacts associated with flooding. EAD calculations generally are restricted to the costs associated with repairing damage to an asset, reconstructing it, or replacing it, as well as costs incurred during the time period required to make the asset whole again (e.g., lost sales/rents, temporary housing costs while displaced). Damage to vehicles or structures that require repair, for example, could be integrated into estimates of EAD, provided that the frequency of these impacts can also be estimated. Such a scheme would need to be devised for incorporation into the 2023 Coastal Master Plan. Other metrics, such as traffic delays or disruption of access to public services, may represent new measures that expand the scope of risks modeled as part of the master plan process. Some of these could potentially be monetized and folded into existing risk metrics.

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APPENDICES

APPENDIX A: PHASE 1 ANALYSIS DETAILS FOR SELECTED FOCUS COMMUNITIES

AMELIA, LA

From 2008 through 2019 (i.e., CRMS-era time period), a total of 15 events (Figure 25) were identified as having crossed a high tide WSE threshold value of +2.1 ft NAVD88 at CRMS5035, which is located on the banks of the GIWW approximately 2.8 river miles east of Bayou Chene (Table 10). Each of these events coincided with a distinct onshore wind signal (Figure 26).

Of these 15 events, four were identified as named tropical events based on timing and water levels, and were therefore removed from the data set for additional analysis. The remaining 11 events were then identified as possible high tide flooding events at this location. Seven of these 11 events occurred when the Atchafalaya River was at flood stage (defined by the National Weather Service (NWS) as +6 ft NAVD88 at Morgan City), including several examples of the flood stage occurring coincident with a cold front or MCS. The four remaining events occurred when the Atchafalaya River was lower than flood stage and a MCS or cold front was present, resulting in WSE exceeding the locally relevant threshold (+2.1 ft NAVD88) (Figure 27 and Figure 28).

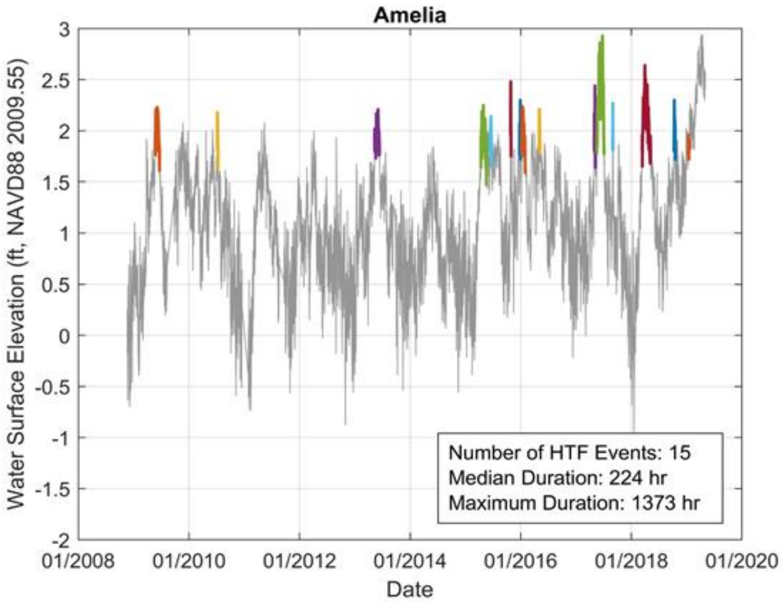


Figure 25. Possible High Tide Flooding Events Shown for the Area of Amelia, LA. Each possible high tide flooding event is indicated by a colored segment of the WSE time series. Exceedance of the local WSE threshold (Table 3) was determined from WSE measurements at CRMS gage CRMS5035.

Table 10. High Tide Flooding Events at CRMS5035 (Amelia).

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	START DATE	END DATE	DURATION (HR)	MAX WSE REACHED (FT NAVD88)	COMMENTS *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
1	5/23/2009 0:00	6/21/2009 20:00	716	2.2	ATCHAFALAYA RIVER @ FLOOD STAGE IN MORGAN CITY
2	7/6/2010 8:00	7/13/2010 0:00	160	2.2	MCS
3	5/10/2013 21:00	6/12/2013 4:00	775	2.2	ATCHAFALAYA RIVER @ FLOOD STAGE IN

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	START DATE	END DATE	DURATION (HR)	MAX WSE REACHED (FT NAVD88)	COMMENTS *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
					MORGAN CITY
4	4/13/2015 0:00	5/21/2015 3:00	915	2.2	ATCHAFALAYA RIVER NEAR FLOOD STAGE IN MORGAN CITY
5*	6/12/2015 19:00	6/22/2015 18:00	239	2.1	BILL
6*	10/25/2015 21:00	10/29/2015 14:00	89	2.5	REMNANTS OF PATRICIA
7	12/23/2015 8:00	1/1/2016 6:00	214	2.3	COLD FRONT
8	1/7/2016 16:00	1/30/2016 2:00	538	2.2	ATCHAFALAYA RIVER @ FLOOD STAGE IN MORGAN CITY
9	4/30/2016 20:00	5/7/2016 17:00	165	2.2	COLD FRONT
10A	4/30/2017 0:00	5/7/2017 15:00	183	2.4	COLD FRONT
10B	5/17/2017 21:00	7/4/2017 13:00	1144	2.9	ATCHAFALAYA RIVER @ FLOOD STAGE IN MORGAN CITY
12*	8/29/2017 16:00	9/1/2017 14:00	70	2.3	HARVEY
13	3/11/2018 20:00	5/8/2018 1:00	1373	2.6	ATCHAFALAYA RIVER @ FLOOD STAGE IN MORGAN CITY

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	**START DATE**	**END DATE**	**DURATION (HR)**	**MAX WSE REACHED (FT NAVD88)**	**COMMENTS** *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
14*	10/8/2018 12:00	10/17/2018 20:00	224	2.3	MICHAEL
15	1/11/2019 2:00	1/17/2019 6:00	148	2.0	ATCHAFALAYA RIVER @ FLOOD STAGE IN MORGAN CITY

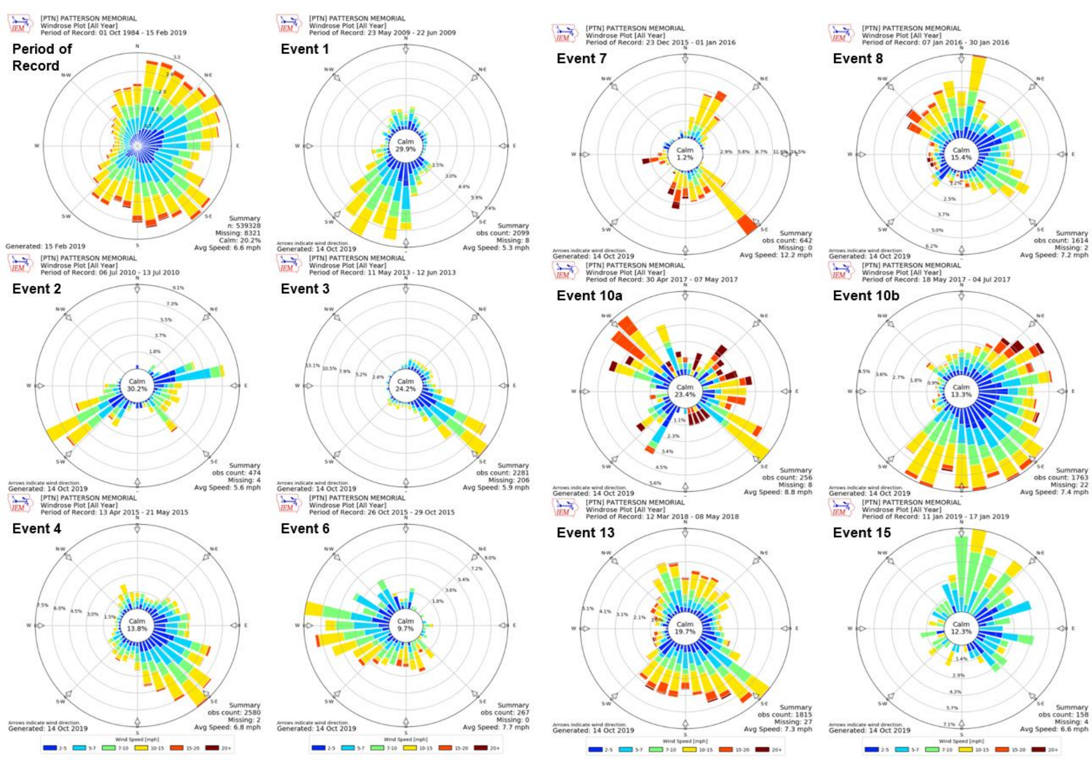


Figure 26. Wind Roses Showing Wind Speed and Direction for each High Tide Flooding Event in Amelia.

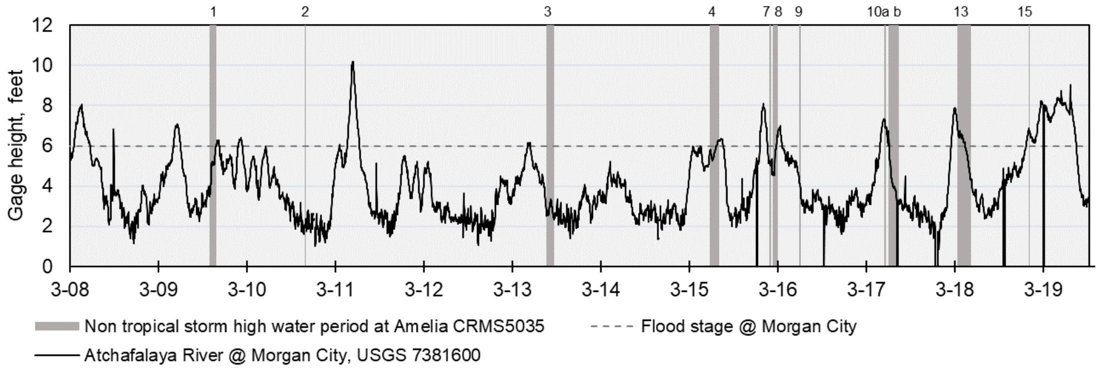


Figure 27. Atchafalaya River Stage at Morgan City (USGS 7381600) and Identified High Water Periods at CRMS5035 near Amelia. Identified high water periods frequently occurred during a period where both the river was high and a meteorological event occurred; but high stage in Morgan City was not, by itself, an indicator of the WSE threshold being exceeded at CRMS5035.

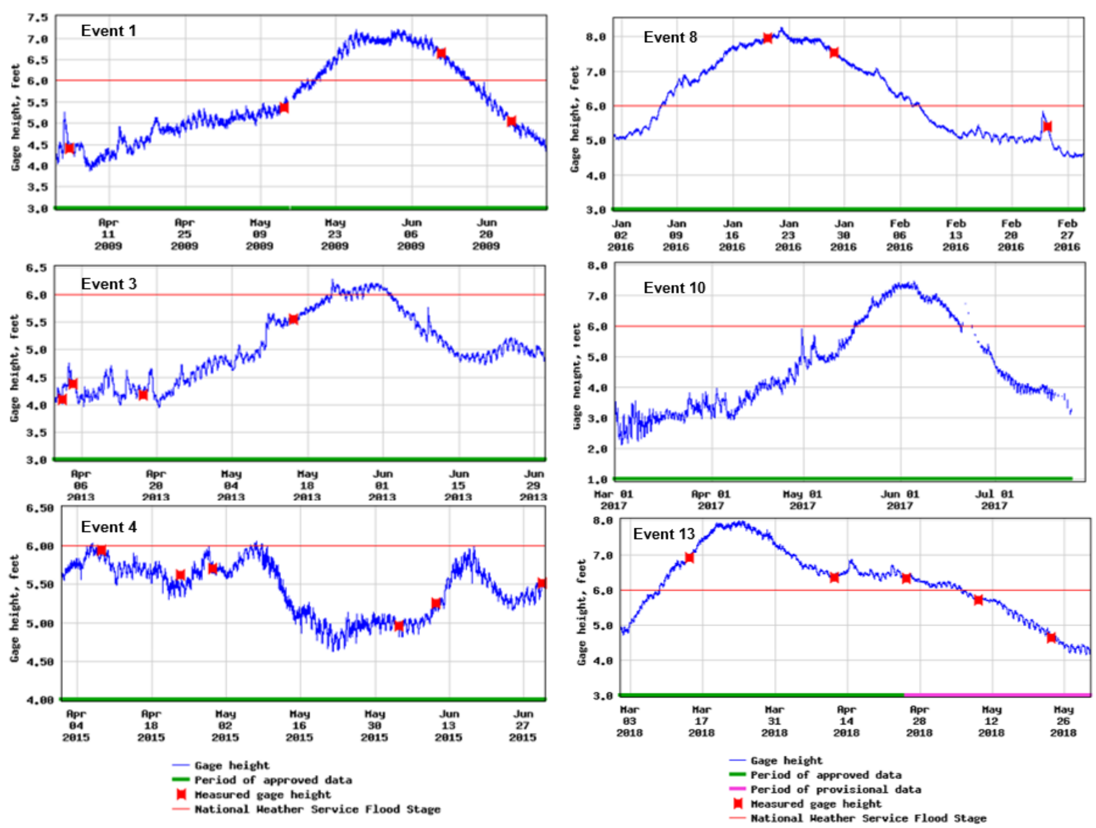


Figure 28. Gage Height Hydrographs for the Atchafalaya River at Morgan City for Periods Exceeding Flood Stage.

CAMERON, LA

From 2008 through 2019, 22 events (Figure 29) were identified as having crossed a high tide WSE threshold of +3 ft NAVD88 at NOAA8768094 (Table 11). One additional event (Hurricane Ike) was excluded from this table due to the observed WSE exceeding the “extreme threshold” described above, indicating a direct storm surge signal on the observation data. Of the 22 events identified, 11 were named tropical events, whereas the remaining 11 events were cold fronts or MCSs which resulted in the WSE threshold of +3 ft NAVD88 being exceeded. Each of these events showed an onshore wind signal (Figure 30).

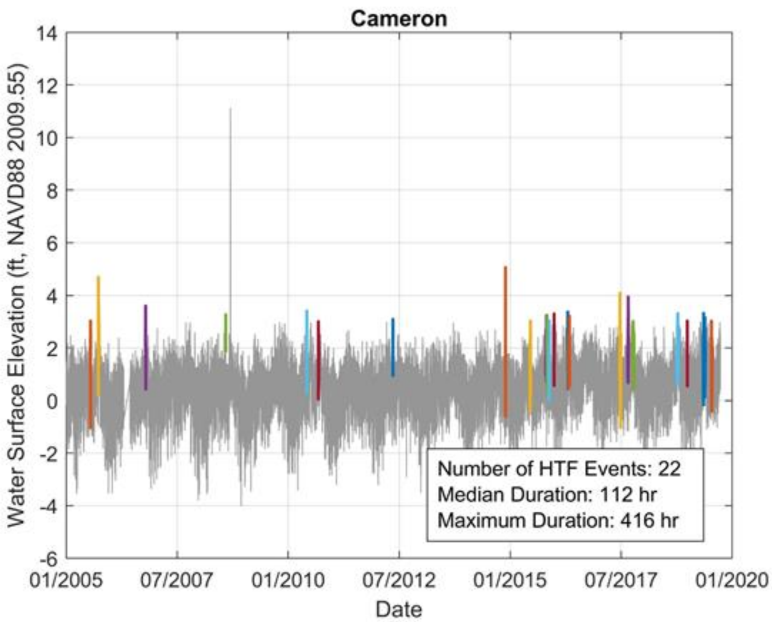


Figure 29. Possible High Tide Flooding Events Shown for the Area of Cameron, LA. Each possible high tide flooding event is indicated by a colored segment of the WSE time series. Exceedance of the local WSE threshold (Table 3) was determined from WSE measurements at NOAA gage 8768094 at Calcasieu Pass.

Table 11. High Tide Flooding Events at NOAA8768094 (near Cameron).

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.

EVENT NUMBER	START DATE	END DATE	DURATION (HR)	MAX WSE REACHED (FT NAVD88)	COMMENTS *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
1*	7/19/2005 6:54	7/22/2005 13:18	78.4	3.1	EMILY
2*	9/22/2005 10:00	9/30/2005 12:42	194.7	4.7	RITA
3	10/15/2006 3:36	10/19/2006 8:18	100.7	3.6	COLD FRONT - LOCATION OF CYCLOGENESIS WAS GOM, IT'S A GULF FRONT, MEANING YOU'RE CLOSER TO THE CENTER OF LOW, MEANING HIGHER WIND SPEEDS
4*	8/5/2008 8:06	8/5/2008 16:06	8	3.3	EDOUARD
5	6/3/2010 11:42	6/3/2010 15:36	3.9	3.4	MCS
6*	9/6/2010 6:24	9/9/2010 22:42	88.3	3.0	HERMINE
7	5/11/2012 11:06	5/12/2012 0:42	13.6	3.1	COLD FRONT
8	11/22/2014 23:24	11/23/2014 23:06	23.7	5.1	COLD FRONT
9*	6/12/2015 16:36	6/18/2015 13:00	140.4	3.0	BILL

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	**START DATE**	**END DATE**	**DURATION (HR)**	**MAX WSE REACHED (FT NAVD88)**	**COMMENTS** *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
10*	10/20/2015 2:06	10/26/2015 7:42	149.6	3.2	REMNANTS OF PATRICIA + COLD FRONT
11	10/30/2015 23:36	11/2/2015 5:42	54.1	3.2	COLD FRONT
12	11/15/2015 0:06	11/19/2015 2:42	98.6	3.1	COLD FRONT
13	12/26/2015 21:48	12/28/2015 6:24	32.6	3.3	COLD FRONT
14	4/16/2016 15:18	4/21/2016 21:06	125.8	3.4	COLD FRONT
15	4/25/2016 12:18	5/4/2016 6:42	210.4	3.2	2 SEPARATE EVENTS (COLD FRONTS)
16*	6/20/2017 15:24	6/29/2017 17:48	218.4	4.1	CINDY
17*	8/25/2017 9:06	8/30/2017 12:36	123.5	3.9	HARVEY
18*	10/2/2017 4:54	10/15/2017 18:06	325.2	3.1	2 SEPARATE EVENTS (NATE +COLD FRONT)
19*	10/3/2018 4:36	10/16/2018 14:18	321.7	3.4	MICHAEL
20	12/26/2018 23:12	12/28/2018 4:36	29.4	3.0	COLD FRONT

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.

EVENT NUMBER	START DATE	END DATE	DURATION (HR)	MAX WSE REACHED (FT NAVD88)	COMMENTS *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
21	5/7/2019 11:12	5/24/2019 19:06	415.9	3.4	2 SEPARATE EVENTS (COLD FRONTS)
22*	7/14/2019 8:00	7/19/2019 14:48	126.8	3.0	BARRY

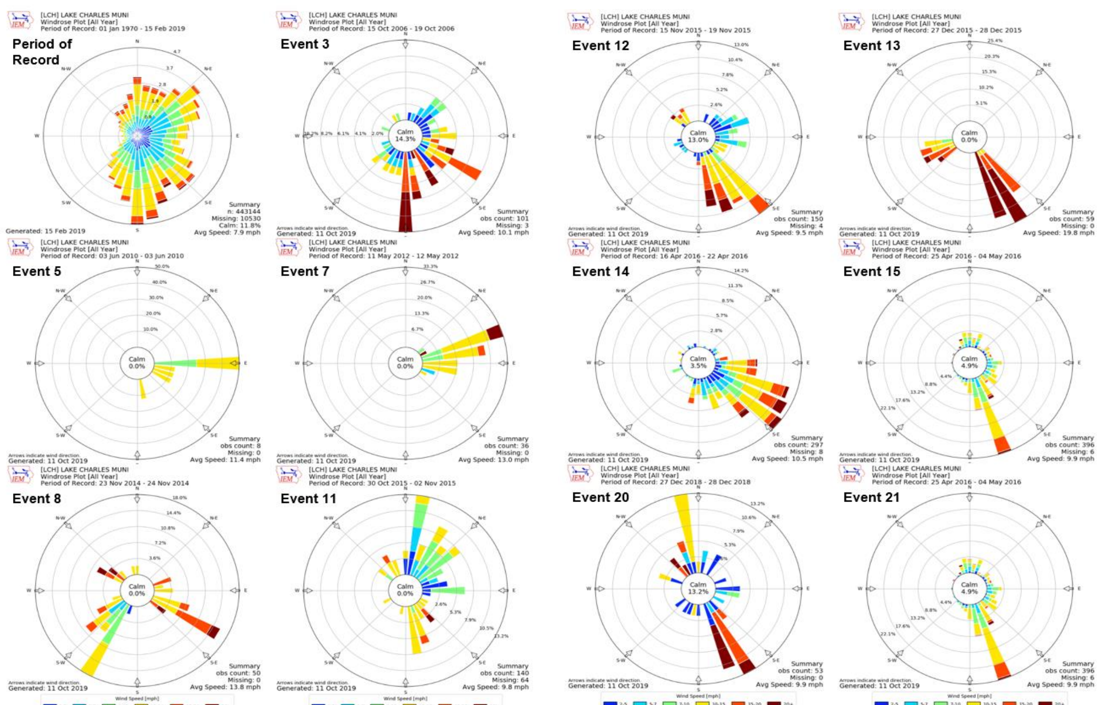


Figure 30. Wind Roses Showing Wind Speed and Direction for each High Tide Flooding Event in Cameron.

COCODRIE, LA

Ten events were identified that crossed a high tide flooding threshold of +2.5 ft NAVD88 that were identified from 2008 through 2018 at CRMS0369, which is located in a marsh area in lower Terrebonne Parish approximately 1.1 miles northeast of the northern intersection of Bayou Sale and Houma Navigation Canal (Table 12). Of these ten events, six were named tropical events, one was identified as a MCS, two were identified as isolated cold fronts, and one was identified as a subtropical event which resulted in high water events.

Figure 31 shows the number of days per year that thresholds of +0.76m (+2.5 ft) NAVD88 and +2.7 ft (+0.82 m) NAVD88 were crossed from 1998 through 2018 at USGS07381349 (Kolker et al., 2019).

Table 12. High Tide Flooding Events at CRMS0369 (Cocodrie).

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	**START DATE**	**END DATE**	**DURATION (HR)**	**MAX WSE REACHED (FT NAVD88)**	**COMMENTS** (UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)
1*	9/1/2008 18:00	9/3/2008 9:00	39	4.58	GUSTAV
2	7/5/2010 13:00	7/8/2010 18:00	77	2.64	MCS
3*	9/2/2011 11:00	9/5/2011 14:00	75	3.91	LEE
4*	8/29/2012 22:00	8/30/2012 23:00	25	2.77	ISAAC
5	10/25/2015 9:00	10/26/2015 22:00	37	4.08	REMNANTS OF PATRICIA + COLD FRONT (SUBTROPICAL)
6	4/29/2017 17:00	5/1/2017 1:00	32	2.98	COLD FRONT

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	**START DATE**	**END DATE**	**DURATION (HR)**	**MAX WSE REACHED (FT NAVD88)**	**COMMENTS** (UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)
7*	6/21/2017 8:00	6/23/2017 0:00	40	3.38	CINDY
8*	8/29/2017 9:00	8/29/2017 19:00	10	2.83	HARVEY
9*	10/8/2018 11:00	10/11/2018 7:00	68	2.94	MICHAEL
10	11/1/2018 8:00	11/1/2018 14:00	6	2.51	COLD FRONT

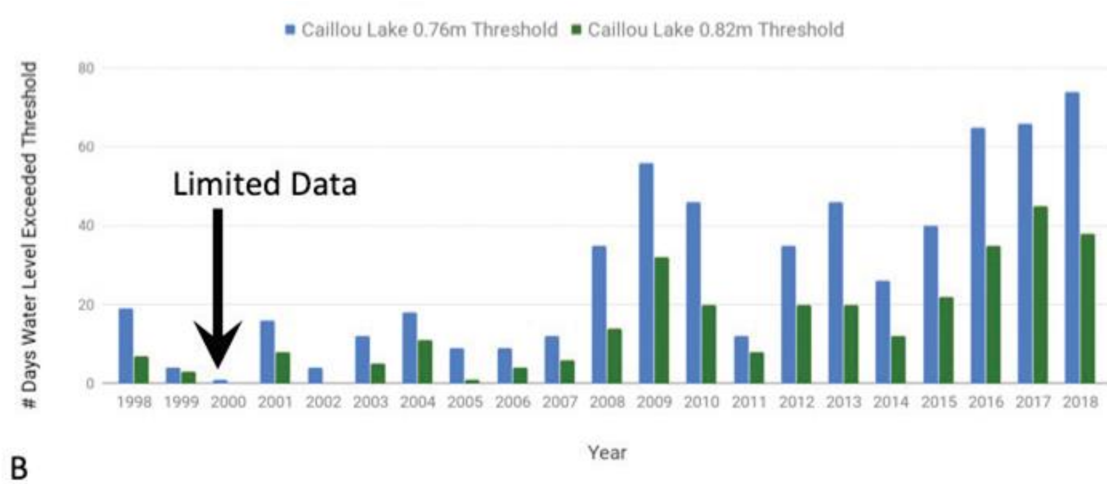


Figure 31. The Number of Possible High Tide Flooding Events near Cocodrie, LA from USGS Gage USGS07381349 (Kolker et al., 2019).

ISLE DE JEAN CHARLES, LA

Seven events (Figure 32) were identified that crossed a high tide WSE threshold of +3.0 ft NAVD88 at CRMS3296 near Isle de Jean Charles (Table 13). This gage is located in an open water channel 0.25 miles east of the southern end of Isle de Jean Charles. Four of these events were named tropical events, whereas three were either a MCS or a cold front. Each of these events showed an onshore wind signal (Figure 33).

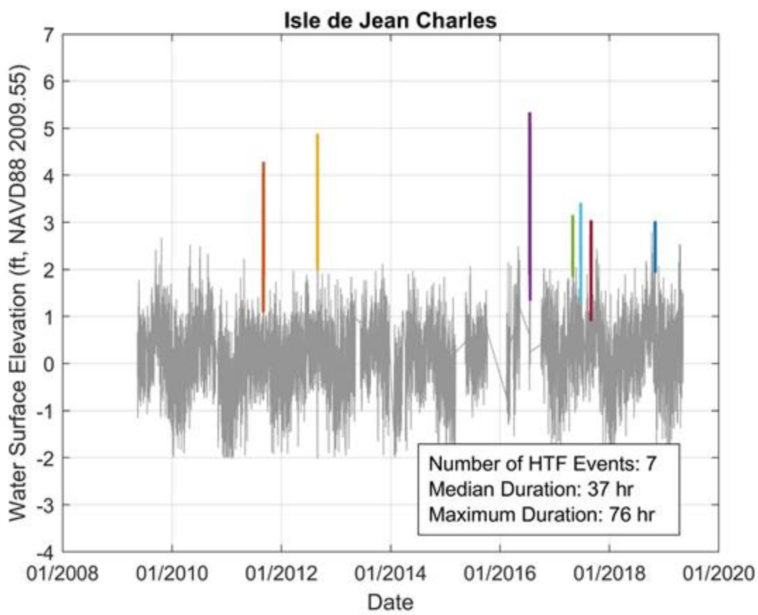


Figure 32. Identification of Possible High Tide Flooding Events near Isle de Jean Charles from CRMS Gage CRMS3296. Each possible high tide flooding event is indicated by a colored segment of the WSE time series.

Table 13. High Tide Flooding Events at CRMS3296 (Isle de Jean Charles).

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	**START DATE**	**END DATE**	**DURATION (HR)**	**MAX WSE REACHED (FT NAVD88)**	**COMMENTS** *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
1*	9/2/2011 11:00	9/5/2011 15:00	76	4.3	TS LEE
2*	8/29/2012 15:00	8/31/2012 0:00	33	4.9	ISAAC
3	7/16/2016 18:00	7/19/2016 18:00	72	5.3	MCS
4	4/29/2017 16:00	5/1/2017 1:00	33	3.1	COLD FRONT
5*	6/21/2017 10:00	6/23/2017 20:00	58	3.4	TS CINDY
6*	8/29/2017 10:00	8/30/2017 23:00	37	3.0	HURRICANE HARVEY
7	11/1/2018 6:00	11/1/2018 14:00	8	3.0	COLD FRONT

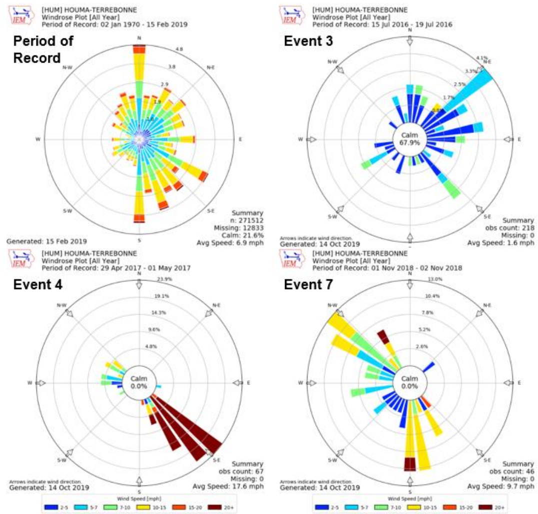


Figure 33. Wind Roses Showing Wind Speed and Direction for each High Tide Flooding Event in Isle de Jean Charles, LA.

MANDEVILLE, LA

Eleven events (Figure 34) which crossed a high tide flooding threshold of +3.0 ft NAVD88 were identified from 2009 through 2019 at CRMS006, which is located in a marsh area on the North Shore of Lake Pontchartrain in Big Branch Marsh National Wildlife Refuge approximately 7.5 miles southeast of Mandeville (Table 14). Of these 11 events, eight were named tropical events and three were isolated cold fronts which resulted in high water events. Each of these events showed an onshore wind signal (Figure 35).

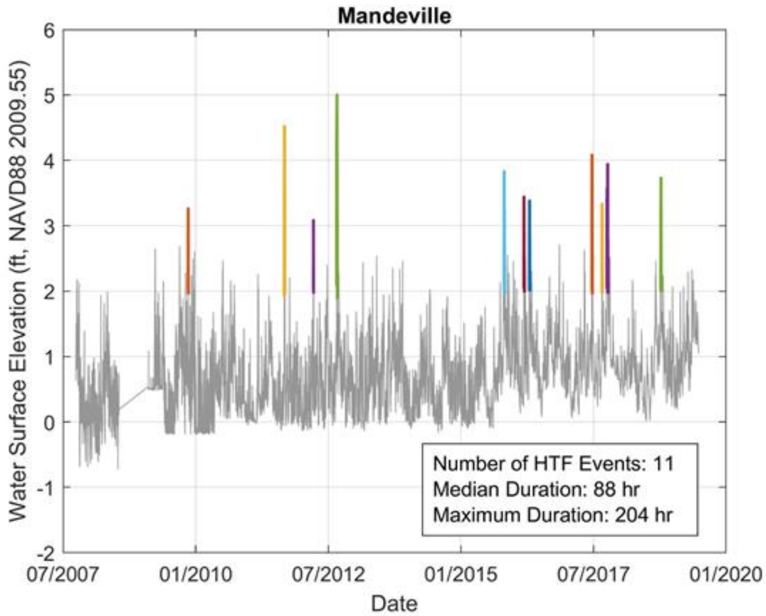


Figure 34. Identification of Possible High Tide Flooding Events near Mandeville from CRMS Gage CRMS0006. Each possible high tide flooding event is indicated by a colored segment of the WSE time series.

Table 14. High Tide Flooding Events at CRMS0006 (Mandeville).

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	START DATE	END DATE	DURATION (HR)	MAX WSE REACHED (FT NAVD88	COMMENTS *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
1*	11/9/2009 6:00	11/10/2009 20:00	38	3.3	IDA
2*	9/2/2011 7:00	9/5/2011 23:00	88	4.5	LEE
3	3/21/2012 1:00	3/22/2012 6:00	29	3.1	COLD FRONT

EVENTS WERE IDENTIFIED WHICH EXCEEDED WSE THRESHOLD (SEE TABLE 2). EVENTS MARKED WITH * ARE TROPICAL EVENTS THAT ARE NOT CONSIDERED HIGH TIDE FLOODING.					
EVENT NUMBER	**START DATE**	**END DATE**	**DURATION (HR)**	**MAX WSE REACHED (FT NAVD88**	**COMMENTS** *(UNDERLINED TEXT IS A HYPERLINK DIRECTING READER TO ONLINE DOCUMENTATION OF THE WEATHER EVENT)*
4*	8/28/2012 18:00	9/2/2012 5:00	107	5.0	ISAAC
5*	10/25/2015 4:00	10/28/2015 8:00	76	3.8	REMNANTS OF PATRICIA
6	3/9/2016 1:00	3/12/2016 23:00	94	3.4	COLD FRONT
7	4/15/2016 10:00	4/19/2016 17:00	103	3.4	COLD FRONT
8*	6/20/2017 19:00	6/23/2017 22:00	75	4.1	CINDY
9*	8/29/2017 4:00	8/31/2017 8:00	52	3.3	HARVEY
10*	10/2/2017 0:00	10/10/2017 12:00	204	3.9	NATE
11*	10/7/2018 16:00	10/11/2018 14:00	94	3.7	MICHAEL

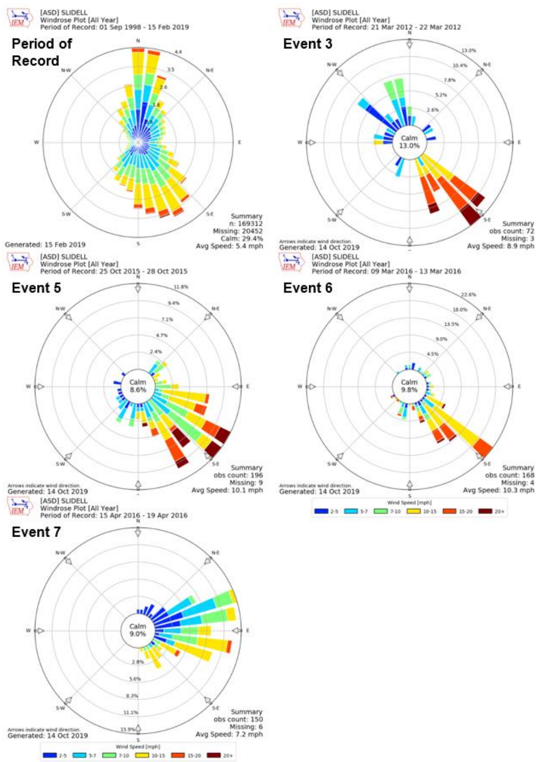


Figure 35. Wind Roses Showing Wind Speed and Direction for each High Tide Flooding Event in Isle de Jean Charles.

APPENDIX B: ADDITIONAL FIGURES FROM ICM PERFORMANCE TESTS

ICM TESTS AT LUMCON FIGURES (SECTION 2.2)

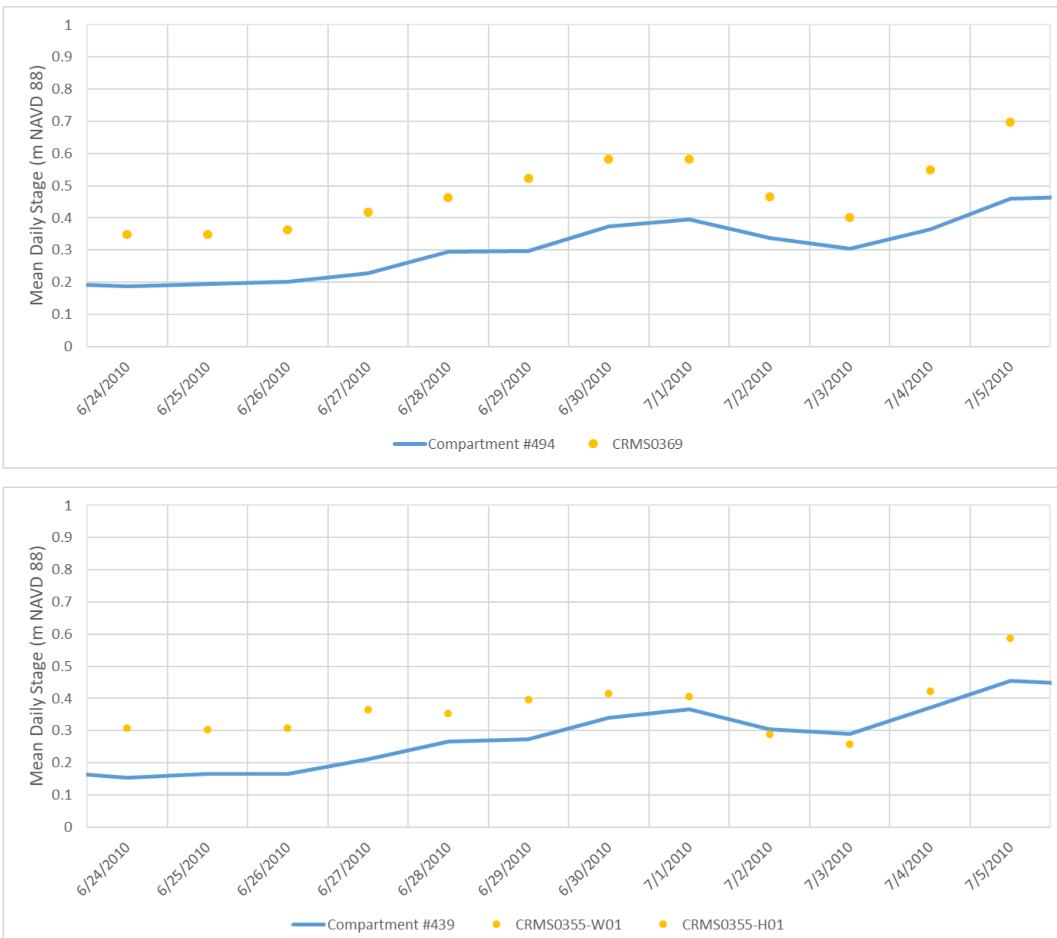


Figure 36. Comparison of ICM Predicted and Observed Daily Mean Stage at LUMCON during the Days before and after the June 29-30, 2010 High Tide Flooding Period.

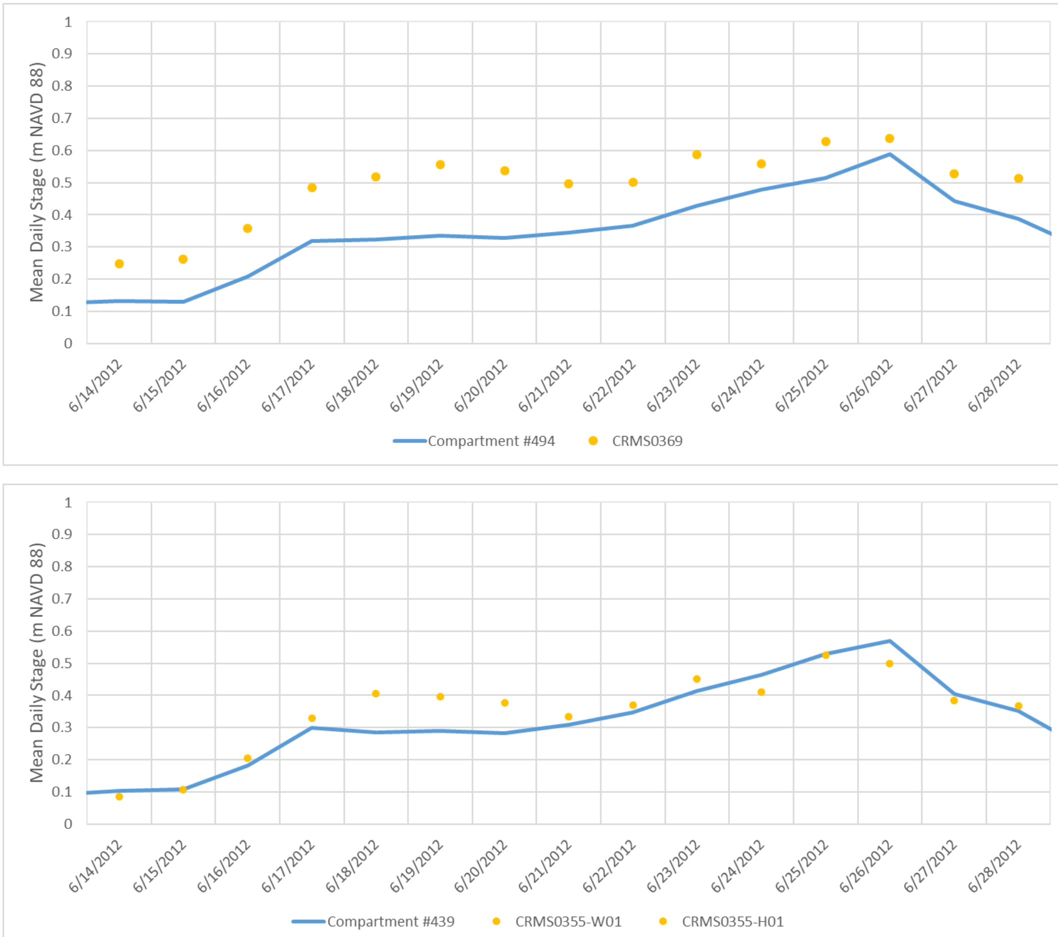


Figure 37. Comparison of ICM Predicted and Observed Daily Mean Stage at LUMCON during the Days before and after the Jun 19-23, 2012 High Tide Flooding Period.

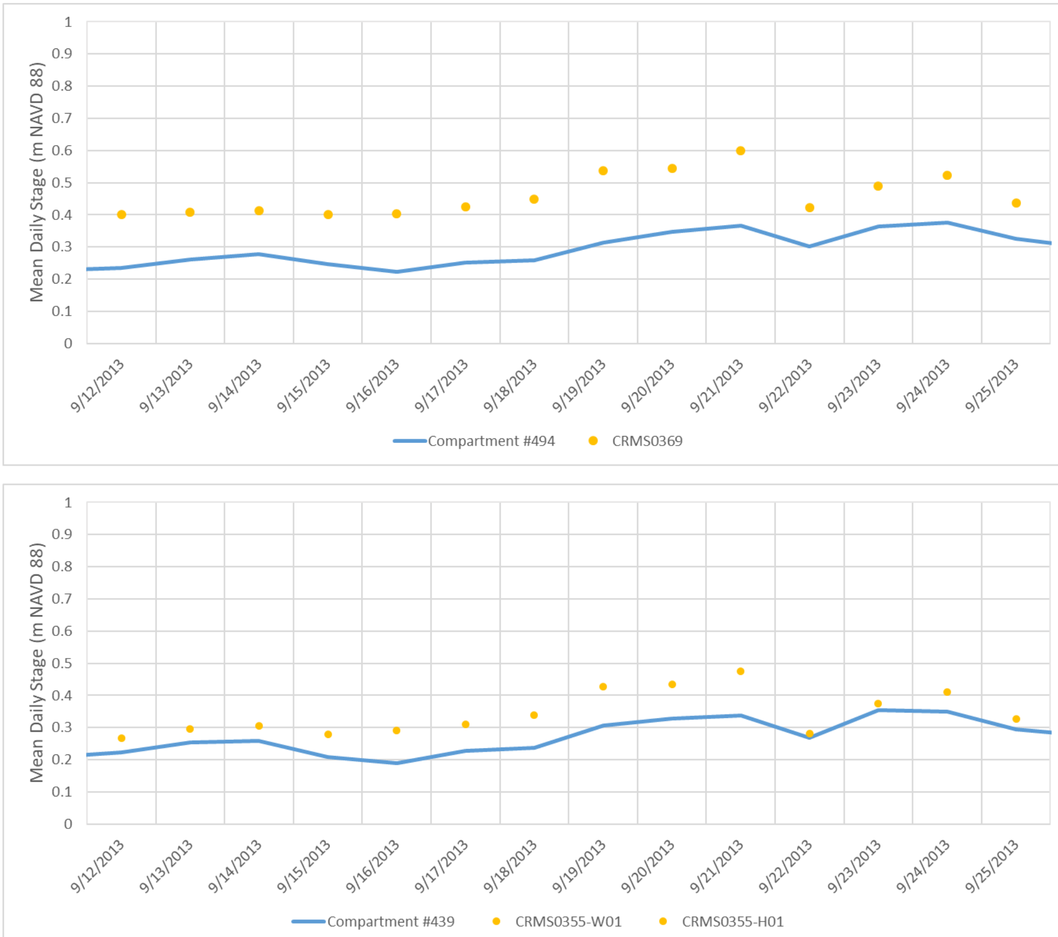
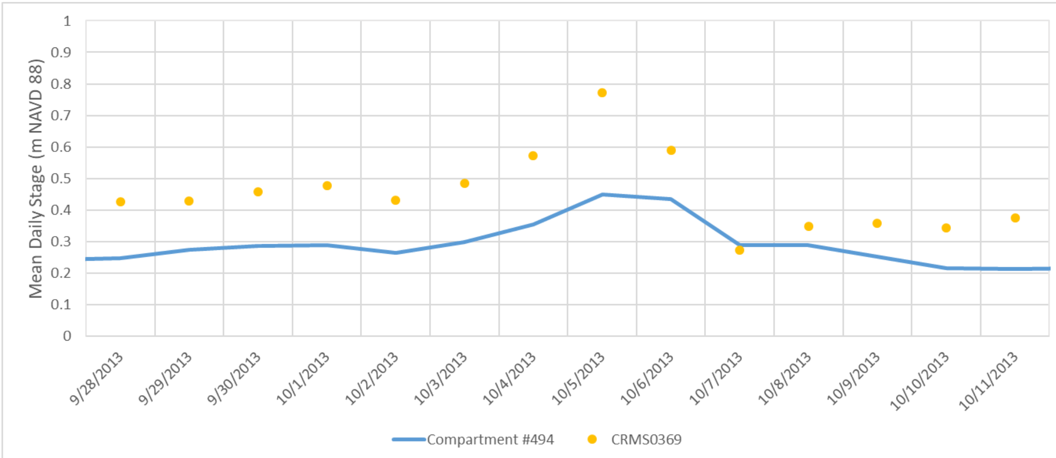


Figure 38. Comparison of ICM Predicted and Observed Daily Mean Stage at LUMCON during the Days before and after Sep 17-20, 2013 High Tide Flooding Period.



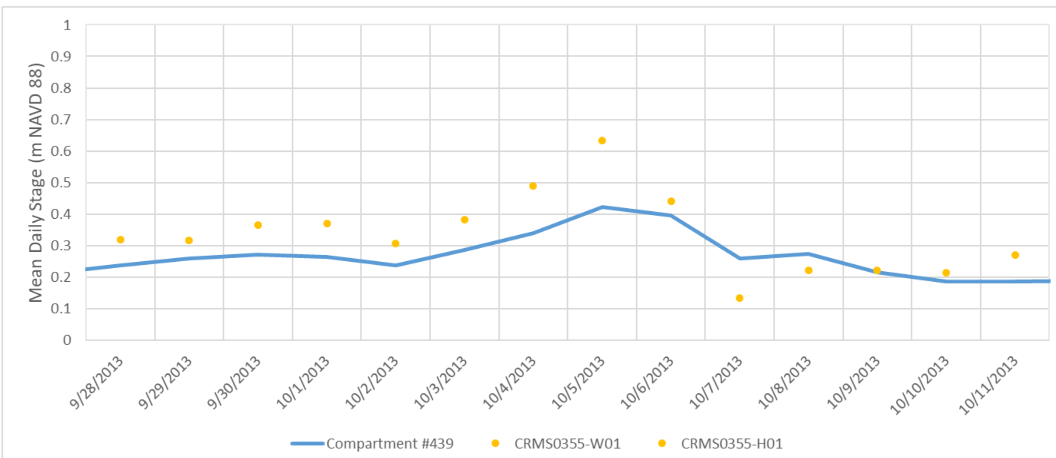


Figure 39. Comparison of ICM Predicted and Observed Daily Mean Stage at LUMCON during the Days before and after the Oct 3-6, 2013 High Tide Flooding Period.

ICM TESTS AT CYPREMORT POINT (SECTION 2.2)

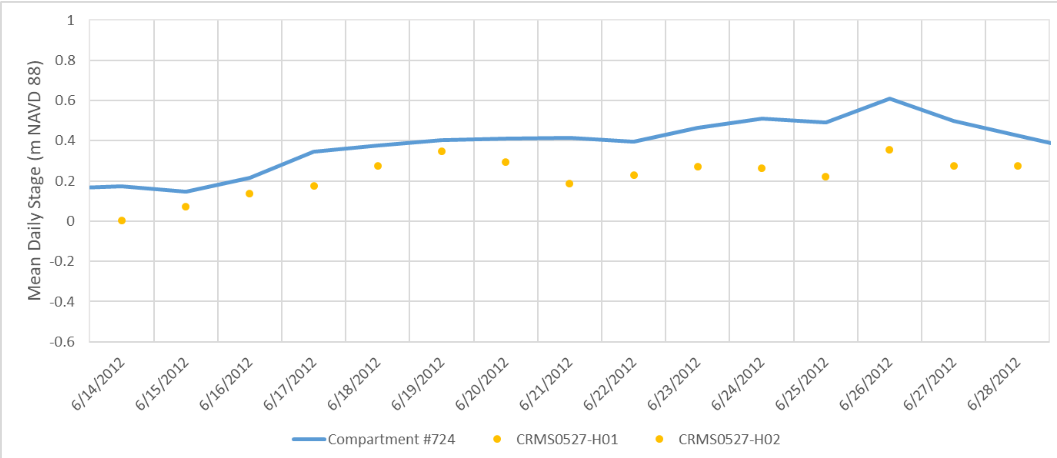
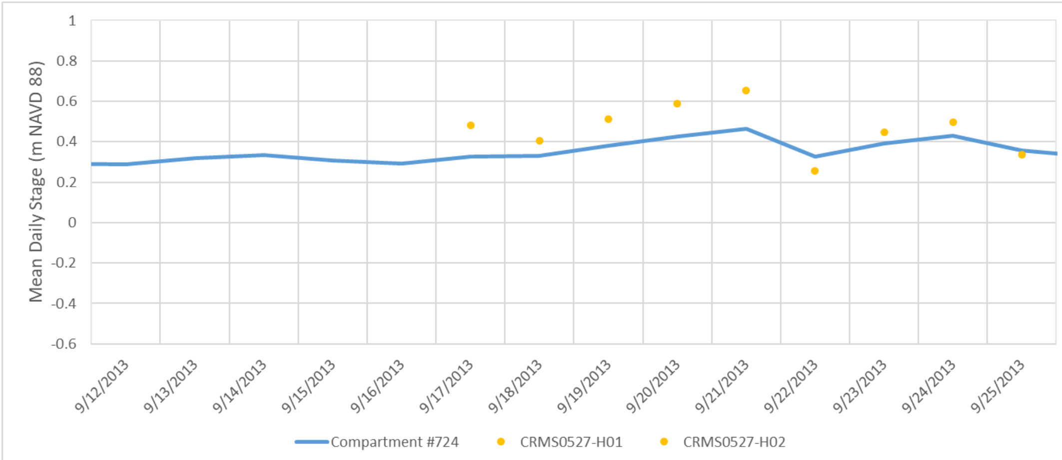


Figure 40. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Jun 19-23, 2012 High Tide Flooding Period.



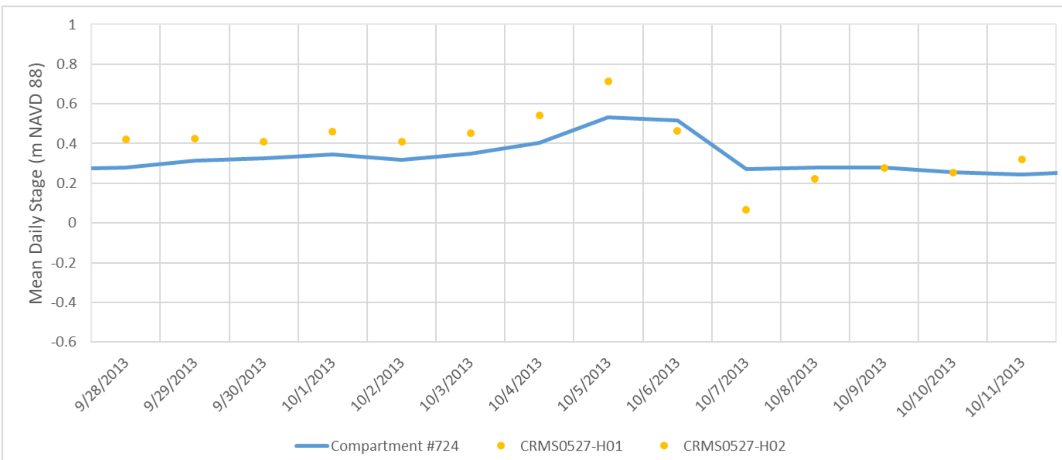
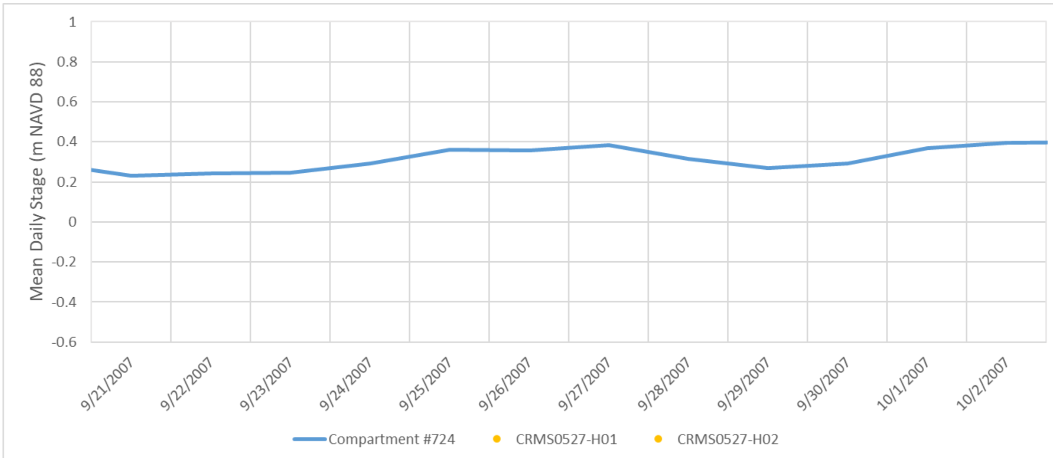


Figure 41. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Sep 17-20, 2013 High Tide Flooding Period and during the Days before and after the Oct 3-6, 2013 High Tide Flooding Period.



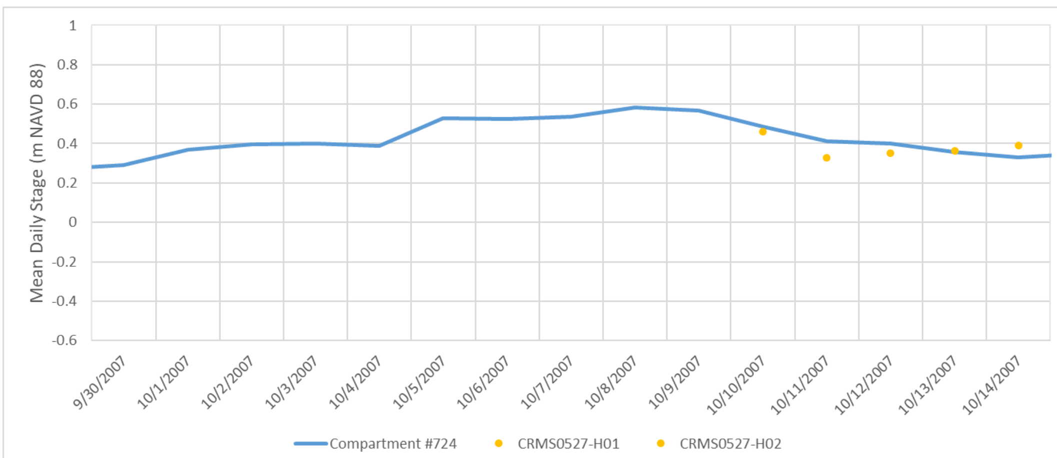


Figure 42. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Sep 26-27, 2007 High Tide Flooding Period (no available observation data) and during the Days before and after the Oct 5-9, 2007 High Tide Flooding Period.

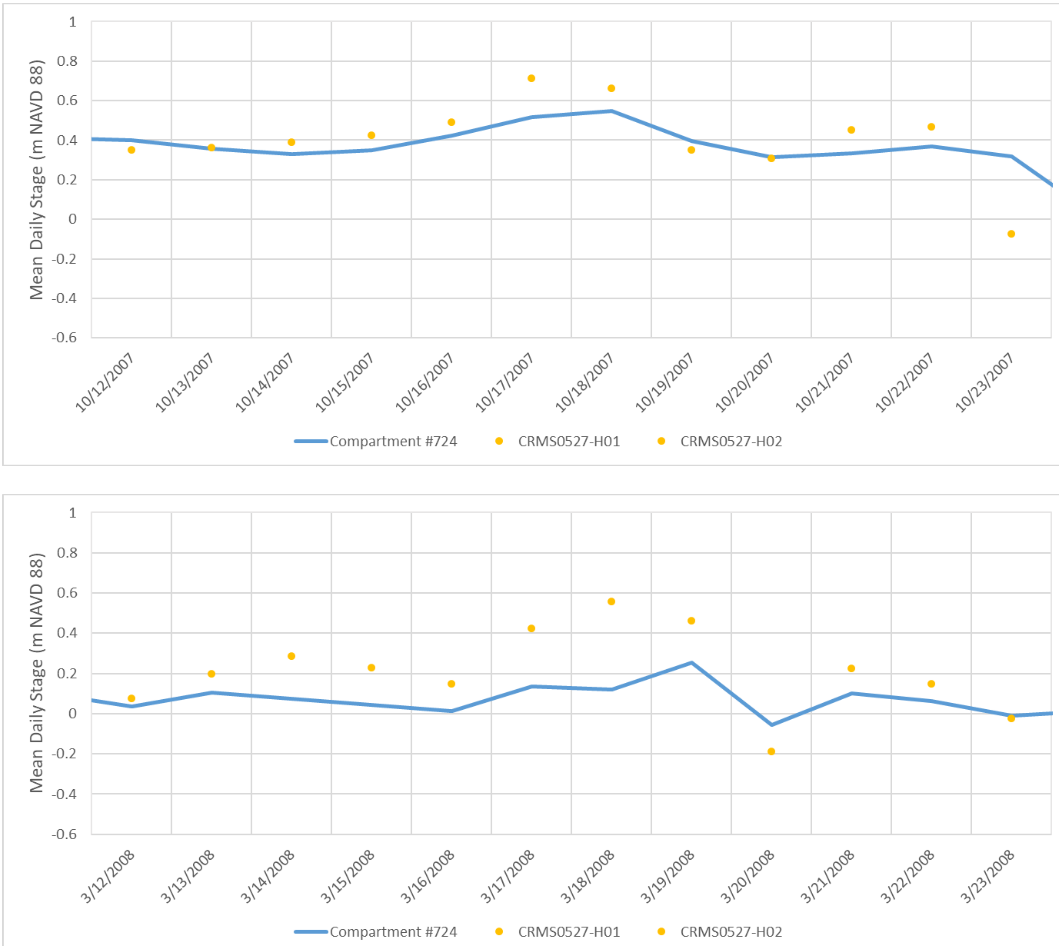
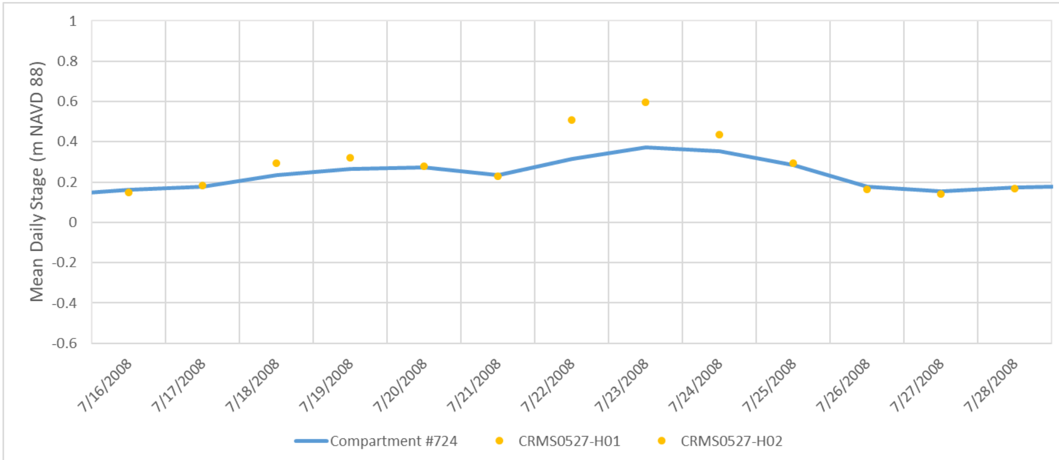


Figure 43. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Oct 17-18, 2007 High Tide Flooding Period and during the Days before and after the Mar 17-18, 2008 High Tide Flooding Period.



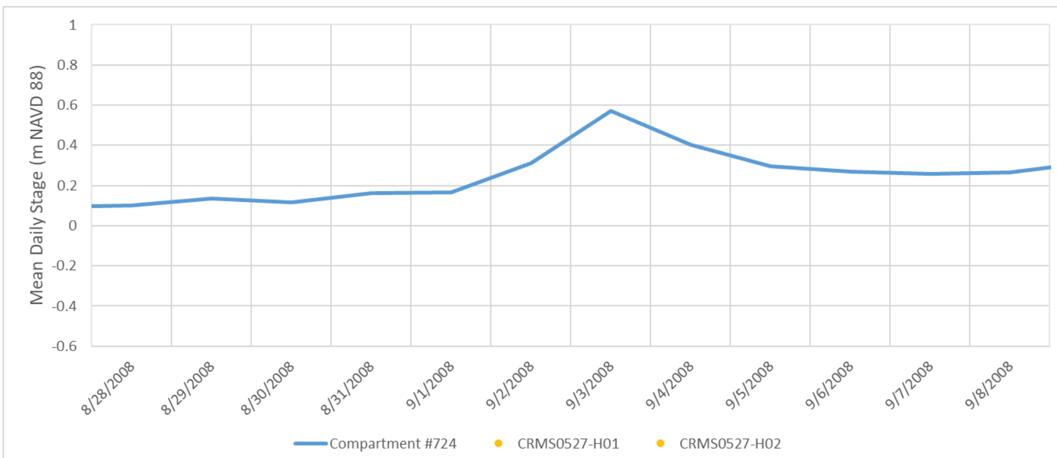
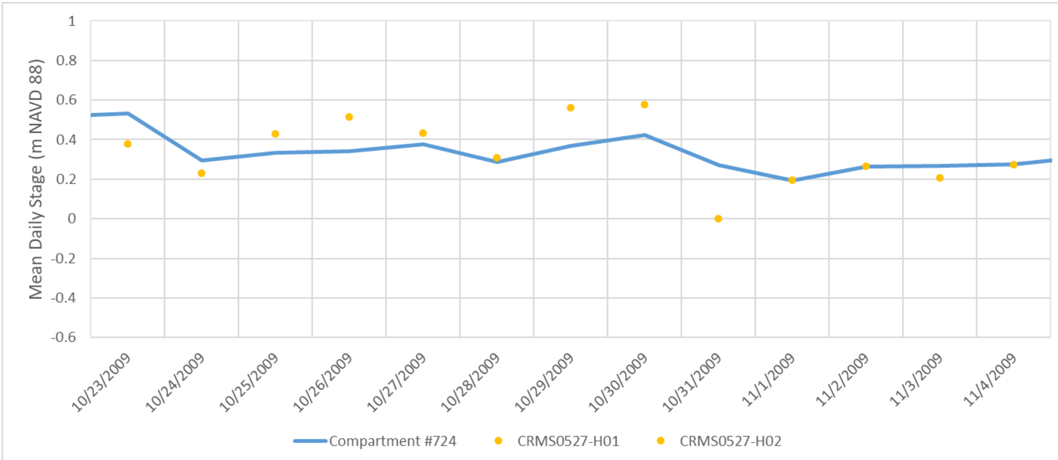


Figure 44. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Jul 21-23, 2008 High Tide Flooding Period and during the Days before and after the Sep 2-3, 2008 High Tide Flooding Period (no available observation data).



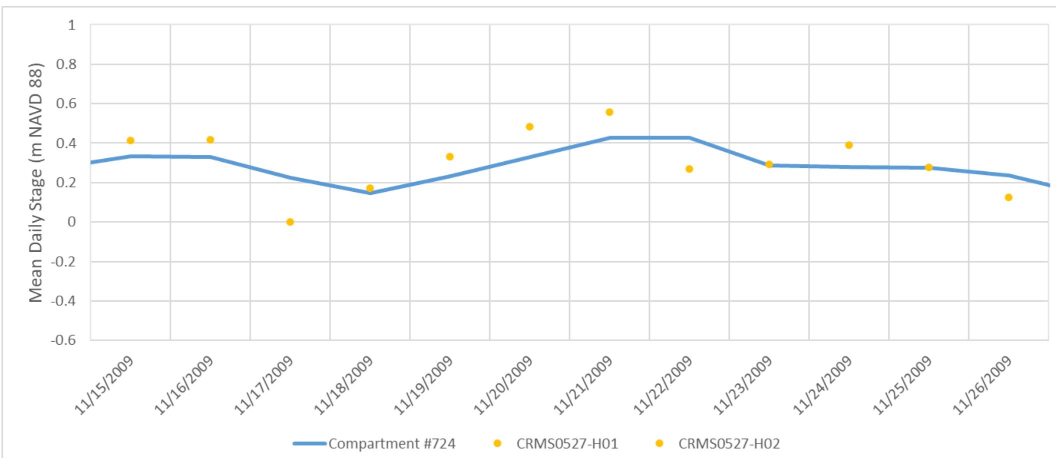
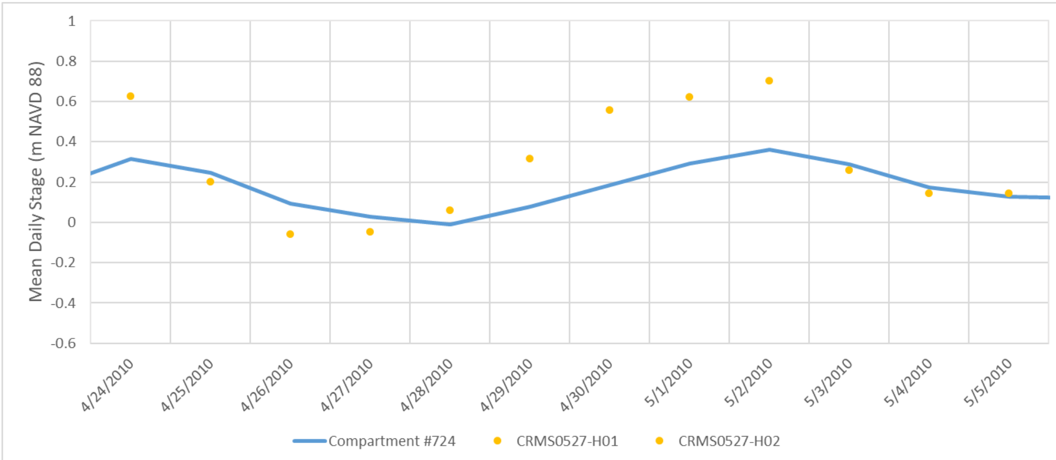


Figure 45. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Sep 2-3, 2008 High Tide Flooding Period and during the days before and after the Nov 20-21, 2009 high tide flooding period.



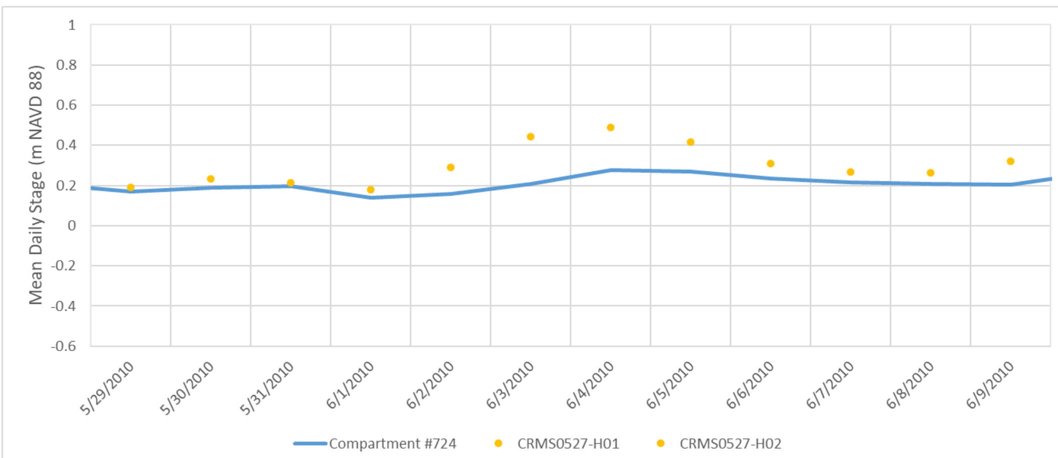


Figure 46. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Apr 29-30, 2010 High Tide Flooding Period and during the Days before and after the Jun 3-4, 2010 High Tide Flooding Period.

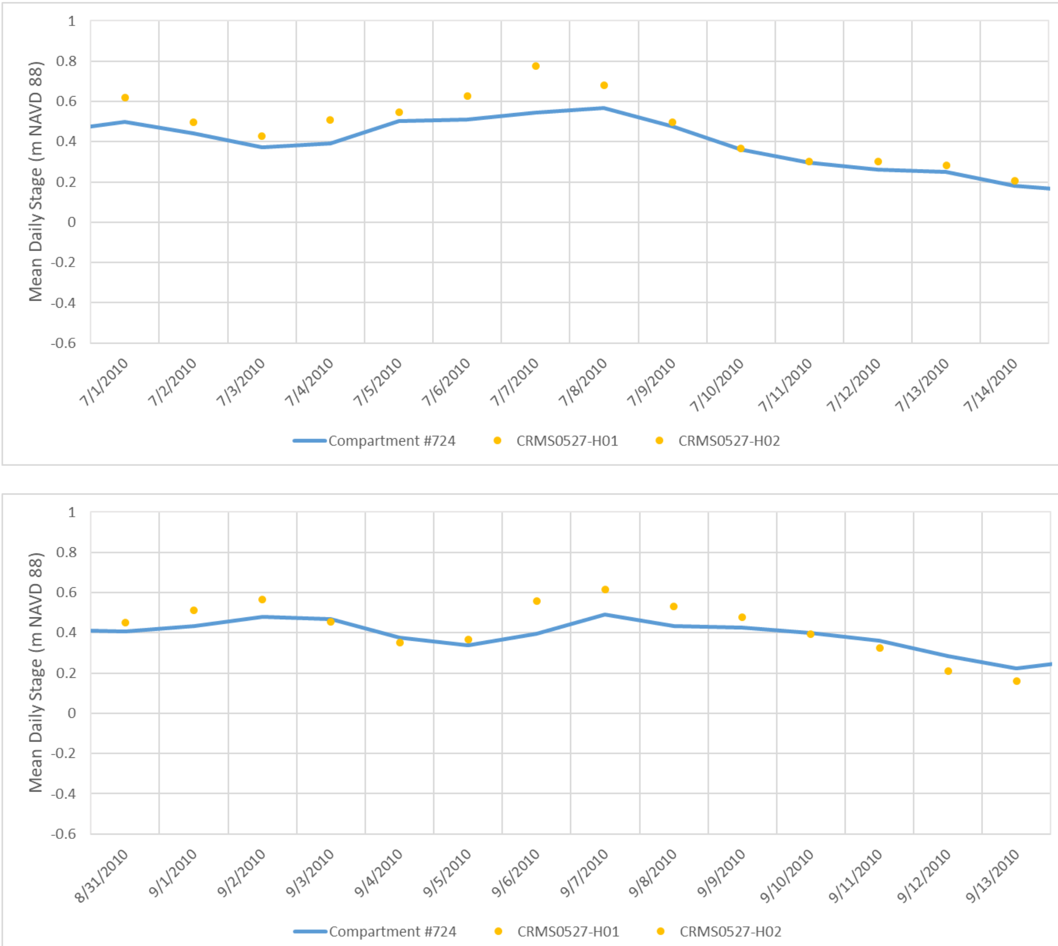


Figure 47. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Jul 7-8, 2010 High Tide Flooding Period and during the Days before and after the Sep 6-7, 2010 High Tide Flooding Period.

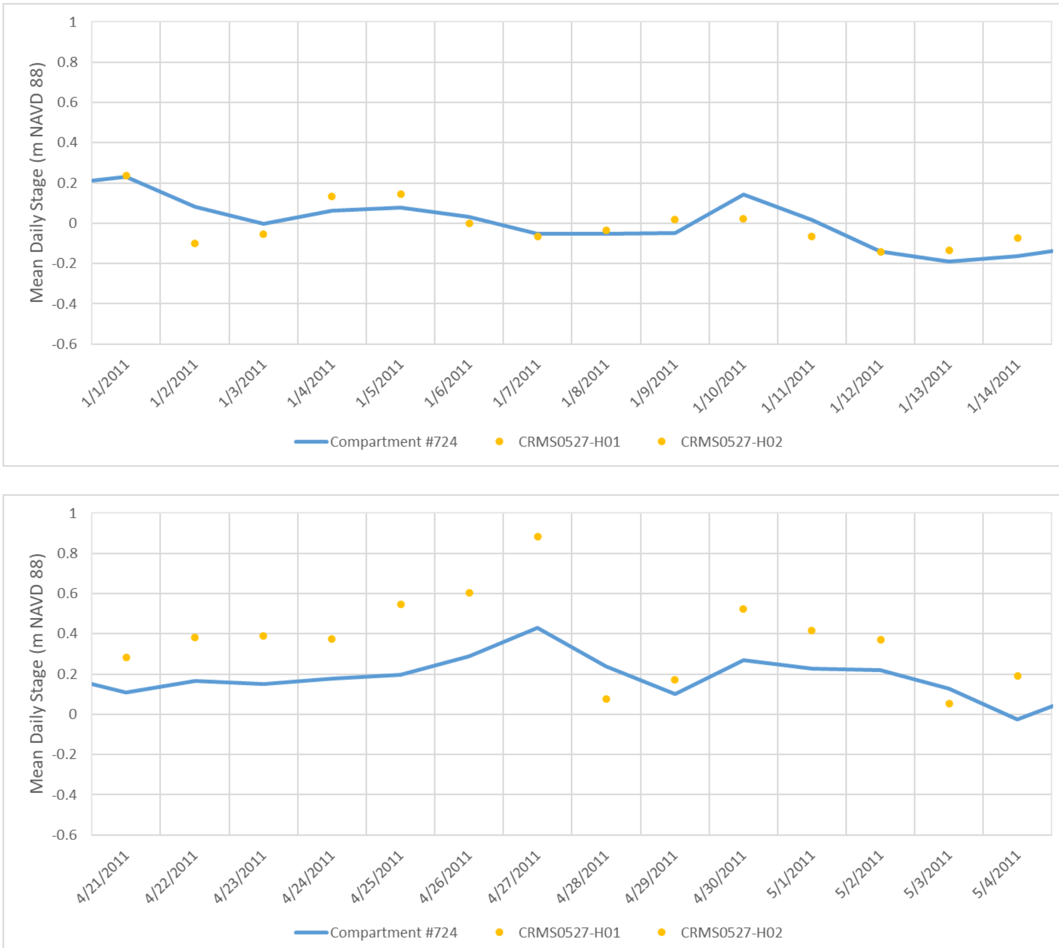
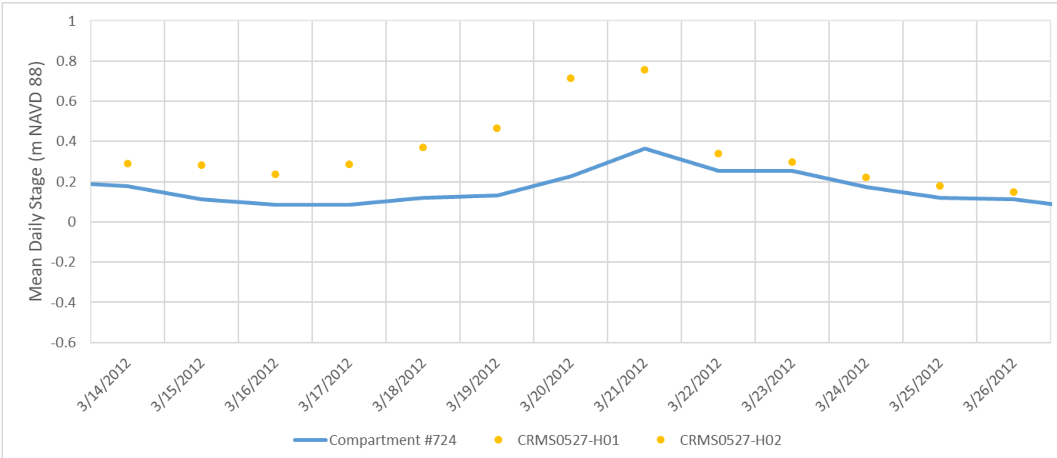


Figure 48. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Jan 8-9, 2011 High Tide Flooding Period and during the Days before and after the Apr 26-27, 2011 High Tide Flooding Period.



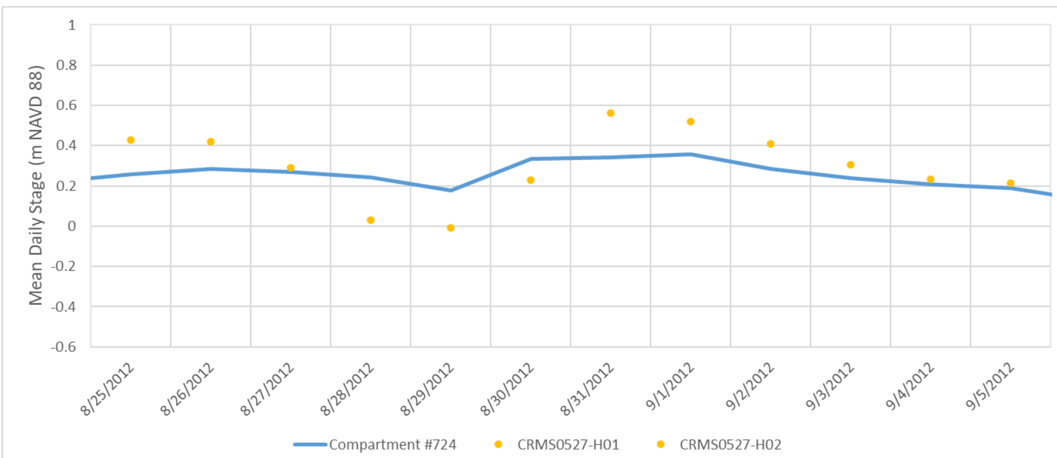


Figure 49. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Mar 19-21, 2012 High Tide Flooding Period and during the Days before and after the Aug 30-31, 2012 High Tide Flooding Period.

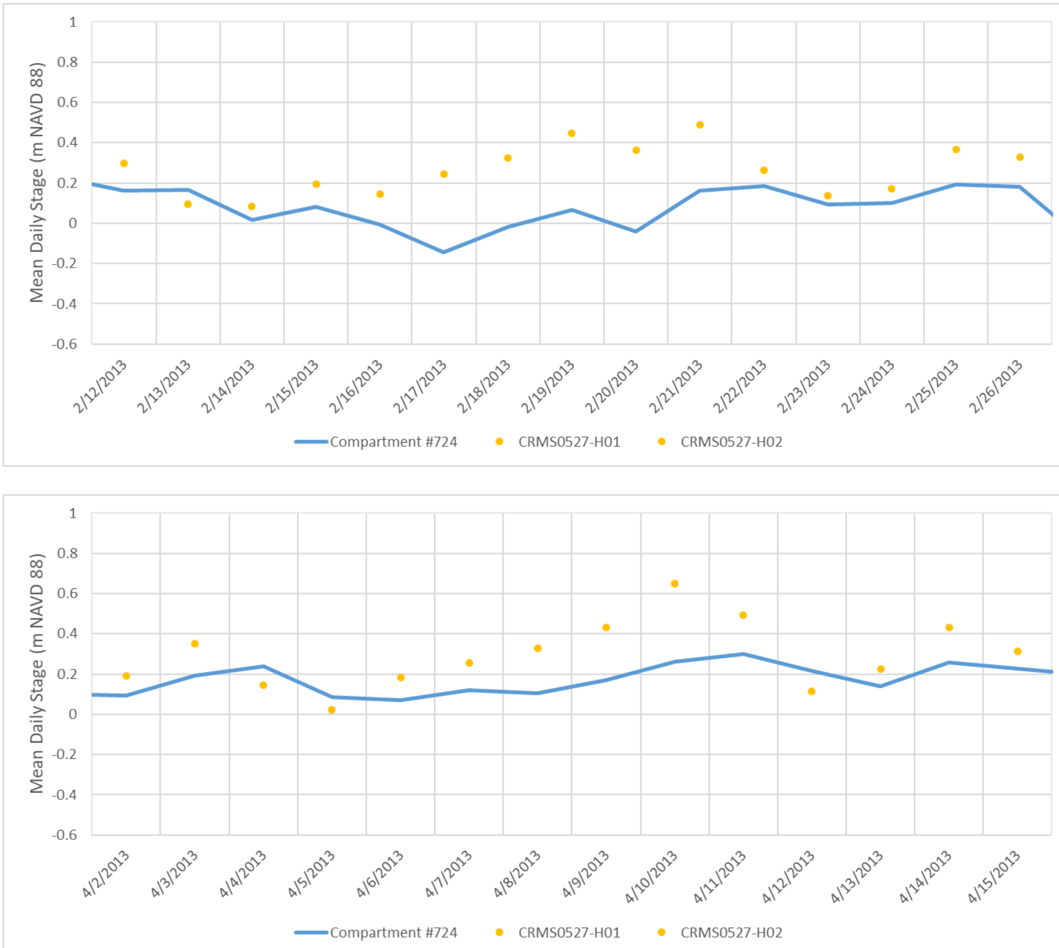


Figure 50. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Feb 20-21, 2013 High Tide Flooding Period and during the Days before and after the Apr 9-10, 2013 High Tide Flooding Period.

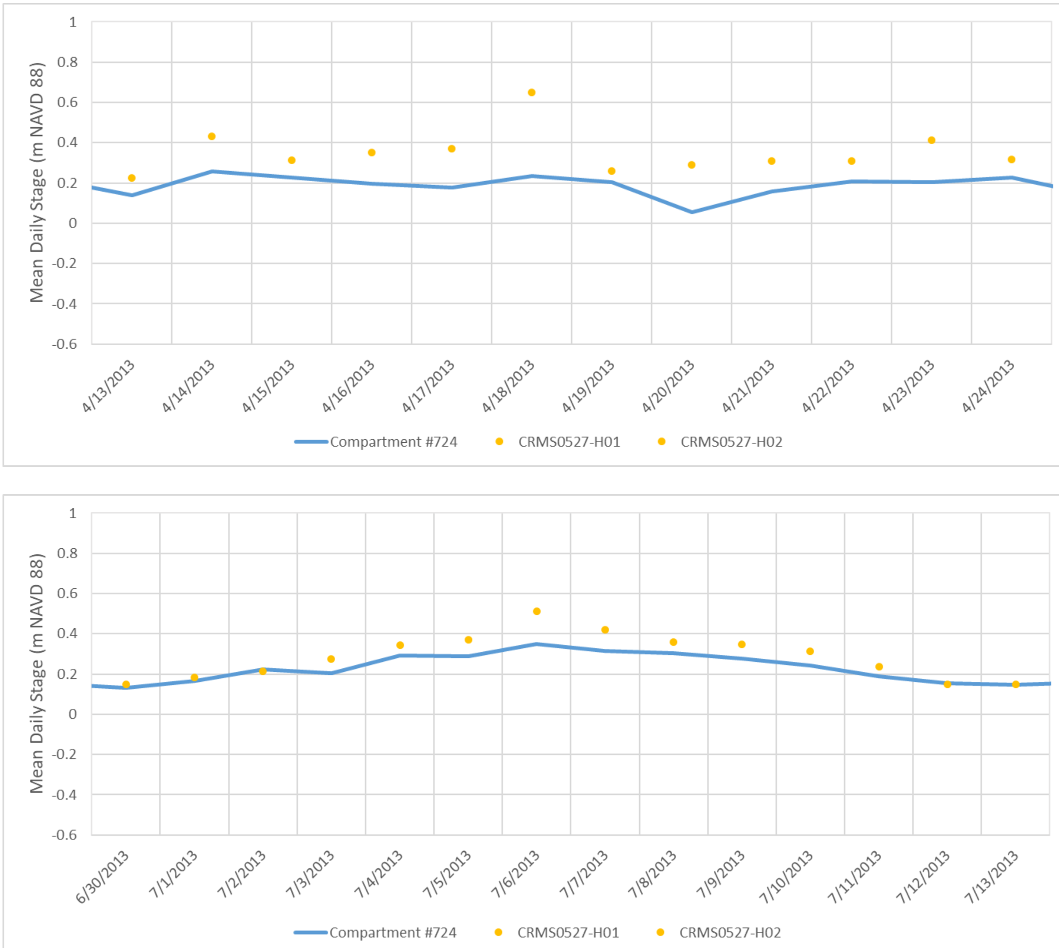
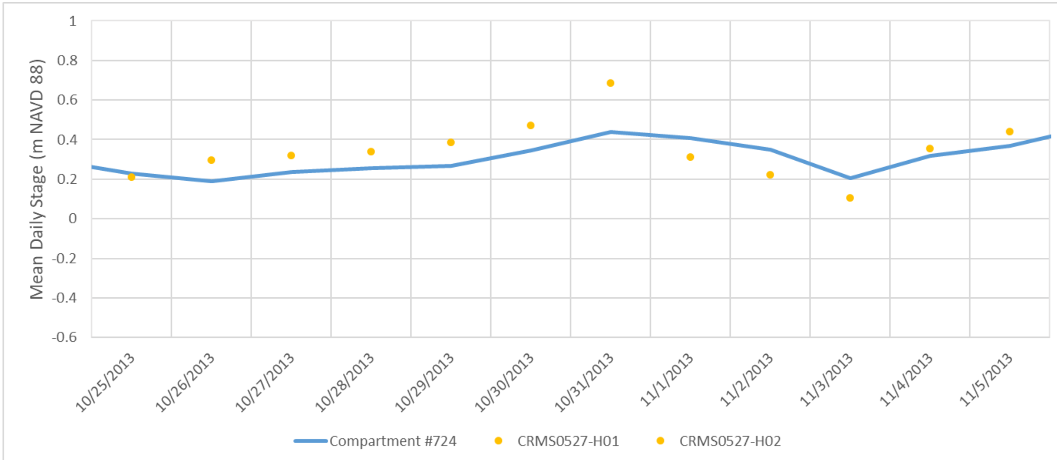


Figure 51. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Apr 18-19, 2013 High Tide Flooding Period and during the Days before and after the Jul 6-7, 2013 High Tide Flooding Period.



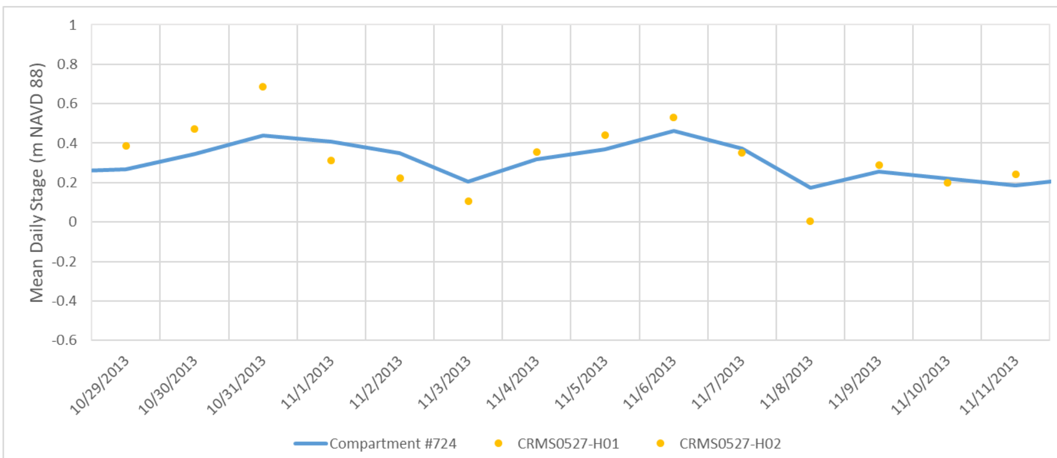


Figure 52. Comparison of ICM Predicted and Observed Daily Mean Stage at Cypremort Point during the Days before and after the Oct 30-31, 2013 High Tide Flooding Period and during the Days before and after the Nov 3-6, 2013 High Tide Flooding Period

ADCIRC STORM TRACKS (SECTION 2.2)

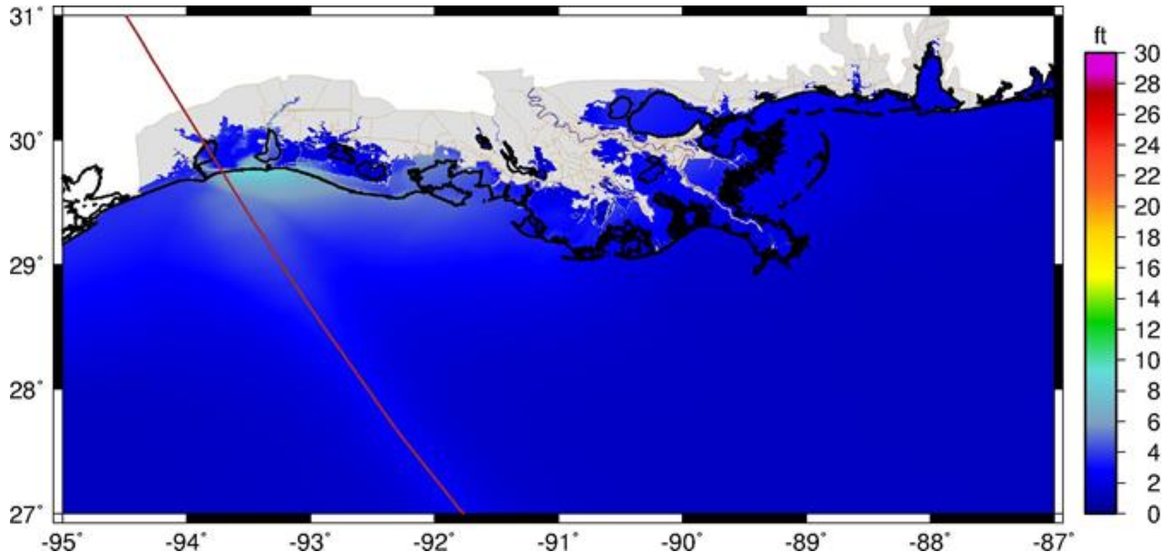


Figure 53. Storm 404 track and maximum WSE (NAVD88).

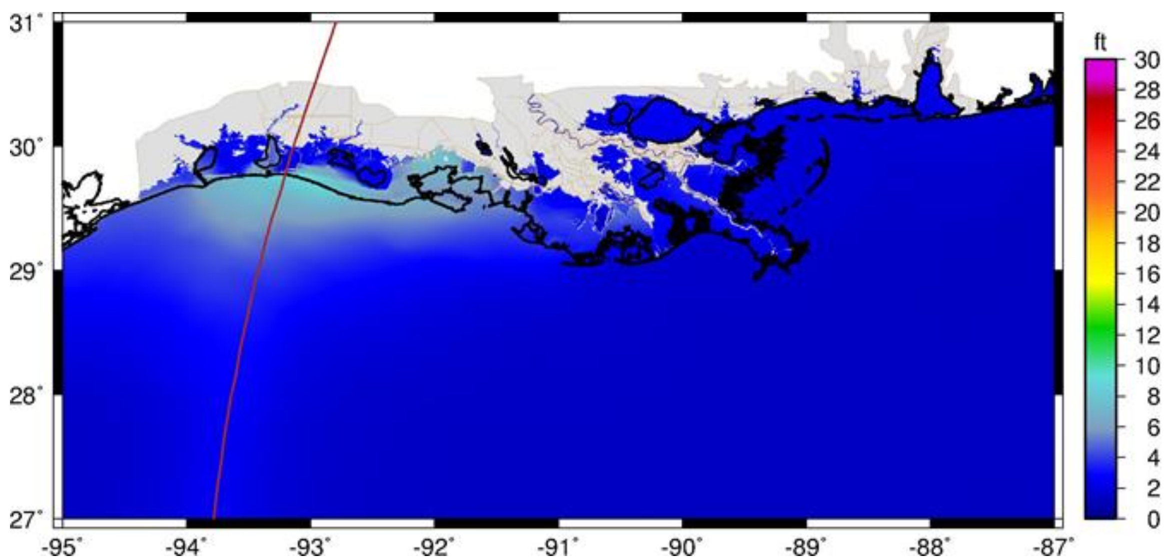


Figure 54. Storm 426 track and maximum WSE (NAVD88).

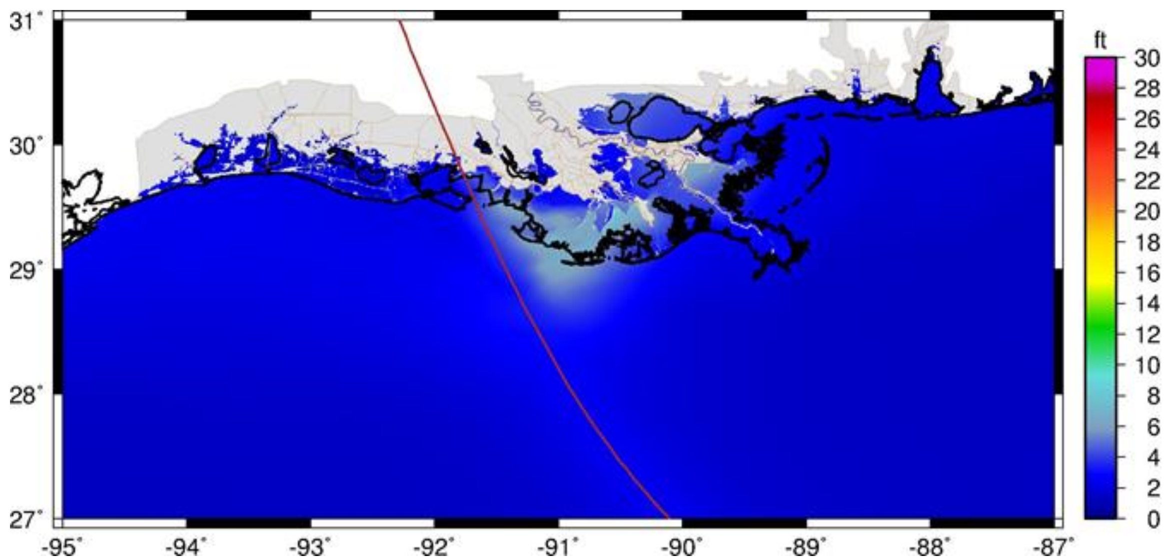


Figure 55. Storm 436 track and maximum WSE (NAVD88).

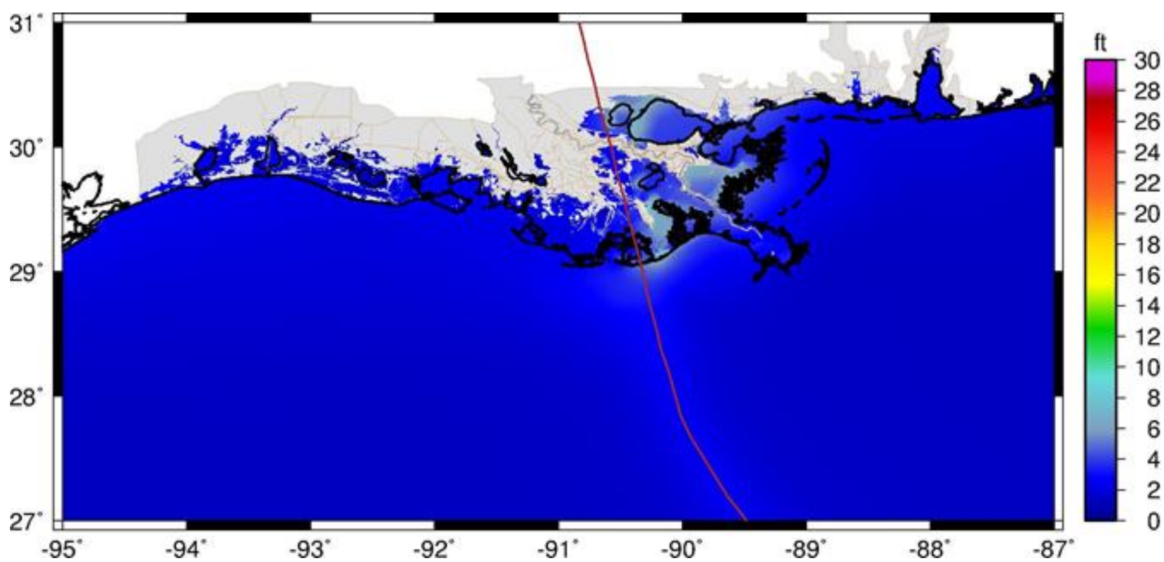


Figure 56. Storm 504 track and maximum WSE (NAVD88).

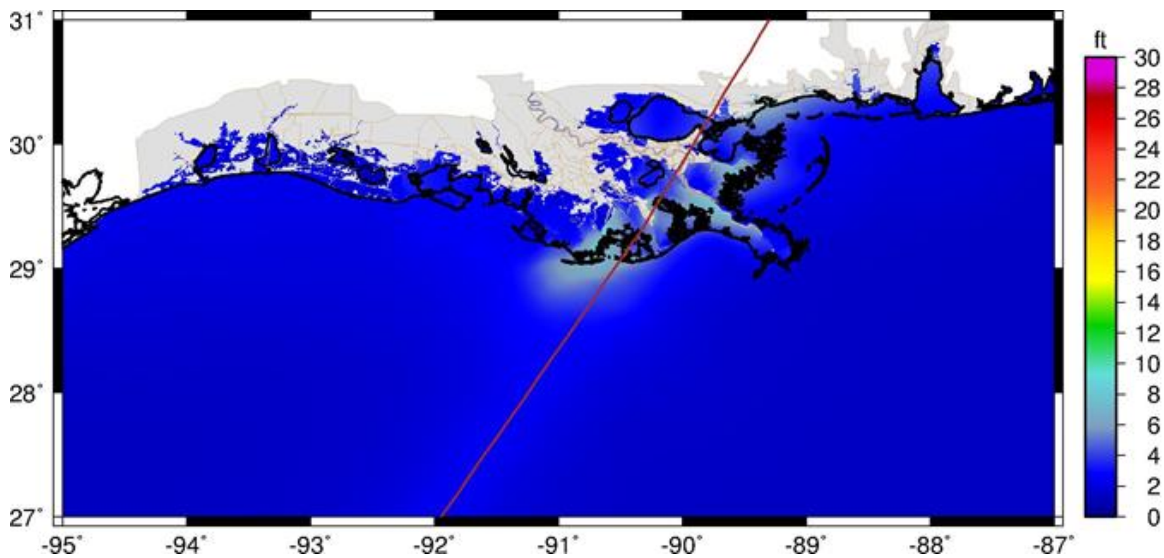


Figure 57. Storm 526 track and maximum WSE (NAVD88).

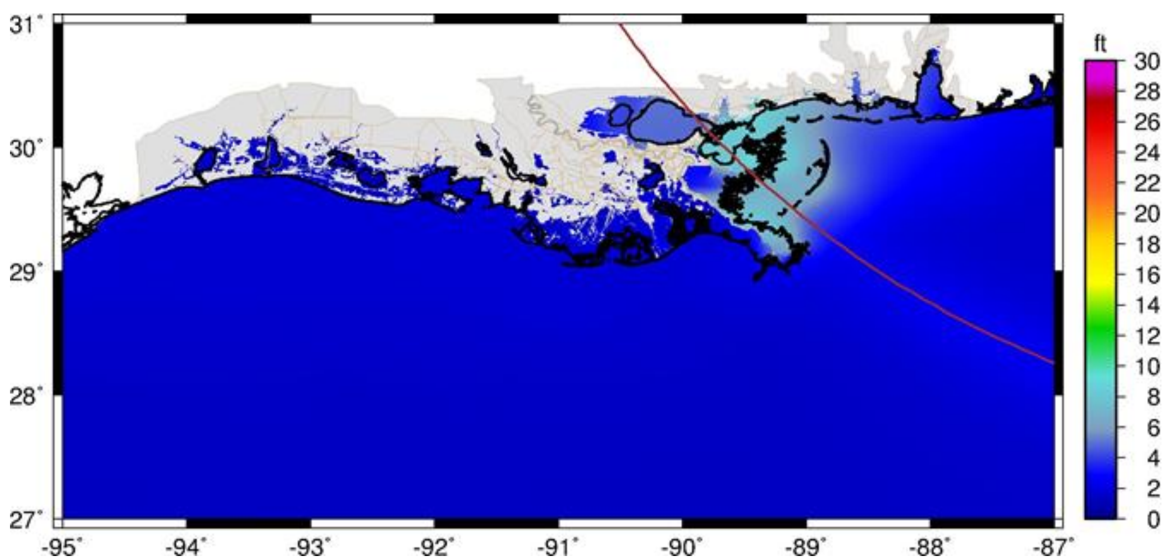


Figure 58. Storm 540 track and maximum WSE (NAVD88).

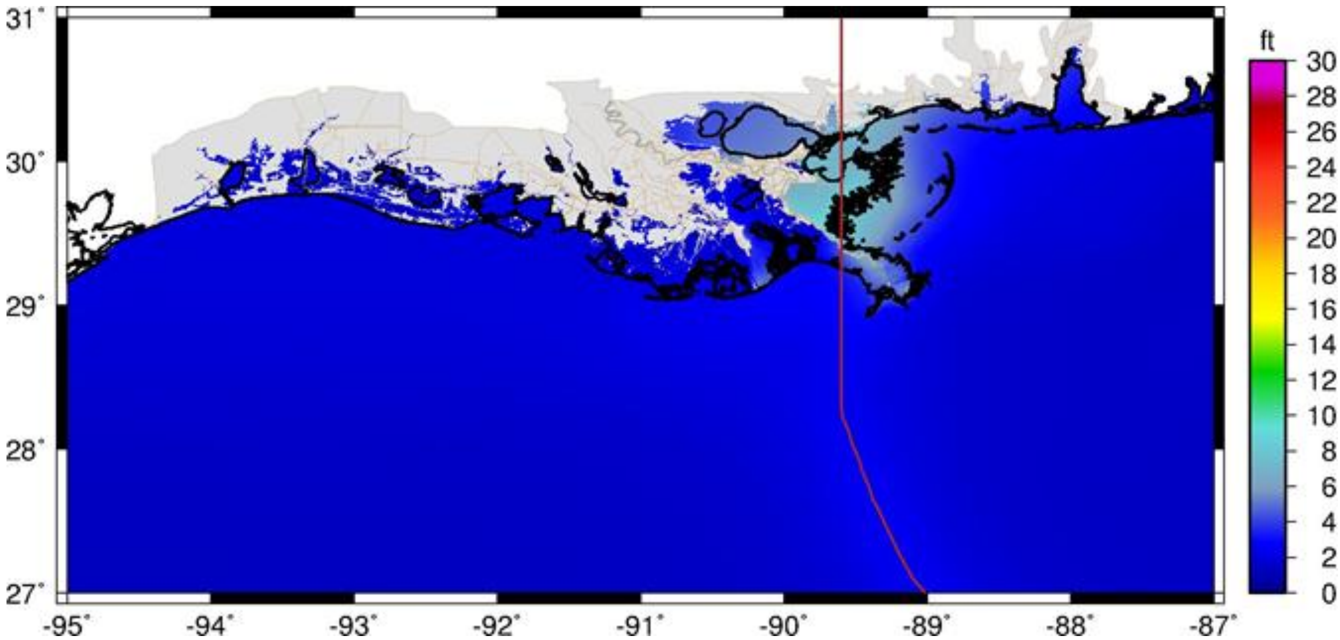


Figure 59. Storm 564 track and maximum WSE (NAVD88).

APPENDIX C: PHASE 2 DRIVE TIME ANALYSIS RESULTS FOR FOCUS COMMUNITIES

Community resilience is a measure of the sustained ability of a community to utilize available resources to respond to, withstand, and recover from hazard events and other adverse situations (Acosta et al., 2017). A great deal of focus has rightfully been placed on the impacts of large-scale disasters on community resilience. However, the impacts of more frequent, but less damaging, hazards events such as high tide flood events may have just as much influence on community resilience. This is particularly true when access to critical and essential services is disrupted. The Phase 2 analysis looks at the impacts of high tide flood events on street flooding and how this may impact community access to critical and essential facilities. Critical facilities include those used for public safety purposes, medical services, and infrastructure maintenance while essential facilities include those that provide for basic necessities or serve government functions (Wood, 2007). The facilities identified for this pilot study include:

- Critical Facilities
  - Hospitals
  - Police Stations
  - Fire Stations
- Essential Facilities
  - Rural Health Clinics
  - Day Care Centers
  - Retail Grocers

A drive time analysis was conducted on the CLARA grid cells in each of the focus communities under clear conditions and under high tide flood conditions in years 10, 25, and 50. The results were analyzed to identify locations within each study area that were cut off from critical and essential services as well as where travel times between residents and facilities increased.

AMELIA, LA

Amelia is located in St. Mary Parish and is bounded on the north by Lake Palourde and on the west, south, and east by the Avoca Island Cutoff. Part of the Morgan City Micropolitan Statistical Area, Amelia has a total land area of 2.8 square mile. The city's population of 2,459 is heavily dependent on Morgan City for many of its critical facilities, including the region's primary hospital and police stations. This dependency makes Amelia socially vulnerable to high tide flood events which may disconnect Amelia from Morgan City on the west. When travel to Morgan City is disrupted, residents of Amelia may experience longer travel times to receive essential services from other communities further afield such as Thibodaux.

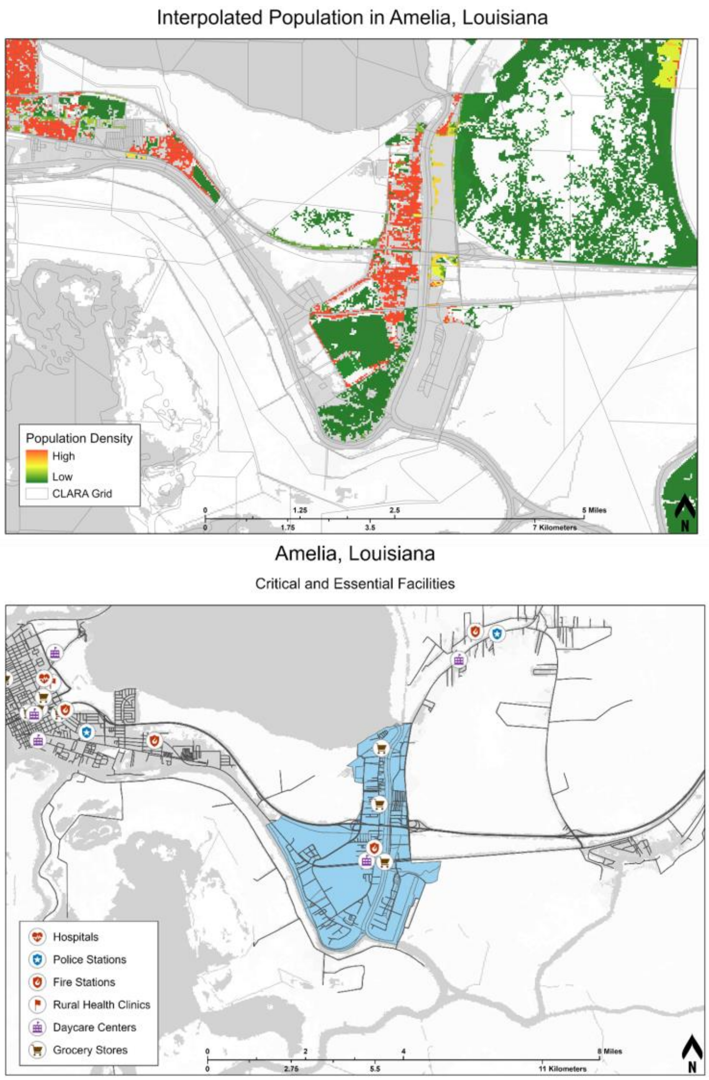


Figure 60. Interpolated Population and Critical/Essential Facilities in Amelia, LA.

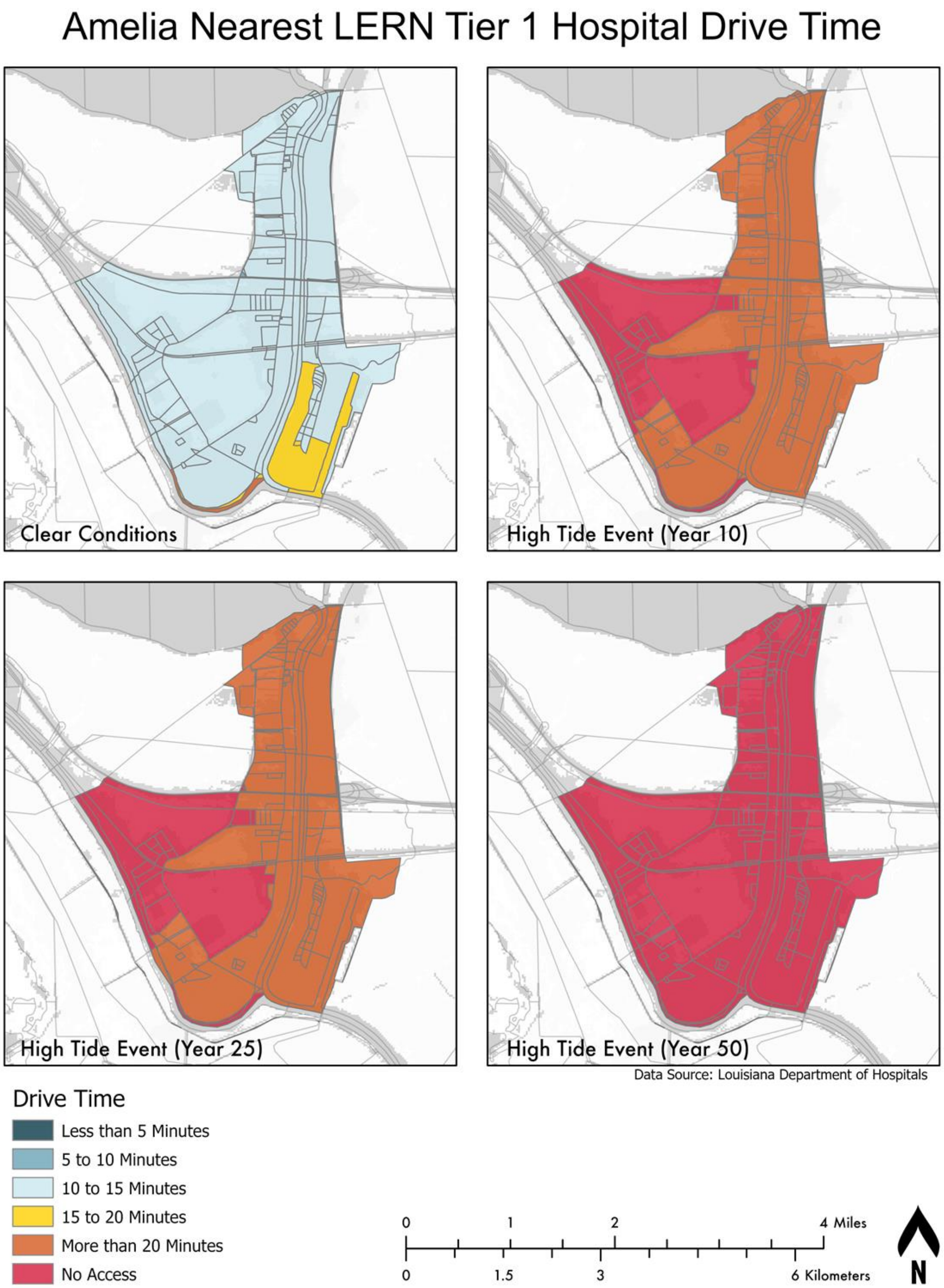
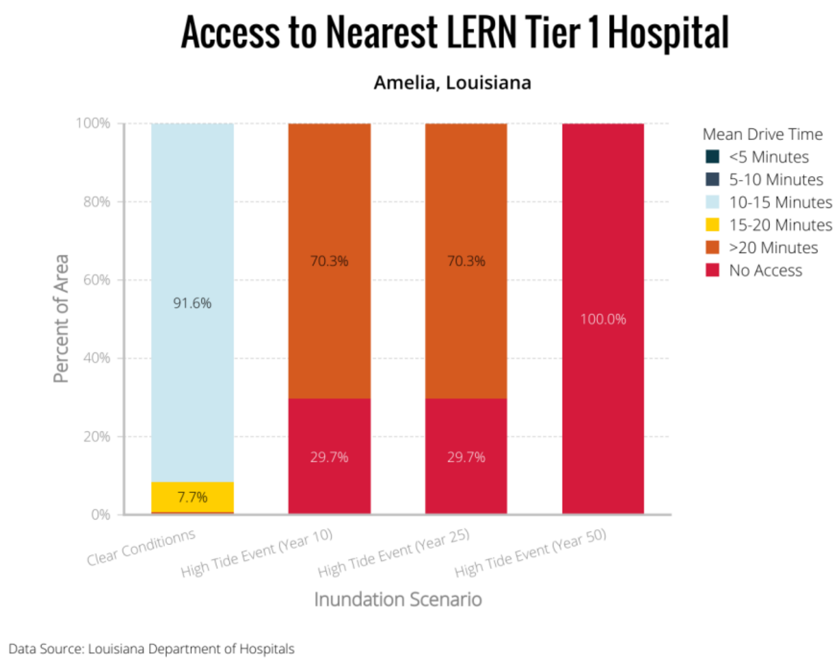


Figure 61. Drive Time to Nearest Louisiana Emergency Response Network (LERN) Tier 1 Hospital, Amelia, LA.



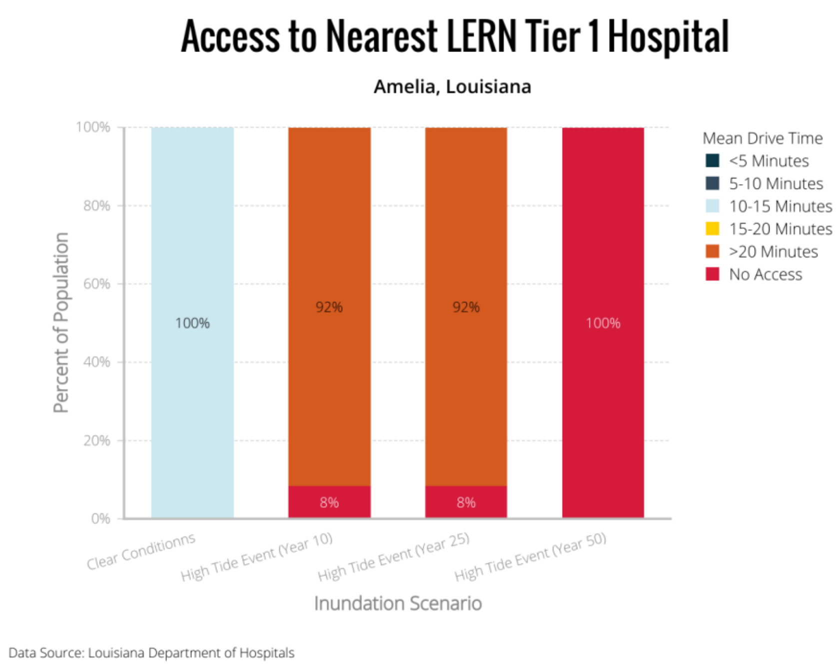


Figure 62. Drive Time Access to Nearest LERN Tier 1 Hospital by Percent of Area and Population, Amelia, LA

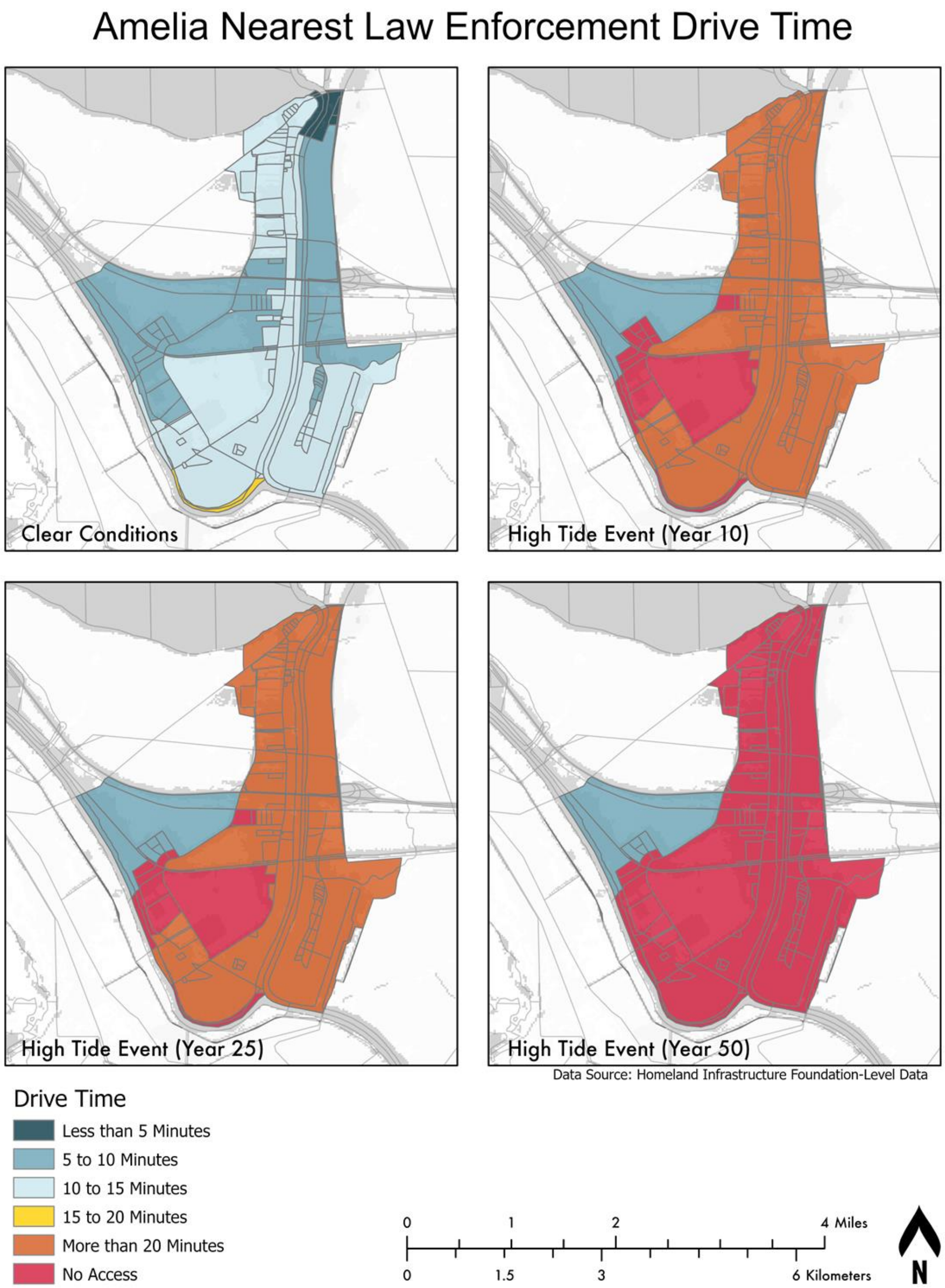
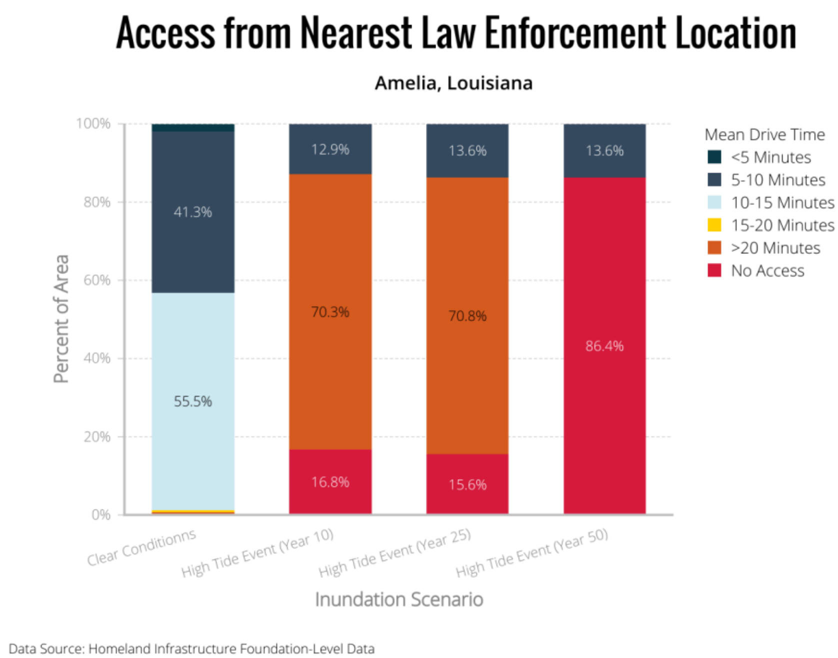


Figure 63. Nearest Law Enforcement Drive Time in Amelia, LA.



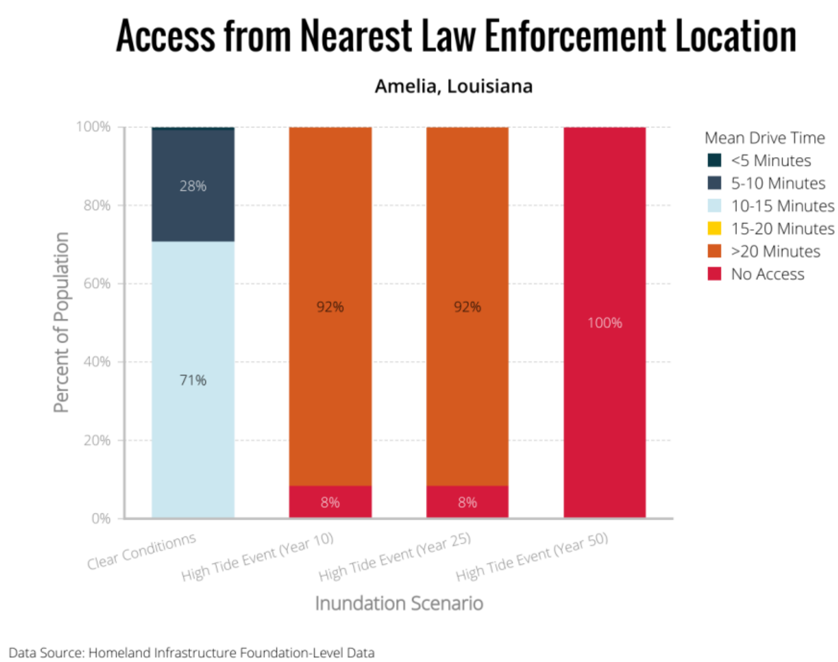


Figure 64. Drive Time Access from Nearest Law Enforcement Location by Percent of Area and Population, Amelia, LA.

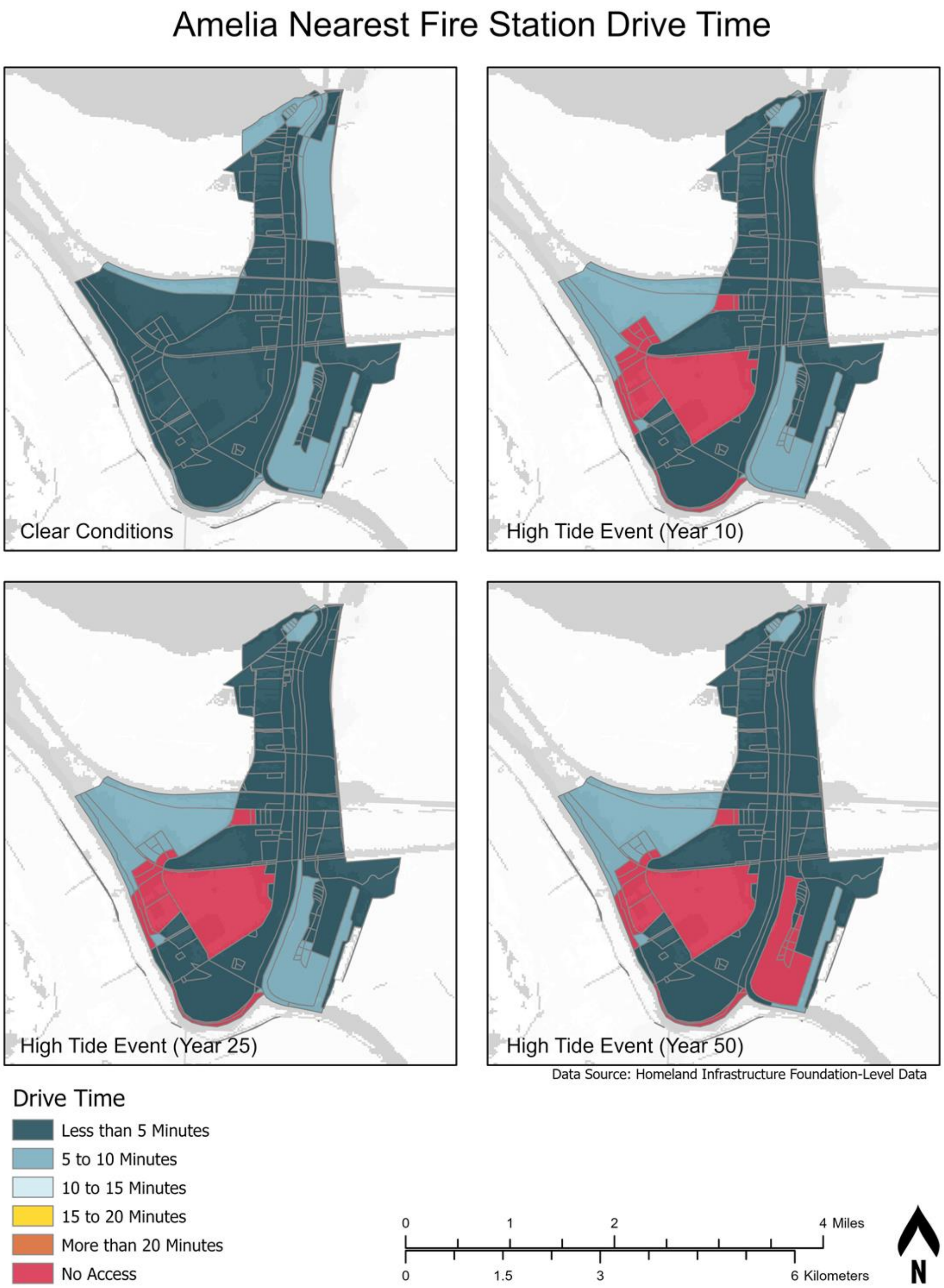
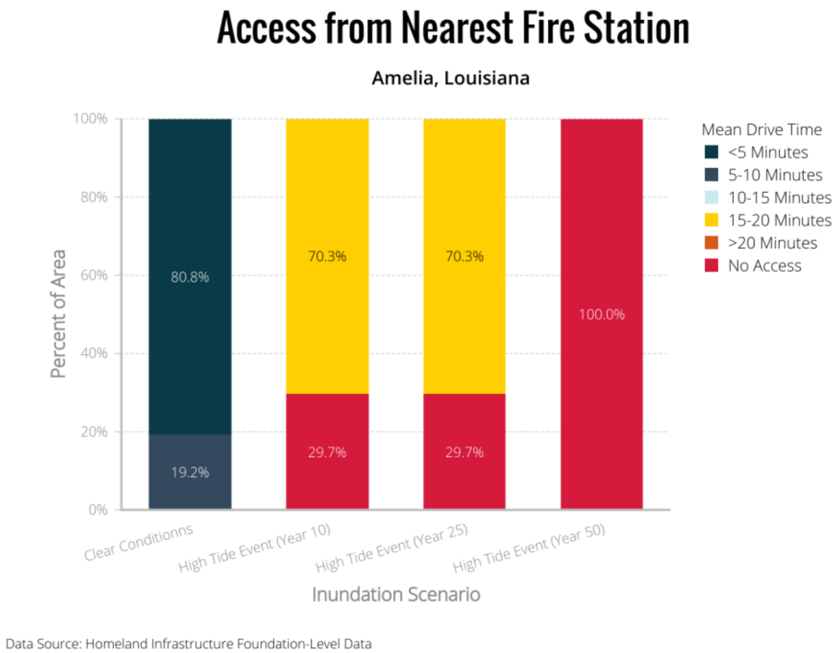


Figure 65. Nearest Fires Station Drive Time in Amelia, LA.



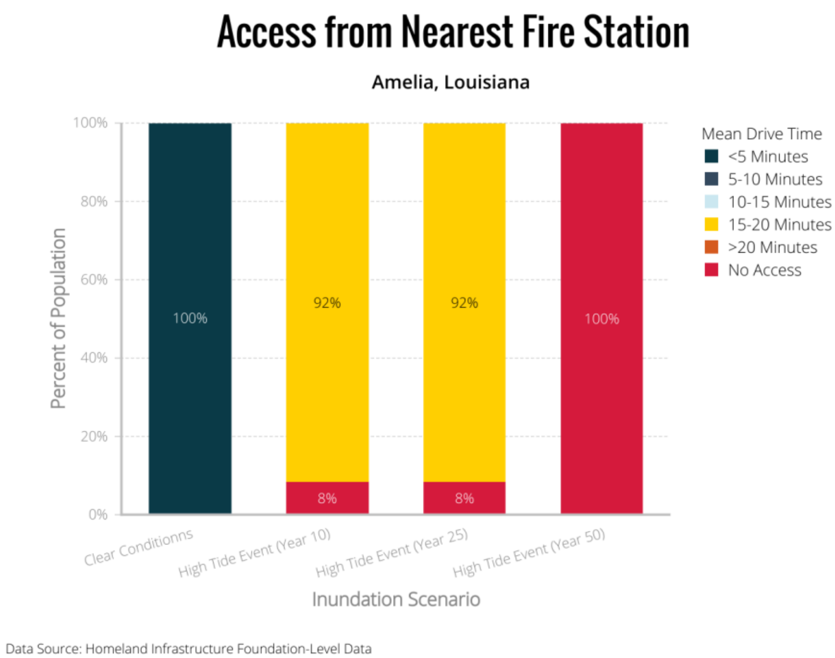


Figure 66. Drive Time Access from Nearest Fire Station by Percent of Area and Population, Amelia, LA.

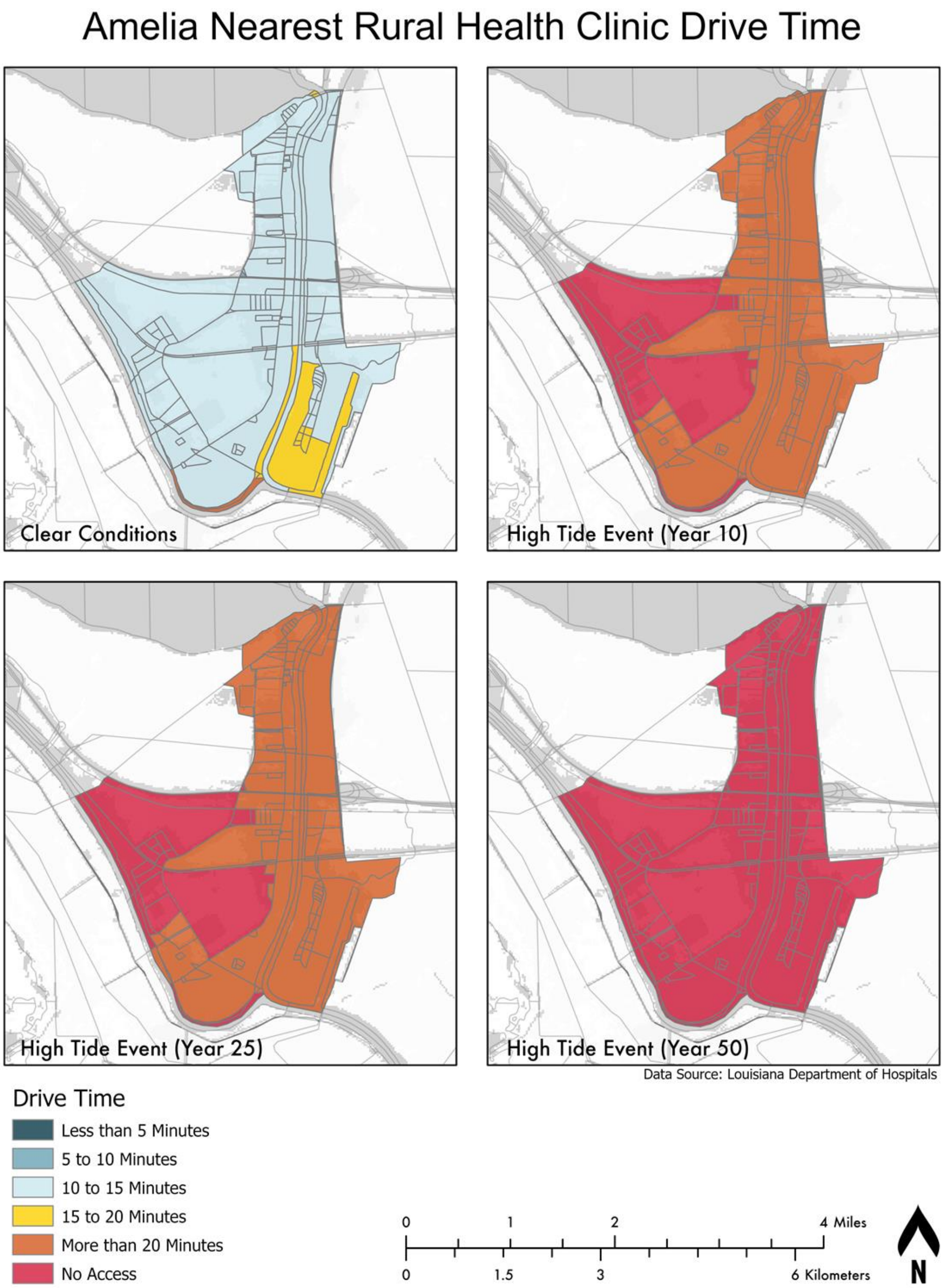
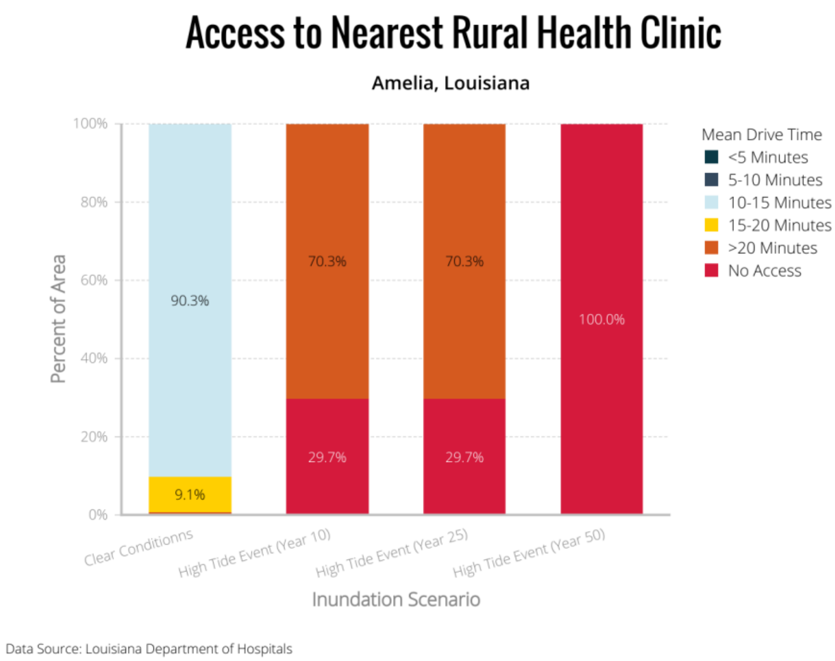


Figure 67. Nearest Rural Health Clinic Drive Time in Amelia, LA.



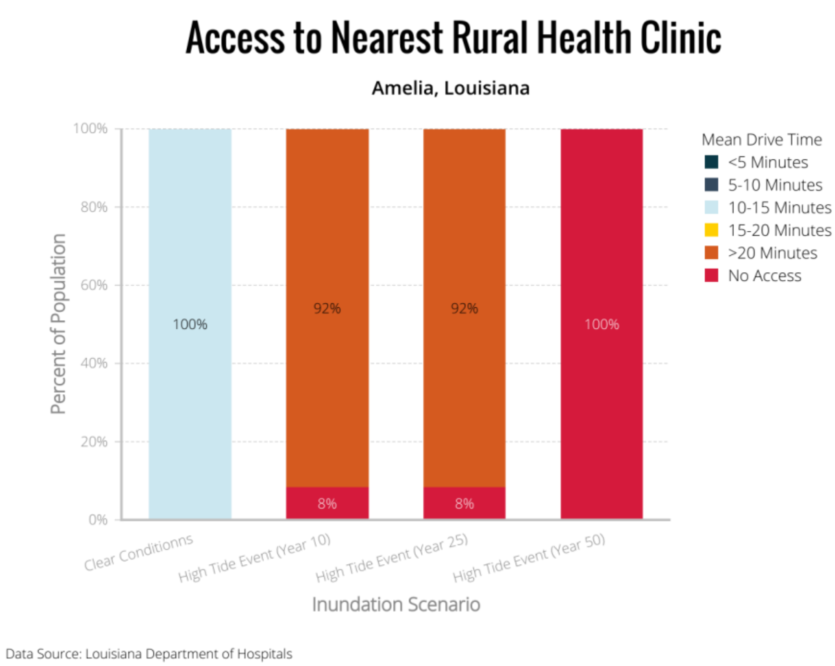


Figure 68. Drive Time Access to Nearest Rural Health Clinic by Percent of Area and Population, Amelia, LA.

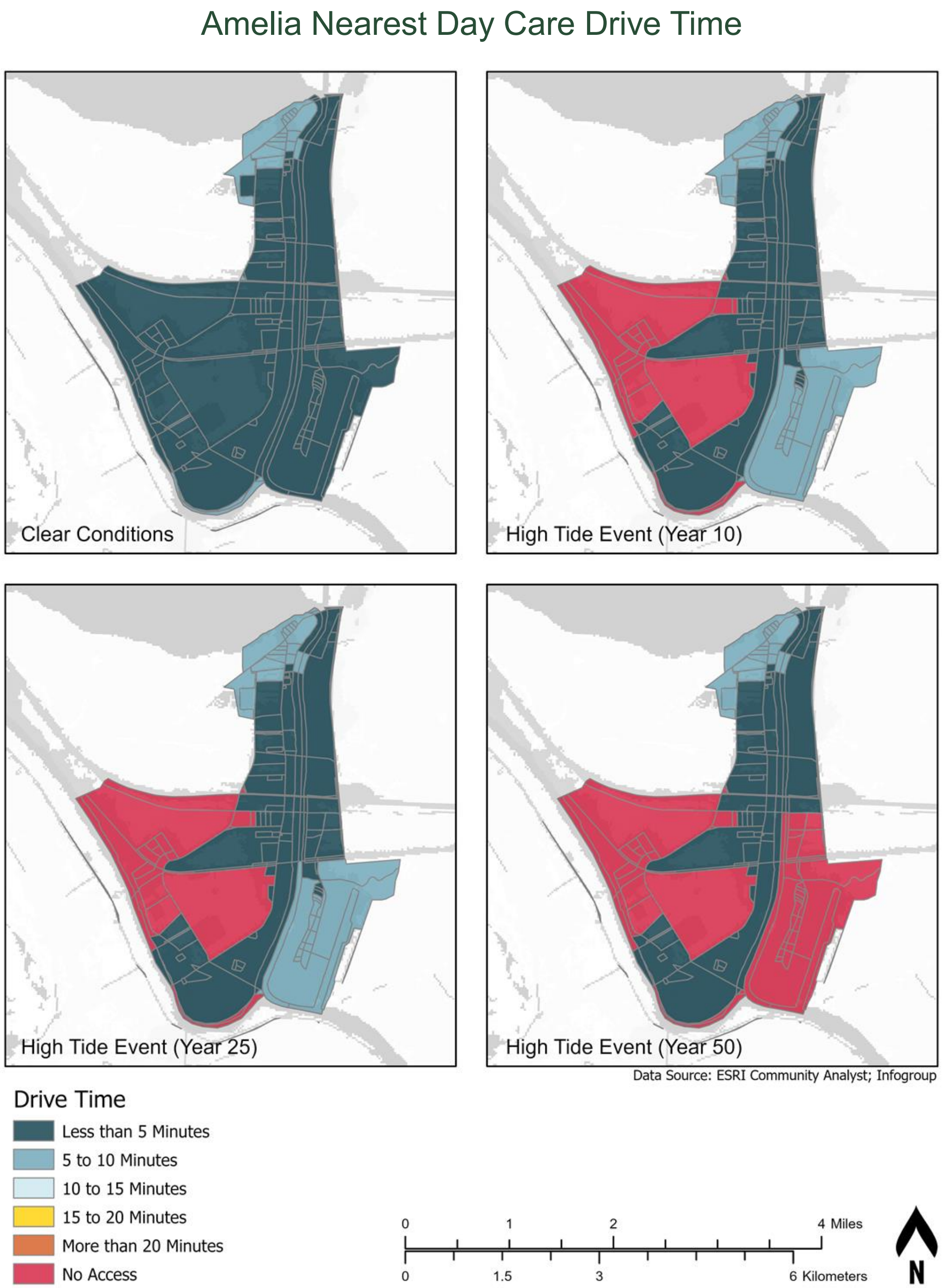
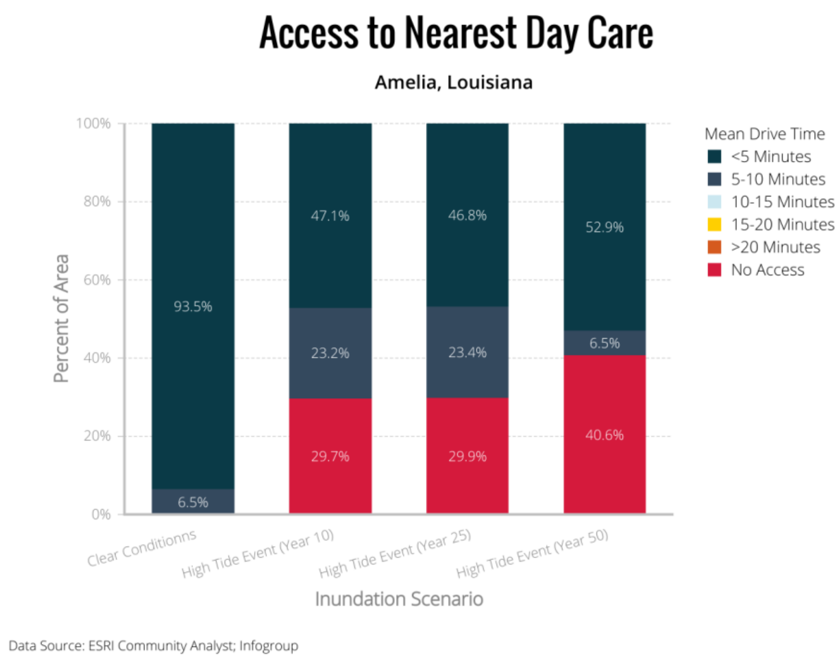


Figure 69. Nearest Day Care Drive Time in Amelia, LA.



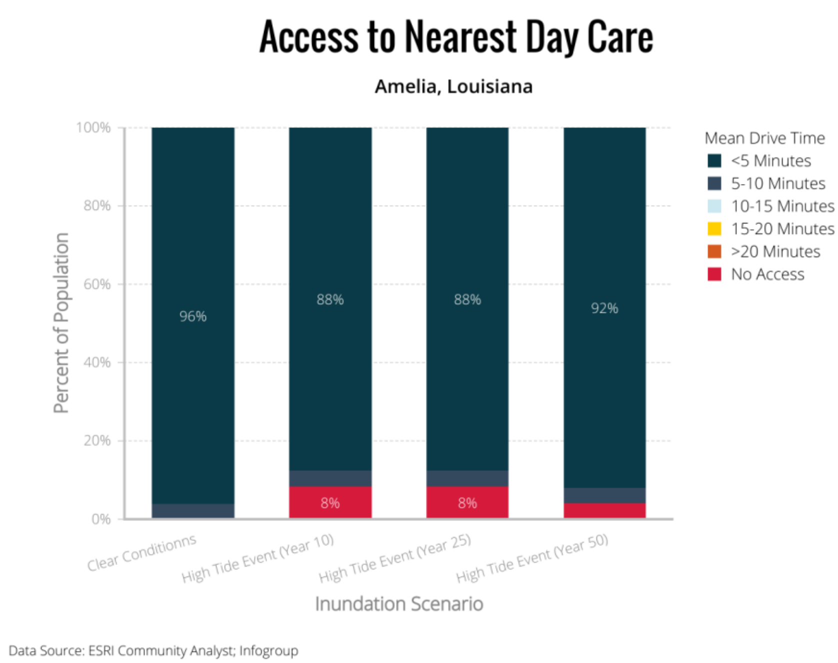


Figure 70. Drive Time Access to Nearest Day Care by Percent of Area and Population, Amelia, LA.

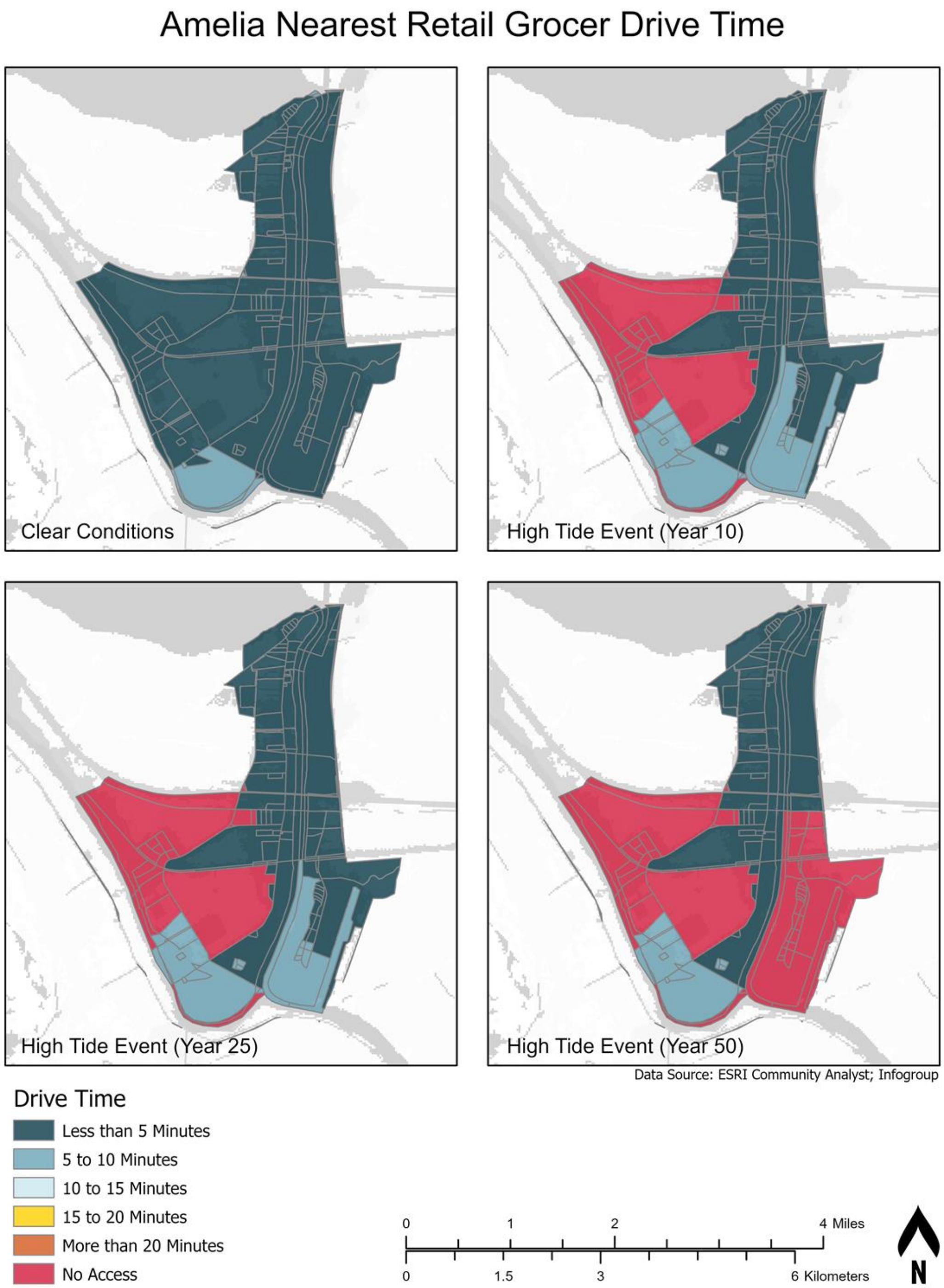
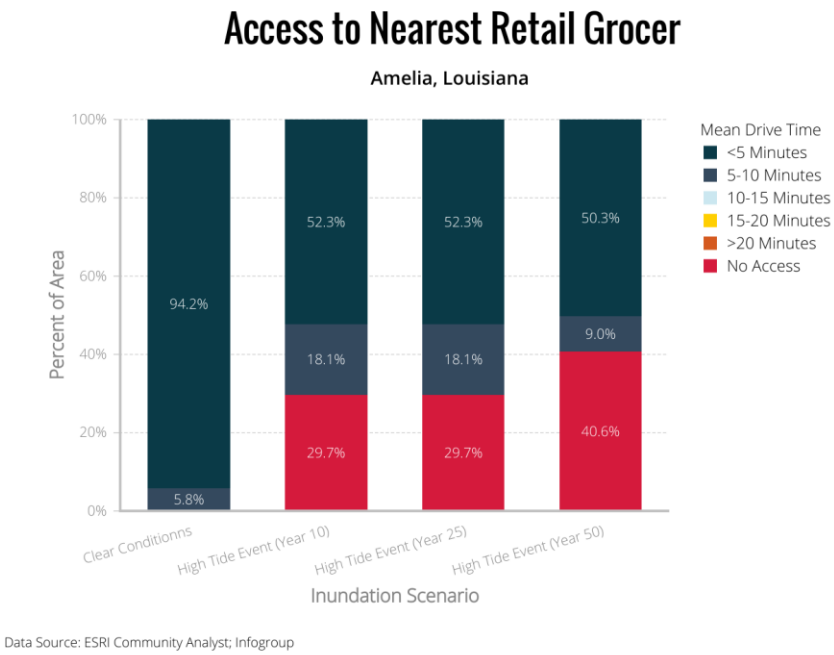


Figure 71. Nearest Retail Grocer Drive Time in Amelia, LA.



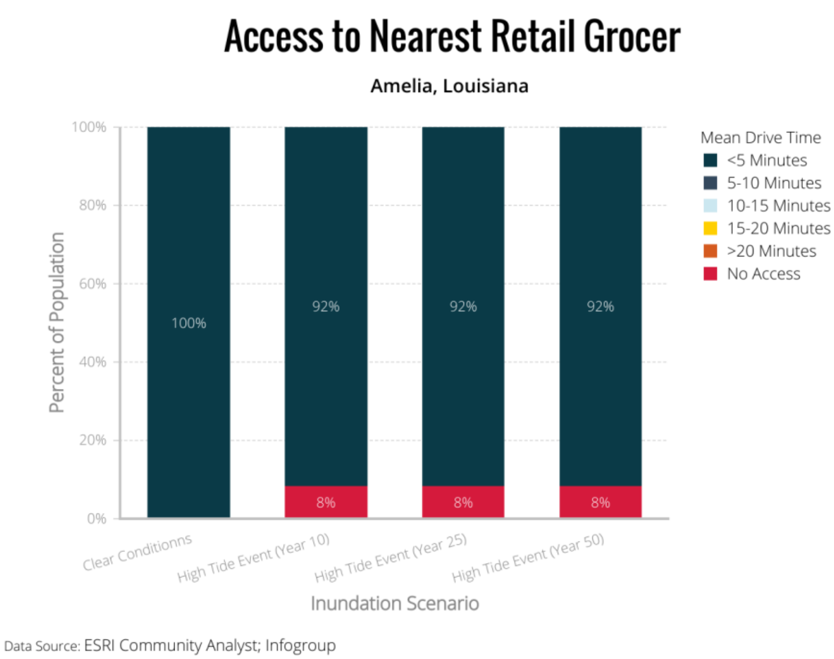
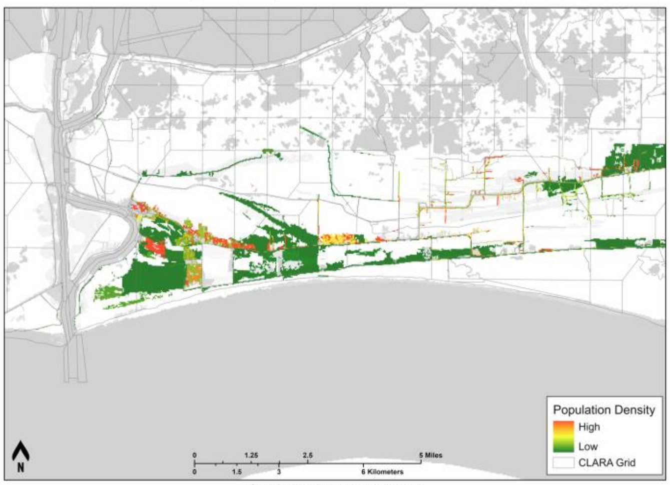


Figure 72. Drive Time Access to Nearest Retail Grocer by Percent of Area and Population, Amelia, LA.

CAMERON, LA

The community of Cameron is located in the southwest region of Louisiana in south-central Cameron Parish. The city serves as the parish seat of Cameron Parish and is part of the Lake Charles Metropolitan Statistical Area. At the time of the 2010 census, 406 residents resided in Cameron. Located on the Gulf of Mexico, Cameron is serviced by highways 27 and 82, which connect its residents to many of the critical and essential facilities that they depend upon. Given the town's location, it is particularly vulnerable to high tide flood events which may flood a number of critical roadway segments and cut residents off from all essential services not located immediately within the town.

Interpolated Population in Cameron, Louisiana



Cameron, Louisiana

Critical and Essential Facilities

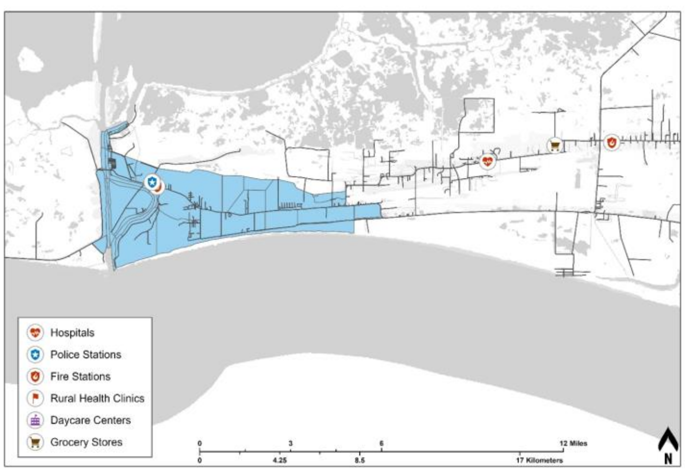
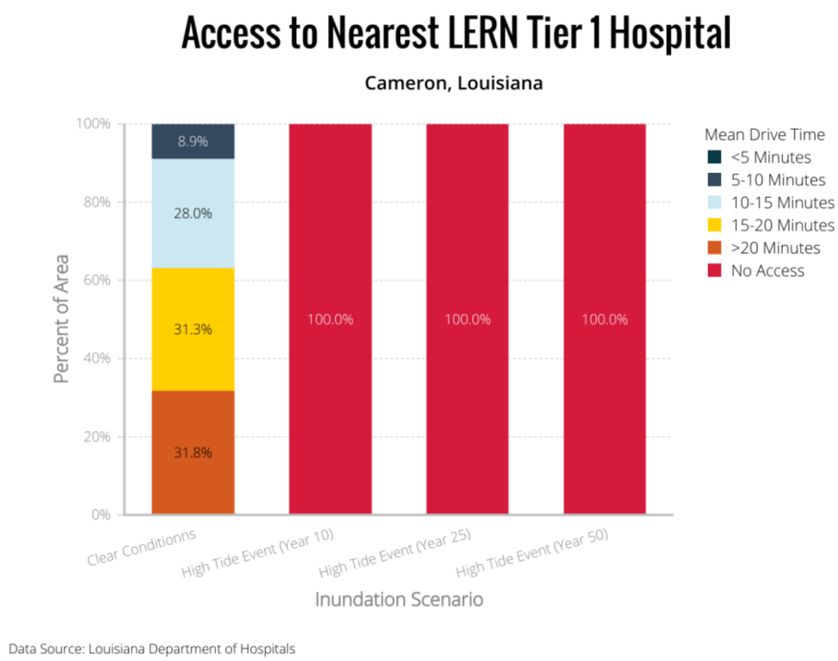


Figure 73. Interpolated Population and Critical/Essential Facilities in Cameron, LA.



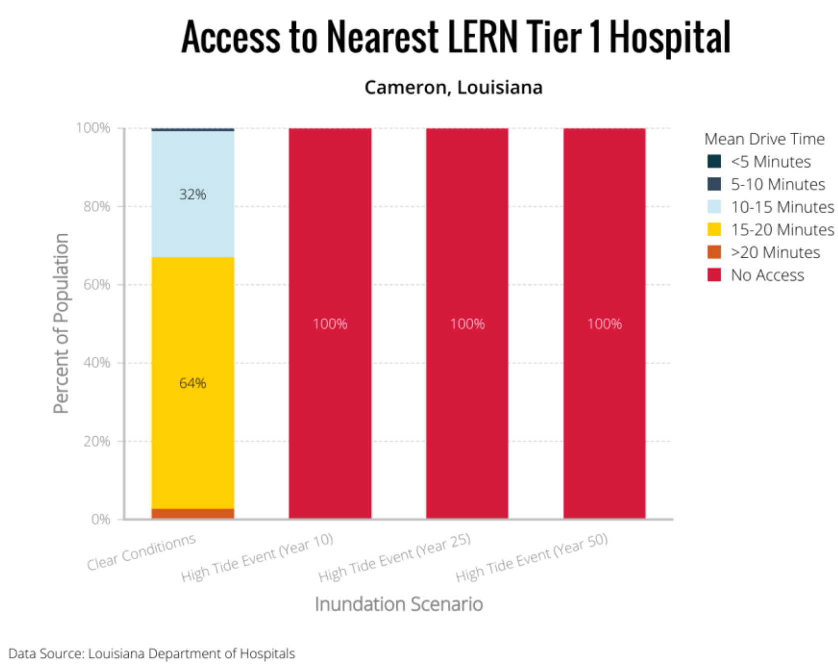
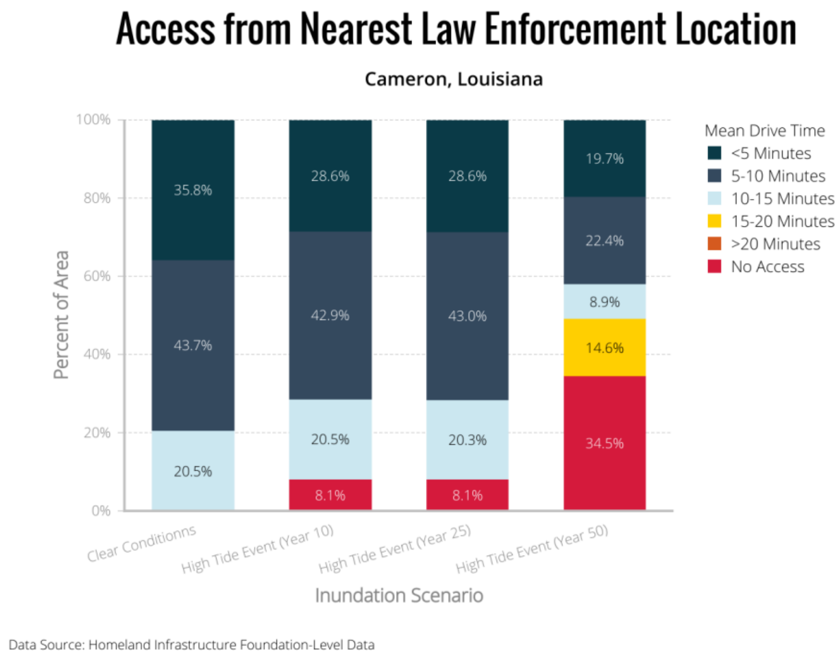


Figure 74. Drive Time Access to Nearest LERN Tier 1 Hospital, Cameron, LA.



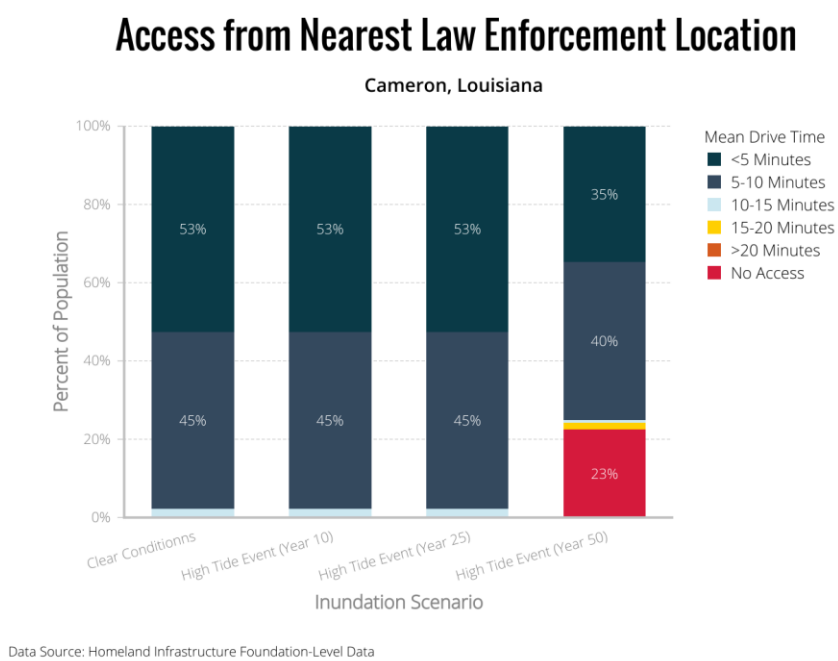
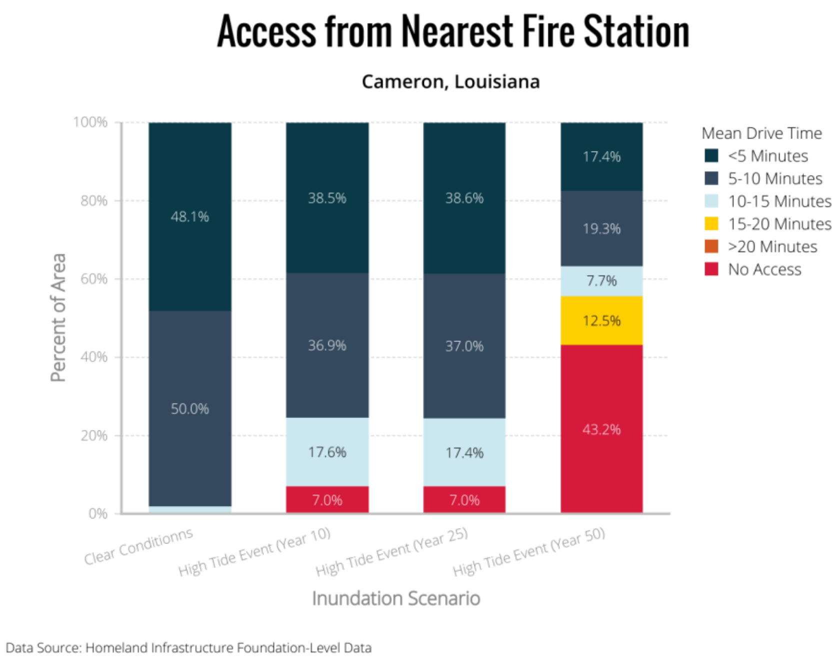


Figure 75. Drive Time Access from Nearest Law Enforcement Location by Percent of Area and Population, Cameron, LA.



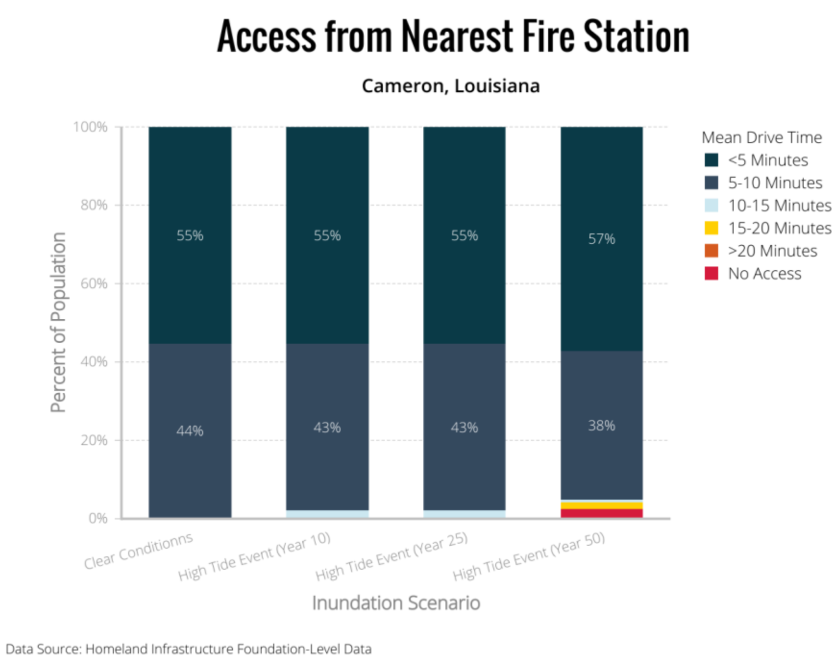
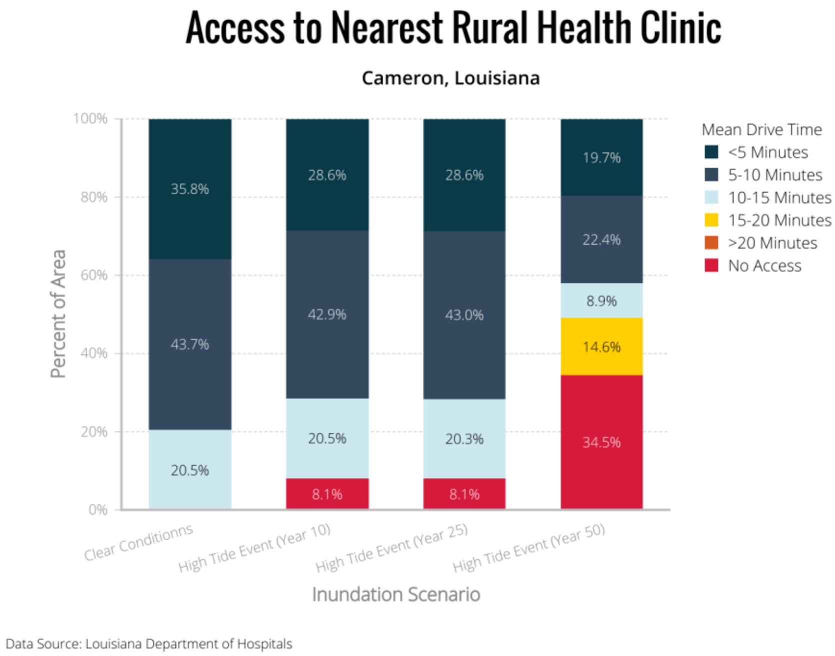


Figure 76. Drive Time Access from Nearest Fire Station by Percent of Area and Population, Cameron, LA.



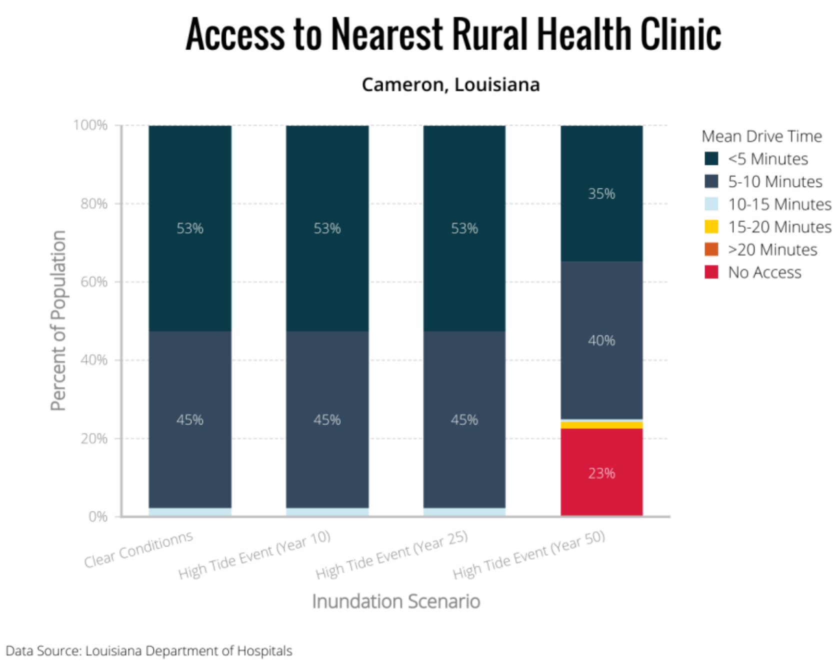
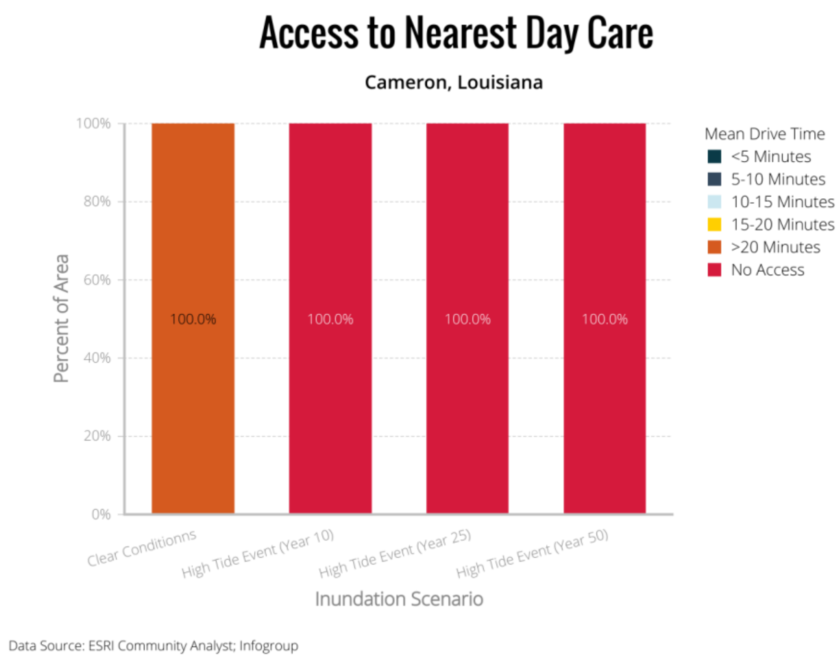


Figure 77. Drive Time Access to Nearest Rural Health Clinic by Percent of Area and Population, Cameron, LA.



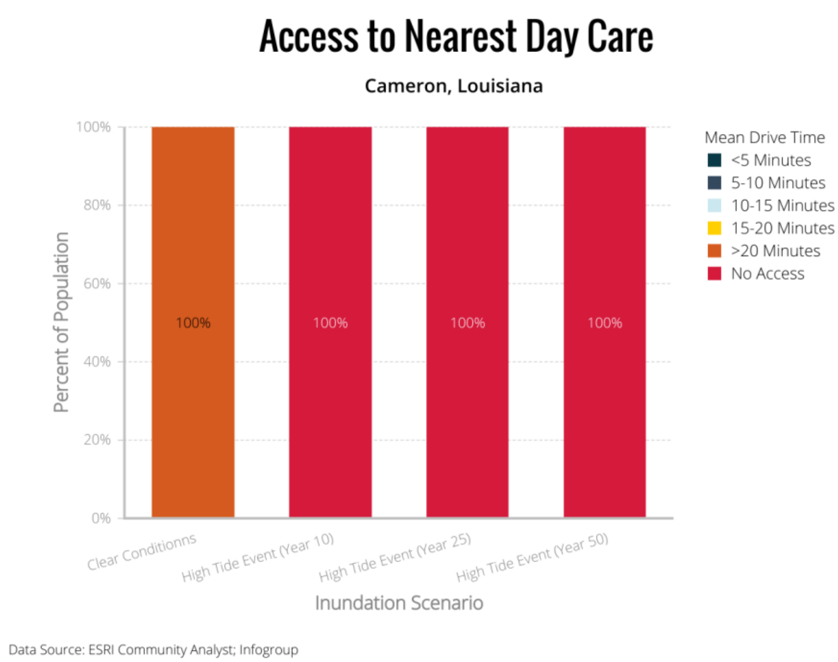
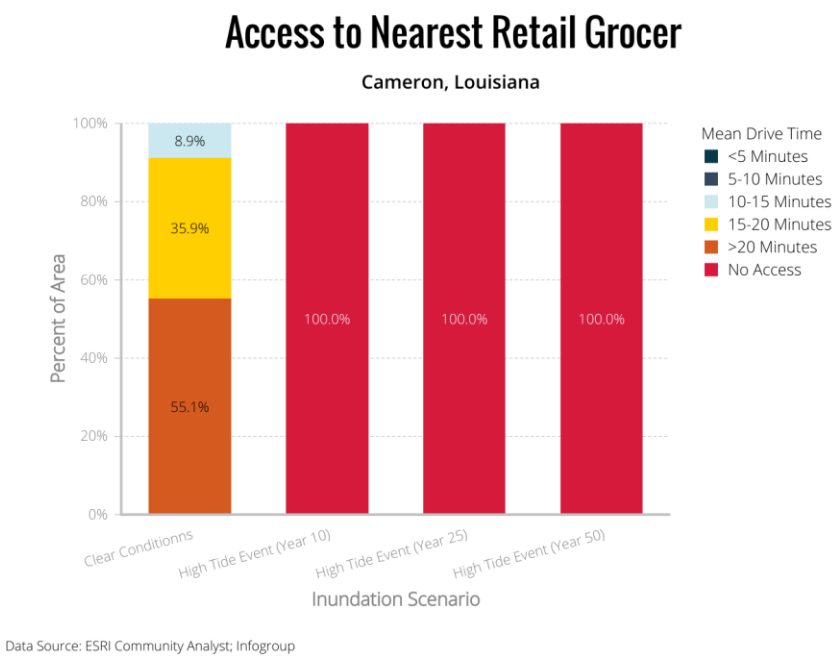


Figure 78. Drive Time Access to Nearest Day Care by Percent of Area and Population, Cameron, LA.



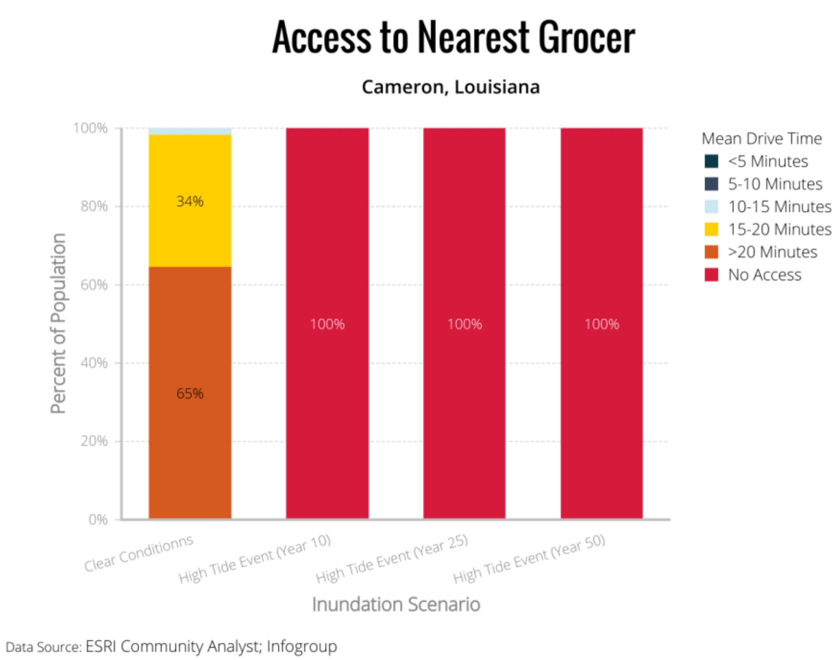


Figure 79. Drive Time Access to Nearest Retail Grocer by Percent of Area and Population, Cameron, LA.

DELACROIX, LA

The small unincorporated fishing community of Delacroix is located in St. Bernard Parish along Bayou Terre aux Bouefs, surrounded on all sides by bayous and wetlands. The majority of the critical and essential facilities that service the community are located along Highway 300, the Delacroix Highway, the only road in or out of Delacroix. During high tide flood events, the highway stays relatively dry, allowing residents to continue to access many of the essential facilities they utilize, the majority of which are located further inland within the federal levee system.

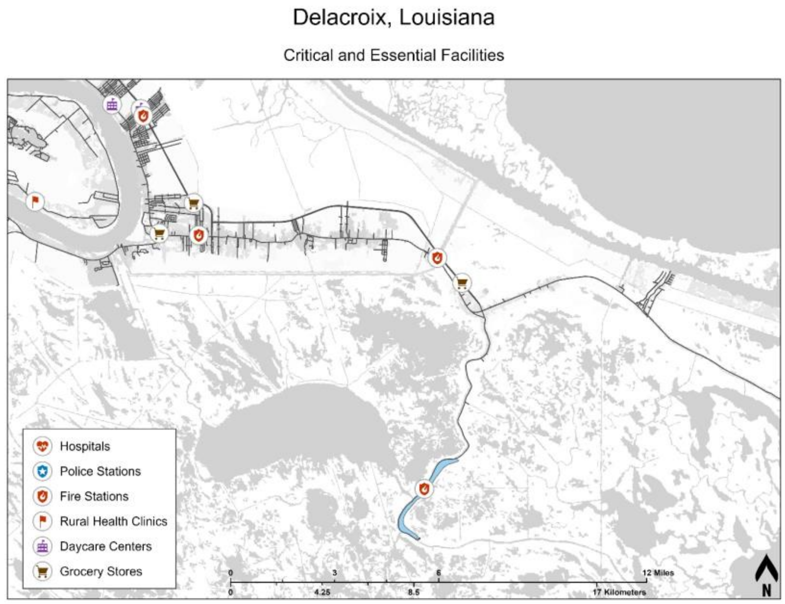
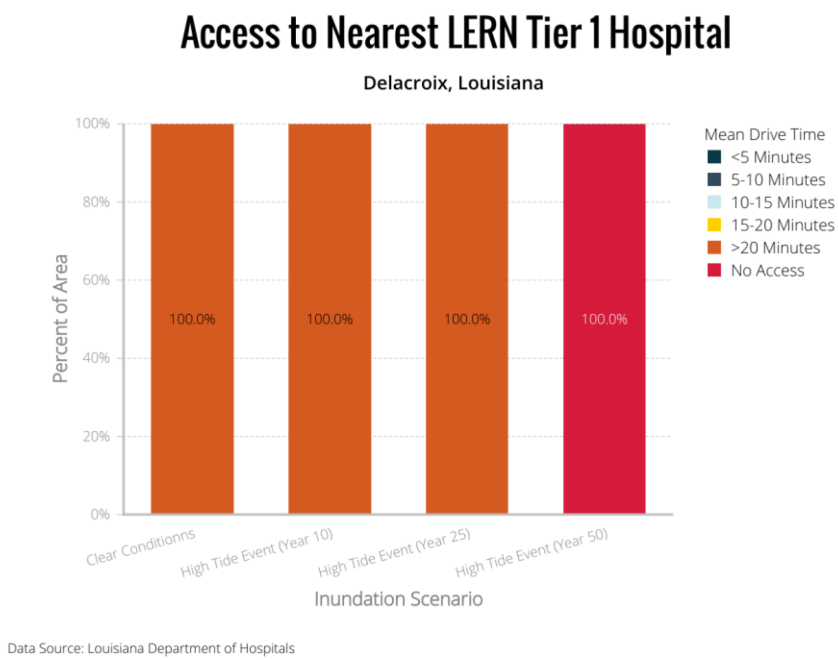


Figure 80. Critical/Essential Facilities in Delacroix, LA.



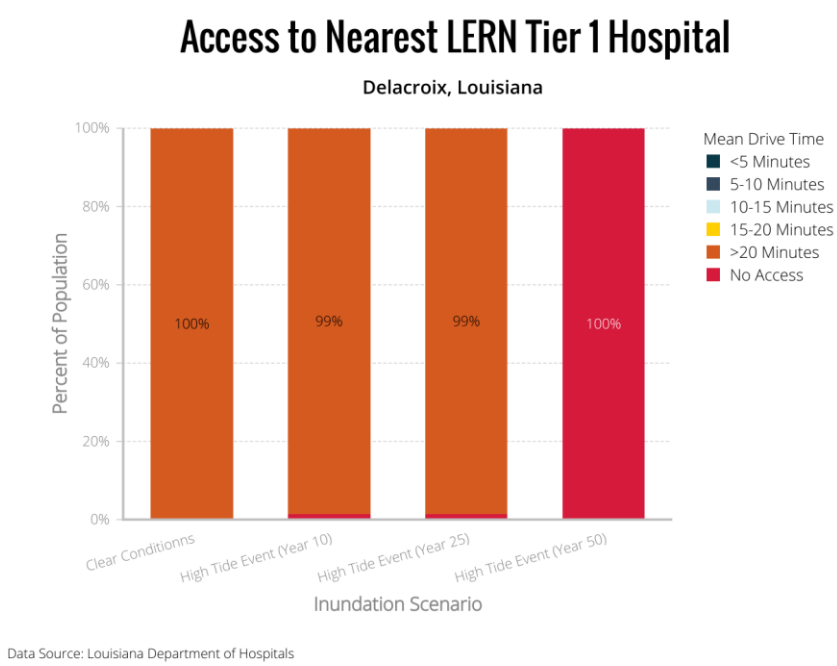
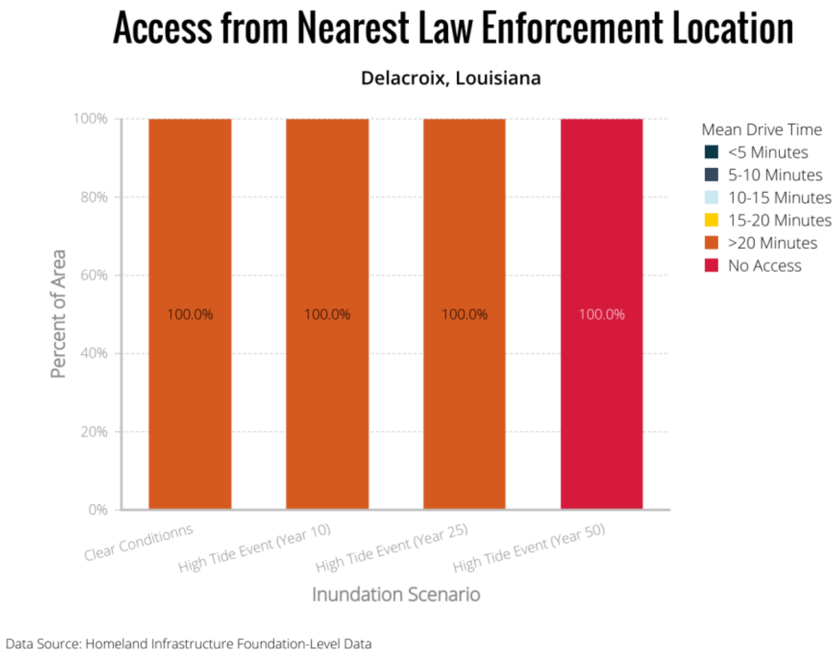


Figure 81. Drive Time Access to Nearest LERN Tier 1 Hospital, Delacroix, LA.



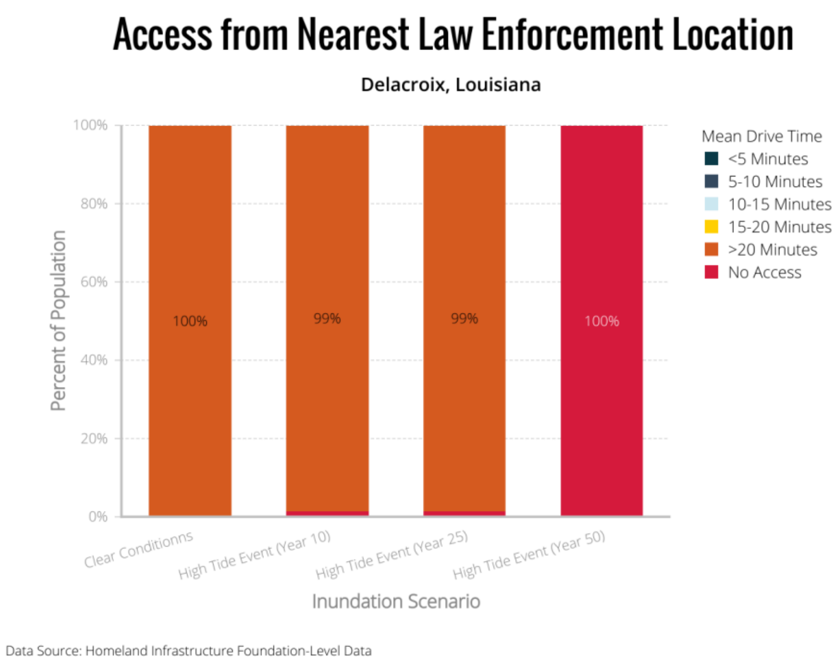
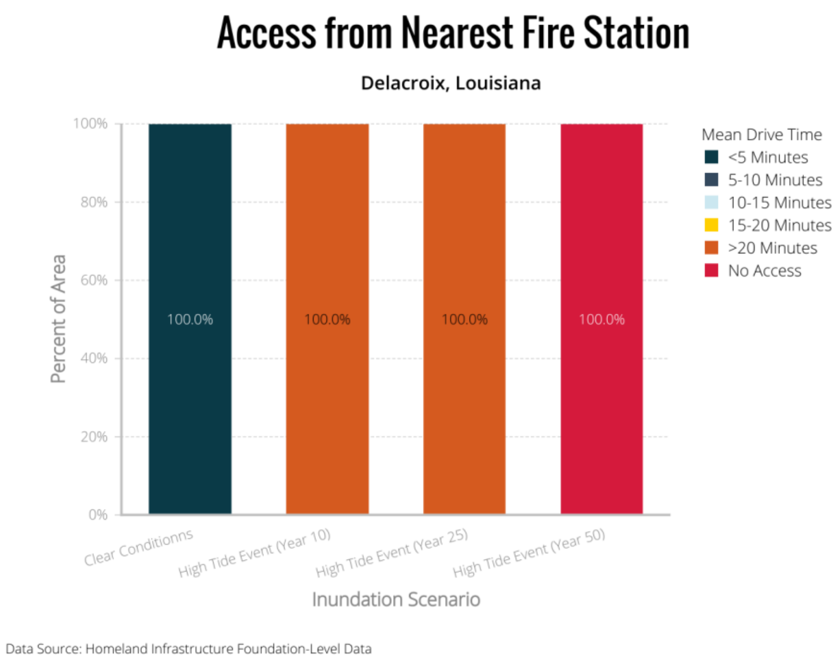


Figure 82. Drive Time Access from Nearest Law Enforcement Location by Percent of Area and Population, Delacroix, LA.



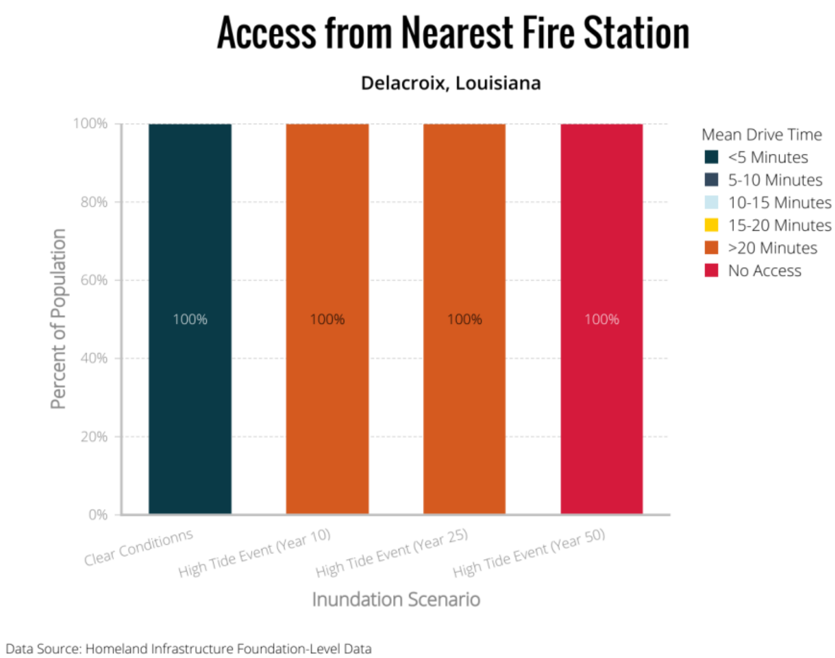
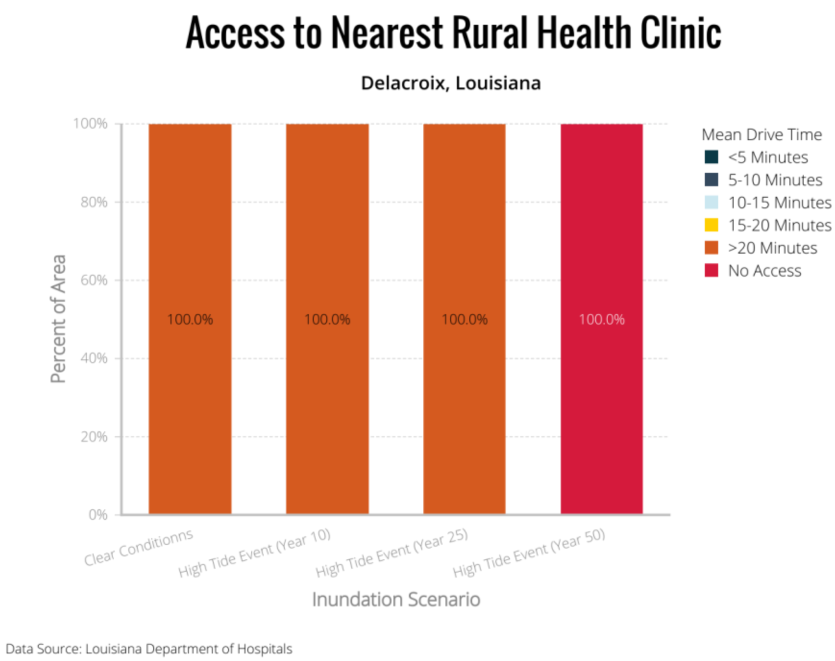


Figure 83. Drive Time Access from Nearest Fire Station by Percent of Area and Population, Delacroix, LA.



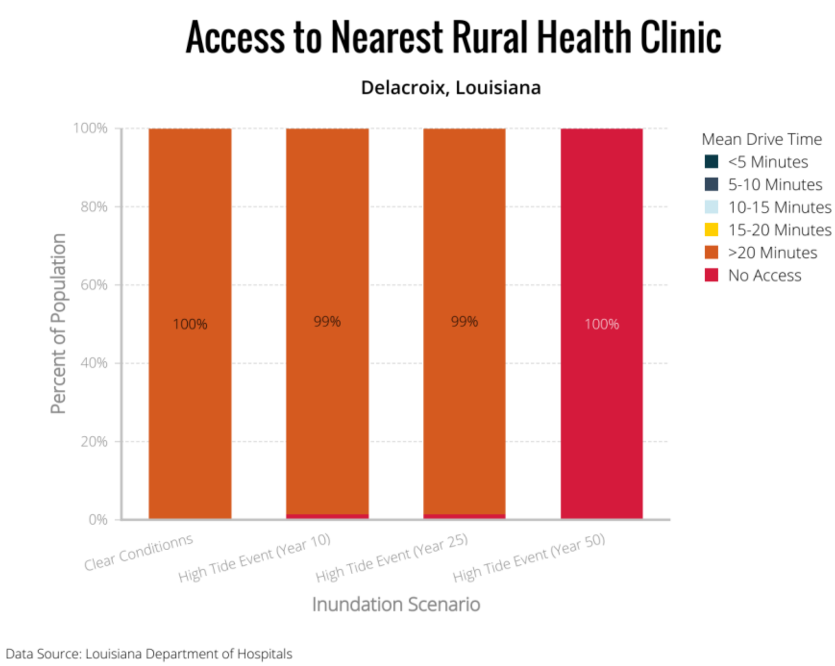
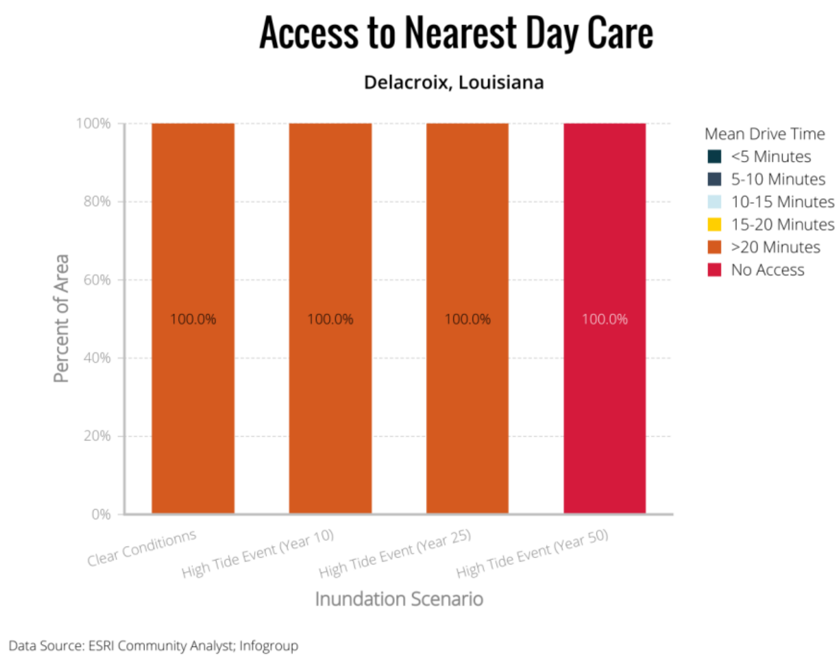


Figure 84. Drive Time Access to Nearest Rural Health Clinic by Percent of Area and Population, Delacroix, LA.



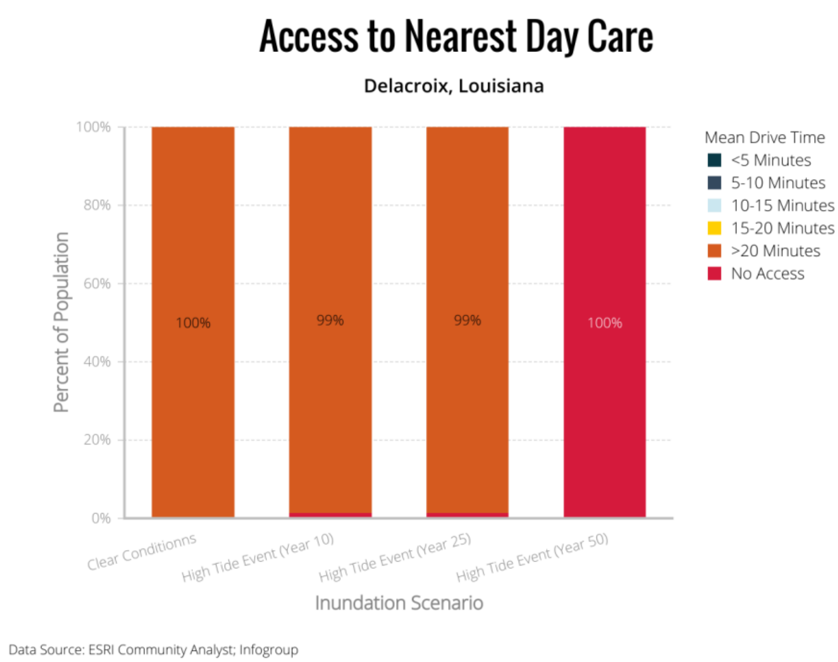
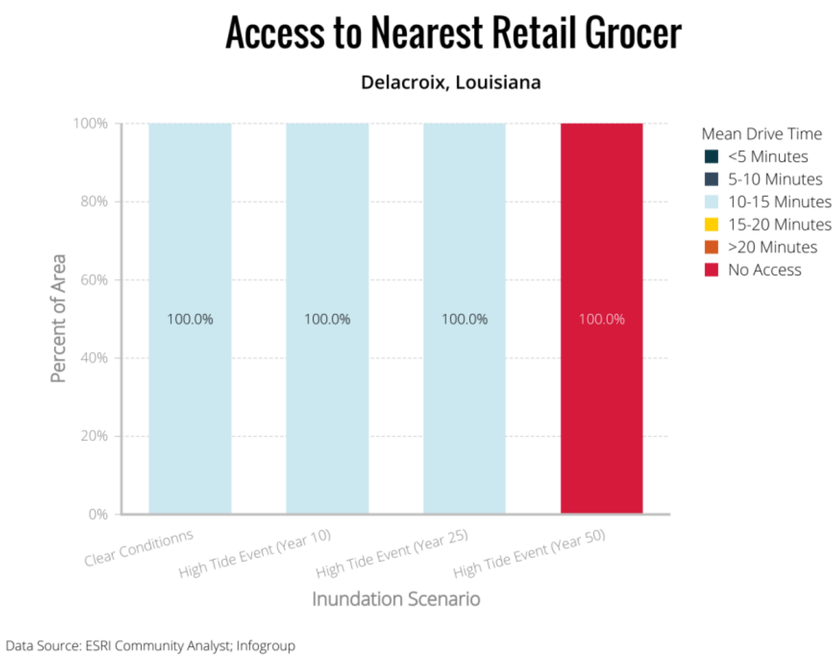


Figure 85. Drive Time Access to Nearest Day Care by Percent of Area and Population, Delacroix, LA.



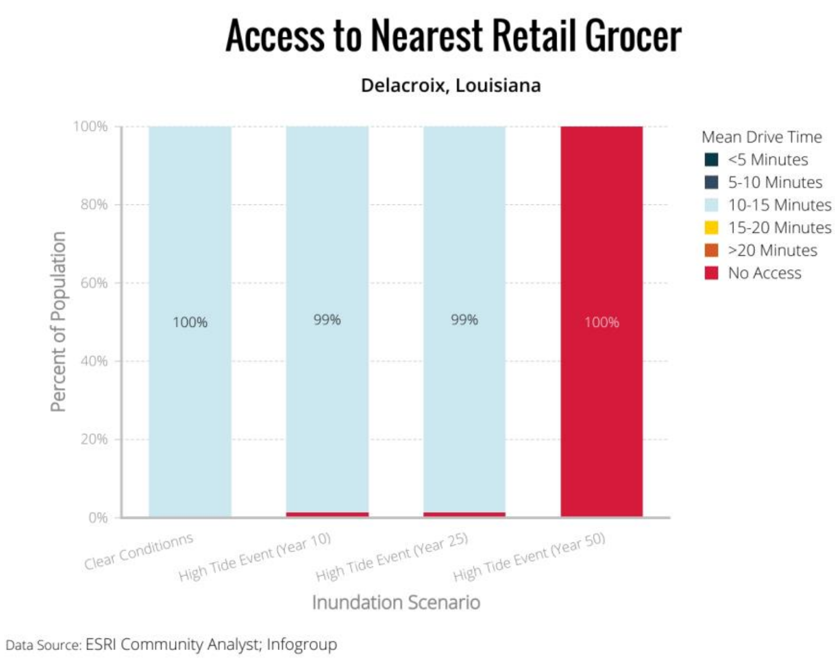


Figure 86. Drive Time Access to Nearest Retail Grocer by Percent of Area and Population, Delacroix, LA.

DULAC AND DULARGE, LA

The communities of Dulac and Dularge are located in southern Terrebonne Parish on narrow threads of high along Bayou Grand Caillou and Bayou Dularge, respectively. Part of the Houma–Bayou Cane–Thibodaux Metropolitan Statistical Area, many residents of these communities are dependent upon the city of Houma for critical and essential services. Bisected by the Falgout Canal, these communities are divided into upper and lower portions. During high tide flood events, many streets within the lower portions of the community become flooded, potentially isolating and cutting them off from the rest of the community.

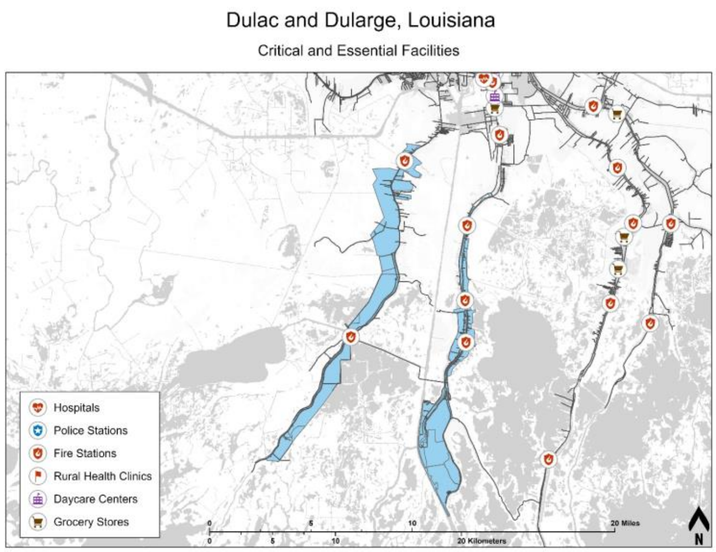
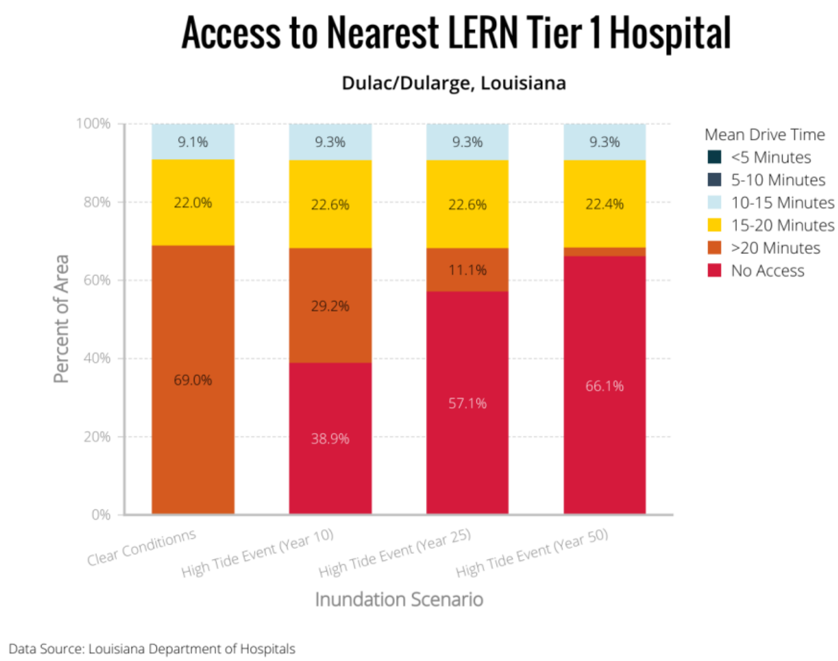


Figure 87. Critical/Essential Facilities in Dulac and Dularge, LA.



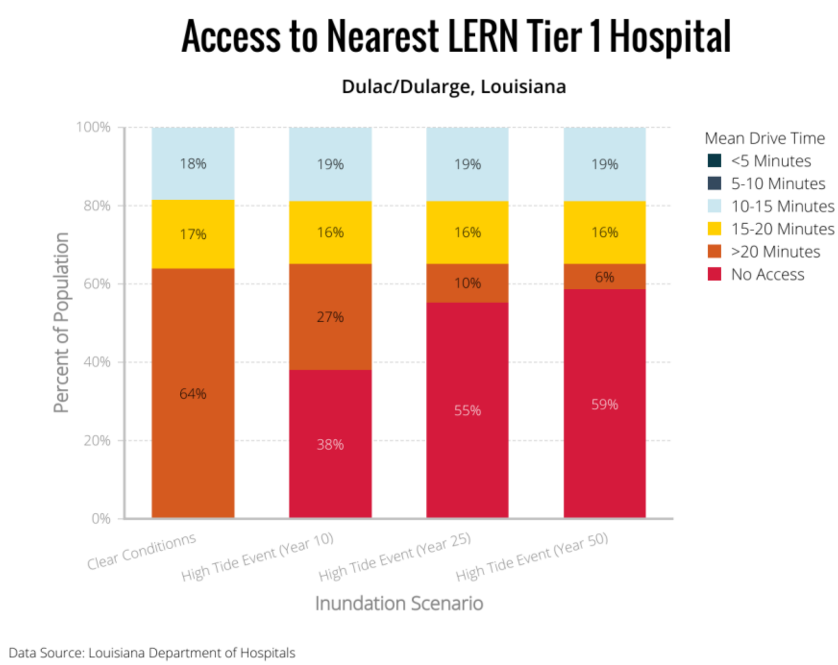
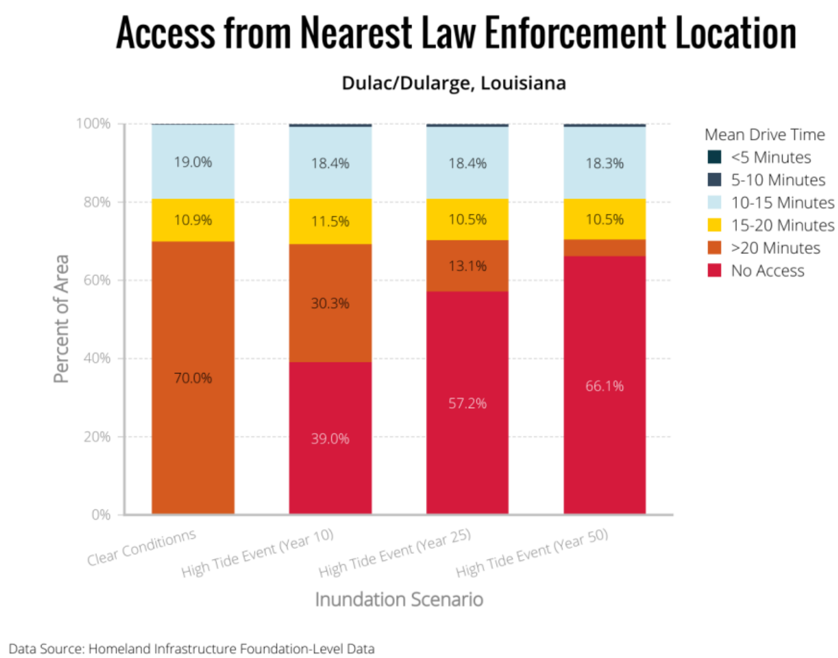


Figure 88. Drive Time Access to Nearest LERN Tier 1 Hospital, Dulac and Dularge, LA.



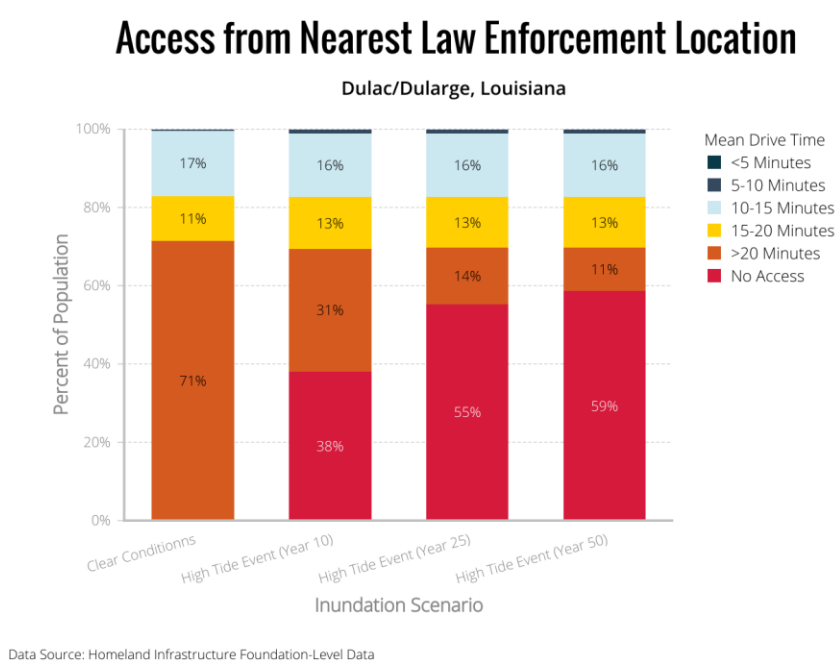
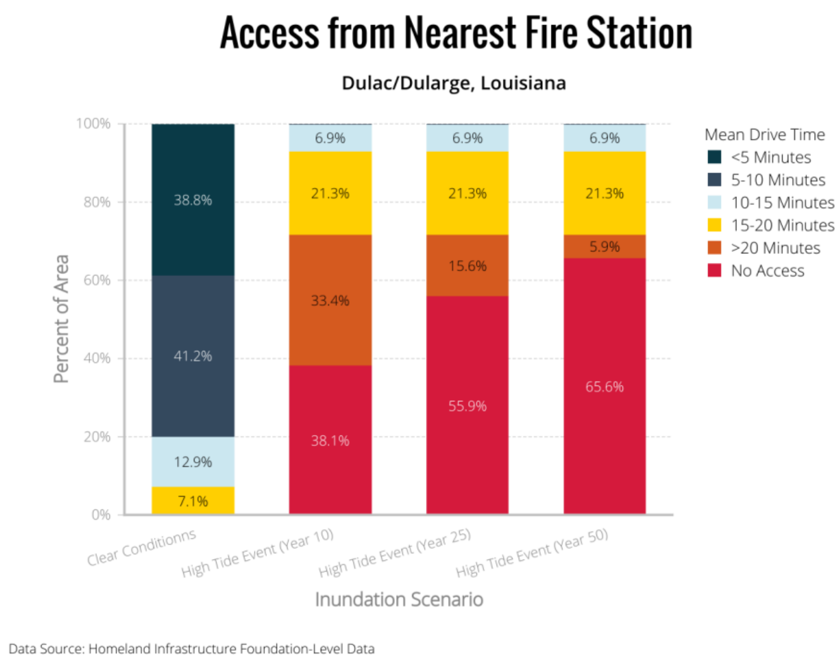


Figure 89. Drive Time Access from Nearest Law Enforcement Location by Percent of Area and Population, Dulac and Dularge, LA.



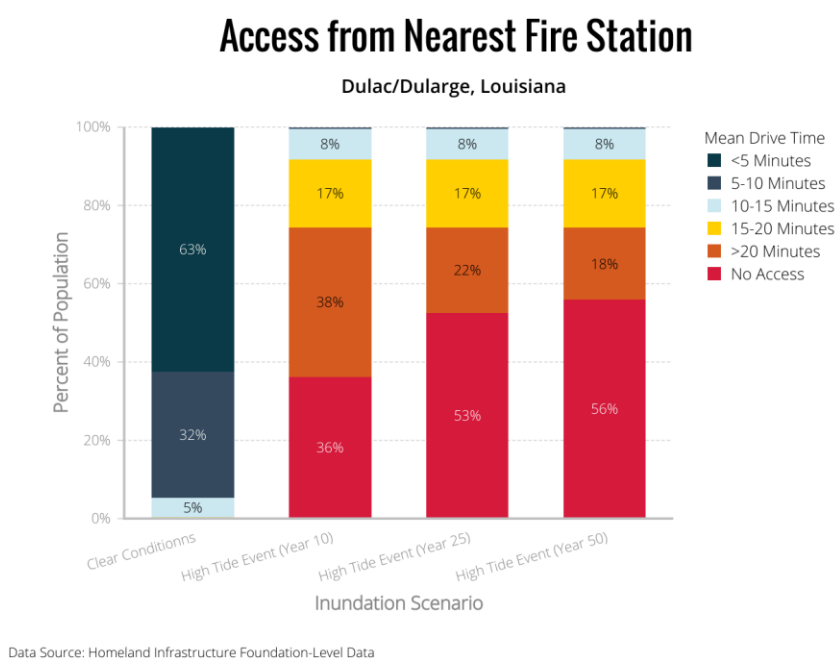
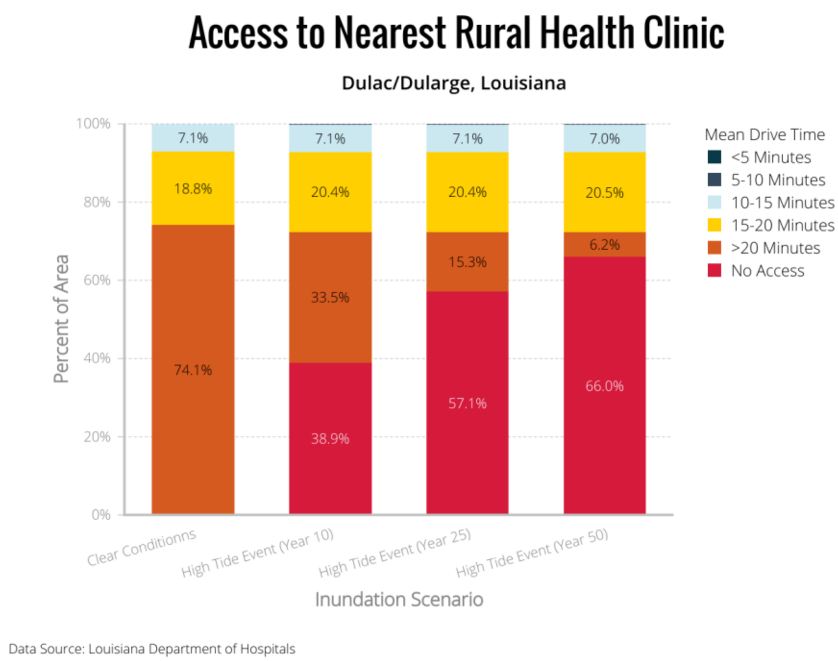


Figure 90. Drive Time Access from Nearest Fire Station by Percent of Area and Population, Dulac and Dularge, LA.



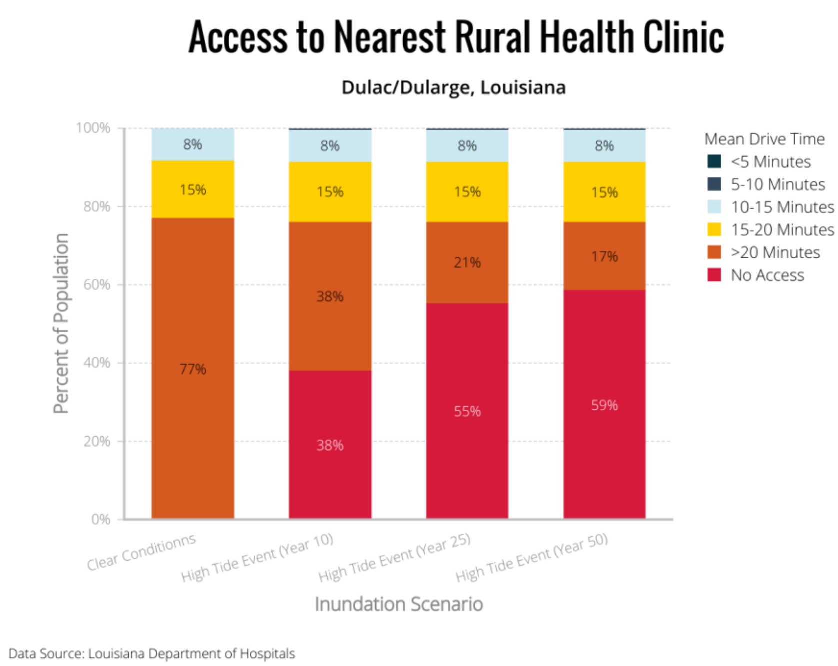
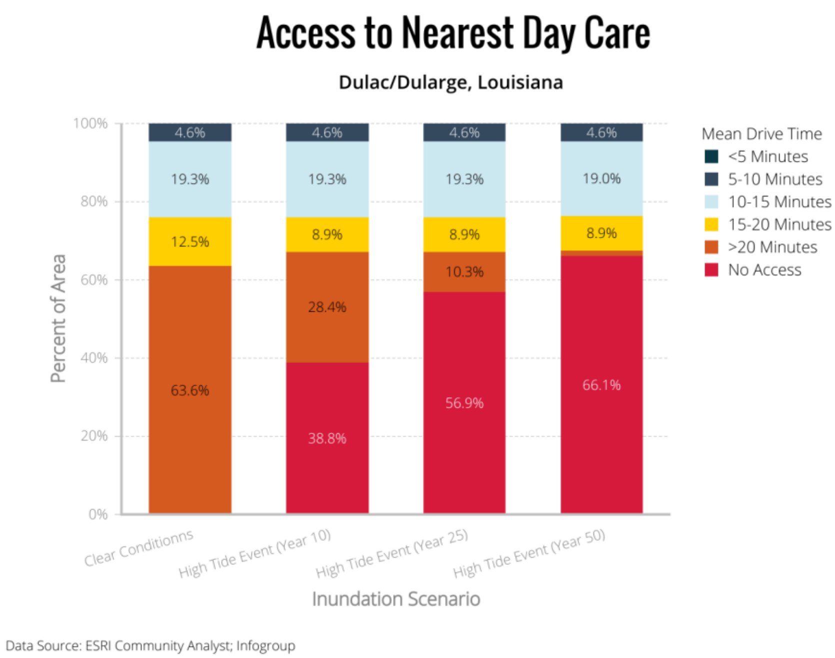


Figure 91. Drive Time Access to Nearest Rural Health Clinic by Percent of Area and Population, Dulac and Dularge, LA.



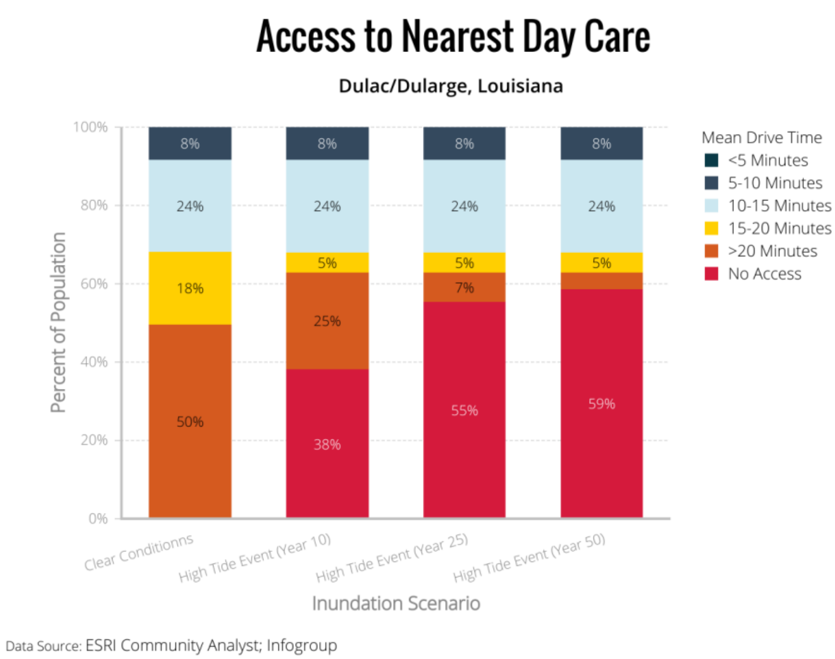
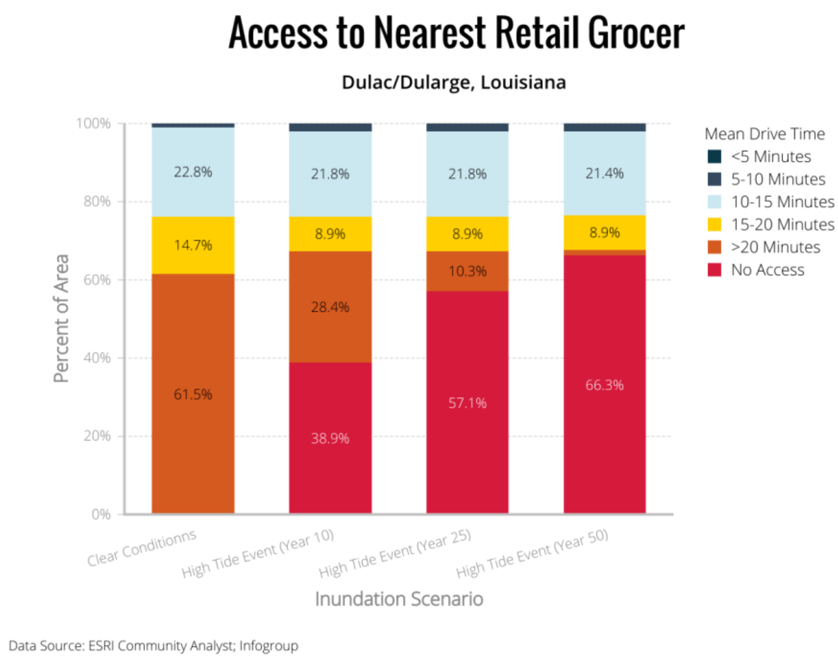


Figure 92. Drive Time Access to Nearest Day Care by Percent of Area and Population, Dulac and Dularge, LA.



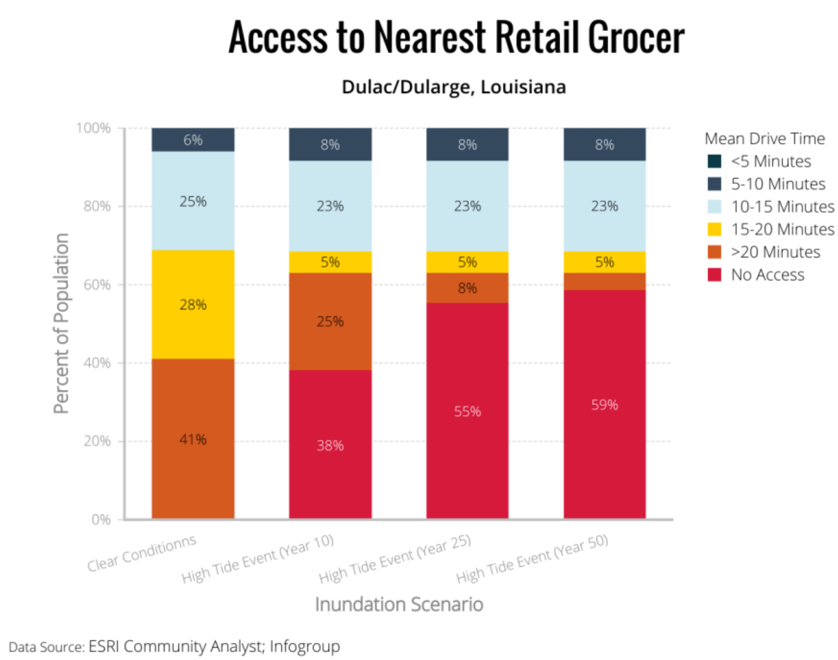


Figure 93. Drive Time Access to Nearest Retail Grocer by Percent of Area and Population, Dulac and Dularge, LA.

SLIDELL AND EDEN ISLE, LA

Slidell and Eden Isle are located in St. Tammany Parish on the northeast shore of Lake Pontchartrain. Part of the New Orleans–Metairie–Kenner Metropolitan Statistical Area, the region is heavily developed and largely urbanized. The city of Slidell has a total area of 15.2 square miles and is home to over 27,000 residents. Eden Isle, located directly on the shore of Lake Pontchartrain, is a census designated place with a total area of 4.2 square miles and is home to over 7,000 residents. Most of Slidell is buffered from high tide flood events by the Big Branch Marsh National Wildlife Refuge, which encompasses some 15,000 acres of land along the shores of Lake Pontchartrain, while Eden Isle is vulnerable to these events.

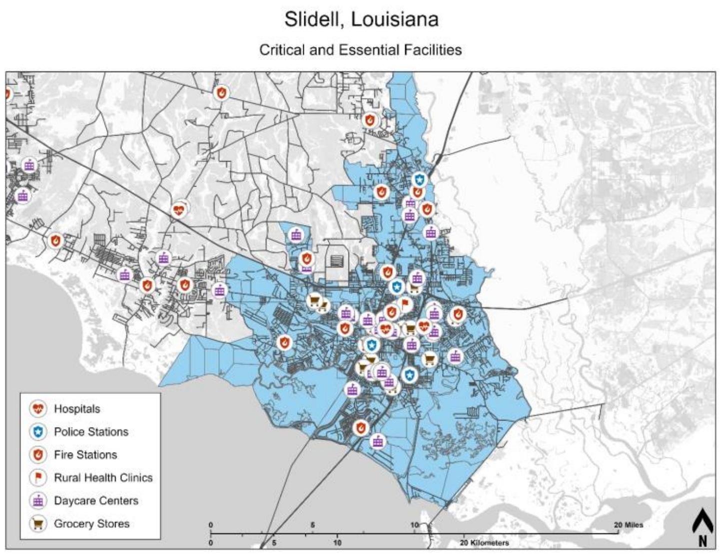
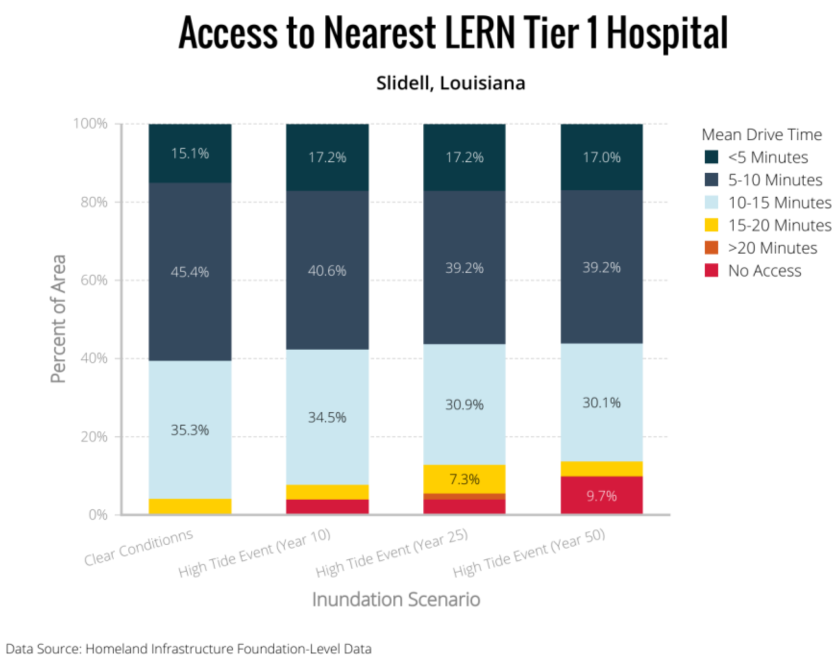


Figure 94. Critical/Essential Facilities in Slidell and Eden Isle, LA.



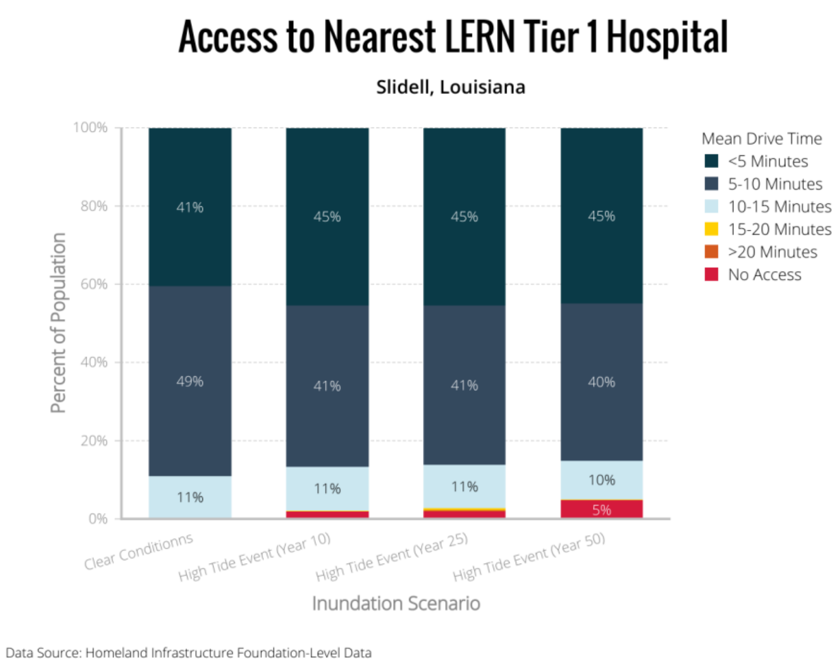
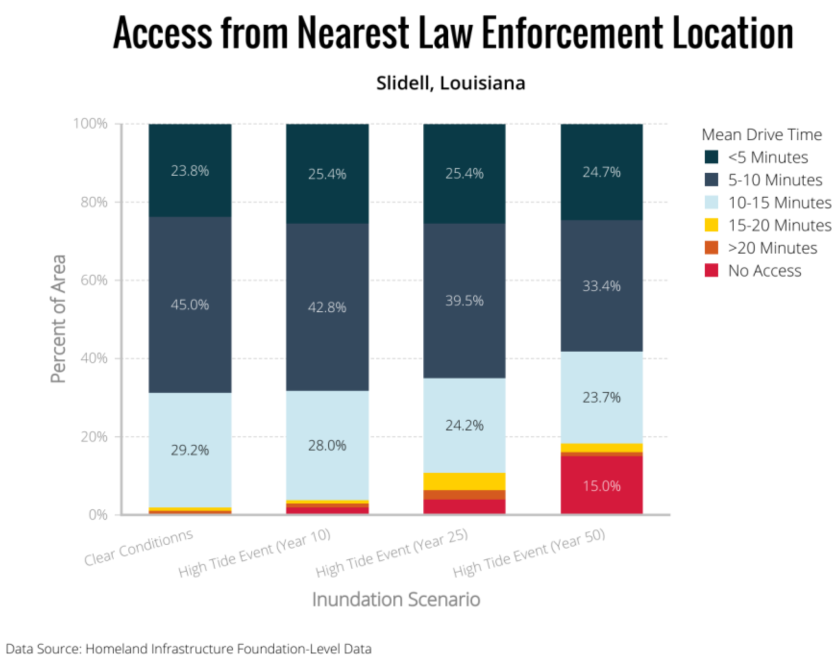


Figure 95. Drive Time Access to Nearest LERN Tier 1 Hospital, Slidell and Eden Isle, LA.



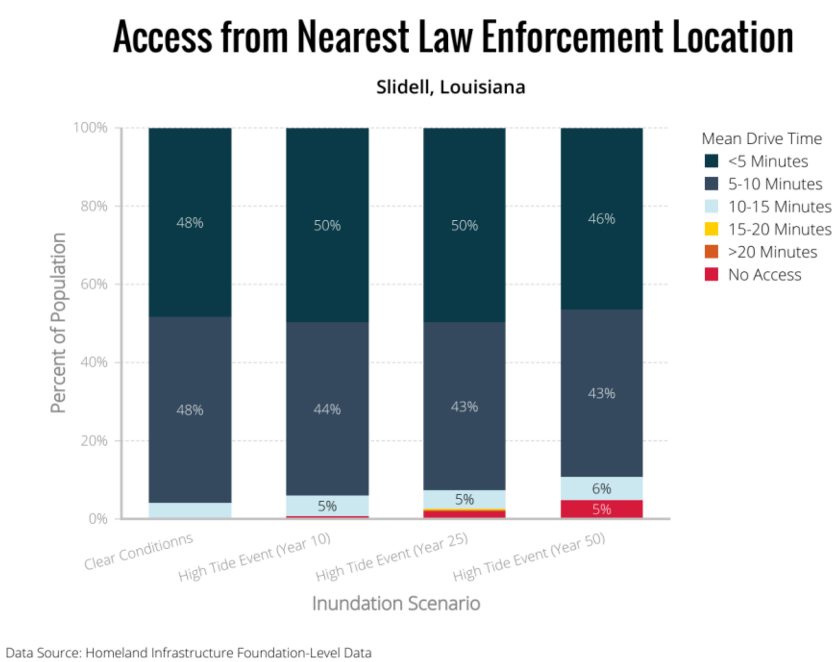
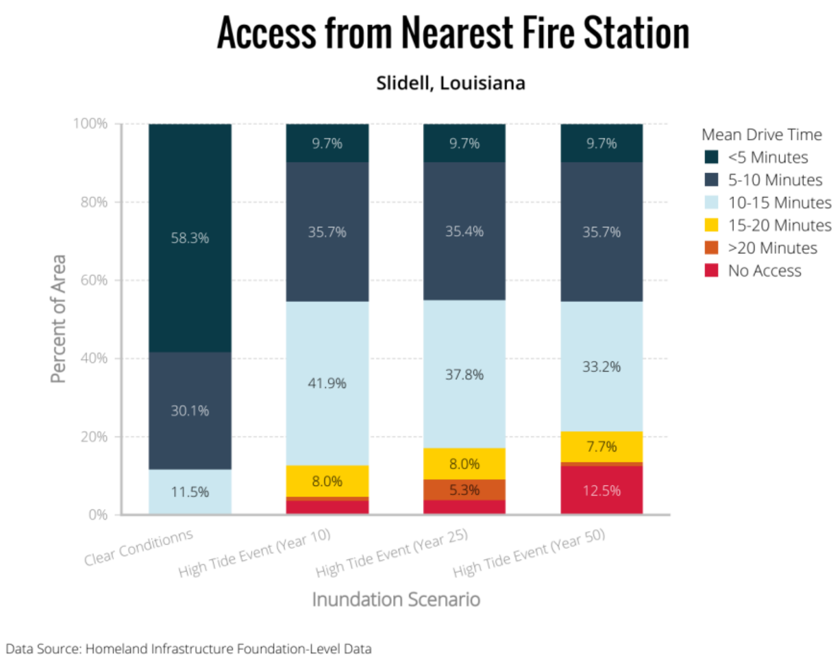


Figure 96. Drive Time Access from Nearest Law Enforcement Location by Percent of Area and Population, Slidell and Eden Isle, LA.



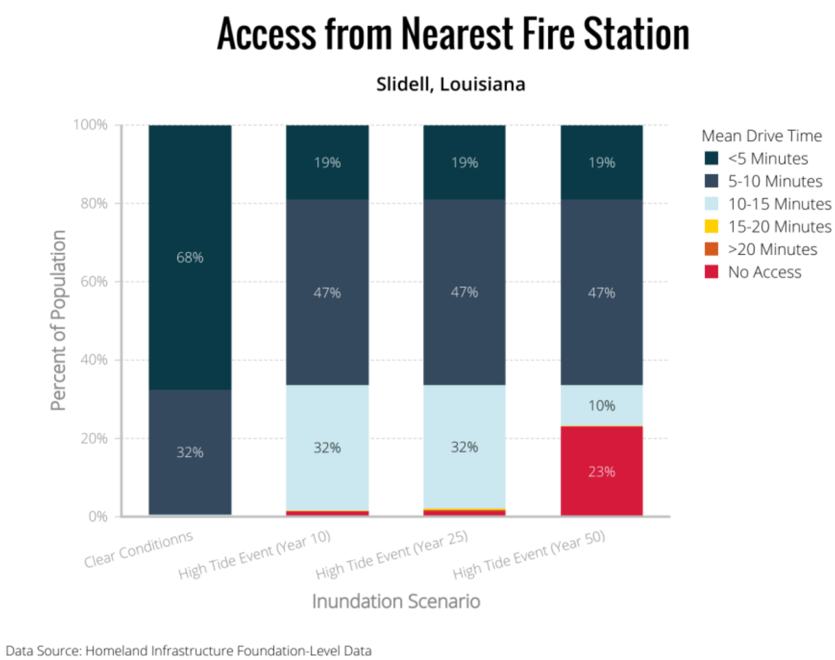
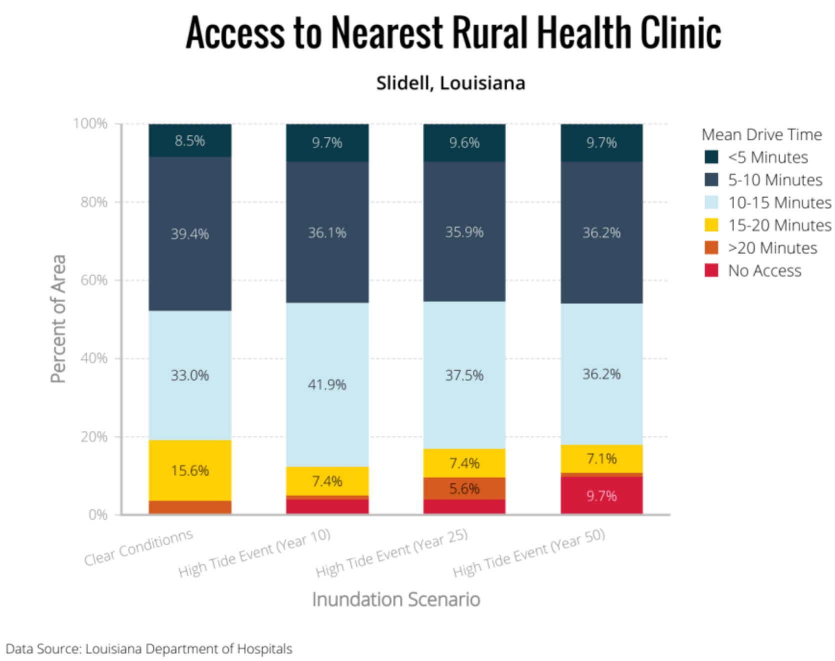


Figure 97. Drive Time Access from Nearest Fire Station by Percent of Area and Population, Slidell and Eden Isle, LA.



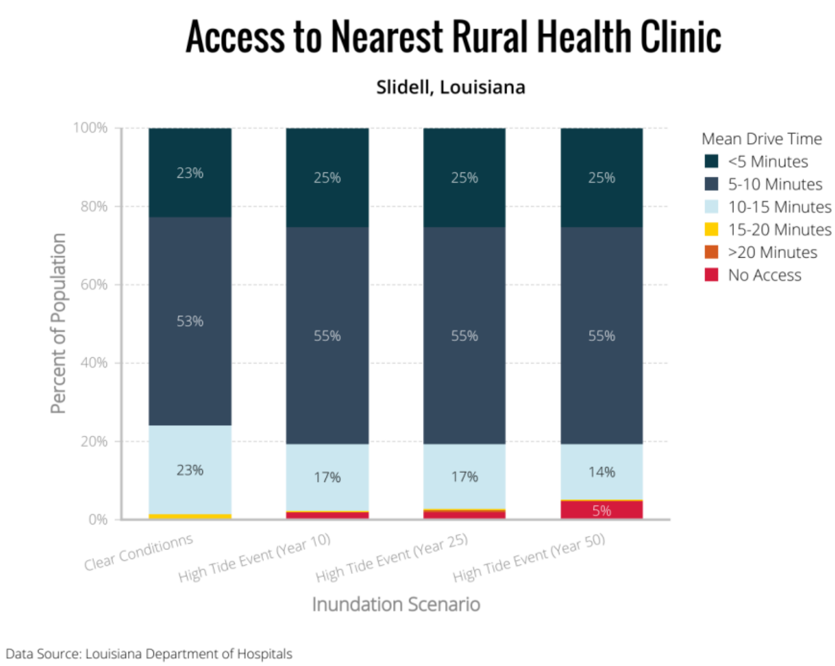
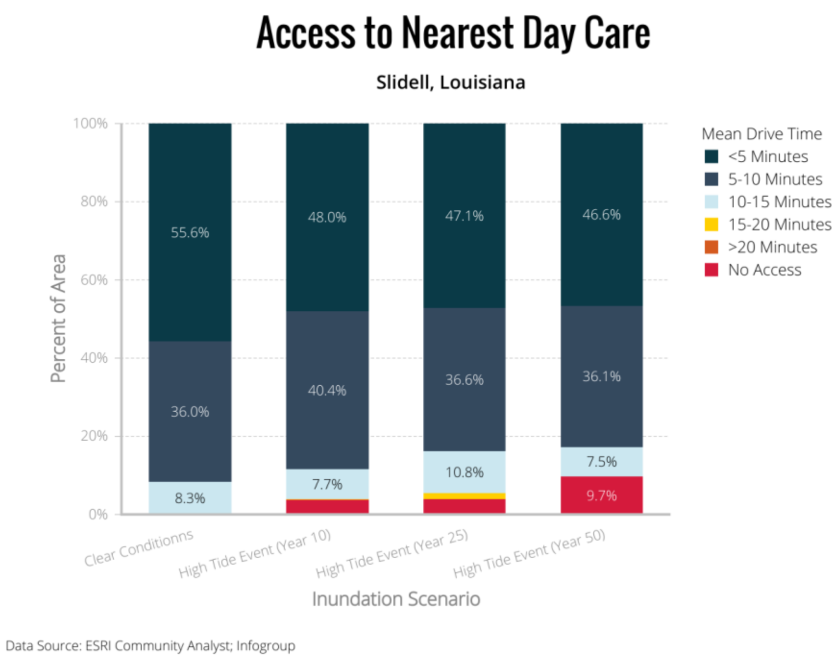


Figure 98. Drive Time Access to Nearest Rural Health Clinic by Percent of Area and Population, Slidell and Eden Isle, LA.



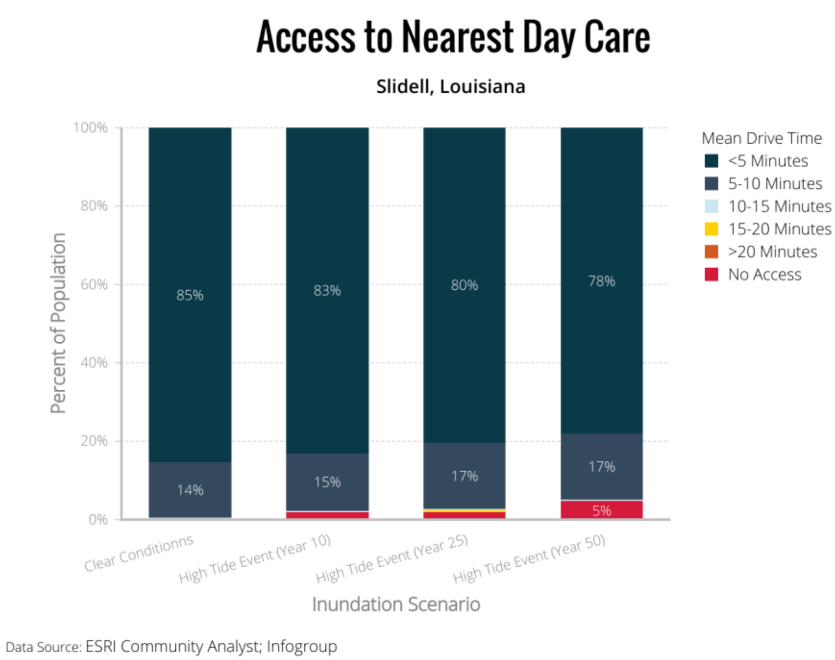
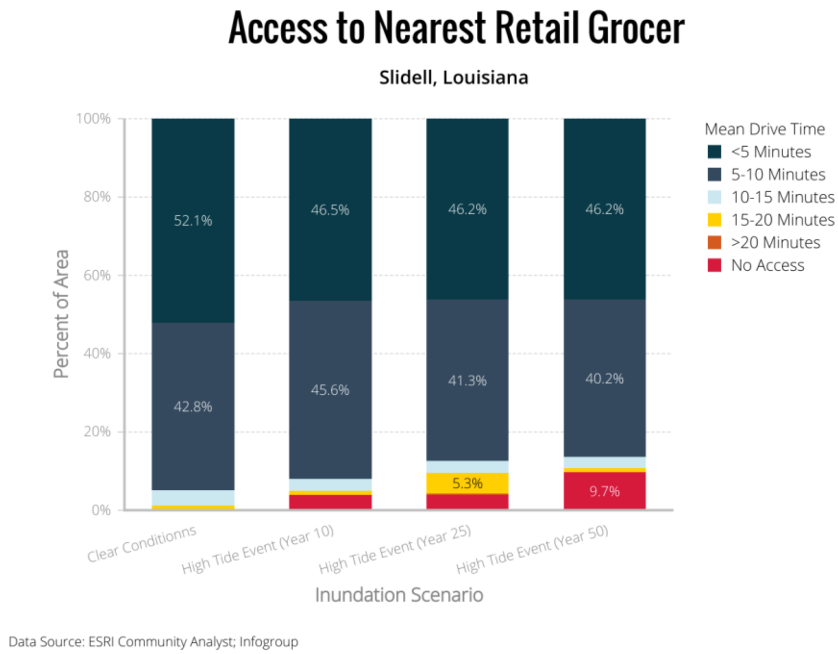


Figure 99. Drive Time Access to Nearest Day Care by Percent of Area and Population, Slidell and Eden Isle, LA.



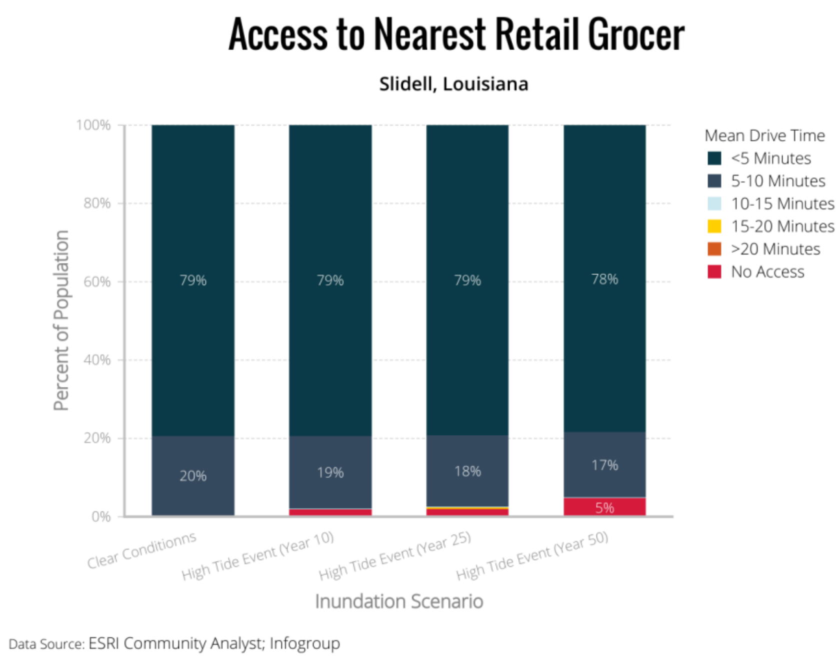


Figure 100. Drive Time Access to Nearest Retail Grocer by Percent of Area and Population, Slidell and Eden Isle, LA.

APPENDIX D: PHASE 2 HYDRO CALCULATIONS IN SUPPORT OF DRIVE TIME ANALYSIS

SEASONAL TIDAL RANGES

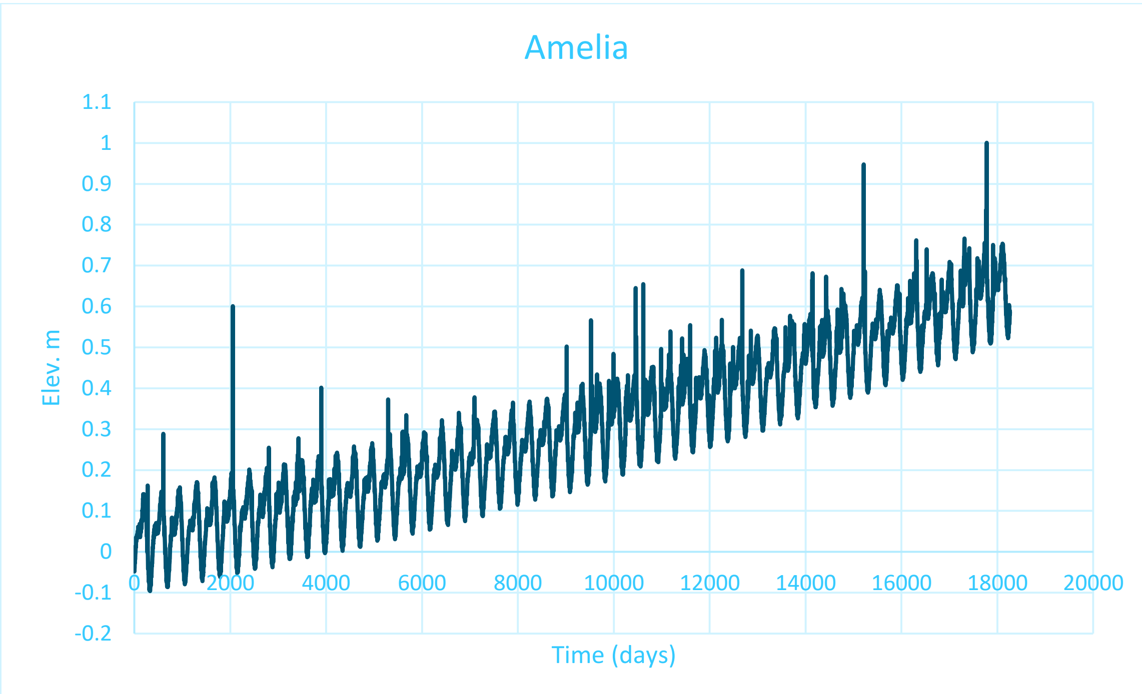


Figure 101. ICM Compartment 498 data used for Amelia high tide adjustment.

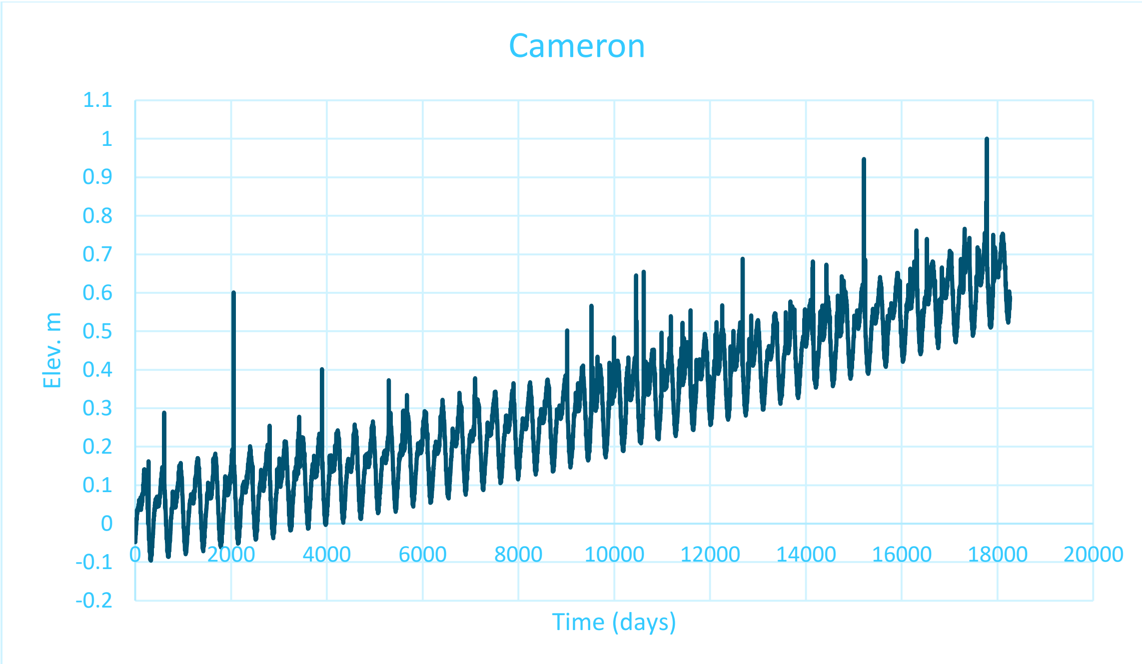


Figure 102. ICM Compartment 874 data used for Cameron high tide adjustment.

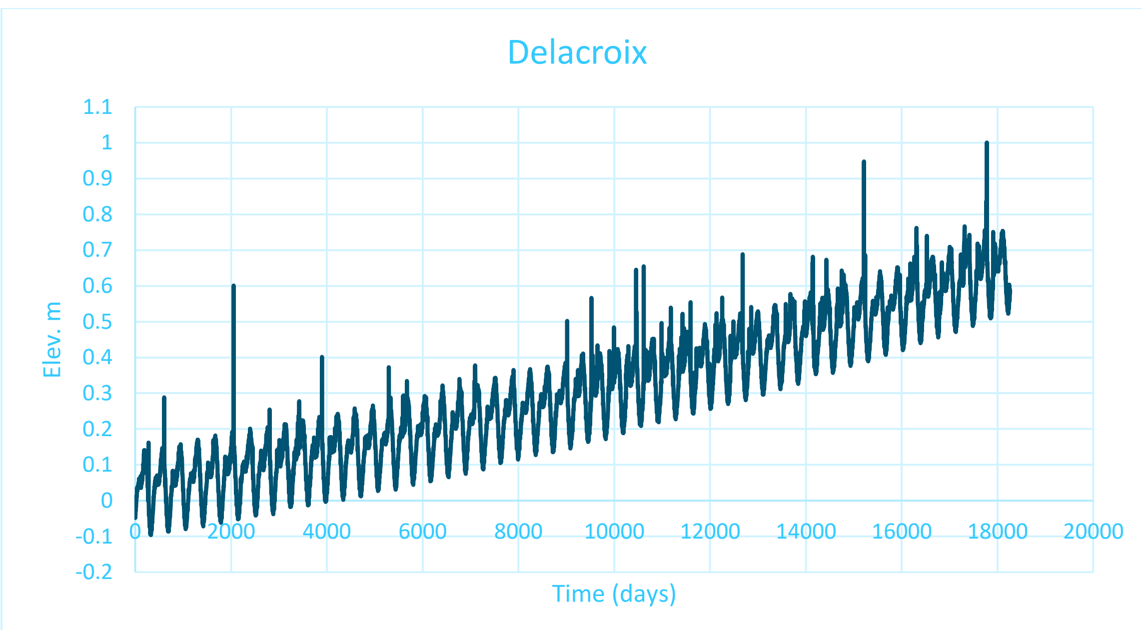


Figure 103. ICM Compartment 81 data used for Delacroix high tide adjustment.

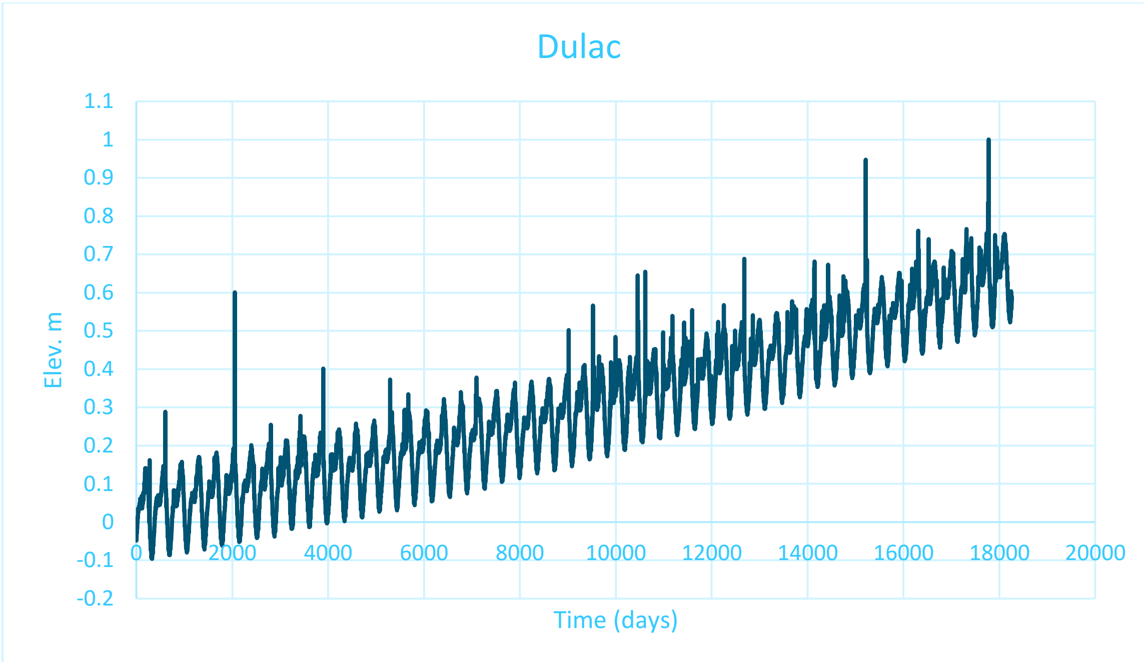


Figure 104. ICM Compartment 425 data used for Dulac high tide adjustment.

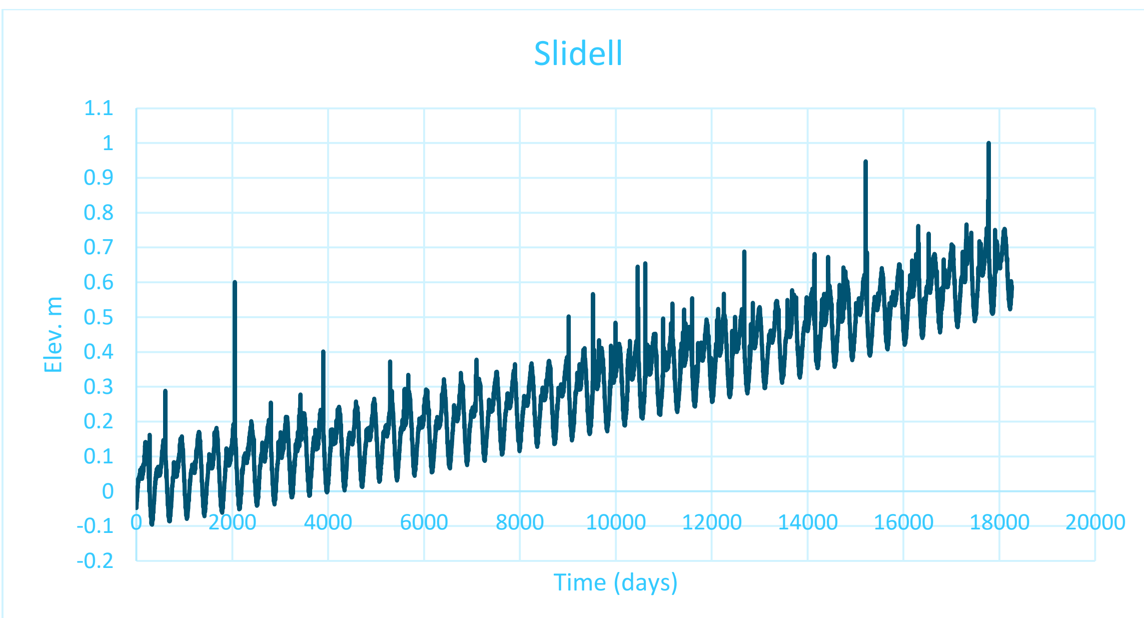


Figure 105. ICM Compartment 37 data used for Slidell high tide adjustment.