Storm Surge Flood Maps Development for the Lower Laguna Madre Coastal Emergency Management

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EXECUTIVE SUMMARY

Hurricanes and their associated storm surges cause catastrophic impacts along the Texas coast, damaging not only the natural and man-made environment but impairing the Texas economy as well. Existing hurricane storm surge forecasting systems and coastal region flood maps, e.g., Flood Insurance Rate Map by FEMA and Hurricane Storm Surge Zone by NOAA, provide valuable potential flood information; however, the forecasted watershed inundation zones could be improved by incorporating the results of the watershed rainfall-runoff flood routing.

To fill the information gap regarding the impact of a hurricane storm surge on coastal inundation, the University of Texas Rio Grande Valley (UTRGV) proposed developing storm surge flood maps for 45 hypothetical storm events including hurricane impact for the Lower Laguna Madre (LLM) watershed in south Texas. Through the CMP Cycle 23 funds, UTRGV coastal flood modeling team completed following tasks: (1) coastal flood interactive GIS maps incorporating hurricane storm surge development, (2) coupling a hurricane storm surge model with a watershed rainfall-runoff model, and (3) a hurricane evacuation navigation tool development in LLM. This project was intended to provide end-users with high fidelity coastal flood geospatial information for local emergency management and planning and robust numerical models that is applicable to ocean/bay flow circulation prediction, flood routing, and emergency route navigation.

Four historical tropical cyclone landfalls were evaluated and used as a means of verification of the ADCIRC hurricane storm surge model simulation results. The parameters used to improve the accuracy of the model are the tidal constituent combination and the surface roughness coefficient, or manning's n value. A total of four different scenarios that use a variety of tidal constituent combinations and nodal attribute files were developed to identify the best case. Statistical analysis, such as normalized root mean squares regression and scatter index, was used to determine the significance of each hydrodynamic computational storm surge result to observed historical water surface elevations. In an effort to improving all models locally, using seven tidal constituents combinations along with a surface roughness nodal attribute grid that assigns values with respect to bathymetric data improves the accuracy of the storm surge model and should, therefore, be implemented for future hydrodynamic studies in the South Texas region.

The efforts detailed in this study describe the coupling/automation of hydrodynamic models for their integration in a coastal flood computation system, which can be useful on emergency planning and disaster management. Expanding the functionality of Python language with several scientific and data processing libraries allowed the development process to focus completely on the automation and coupling strategy and less on the development of tools. The strategy and implementation on the LLM flood prediction proved successful. The system enables to transfer hurricane storm surge data predicted by ADCIRC model to HEC-RAS watershed flood model to be used as its water surface elevation boundary conditions.

The inland rainfall-runoff models were developed to generate 10 hypothetical storm events for the Cameron and Willacy County watersheds using HEC-HMS model. The hypothetical storm is a matrix of five frequency storm events (10, 25, 50, 100, and 500-year) and two precipitation durations (1-day and 2-day). As results, a total of 510 sets of design flowrates, peak discharge and time were computed. In additions, HEC-RAS flood routing model was adopted to predict watershed inundation due to excessive channel flow, estimated by the HEC-HMS model. Three and two major drain channels were developed for the Cameron County and Willacy County HEC-RAS model, respectively. Total computational runs were 50 with a matrix of 5 geometries (channel) by 10 hypothetical storms (inland rainfalls). Computational results from each major channel were compiled for displaying the LLM watershed coastal inundation maps.

A website-based emergency evacuation navigation tool was developed to provide emergency first responders and impacted communities the ability to navigate flooded areas safely. By incorporating with DriveTexas web application, which provides real-time road-side information maintained by TxDOT, the project website, VCORE (**V**alley **CO**astal disaster **RE**siliency system) https://vcore.utrgv.edu/ to visualize the detoured routes to avoid flooded areas. In addition, the website hosts and displays the computations results from HEC-RAS rainfall-runoff flood layers and ADCIRC hurricane storm surge layers.

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1. INTRODUCTION

1.1 Study Area and Coastal Flood Control Practices

The Rio Grande Valley (RGV) is a region located in the southernmost region of the state of Texas. The RGV consist of four counties, which include Cameron, Hidalgo, Willacy, and Starr. The focus of this study will be the two eastern coastal counties, Cameron County and Willacy County. These two counties are prone to coastal storms, such as hurricanes and tropical storms, during the hurricane season. These storms create high intensity rain events that in turn can create this region into a flood prone area if the drainage infrastructure is not up to date and well designed. In the RGV the drainage infrastructure consists of a series of drainage canals that flow from the west to the east. Each drainage canal outfalls into another drainage canal that will convey stormwater runoff into one of three main drainage channels depending on the location of the drainage infrastructures. The Arroyo Colorado (located in Cameron County), the Brownsville Ship Channel (located in Cameron County), or the Main Floodway (located in Willacy County). These three channels then outfall into the Laguna Madre Bay which in turn outfalls to the Gulf of Mexico (GOM). Most rainfall that falls near the Rio Grande River flows towards the river; this water will also outfall to the GOM.

For this study, the region that will be specifically looked at is the Lower Laguna Madre watershed (LLMW), which is found within Hydrologic Unit Code (HUC) 12110208 within Cameron County [1]. Currently this watershed is in line to become a protected watershed with approval from the United States Environmental Protection Agency (EPA). One of the requirements is to create a hydrologic model for the watershed to determine the response of stormwater flow in the watershed. Figure 1 shows the sub-basin watershed boundary over the Rio Grande Valley.

The geologic attribute of a valley consists of a land mass surrounded by various mountains or hills. The RGV is not this type of geological feature, but the RGV is a coastal plain. The terrain in this region is very flat averaging a land slope of 0.5 to 1 percent. A hydrologic characteristic that can cause flooding in areas due to the overland storm flow not being able to quickly and freely move down stream. The land use is typically combined as both agricultural and urbanized. The climate is arid with occasionally droughts seen in some years to semi-arid [2].

Recently storm events have been increasing in intensity, causing risk for flooding events as well as flash flood events. In late June of 2018, the RGV experienced heavy rainfall that equated the intensity of a 500-year storm event. This rainfall created flooding in many urbanized subdivisions, forcing residents to evacuate their homes. Cause for this flooding was attributed to oversaturation of the soils form a previous small rain event a few days before the larger one, as well as poor drainage infrastructure [3]. Reactive measures have taken place by studying the current drainage infrastructure via modeling or hydrologic calculations.

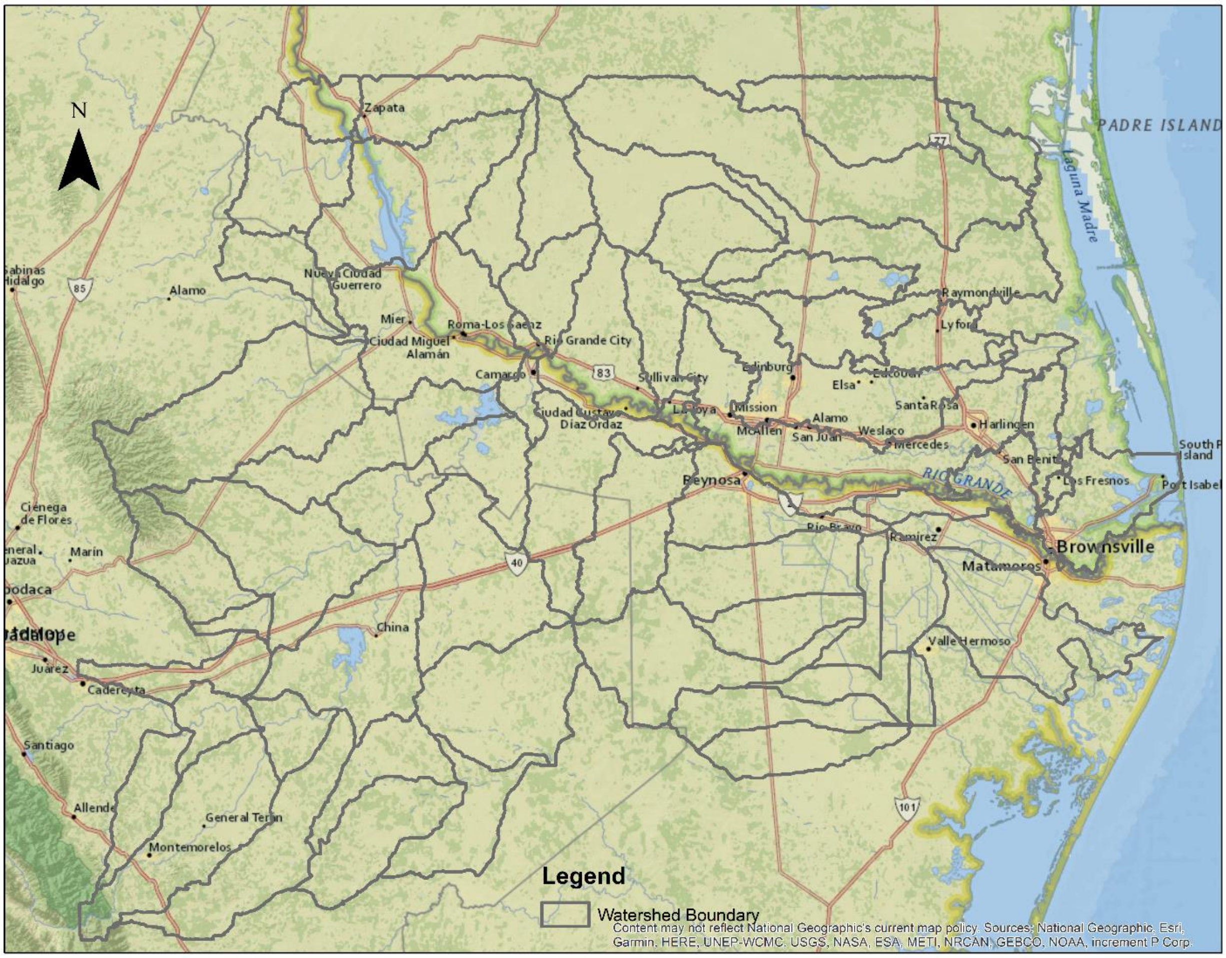

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Figure 1. Existing flood drain canal networks of the Lower Rio Grande Valley

1.2 Existing Flood Protection Plans and Hydrologic and Hydraulic Modeling Efforts

In the RGV, each County has their own drainage district that manages the maintenance of the drainage infrastructure. Hidalgo County has four county drainage districts, which manage the rural infrastructure of the county, while the city manages their infrastructure internally with aid form the county whenever necessary. Willacy County has two drainages districts, one funded by the county and another that is privately owned. The Willacy County Drainage District #1 (County funded) is aided in times by the Hidalgo County Drainage District, as they have allowed access to a main floodway to convey stormwater from Hidalgo County to Willacy County, which will discharge into the Lower Laguna Madre. Cameron County is divided into five Drainage Districts, each District manages a city as well as parts of the surrounding rural areas. Other drainage conveyance systems such as irrigation canals are managed by Irrigation Districts within the County. The rural drainage infrastructure is maintained and managed by the main Cameron County offices. Each District has a main floodway or channel that conveys stormwater runoff into the Lower Laguna Madre, Figure 2 depicts Drainage Districts coverages and main channels of the three Counties.

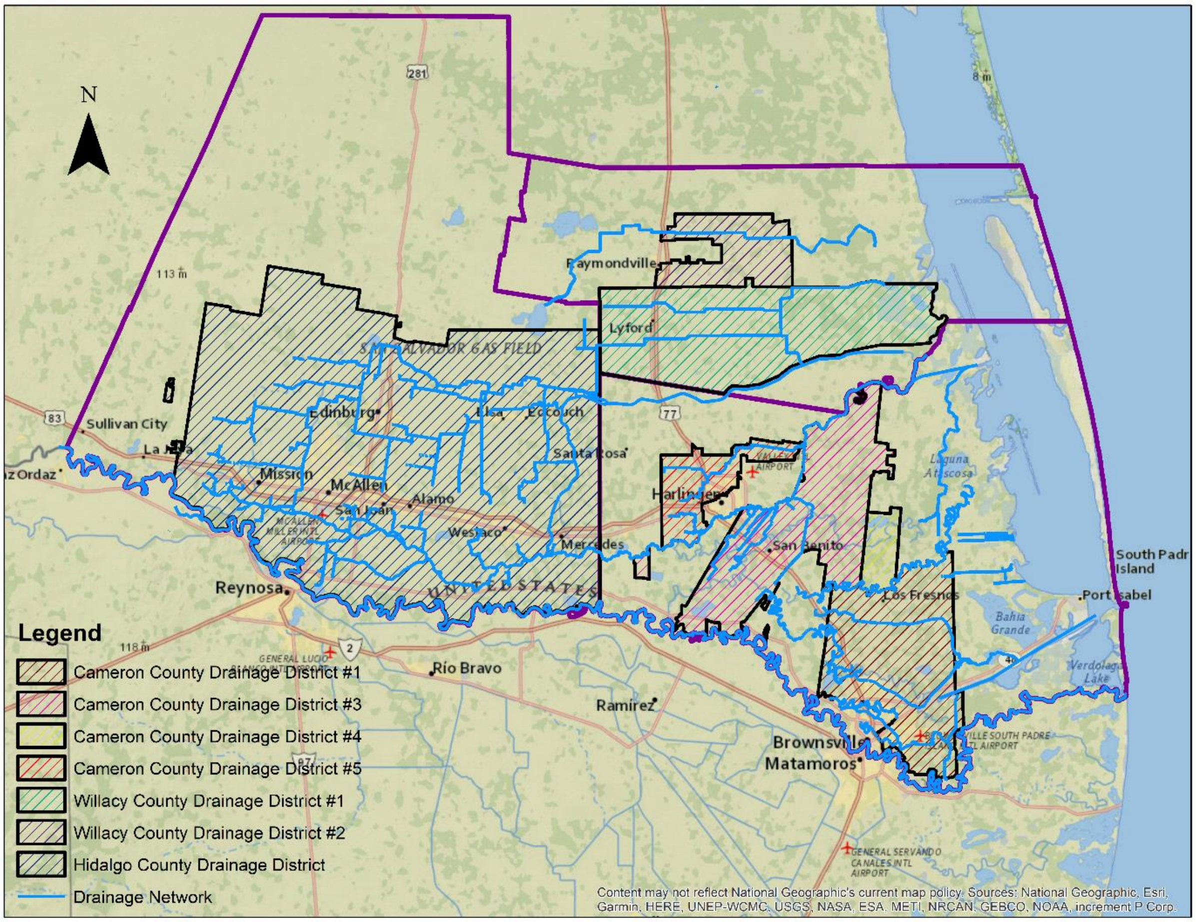

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Figure 2. RGV drainage districts and main drain channels

To mitigate flooding in the region, various cities and drainage districts developed either Flood Mitigation Plans, Flood Protection Plans, or Master Drainage Plans. Each of these plans includes an assessment of the state of the current drainage infrastructure, the assessment also includes a resolution or alternatives to avoid flood damages or improve the infrastructure. The National Flood Insurance Program (NFIP) awards cities that are creating flood mitigation plans and are bringing awareness of flooding into the communities by giving a reduced premium on flood insurance. Most of these documents include a hydrologic or hydraulic model that shows the response of overland storm flow within the watershed the city located.

An engineering report was developed to help the Cameron County Drainage District #3 (CCDD3) assess their drainage infrastructure as well as create contingency plans for future flood events using Hydrologic and Hydraulic (H&H) modeling. The area and jurisdiction of CCDD3 contains the city of San Benito as well as parts of Los Indios and Rio Hondo. The engineering firm Espey Consultants, Inc. oversaw the development of the models as well aid in the infrastructure's assessment. The engineering firm developed the models and then developed flood event scenarios. With the results from the model a series of plans were created to alleviate flooding, by either structural repair to the infrastructure or by nonstructural repair. This study was completed in 2010 [4]. Figure 3 illustrates the coverage of the H&H modeling of each drainage district and city in the LLMW.

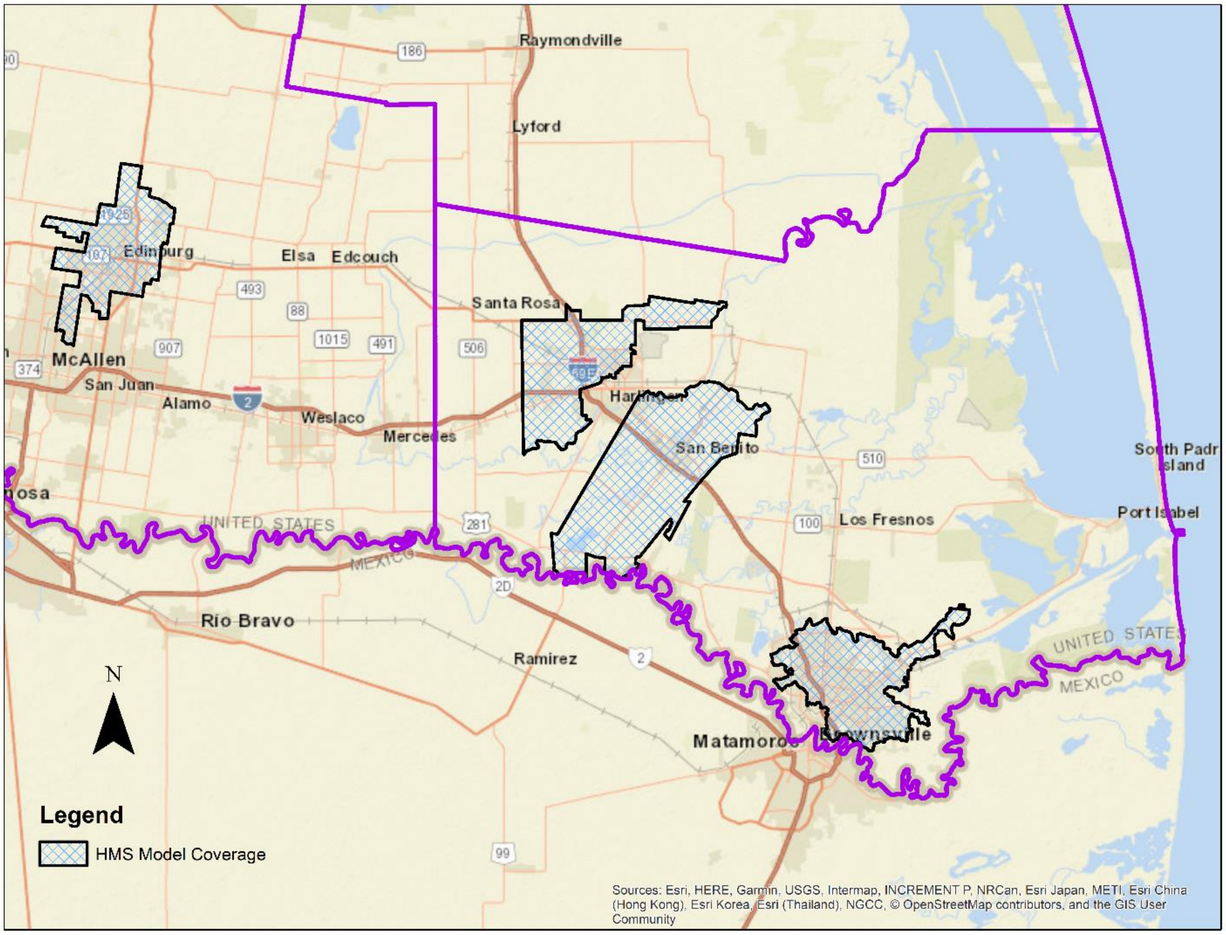

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Figure 3. Existing representation of the Lower Laguna Madre coastal watershed

Another flood protection study was done by Espey Consultants, Inc. for Cameron County Drainage District #5 (CCDD5). Similarly, this study was also to assess the drainage infrastructure for the drainage district with the use of H&H models. This study included the City of Harlingen as well as the smaller Cities of Palm Valley, Combes, and Primera. The same process and procedures were used from the previous study have adapted to this area. HEC-HMS and HEC-RAS were the two models used in the CCDD3 and CCDD5 study. This study occurred before the study in CCDD3, which was completed in 2010, two years after the study in CCDD5 which was completed in 2008. Currently CCDD5 is updating their H&H models, and planning to improve on their flood protections plan and protocol [5]. The H&H models, coverages, and creators are listed in Table 1.

Table 1. Current Hydrologic and Hydraulic models found in Cameron and Hidalgo County

Location of Model	Type of Model	Model Creator	Year of Model
Harlingen, TX	HEC-HMS	ESPEY Consultants	2008
San Benito; Los Indios, TX	HEC-HMS	ESPEY Consultants	2010
Harlingen, TX	HEC-RAS	ESPEY Consultants	2008
San Benito; Los Indios, TX	HEC-RAS	ESPEY Consultants	2010

Brownsville	HEC-HMS	Ambiotec Group	2006
Brownsville	HEC-RAS	Ambiotec Group	2006
Brownsville	Vflo	Ambiotec Group	2006
Edinburg	HEC-HMS	Civil Engineering Systems	2014
Edinburg	HEC-RAS	Civil Engineering Systems	2014
San Juan	Rational Method Calc.	Cruz-Hogan Consultants	-

In 2006, a Flood Protection Plan was developed for the city of Brownsville by Ambiotec Group in conjunction with the Rice University [6]. The document details the current conditions of the City as well as any existing flooding issues that occurred mainly near the local Resaca and drainage canals. The development of three different type of models were used to characterize the watershed, understand the H&H response of the watershed, and a third model was used to understand the hydraulics of the reach systems (canals and Resacas). With the use of the models, different options were developed to alleviate the current conditions when flooding would occur.

In 2015, the City of Edinburg tasked the engineering firm Civil Systems Engineering, Inc. to prepare a Master Drainage Plan for the city. The purpose of the plan was to help the city to develop a plan to prioritize where city funding should be spent for its drainage infrastructure. The document details an evaluation of the current drainage infrastructure using H&H models. With the evaluation of the infrastructure using computer models, a cost analysis was created to prioritize where future funding should ideally be spent to properly improve the drainage infrastructure of the city in a beneficial cost-effective manner [7].

The City of San Juan had a Master Drainage Plan prepared for them by Cruz-Hogan Consultant, Inc. with the intent to help aid the city in understanding its current drainage infrastructure. This study was also used as a basis to determine how new development and new road construction would hydrologically affect the city. With the use of the rational method, the overland storm flow and drainage patterns were determined to understand the current capacity of the drainage canals and other drainage structures [8].

Each of these studies conducted an analysis of the current infrastructure by using H&H models as well as the Rational Method computation. In the LLMW only the City of Brownsville has had a study conducted within its city limits. This study occurred in 2006 nearly 12 years ago and the City of Brownsville is only one of other communities that can be found inside the watershed that are also growing and urbanizing. With the development of a new updated model, new and updated scenarios can be developed to predict high frequency storm events, such as the one that was seen on June 2018.

CCDD5 is currently working to update their 2008 model by early 2019. Cameron County Drainage District #1 (CCDD1) in conjunction with the City of Brownsville is creating a flood protection plan. The goal of this plan was to develop or update any gauge stations found within the main drainage canals or drainage laterals. The plan of this study is to predict possible flooding events with the use of predictive measurement based on the behavior of flow within the reaches.

Hidalgo County Drainage District #1 (HCDD1) is looking to create models for any areas that currently see high flood waters during any storm event, with an emphasis in the areas affected by the June 2018 Flood. HCDD1 is also in charge of some of the drainage in Willacy county due to Hidalgo County's main floodway drains out towards the Willacy County. The two counties developed an agreement that Hidalgo, being the larger drainage district, will help Willacy county maintain their drainage infrastructure for Willacy County Drainage District #1 (WCDD1). There is currently a bond in place to help develop a new drainage canal (Raymondville Drain) that will help alleviate the high amounts of water flow enter the Willacy County's Main Floodway.

In 2014, the Texas Water Development Board (TWDB) developed a Stormwater Drainage Plan to mitigate flooding in small communities located on the Texas-Mexico Border called Colonias. These small residential communities are defined as areas near the Texas-Mexican border that do not have communal necessities such as potable water, sewer systems, paved roads, and safe and sanitary housing. These Colonias can be seen in areas in Hidalgo, Cameron, and Willacy Counties. This plan was developed as a reactive major to the flooding seen during the 2008 hurricane Dolly, which affected all three counties with its destructive flooding. The plan details the goal to identify the state of the drainage infrastructure and determine a resolution if any problems arise. The current state of this plan is to determine which Colonias issues or have inadequate drainage systems, compile necessary data to make these assessments, and to determine if any hydrologic or hydraulic modeling will be required to improve the assessment [9].

In 2014, Cameron County developed a document entailing details for flood plain management and regulations. The purpose of this document is to develop rules and regulations that protect the life, property, health, and safety of the citizens of the Cameron County during any flooding events in the county caused by tidal waters from the GOM, obstruction effecting the floodplains causing an increase in flood heights, or the occupancy in possible flood hazard areas. This document also states methods for reducing flood loss. These methods include establishing and understanding flood zones that are established by the Federal Emergency Management Agency (FEMA) flood insurance studies or flood insurance rate maps. These studies and maps that are developed by FEMA require a comprehensive hydrologic analysis of the region, which is usually done by H&H modeling [10].

A Flood Mitigation Plan (FMP) for the City of Raymondville was developed in 2004 by MGM Engineering Group, LLC. The FMP purpose was a document to help aid the city inform the residents of what possible actions it would take in flood events as well as inform the residents on the potential risks and dangers of flooding in the city. With the development of the FMP the National Flood Insurance Program (NFIP) awards the city discounted flood insurance premiums to the residents of the city. The document then details the current flood hazards and problems found in the city and then establishes and action plan to improve on the current situation. One of the problems stated in the document is the lack of a flood plan in place for a city that is deemed in a 100-year flood zone by FEMA; one of the resolutions given is to develop and utilize modeling and predictive techniques in the development of a drainage masterplan [11].

The Hidalgo County Drainage District tasked TurnerCollie&Braden Inc. to develop a Flood Protection Plan for Hidalgo County. This flood protection plan was developed in September 1997. This document details the previous drainage studies done for the drainage district, current layout and conditions of the drainage infrastructure, and a capital improvement plan, which details the cost of possible improvements to the drainage system of the time. One of the purposes of this study is to evaluate the current drainage criteria and recommend modifications to the drainage policy, identify any watersheds associated with the drainage system, and develop a basic mapping system [12].

1.3 Study Purpose and Deliverables

The purpose of this study was to develop end-users with high fidelity coastal flood geospatial information for local emergency management and planning and robust numerical models that will be applicable to flow circulation prediction, flood routing, and emergency route navigation. To achieve the goal Therefore, University of Texas Rio Grande Valley (UTRGV) proposes coupling hurricane storm surge and watershed flood models by using the storm surge heights computed by the storm surge model as input data to the watershed flood model. CMP Cycle 23 funds used to (1) improve coastal flood interactive GIS maps incorporating hurricane storm surge, (2) couple hydrodynamic models to predict hurricane storm surge and flow circulation, and (3) improve local emergency evacuation routes based on coastal flood maps in the Lower Laguna Madre (LLM). The Project deliverables are composed of four technical tasks.

1.3.1 Development of Hurricane Storm Surge Model

A hurricane storm surge model will be developed to be used for the LLM and the Gulf of Mexico coastal region. The Advanced Circulation Model (ADCIRC) will be used to model flow circulation and geospatial and bathymetric input data will be obtained from NOAA SRTM3_PLUS V6.0. (http://topex.ucsd.edu/WWW_html/srtm30_plus.html). UTRGV will create a 2-D mesh model of the LLM with nodal elevations interpolated from the merged raster and assign the tidal and wind forcing data.

Hurricane tracking data, water surface level data, tidal constituents and bathymetric bottom friction coefficients will be also used to calibrate the model. The model will be simulated at 5 different hurricane wind speeds.

1.3.2 Coastal Watershed Flood Routing Model Development

To address flood routing issues in the LLM, the watershed hydrologic model with flood routing model will be developed. The hydrologic watershed model produces the design peak flow for ten (10) hypothetical storm scenarios of 10, 25, 50, 100, and 500-frequency year for 1 and 2-day precipitation duration. The HEC-HMS (Hydrologic Engineering Center Hydrologic Modeling System, USACE) model will be developed. The model results will cover most of the Cameron and Willacy Counties to reflect the upstream floods to the coastal watershed. Two-dimensional HEC-RAS (Hydrologic Engineering Center River Analysis System, USACE) flood routing model will also be developed to predict watershed inundation due to excessive channel flow.

1.3.3 Coastal Storm Surge Flood Maps Development

The ADCIRC storm surge model will be coupled with the 2-D HEC-RAS watershed flood routing model to produce the watershed flood maps. UTRGV is planned to simulate 50 modeling scenarios using the calibrated coupled model. With the computation results, the watershed flood maps will be developed using GIS processing of the raster surface terrain interpolation with the predicted storm surge heights along the shoreline.

1.3.4 Local Emergency Evacuation Routes Analysis and Recommendations.

UTRGV will use potential water levels and areas with high likelihood of flooding, information on roadway conditions, and existing emergency evacuation routes and shelters to develop a navigation system in the LLM. This work will produce an emergency route navigation indicating fastest route avoiding coastal flood areas from the current location to the existing emergency evacuation route and public shelters operated by the County emergency management offices. This navigation system will provide a vital information to coastal communities assisting their safer evacuation. In addition, it will allow local agencies to better distribute information about alternative routes and target potential evacuees to spread out along the network. This information will be made available to local agencies and the public through UTRGV VCORE website, https://vcore.utrgv.edu/.

1.4 Modeling System

A system will be developed to couple the models together and execute their computations automatically to estimate floods based on precipitation and storm surge contributions. The automation and coupling work allow the system to operate unsupervised and reliably. The flood estimations will then be distributed through a publicly accessible delivery system. In extreme emergency management, providing the right set of tools could be the difference that prevents the deployment of sub-optimal responses to disasters. As explored by many studies such as [13] [14] the use of interactive systems that provide a better picture of what a potential disaster can look like is vital. The system can also deliver time-series maps of flood coverage to visualize the evolution of the disaster event. This provides emergency bodies with the capacity to see how the inundation will spread over time into the affected area and prioritize their efforts to areas that will be immediately affected. The granularity and the detail that can be extracted from the provided maps can be of great help for emergency response and help focus the resources available more efficiently.

1.4.1 Model Coupling and Automation

This coastal flood computational system is composed of three major phases to maximize practical benefits of the flood prediction: external data retrieval pre-processing; hydrodynamic computational model; and prediction results post-processing as depicted in Figure 1. This diagram shows the succession of events and the communication steps that the system takes to produce and publish the final computed flood maps.

In the pipeline of the computational events, this pre-processing section is concerned with the acquisition of such data automatically. The computational system requires externally predicted data to initialize the models and provide the data as input for their computations.

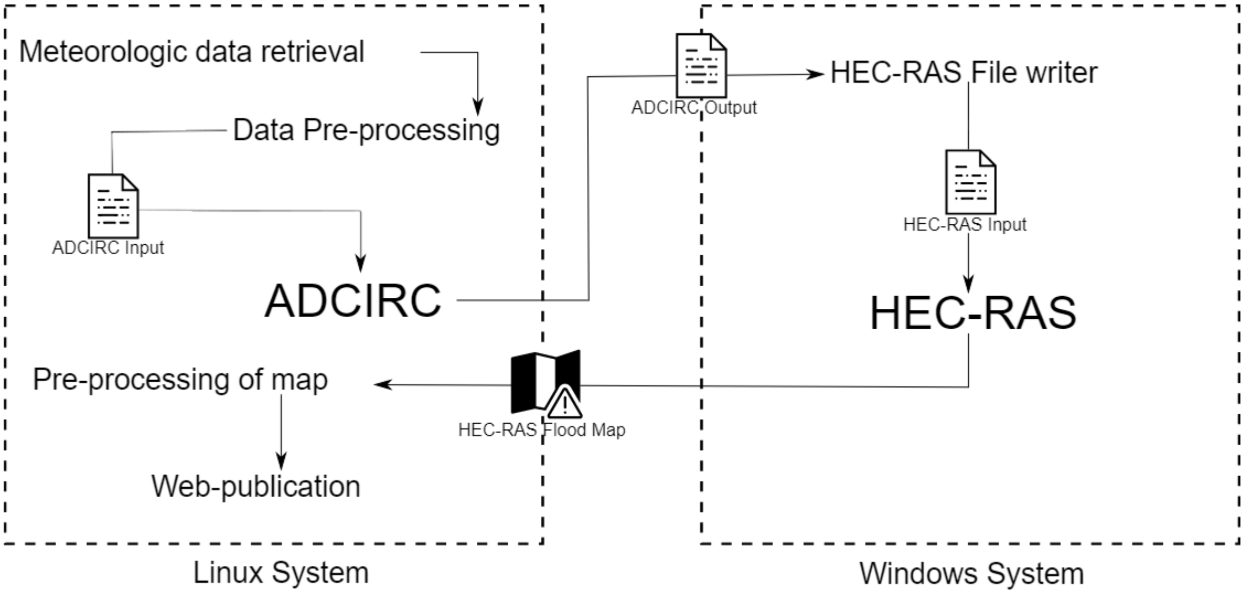


Figure 4. High-level representation of the proposed comprehensive modeling system

1.4.2 Hydrodynamic Computations Models

The hydrodynamic computation model is a main compartment of the forecasting system and is responsible for the computation of the flood prediction. This phase is composed of two numerical models of the ocean flow circulation model and the watershed flood model to compute the coastal storm surge and its impact on precipitation surface runoff. ADCIRC program was adopted for the ocean flow circulation computation. This model produces an estimation of water surface elevation due to forecasted atmospheric conditions retrieved during the data retrieval and processing step. The estimation from the ocean model will be forwarded to HEC-RAS a computer program used in this system to predict coastal watershed floods events. This watershed flood model also produces final watershed flooding maps. To ensure an efficiency of the comprehensive forecasting of the coastal flood event due to the inland surface runoff and coastal storm surge, the model runs of the system were automized. The watershed flood model runs under a Windows operating system, while the ocean circulation model uses a Linux operating system as shown in Figure 4. In this study, a communication framework that handle data transfer between the two different operation systems and the models. The framework is responsible of coupling the models needs to create a pathway of communication between the operating systems and a way to signal the succession of events to both models. This flow of events starts from the acquisition of data and can be followed all the way to the distribution of the map in a delivery system. The post-processing section was implemented for the computation output data processing and distributions as a final phase of the prediction system. A linkage between the hydrodynamic models and a web application running GIS tools was also developed to complete the model automations. Python was adopted for the creation of the forecasting flood system automations due to its flexibility and applicability of modules and libraries such as NumPy and SciPy [15]. The final step in the flood prediction system is the implementation of a delivery system. This delivery system is aimed at distributing the results produced by the numerical models. The flood forecasts produced will be posted on an interactive web map which will display the locations where floods will occur in South Texas coastal areas.

2. HURRICANE STORM SURGE MODEL DEVELOPMENT

Increasing reliability of infrastructure systems, whether it be economic, political, and social, depends on the careful determination of surge vulnerability [5]. These natural hazards bring about tides, storm surge, and rain that ultimately are the cause of the damage. Storm surge, which is the abnormal rise in seawater, is one of the most prominent components to flood propagation in South Texas. Flood protection measures should be considered since the developments of this region are not sufficiently designed for extreme surge events [5]. The reason for this is because of how severe these storms are and the insufficient data available to predict the potential damage of these storms adequately. Because they do not occur periodically in this region as opposed to rainfall, there is no previous data available about previous models that have measured storm effects, such as storm surge. Developing a coastal storm surge inundation model has the potential to allow emergency responders of the region to improve the resilience of the area.

There have been numerous studies that have shown an effort to address natural hazard mitigation through appropriate and accurate storm surge model development. The National Storm Surge Hazard Map developed by the National Hurricane Center (NHC) displays worst-case storm surge flooding scenarios using the National Weather Service (NWS) hydrodynamic storm surge model. This NWS model uses Sea, Lake, and Overland Surges from Hurricanes (SLOSH) to create hypothetical storms using varying conditions to visually map out the inundation across 27 basins in the United States [6]. When a hypothetical Category 4 hurricane like that of Harvey (2017) is implemented into a grid that entails the Texas Coast, an estimated peak surge of 3.84 meters was generated in Calhoun County, Texas, which agrees with actual measurements [7]. The SLOSH model can assist in the validation of the developed South Texas hydrodynamic model by comparing surge heights of the historical and hypothetical hurricane scenarios. A comprehensive storm surge database, SURGEDAT, provides historical storm surge observations for the entire globe [8]. As an example, the SURGEDAT database provides the historical storm surge measurements for hurricanes that have made direct landfalls on the south Texas coast, such as the Dolly (2008) 1.22-meter surge and the Emily (2005) 1.52-meter surge. These measurements are useful to this study because we can use these values to compare and validate the developed model.

An Advanced Circulation (ADCIRC) model specific to the Gulf of Mexico region implements hindcast studies, which are dependent on specific model input parameters, such as surface roughness coefficients [9]. Additionally, an ADCIRC model was developed for the Houston, Texas area for adequate sea barrier implementations, and values such as the surface roughness were also modified and observed for better accuracy of the model [5]. Although the TxBLEND water circulation model developed by the Texas Water Development Board (TWDB) is not a model designed for storm surge functions, it is a serviceable model to this study since it provides practical information for essential parameters like surface roughness values for the Texas coasts [10]. All these imperative analysis efforts are needed to provide essential data and communicate it to the public effectively. The appropriate selection of parameters will result in the accurate representation of computations from these models and maps. The objective of this paper is to select the best possible input variables that can provide the most accurate representation of extreme water levels during any hurricane event in the South Texas region.

2.1 Laguna Madre Flow Circulation Model Geometry

2.1.1 Model Application Plan

Coastal modeling is essential to promote conservation and adequate emergency management and planning [9]. Therefore, the primary focus of this project is to assure model accuracy being developed to achieve this data. A hydrodynamic model was adopted for the area of the South Texas coast, specifically focusing on areas near the Lower Laguna Madre. Figure 5 entails the Gulf of Mexico in its entirety, with a focus on the Lower Laguna Madre area.

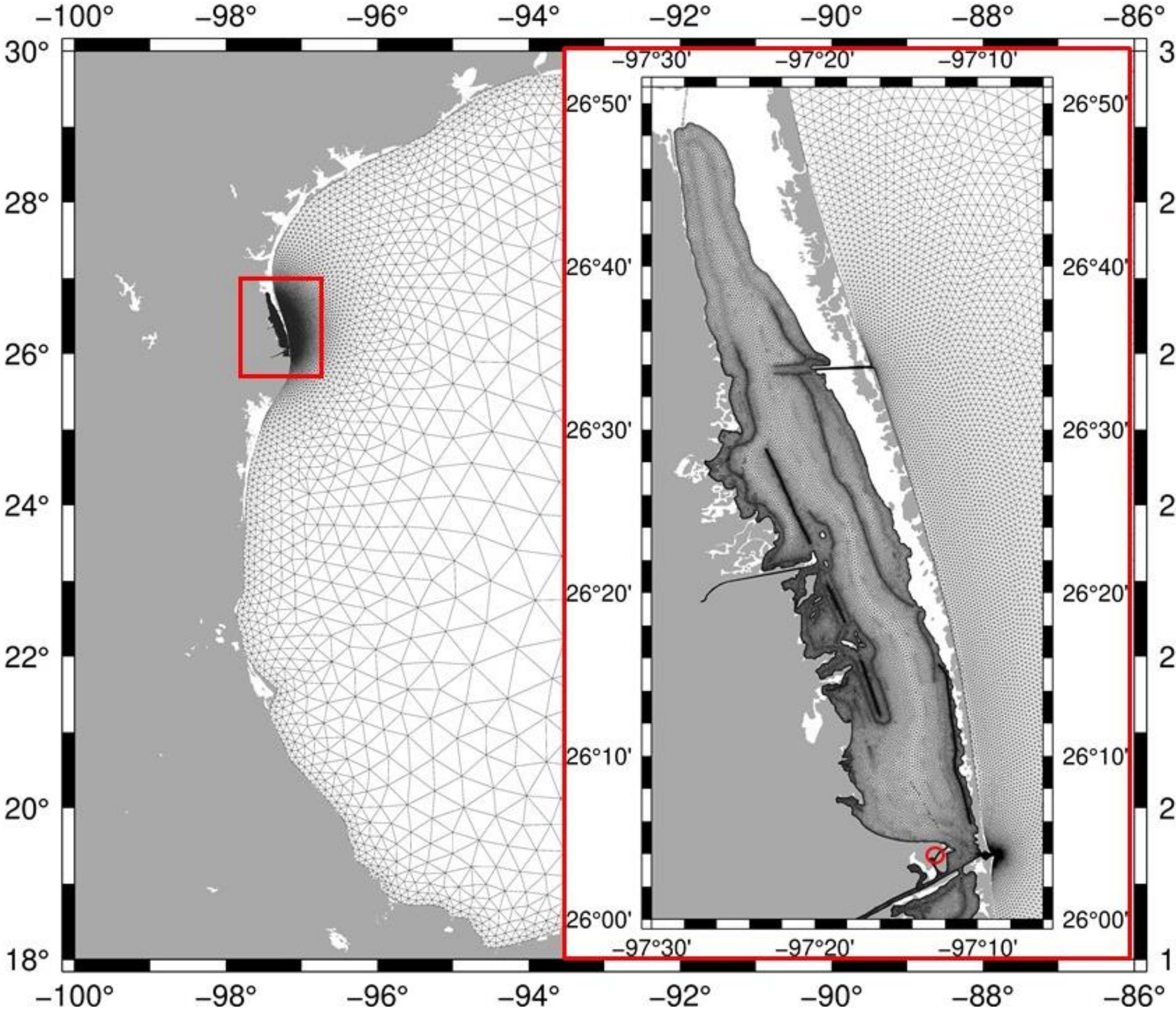


Figure 5. Finite element mesh model domain focusing on the south Texas coast

All modeling requires a level of engineering judgment, primarily when focusing on the accuracy and model improvements. For this hydrodynamic model, the crucial parameters to focus on for proper calibration and model development is the tidal constituents and surface roughness coefficients. This paper entails the model improvement methodologies and the judgment that was made based on previous literature that has dedicated their time to similar projects. The goal is to improve the current hydrodynamic model developed for the South Texas region by determining the best tidal harmonic constituent combination and the surface roughness of the model domain. These parameters are tested by executing the hydrodynamic model with four historical hurricanes that have made landfall in the South Texas area. The four historical hurricanes include Bret (1999), Dolly (2008), Emily (2005), and Alex (2010). The computational data that is retrieved from the hydrodynamic model execution and then compared to the water surface elevation data provided by the National Oceanic and Atmospheric Administration (NOAA) Buoy Stations. Statistical analysis, such as linear regression, root mean squared error method, scatter index, and percent increase, is used to analyze the accuracy of each computational result. An accurate model would ultimately increase the usefulness to the communities in the nearby locations, for they are using a model that is reliable and accountable for their emergency management planning.

2.1.2 Model Numerical Domain

The Surface Water Modeling System (SMS) software is used for the pre-processing and post-processing of the finite element mesh development of respective areas [11]. The ADCIRC model is a finite element program that executes the hydrodynamic scenarios, such as symmetrical and asymmetrical wind events. Because ADCIRC is conventionally used to simulate wind-driven ocean circulation, tides, and storm surge along the United States coasts, it is a perfect tool for this project [5]. The required ADCIRC files are assigned through the SMS Geographic User Interphase (GUI) program to assist in the generation of the correct inputs for the hydrodynamic model. Mainly, bathymetric data, node strings, wind forcing data, control variables, and finite element mesh generation toolbox are what ADCIRC needs to execute successfully. The bathymetric data and node strings are the boundary conditions implemented for mesh generation, while the wind forcing data and control variables are the input parameters needed for appropriate simulation of the hydrodynamic model.

The model domain includes the Gulf of Mexico and Laguna Madre. The enclosed finite element mesh is for the model to distinguish between water and land, as seen in Figure 2. The solid circle represents Emily (2005), the hollow circle for Dolly (2008), triangle for Alex (2010) and the squares for Bret (1999). The boundary created by the nodes distinguishes what classifies as land and what the ocean is. The accepted model domain covers above the areas that contain bathymetric information. Bathymetry is obtained from the National NOAA databases. In this study, two bathymetric datasets are modified and merged to fulfill the required data needed for the domain coverage. For the Gulf of Mexico Bathymetry, the dataset used had to be manipulated for the model to read the elevations accurately. Specifically, conversion from mesh grid data to scatter data had to be conducted within the SMS software. For the Laguna Madre dataset, a 1/3 arc-second raster dataset is obtained. The data was manipulated, so SMS software can read the data provided by the raster file and converting it to scatter data [12].

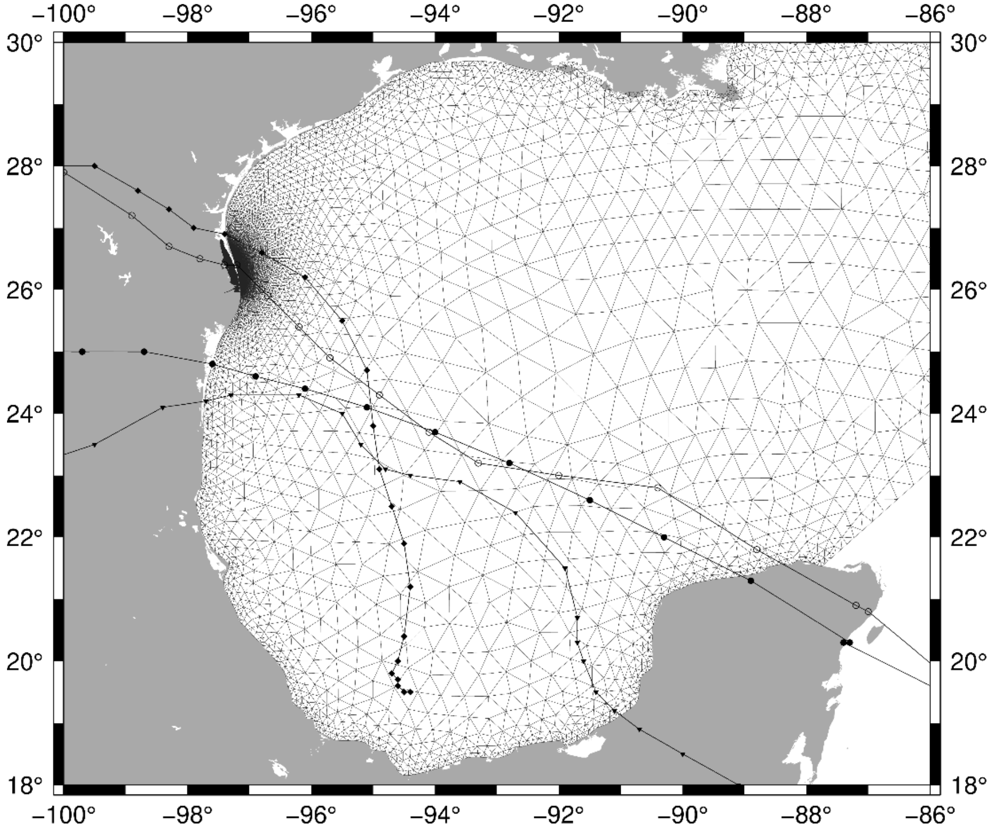


Figure 6. Gulf of Mexico finite element mesh with historical hurricane tracks

The range of mesh sizes are dependent on the importance of data accuracy, and this is due to a variety of reasons. Because the model is going to cover such a large domain, it is essential to minimize as much computational time as possible while still obtaining accurate results. If the model contains most of the small-ranged mesh, then the computational time is exponentially more considerable. Additionally, the smaller mesh is most useful in areas of interest, such as coastal zones, since it is proven that there is less interpolation required along with those areas throughout the tidal execution process. Therefore, when creating the node strings that serve as boundary conditions to the model domain, detailed modeling of nodes was distributed among the Laguna Madre area, and more relaxed nodes were distributed in open ocean conditions. Moreover, there was an interest in several channels in South Texas, such as the Arroyo Colorado and the Brownsville Ship Channel, which is why they are integrated into the domain. The geometry is triangulated through the nodes that were developed from the bathymetric raster data, so it contains appropriate interpolated elevation values as well as coordinates respective to the area. The entire grid has 64,271 nodes in the model. The triangular mesh aspect ratio, which is the element width divided by the element length, is 0.04.

2.2 Model Implementation

2.2.1 Tidal Constituents

Tidal constituents are composites of multiple partial tides at any given location. They are formed by the gravitational attraction between the earth, moon, and sun. Additionally, they contain tidal and space-dependent information that is unique to each constituent [13]. It is essential to implement tidal constituents into the hydrodynamic model used for this study, for without them, the model would be unrealistic and cause stability issues. The tidal constituents used are provided by the US Army Corps of Engineers database [13]. Specifically, the information Gulf of Mexico database obtained covers all waters west of 60 degrees west meridian and east of the North American continent. The version of the database used for the model improvement practices was the East Coast 2001 (EC2001). The published tidal constituent data that is provided by this dataset is the seasonal sea surface expansions that occur in the oceans, and they are classified as the Sea Solar annual and the Sea Solar semiannual. All 37 constituents in this database provided are barotropic [14]. There is another version of the EC2015 dataset that provides both the pressure and density analysis, obtains velocity parameters from hurricane data files.

These phases are relative to the Greenwich Meridian. These tidal constituents that are used in this study with a variety of combinations include M_2, S_2, K_2, N_2, O_1, K_1, Q_1, and P_1. The subscript "1" indicates that it is a diurnal constituent, and the subscript "2" means it is semidiurnal. Diurnal constituents' cycle once a day while semidiurnal cycles twice daily. Several tidal constituent combinations were implemented into the hydrodynamic model to identify which scenario worked best for the South Texas coast area since there has never been a model developed that is specific to this area before this study. The best tidal constituent combination that was selected can be implemented to achieve the goal of this paper. Figure 3 below indicates the behavior of the hydrodynamic model developed within 30 days of regular environmental interactions on the South Texas coast, which is the domain of this model. Each graph depicts the different tidal constituent combinations used, as well as the accuracy of each scenario. Figure 3a uses the global tidal constituent M_2. Additionally, Figure 3b uses four tidal constituents that include K_1, O_1, P_1, and Q_1. Further, Figure 3c uses seven tidal constituents that include K_1, O_1, P_1, Q_1, M_2, S_2, and N_2.

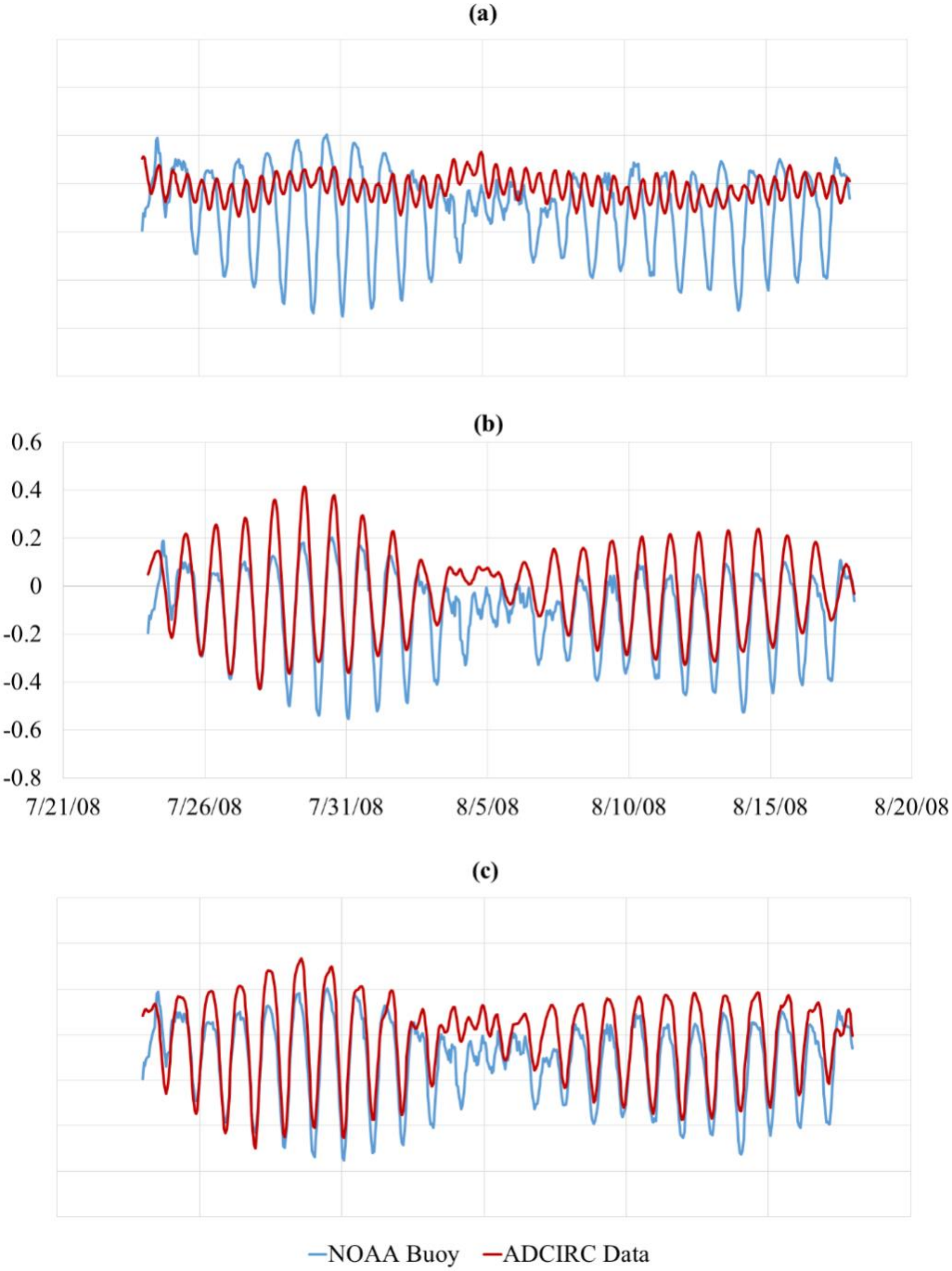


Figure 7. 30-day simulations with the everyday wind using (a) one tidal constituent, (b) four tidal constituents, and (c) seven tidal constituents

2.2.2 Wind Forcing and Tropical Cyclone

Wind forcing data is one of the essential parameters for this study because intense storms that generate a large amount of wind also generate a large amount of storm surge, and that is what this hydrodynamic model is attempting to compute. The wind forcing data obtained and used throughout the project is the "Best Track" hurricane data files provided by the NOAA database, as well as the Colorado State Extended Best Track hurricane data files [15]. These wind velocities are derived from meteorological models that produce spatially and temporally dynamic wind fields that assume open ocean conditions [16]. There is a total of four historical hurricane events that are used for this study, and the essential parameters needed from them can be found in Table 2 below. These hurricanes were selected due to the impacts they caused along the South Texas area, and their close landfall proximity to the Laguna Madre. Due to their close range to the specific area of study, they would be most prominent in propagating a significant amount of surge. Additionally, their durations and the landfall directions vary, which would then propagate different results. This is essential for model improvement measures since the model needs to be able to execute accurately with any type of hurricane condition given to it. Further, it is crucial to recognize that storm surge propagation can vary depending on hurricane size and intensity. Saffir-Simpson scale that is currently used to indicate whether a hurricane would cause significant damage to an area is based on wind speed alone and this information is not enough [17]. The purpose of implementing historical hurricane data into the hydrodynamic model is to compare observed water surface elevations during the time of these events with the computational results. Only then can we verify that the model is producing consistent results. ADCIRC reads several parameters from this wind forcing data, and that includes the intensity and the size of the hurricane. The intensity consists of translation speeds, maximum sustained winds, and minimum central pressure, while the size consists of radii of maximum winds and the radii of last closed isobar.

Table 2. Tropical Cyclone intensity parameters assigned in the model test runs

Name	Date	Duration (hr)	Category	Max Sustained Wind (kt)	Min Central Pressure (mb)
Bret	08/1999	150	4	112	944
Emily	07/2005	252	5	126	929
Dolly	07/2008	156	1	75	963
Alex	06/2010	174	2	86	946

2.2.3 Bathymetry Surface Roughness

Manning's roughness coefficient is another parameter that is carefully considered when wanting to improve an ocean model. It is essential to parameterize this information since it is a critical element of the application of storm surge models. This is because surface roughness can significantly impact the effects of inundation caused by tides and surges. Because of the scarcity of ocean data, however, these factor estimations require a level of engineering judgment. The ADCIRC program assigns a default value of 0.0025 across the whole finite element grid using the model control (fort.15) since it is the most commonly used deep ocean coefficient [23]. The Gulf of Mexico's average depth is 1615 meters, so the seafloor roughness is negligible in that area of the domain [24]. Although 0.0025 is a reasonable surface roughness value for the Gulf of Mexico region of the model, this is a significantly low number for coastal regions. Additionally, there is a variation of surface roughness along the coasts in general, so an appropriate range to depth needs to be considered. Therefore, the nodal attribute file is implemented into the model, to adequately assign manning's n friction coefficients with accordance to depths. The TxBLEND water circulation salinity transport model was used as a reference when assigning roughness coefficients [10]. The open ocean contains the most considerable value of 0.067, while it decreases with accordance to water elevations [9]. Table 3 below depicts the conditions used to automate the factors onto the finite element grid nodes using the nodal attribute file (fort.13) surface roughness assignment.

Table 3. Range of surface friction factors concerning water depth that is implemented onto the finite element grid

Distance from Sea Level	Manning's n Coefficient

0 m – 1 m	0.067
1 m – 2 m	0.0667
2 m – 3 m	0.06
3 m – 5 m	0.055
5 m – 20 m	0.02

For any value that ranges between zero to one meter, the coefficient that is implemented onto the node is 0.067. This value is used for the entirety of the Laguna Madre since the elevation depths are an average of one meter. [4] Any node reading an elevation of 20 meters or higher receives a default coefficient of 0.02. Further, a contour map is provided below in Figure 4 to visualize the relationship between the roughness factors and the coastline. It also depicts the numerical values that are inside the Laguna Madre bay area. The red shading in Figure 4 expresses a higher roughness coefficient while the blue is a lower number. Adequate roughness factors were implemented into the channels within the finite element domain, like the Laguna Madre, the Brownsville Ship Channel, and the Arroyo Colorado. Theoretically, surface roughness tends to be higher in these areas due to their low elevation and biological factors that increase the friction, such as seagrass.

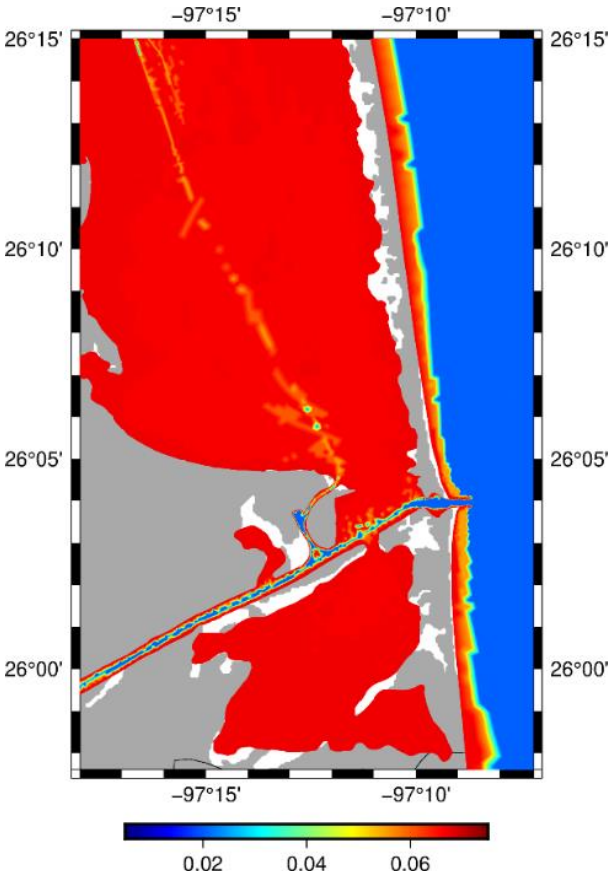


Figure 8. Map of Manning's friction coefficient contour values along the Lower Laguna Madre

2.2.4 Model Parameter Control

Because there is uncertainty with every model developed, improvement efforts are required to achieve the most sophisticated data possible. For hydrodynamic modeling, specifically, parameters like tidal harmonic constituent selection and manning's n values are essential to establish. The ideology behind this model improvement involves a series of steps. The first is to identify an excellent tidal constituent combination and then integrate the appropriate manning's n friction coefficient values. The conglomerate simulation result of both adequately evaluate, which tidal constituent combinations and surface roughness implementation are best suited for the south Texas hydrodynamic model. The model parameter and periodic boundary condition file must be adjusted before executing the hydrodynamic model. This file contains most of the parameters required to run the finite element mesh model successfully [19]. For the model to execute the most accurate results possible, it is vital for it to have a cold start time. The model uses this time as a means of warming up before executing the model. The longer the cold start time, the more accurate the model is, but due to the limited amount of wind forcing data time steps, the most reasonable cold start time for most simulations was of one day. The finite-amplitude terms, such as wetting and drying function, were not used in this study due to the instabilities it causes the model execution process. It is essential that the tidal constituent combinations selected for the execution match with the start time of the execution to prevent any phase shifting of results and inaccuracies of the model.

A nodal attribute file was used in several scenarios in this study primarily to replace the surface roughness parameter from the model parameter and periodic boundary file. When the nodal attribute file is used, it takes precedence of the computational file. Notably, during execution, the manning's n value specified in the nodal attribute files are converted to an equivalent quadratic friction coefficient before bottom stress is calculated. These nodal properties are constant, but spatial variables must be provided, and in this case, it is by the TxBLEND salinity transport model [10]. For this study, the water surface elevation function is turned off since the finite-amplitude terms are turned off.

As previously mentioned, this study verifies the accuracy of the hydrodynamic model by comparing it to already existing water surface elevation data. It is a method commonly used when calibrating storm surge models [20,21]. This information is extracted from a buoy station that has historical water surface elevation data provided by the NOAA buoy station PTIT, 8779770, located in Port Isabel, Texas [22]. This NOAA station was established in 1944 and had since then been recording a variety of parameters. The exact buoy station location in the hydrodynamic model is marked with a hollow circle in Figure 1. The only parameters that are extracted from the database for the use of this study are the water surface elevation, and it is used with the Mean High Water (MHW) elevation datum. This datum is used primarily due to it being the average of all high-water heights observed in that buoy station location and is, therefore, the most useful for this study.

2.3 Model Calibration and Validation

Figure 9 depicts the developed scenario's computational results being compared to the actual observed water surface elevation data from NOAA. The computational results and the NOAA data depict the water surface elevation, or storm surge, produced by each of the storms in meters. The legend in the figures provides the color specification for each respective computational result.

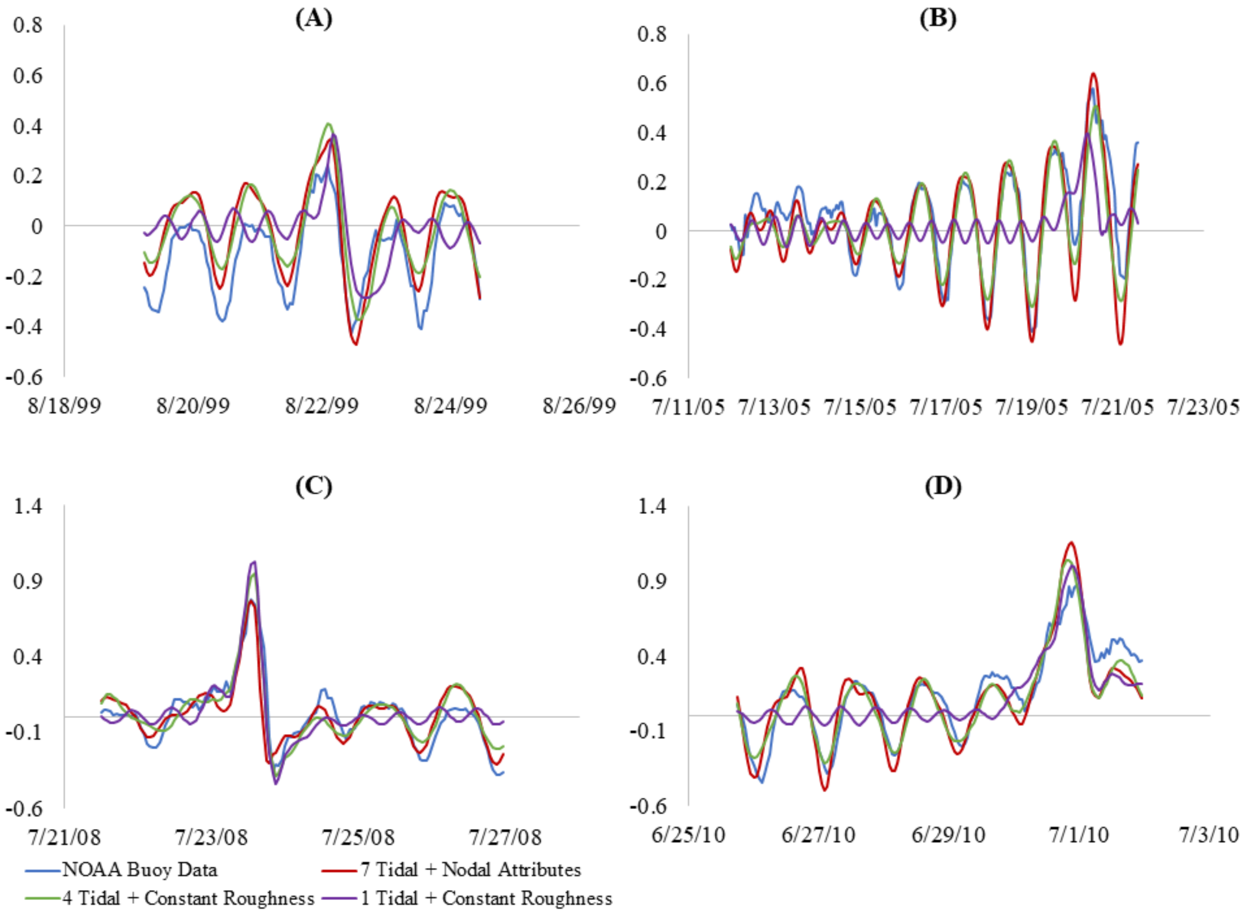


Figure 9. Hydrographs representing water surface elevation during the historical hurricane event

Scenarios 1, 2, and 3, are identified as colors purple, green, and red in Figure 9, respectively. Additionally, the default ADCIRC surface roughness value used is referred to as the "Constant Roughness" parameter. These results re-confirm the theory that tidal constituents have a pivotal impact on the model stability, for Scenario 1, which only had one tidal constituent, was the most unstable. Scenario 1 proves that global tidal constituents, like M_2, are stable in the deep ocean but lack resolution for coastal areas. The multiple tidal constituents allow for a higher resolution harmonic analysis [14]. Figure 10 below also visually indicates the wind stress that contributes to the storm surge propagation along the Lower Laguna Madre.

Hydrodynamic models must be computationally reasonable, which is why observing the wind stress vector data and the water surface elevation data is an integral part of the model development and improvement process. If results show instability, then the numerical values also depict variable data.

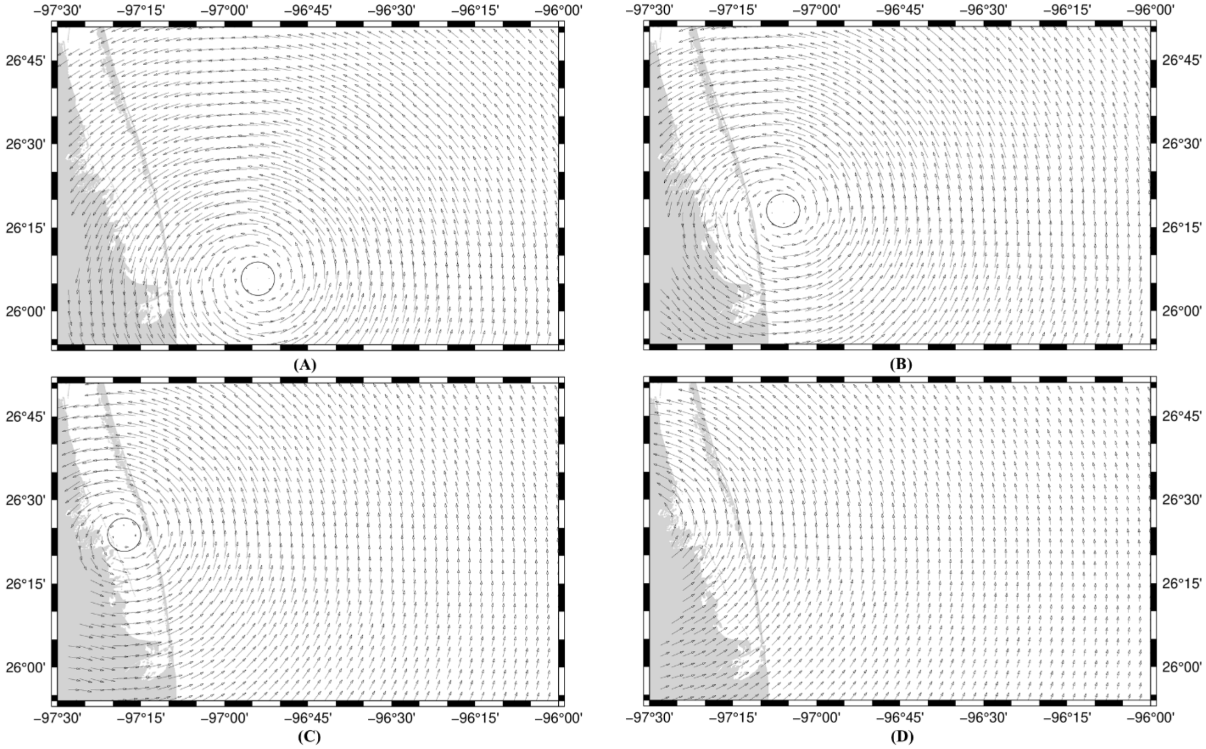


Figure 10. Hurricane Dolly, 2008, wind stress variation with a two-hour interval

Since Hurricanes are symmetrical, the results of the vectors must clearly define the relationship of these phenomena. The eye is the calmest part of the storm, which would then mean that the wind stress is not as intense. Figure 10 indicates the Hurricane Dolly wind stress that the hydrodynamic model computed. The results shown are from a Scenario 3 model set up, which consists of using seven tidal constituents and adequate manning's n extracted from the nodal attribute files. The wind stress is a significant contributor to storm surge propagation. Specifically, the gusts tend to push water in the circular motion of the symmetrical cyclone. Hurricane Dolly's landfall makes a direct impact on the Laguna Madre, as shown in Figure 10 (c). From this theory, the surge Hurricane Dolly propagates is pushing the water from the island side to the mainland in a distributed fashion. Figure 11 below depicts the water surface levels from each hurricane tested.

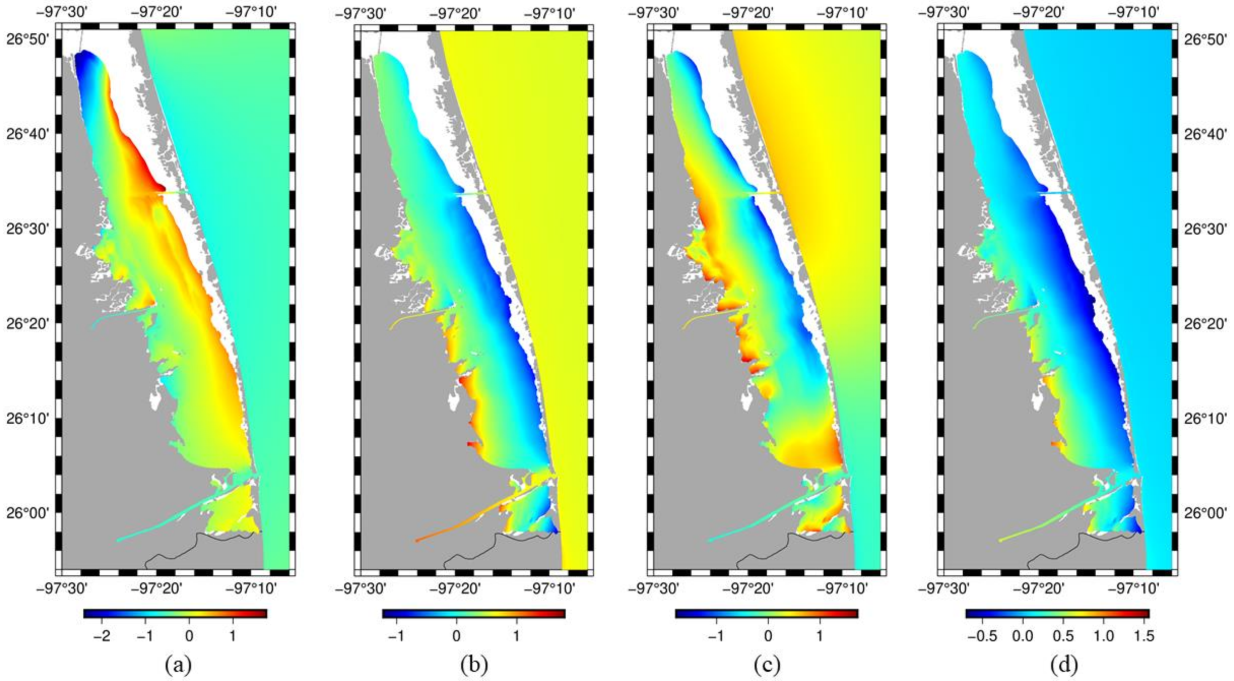


Figure 11. Water Surface elevation maps extracted from scenario 3 of (a) Hurricane Bret (1999), (b) Hurricane Emily (2005), (c) Hurricane Dolly (2008), (d) Hurricane Alex (2010)

The locations vulnerable to storm surge alters depending on the landfall location and direction the storm is moving, which Figure 11 above explains. Generally, the effects of storm surge affect the same regardless of symmetrical tropical cyclone landfall and direction. These maps are depicting peak surges along the area, with the red contour being the severely impacted locations. As seen in these figures, the storm translation speeds contribute significantly to how the storm surge propagates. As the hurricane is making its transition from ocean to landfall, its circular wind speeds push surface water towards the land as well. The red contour indicates higher levels of inundation caused by these wind behaviors. Hurricane Bret, as seen in Figure 6, pushes the water towards the barrier island side due to its landfall location being further up north. Hurricane Alex, on the other hand, pushes the water to the Bahia Grande side due to its landfall location being further down south. Hurricane Dolly makes landfall in the middle of the Laguna Madre, which is why the water inundation across the mainland is uniformly distributed.

Figure 12 indicates the regression analysis that was implemented to identify which scenario worked best with this South Texas hydrodynamic model. The blue solid points are of scenario that did not contain a nodal attribute file, while the red hollow points include one that assigned a specific roughness value to each node present in the model domain. The graphs with the coefficient A depict the relationship of hurricane Bret (1999) with one, four, and seven tidal constituent combinations, which are labeled as A1, A2, and A3, respectively. The B coefficient represents the relationship of hurricane Emily (2005), the C coefficient for Hurricane Dolly (2008), and the D coefficient for Alex (2010). From the visual representation above, the third scenario consisting of the seven tidal constituent combinations depicted the best results. Additionally, the nodal attribute file deemed more accurate than the constant roughness parameter implementation for all scenarios.

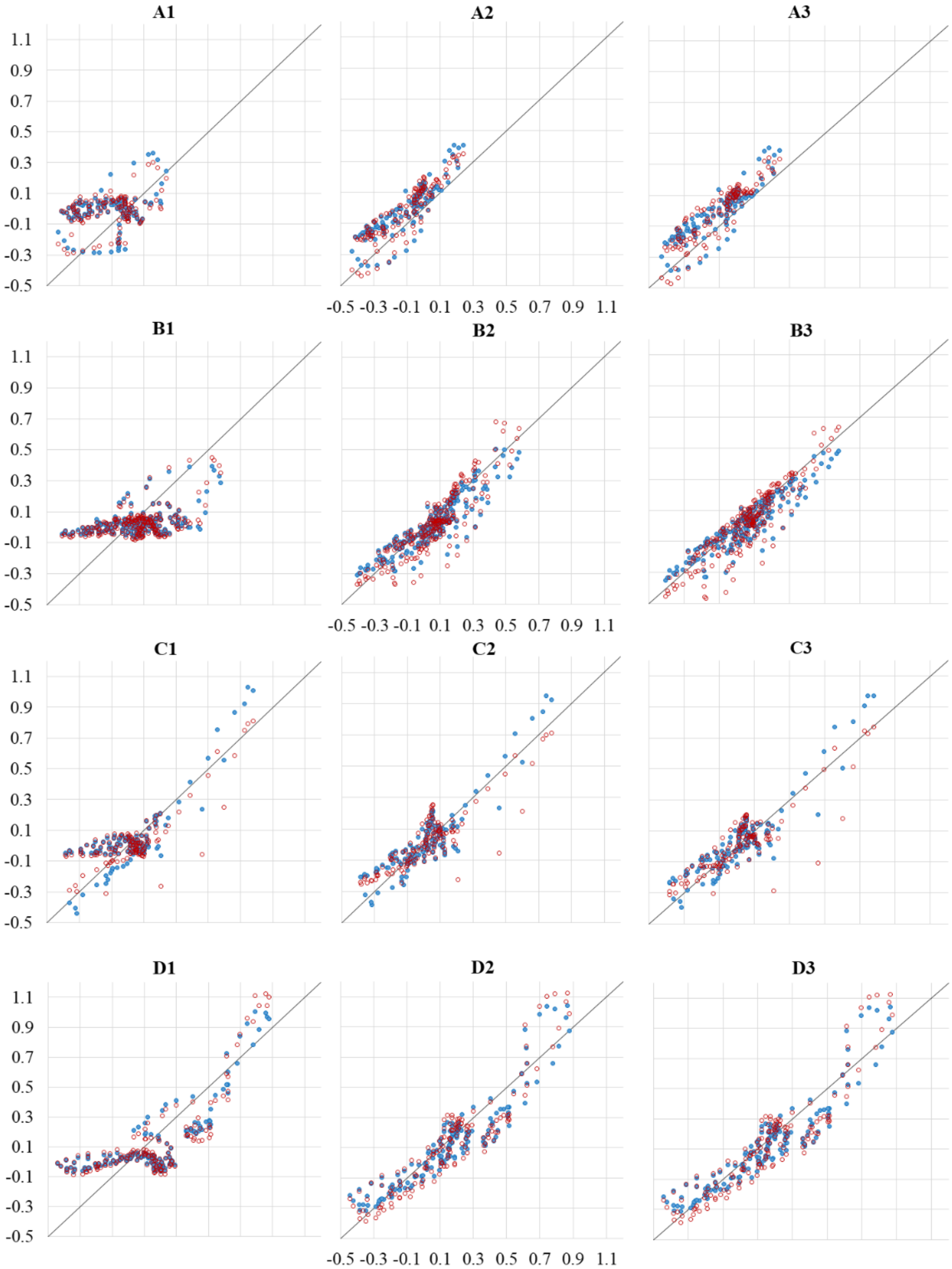


Figure 12. Regression lines of each hurricane scenario where the blue points indicate the constant roughness attribute and red points indicate nodal attribute parameter

A statistical index was performed to quantify the accuracy of the hydrodynamic model produced through the three scenarios. The normalized root means square error (NRMSE) of each execution was calculated to compare these scenarios and identify the most accurate one, as seen in Table 3 below. The formula used for the calculation of NRMSE is shown below:

$$E_{rms} = \sqrt{\frac{\sum_{i=1}^{N} (\chi_c - \chi_m)_i^2}{N}}$$

Where, X_c stands for the observed value, X_m stands for the experimental value, and N is for the number of times steps each computation entails. The scatter index of the hurricane events was also identified using the following formula:

$$SI = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N} (S_i - O_i)^2}}{\frac{1}{N}\sum_{i=1}^{N} O_i}$$

Where, S_i is the observed value, O_i is the experimental value, and N is the number of time steps of each of the computational results. Essentially, it is the NRMSE divided by the mean observation. The percent improvement at the peak surges for each of the hurricane scenarios is also computed to gauge the accuracy of the model, and that is calculated using the following percent error formula:

$$\%\ Increase = \frac{S_i - O_i}{O_i} * 100$$

The reason for this percent improvement calculation being focused primarily on peak surge is because the goal of this study is to improve the storm surge model, accurate storm surge height predictions must be generated.

All the statistical analyses can be seen in Tables 3 and 4 below. The value in front of the T stands for the number of tidal constituents that were used for that computation. The variables after are describing what surface roughness analysis was used. The NA stands for Nodal Attribute, which means that the nodes were assigned a specific surface roughness dependent on water elevation, while the CR stands for constant roughness, meaning there was only one manning's roughness coefficient value of 0.0025 applied to the entire grid.

Table 4. Statistical analysis of Lower Laguna Madre flow circulation model scenarios

Scenario	**Alex 2010**		**Dolly 2008**		**Emily 2005**		**Bret 1999**	
	RMSE	**SI**	**RSME**	**SI**	**RSME**	**SI**	**RSME**	**SI**
1T+NA	0.1949	1.2818	0.1329	6.0572	0.1678	2.8853	0.1870	-1.6673
1T+CR	0.1847	1.2151	0.1278	5.8248	0.1715	2.9491	0.1925	-1.7161
4T+NA	0.1302	0.8568	0.1093	4.9822	0.1035	1.7798	0.1237	-1.1032
4T+CR	0.1143	0.7521	0.0950	4.3294	0.0920	1.5819	0.1302	-1.1608
7T+NA	0.1365	0.8982	0.1106	5.0379	0.0978	1.6810	0.1215	-1.0831

7T+CR	0.1167	0.7679	0.0949	4.3249	0.0835	1.4355	0.1283	-1.1438

The best consistent computational result includes the seven tidal constituent combinations of K1, O1, P1, Q1, M2, S2, N2, and the nodal attribute file implemented to assign manning's n coefficients to each node within the finite element grid. Seven of the eight primary tidal constituents provided by the EC2001 were implemented into the model for execution, and it significantly increased the accuracy in the results of the storm surge hydrographs. Comparing the peak surges between the recorded NOAA Buoy data and the best computational result using the percentage error method, Hurricane Dolly 2008 computation had a 0.89% error margin.

Table 5. Percent increase of water surface elevation points of respective hurricanes

Scenarios	Alex 2010	Dolly 2008	Emily 2005	Bret 1999
1T+NA	28.5388	4.36456	10.3806	26.1411
1T+CR	14.4977	32.2207	-12.8028	51.0373
4T+NA	28.4246	-8.34403	-89.4464	44.3983
4T+CR	18.8356	21.6944	-16.7820	68.4647
7T+NA	32.7625	-0.89858	17.6471	43.1535
7T+CR	20.7762	24.6469	-21.7993	68.4647

The modeled significant storm surges closely match the measured peak heights the buoy station recordings. There is only one buoy station along this area that has historical water surface elevation levels, so the error that may be caused by missing physics of measurement cannot be avoided. The 7T+NA scenario, which included the seven tidal constituents and nodal attribute files, was pronounced the most accurate. Just as the tidal constituents were essential for the performance of the model, so was the nodal attribute file. A model improves in quality if nodes are specified with the value much closest to their environmental value, rather than having a generic surface roughness for the entire model. Overall, the magnitude of the water surface elevations from all scenarios matches those of the recorded NOAA buoy station. Also, all statistical analysis that was used to quantify the validation of the model computational result agreed with the best scenarios of the seven tidal constituent combinations and integration of nodal attribute file.

2.4 Determination of Representing Hurricanes

2.4.1 Hurricane Tracks Determination Criteria

Five different hurricane scenarios are to be implemented to this area, and each scenario will entail different parameters, in which will be placed into a database before incorporating it into the hurricane storm surge model. Location of landfall, direction, maximum sustained winds, and atmospheric pressure are what will be controlled in each scenario. Each of the five hurricane scenarios will consist of different categories, and those categories are determined by the Saffir Simpson Scale [16]. This scale used to classify hurricanes depending on a Hurricane’s present intensity. The parameter used in the Saffir Simpson scale to classify hurricanes is the wind speed solely (storm surge, flood, and size can vary amongst hurricanes of different categories). This scale determines the potential damage a hurricane can cause to an area [16]. Each category has a range of atmospheric pressure, which is dependent on wind speed. Below is a detailed description of what each category entails, as well as the projected damage they are likely to cause in any coastal area.

2.4.2 Texas Hurricanes by Category

Category 1
Sustained Winds (74-95mph; 119-153km/h)
Atmospheric pressure: >981mb [17]
Potential Damage: Very dangerous winds that will produce some damage [18]; storm surge generally 4-5ft above the normal condition; no real damage to well-built structures, minor pier damage [17]
Texas Hurricanes: Cindy (1963), Humberto (2007), Claudette (2003) [16]

Category 2
Sustained winds (96-110mph; 154-177km/h)
Atmospheric Pressure: 965-979mb [17]
Potential Damage: Extremely Dangerous winds will cause extensive damage [18]; storm surge generally 6-8 ft above normal conditions; some roofing damage, coastal low-lying areas must evacuate 2-4 hours before storm makes landfall [17]
Texas Hurricanes: Rita (2005), Dolly (2008), Edith (1971) [16]

Category 3 (major)
Sustained Winds (111-129mph; 178-208km/h)
Atmospheric Pressure: 945-964mb [17]
Potential Damage: Devastating damage [18]; storm surge 9-12 ft above normal conditions, mobile homes, signs are completely destroyed; any area lower than 5 ft above mean sea level and within 6miles inland must evacuate [17]
Texas Hurricanes: Bret (1999), Alicia (1983) [16]

Category 4 (major)
Sustained Winds (130-156mph; 209-251km/h)
Atmospheric Pressure: 920-944mb [17]
Potential Damage: catastrophic damage [18]; storm surge generates 13-18 above normal conditions; roof structure failure, power outage, blown down trees might isolate neighborhoods, uninhabitable for days, any area lower than 10 ft above mean sea level and within 6 miles must evacuate [17]
Texas Hurricane: Carla (1961) [16]

Category 5 (major)
Sustained winds (157mph>; 252km/h>)
Atmospheric pressure: <920mb [17]
Potential Damage: catastrophic damage [18]; storm surge generates higher than 18ft above normal conditions; trees are uprooted, severe and extensive window and door damage, complete roof failure in some well-built structures any area less than 15 ft above mean sea level and within 5-10 miles of shoreline must evacuate [17]
Texas Hurricane: Beulah (1967) [16]

2.4.3 Proposed Hurricane Modeling Scenarios

Scenario 1

Category: 1 (based off Hurricane UNNAMED, 1886) [19]
Direction and Duration: N, 5 days
Proposed Location: Landfall Brownsville, Texas
Max. Wind Speed: 98mph
Min Atmospheric Pressure: 979mb
Radii of Max. Wind: 115 mi

These parameters are chosen since this scenario has occurred in the past and made landfall in Texas. When this hurricane modeling scenario is simulated, there will be a comparison of computational result between a historical storm. The key difference here, however, is that the hurricane will be making landfall in the South Texas – Coastal area. These parameters are chosen because typically, hurricanes along the Gulf of Mexico have a trend of moving through North/north west direction.

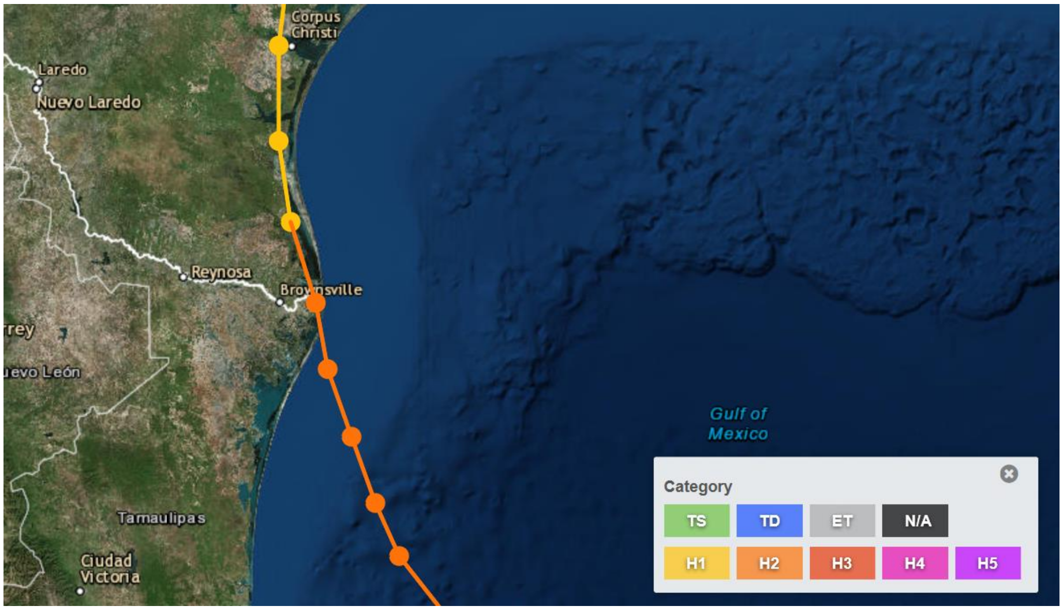


Figure 13. Hurricane UNNAMED 1886 track [3]

Scenario 2

Category: 2 (based off Hurricane Dolly, 2008) [20]
Direction and Duration: W/NW, 10 days
Proposed Location: Landfall in Arroyo Colorado
Max. Wind Speed: 95mph
Min Atmospheric Pressure: 967mb
Radii of Max. Wind: 100 mi

These parameters are chosen to reflect a famous historical hurricane that passed right through the South Texas: Hurricane Dolly. With the parameters of Hurricane Dolly, the computational results will let us see what areas need more focus when needing to prepare for a hurricane of this magnitude. The parameters are also chosen so that the measurement data received from computational result can be compared to actual measured data that NOAA provides to the public.

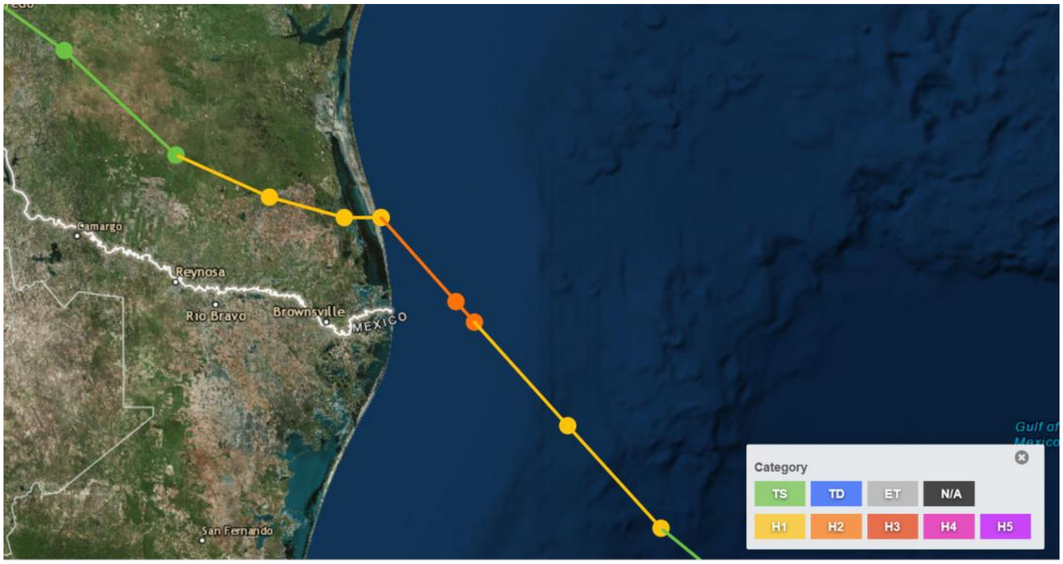


Figure 14. Hurricane Dolly 2008 track [3]

Scenario 3

Category: 3 (based off Hurricane Bret, 1999) [21]

Direction and Duration: N/NW, 5 days

Proposed Location: Landfall in Kenedy County

Max. Wind Speed: 140 mph

Min Atmospheric Pressure: 952 mb

Radii of Max. Wind: 40 mi

Why these parameters? These parameters are chosen to reflect a historical hurricane that has once passed through the South Texas Coast, Hurricane Bret. This scenario is different from the others in that it is a category 3, however, the radii of maximum winds is significantly smaller in size compared to other scenarios. The duration of the hurricane will also be shorter than the others, to indicate whether the duration of the hurricane and small size will contribute to the impact it will have on the area.

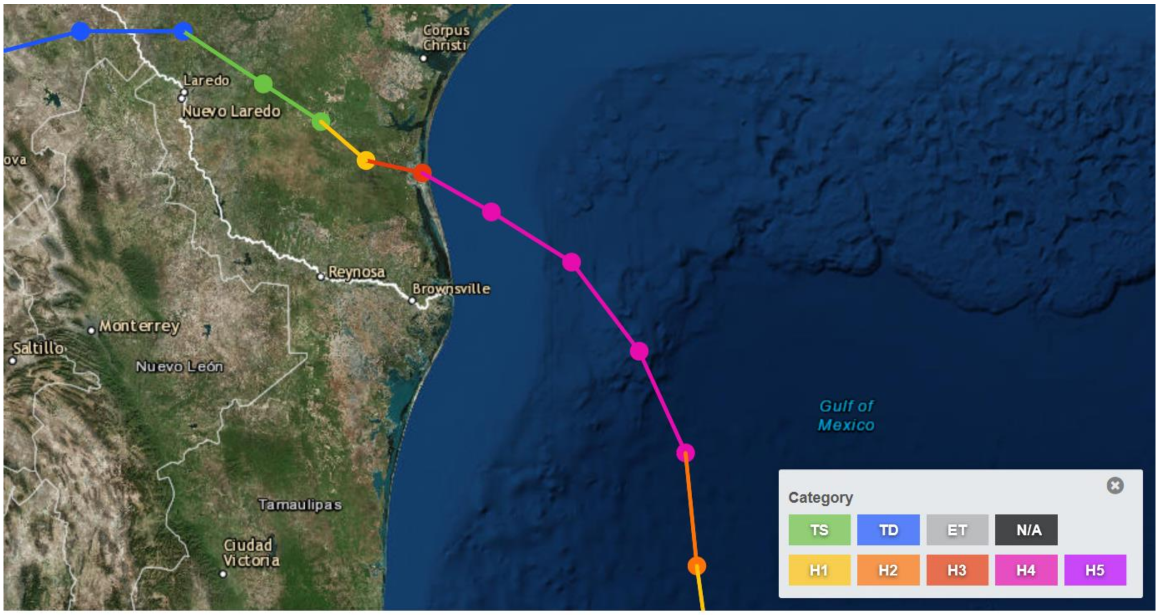


Figure 15. Hurricane Bret 1999 landfall [3]

<u>Scenario 4</u>
Category: 4 (based off Hurricane Allen, 1980) [19]
Direction and Duration: NW, 10 days
Proposed Location:
Max. Wind Speed: 140mph
Min Atmospheric Pressure: 931mb
Radii of Max. Wind: 40 mi

These parameters are chosen to reflect those of a strong historical hurricane that has made landfall in South Texas, Allen in 1980. The parameters are chosen to determine if the damages/impacts caused by the hurricane will still be the same as per in 1961. Another reason these parameters are chosen is to diversify the scenarios: this will be a scenario in which the hurricane is small in size but large in intensity, and forecasting the impacts is essential. Because South Texas hasn't had a hurricane of this magnitude pass by recently, it would be a beneficial scenario to perform to better see whether we are prepared for major hurricanes or not.

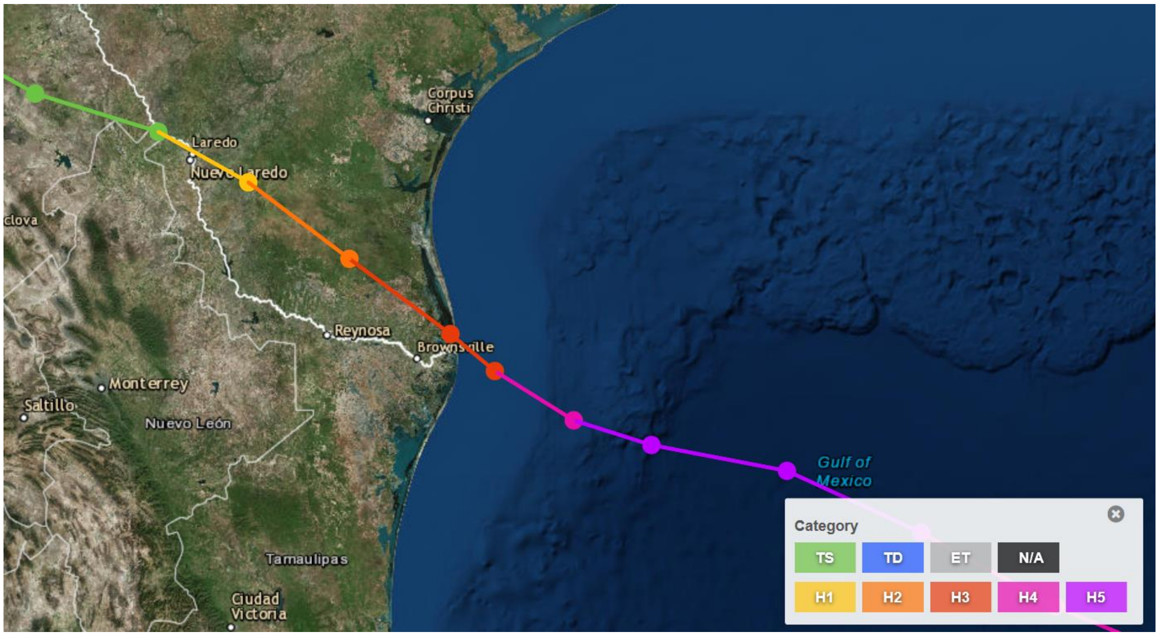


Figure 16. Hurricane Allen 1980 landfall [3]

Scenario 5

Category: 1 (based off Hurricane Beulah, 1967) [22]
Direction and Duration: N/NW, 15 days
Proposed Location: Landfall in Brownsville, Texas
Max. Wind Speed: 160mph
Min Atmospheric Pressure: 923mb
Radii of Max. Wind. 325 mi [23]

These parameters are chosen to reflect Hurricane Beulah, one of the most destructive hurricanes that crossed though the South Texas. Although Beulah did not make landfall as a category 5 hurricane, it was massive in size and it has been one of the strongest hurricanes to have ever crossed South Texas. Modeling a scenario in which another “Hurricane Beulah” crosses through South Texas to see the potential damage it can do to present day RGV is key to determining whether there needs to be changes made in the emergency evacuation/preparedness plans.

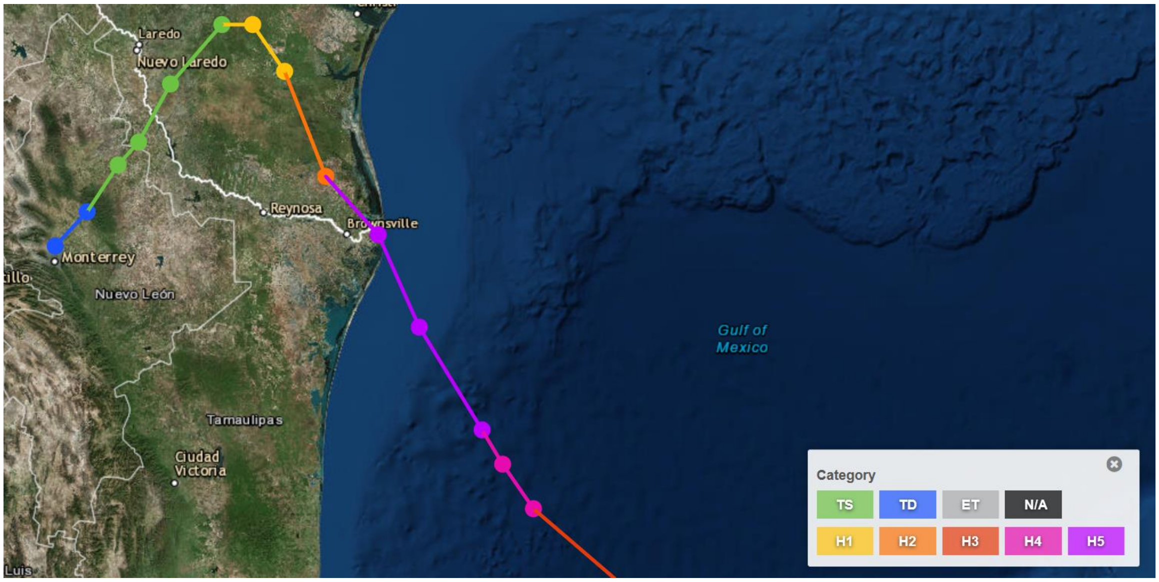


Figure 17. Hurricane Beulah 1967 landfall [3]

2.5 Lower Laguna Madre Storms Surge Maps of Hurricane Categories

With the aid of the ArcMap software, the representation of flooding based on water elevations can be illustrated through the use Digital Elevation Models (DEMs). DEMs showcase the geographical elevation of different locations horizontally in a specified projection or coordinate system; The DEMs used for the purpose of this representation were sourced from the National Elevation Dataset (2013) provided by the United States Geological Survey (USGS: https://www.usgs.gov/products/maps/gis-data). Due to the specifications of the project, the DEM's focused on the Willacy and Cameron county.

Furthermore, to highlight county boundaries for clarification purposes, the Texas County Boundaries (line) were used and sourced from the Texas Department of Transportations https://gis-txdot.opendata.arcgis.com/datasets/texas-county-boundaries/explore. Based on the Hurricane modelling previously developed, it was determined that the storm surge values according to the severity of the hurricane. The raster was modified to showcase these elevations in specific colors and highlight the severity of the storm surge according to the corresponding hurricane category. The elevations were changed into a unit of meters due to the DEM metric system. Further modifications such as clipping and extracting by mask were conducted to ensure the data would reflect the corresponding geographic location of the project. Figure 18 shows hurricane storm surge flooding severity based on hurricane categories over the Cameron and Willacy Counties. The map will be posted in the project website, https://vcore.utrgv.edu/.

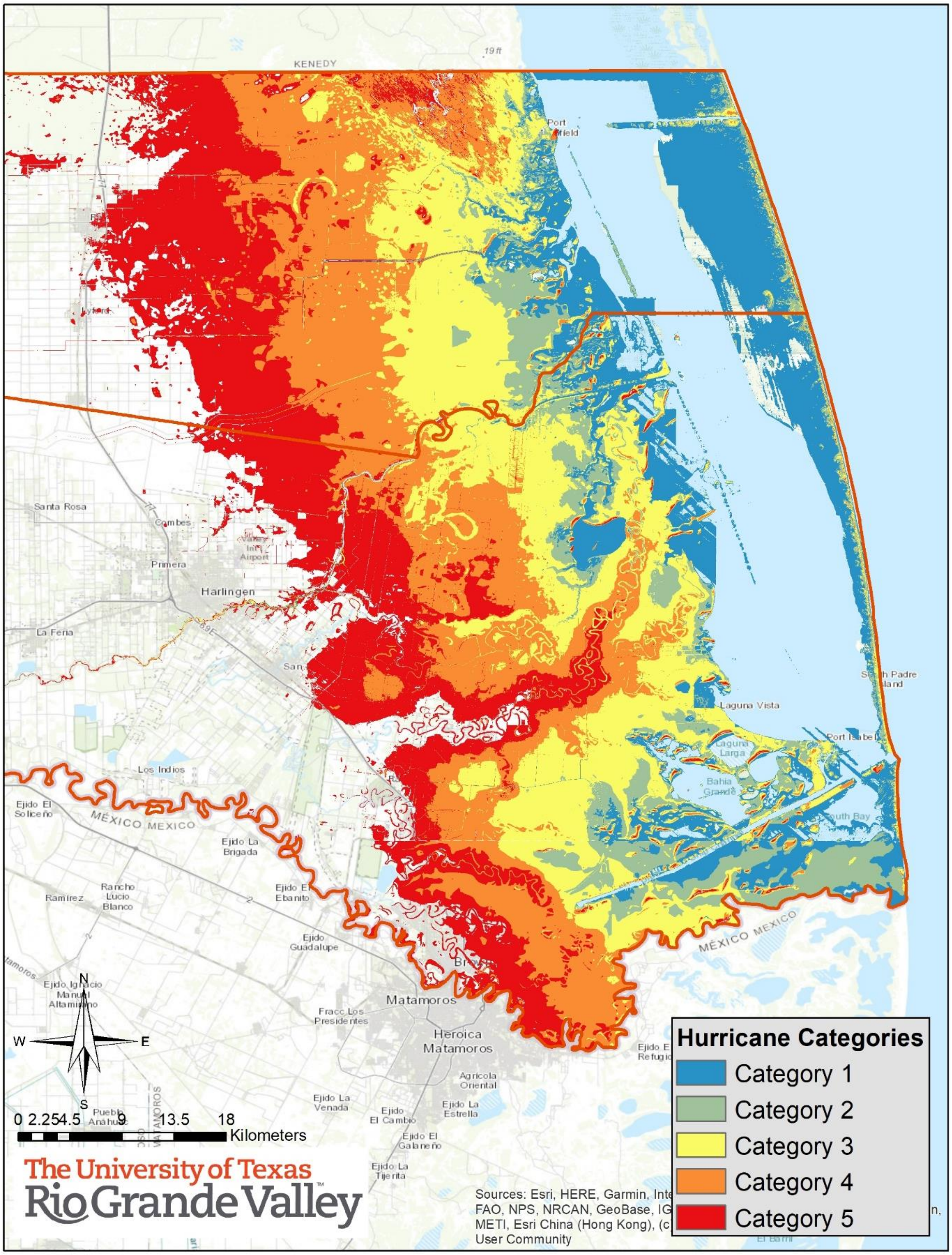


Figure 18. Hurricane storm surge predictions based on five hurricane categories

3. INLAND RAINFALL-RUNOFF MODEL DEVELOPMENT

The objective of this task is created on surface water quantity, where the questions on the hydrologic modeling such as how the precipitation-runoff determines how much water will become runoff given a storm event on a landscape. Being able to obtain such information will create the opportunity on to use a terrain to model the direction and quantity the water will take.

3.1 Watershed Hydrologic Model

The goal is to find the discharge at the location for a precipitation storm event. In this case the HEC-HMS modeling tool will be used as explained further on this report. GIS will be used to create the terrain and the hydrological characteristics that will create the watersheds that will be the input for the HEC-HMS model. In order to achieve this, various factors of inputs will be used to create the terrain and hydraulic characteristics. Using these factors, the watershed delineation by using various ArcGIS tools to be prepared as the inputs for HEC-HMS model and compare the storm hydrograph at different locations across a watershed.

3.1.1 Model Geometric Data

Various aspects of the terrain will be needed such as the terrain digital elevations, hydrography, soil types, and that of impervious areas. The bulk of these datasets are obtained from public websites such as the following:

- Digital Elevation and Land Cover
  https://apps.nationalmap.gov/download/
  https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/ngce/
- Hydrography
  https://www.usgs.gov/core-science-systems/ngp/national-hydrography
- Soils
  https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/tools/?cid=nrcseprd1407030
- Frequency Storm Data
  https://pubs.usgs.gov/sir/2004/5041/pdf/sir2004-5041.pdf

The first step would be to prepare the Digital Elevation Map and prepare it as a terrain. Once you've downloaded the DEM (Preferably as a Terrain Dataset), make sure that it is placed on the on the same projections as the other data sets. Figure 19 shows the terrain data of the Willacy County watershed.

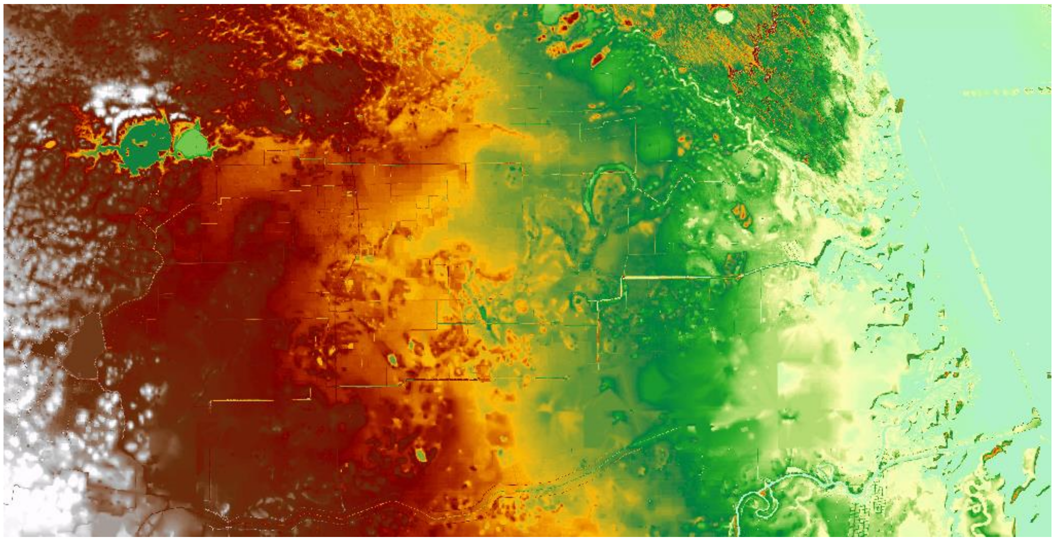


Figure 19. Example of Digital Elevation Map (Terrain)

Once this is done, the terrain can be prepared by ArcGIS tools. Albeit the ArcGIS toolbox can be used to prepare the terrain, an extension will be used that simplifies the processes by automatically referencing these tools rather that looking them up individually. This ArcHydro extension can be downloaded from: http://downloads.esri.com/archydro/archydro/. This tool can be used to simply follow the steps in order to delineate the watersheds as seen below. Various aspects of the terrain will be needing to change in order to represent what reflects reality. Such factors that may affect the watersheds are the time the DEM was taken from, such case if there have been any land developments, ditch creations, or change in land elevations, these factors must be reflected on the terrain. Another factor is those of large bodies of water, DEM's are not the best at representing the water elevations, like those of rivers, lakes, ditches; meaning that when flow lines derivation from the terrain can be concentrated to such locations. Concentration of high populations are also another factor that can change the amount of runoff a watershed can produce based on impermeability.

DEM "errors" and natural lakes must be filled in when creating the watersheds in order to assert the correct flowlines. Water may overflow within a full body of water, but the DEM might indicate this depression as a simple low land covered area, where water might pool in, in order to avoid this the sink fill feature might be used to fill in these gaps. The opposite of a depression within the Dem might be encountered, that of missing bodies of water such as man-made ditches, where the digital terrain might not include such feature due to its dated DEM. The option to impose a flow pattern, or "burn", onto the DEM can be used in order to create a polyline that sinks into the DEM in order to recreate a ditch/stream.

3.1.2 Subbasin Delineations

Upon preparing the Terrain over, the watershed delineation is ready to be processed, this will be done by the ArcHydro tool where it will be used to analyze the terrain, trace and accumulate the networks of paths of streamflow, develop a schema node-link that creates both the flow direction based of elevations and creates watersheds based on the source from the runoff. Although the mechanisms of this process are beyond the scope of this report, the focus of two major functions are mildly explained, those are the drain lines and watersheds. As seen in figure 4, the elevation raster maps can be used to derive hydrologic characteristics of a land surface such as the direction of flow from the elevation cells. ArcMap uses a Flow Direction tool from which it uses the elevation raster elevation data in order to obtain a ratio of maximum exchange in elevation from each cell (maximum elevation) along the direction of flow to the path length between centers of cells (lowest elevation) and is expressed in percentages. The direction of flow is determined by the steep slope change from each cell and calculated by:

$$MaxSlope = \frac{Change\ in\ Elevation}{Distance \times 100}$$

Where the distance is calculated between cell centers, where the differential cell consideration is in effect to constitute both differences of percentages between center and outlaying cells. If the maximum descent to several cells is the same, the neighborhood is enlarged until the steepest descent is found. This process is repeated throughout the terrain until the direction of steepest descent is found, that direction is used. Using the same cells, the ArcHydro tool can locate the outer boundaries of the highest points to locate the extents of each watersheds, where the lowest points will be the source of the runoff.

3.1.3 Volume-Time Method for Watershed Runoff

Volume-time method can be used to establish the relationship between the flow input of a watershed and runoff. To determine the relationship between the detention and the output, where the land, soil, and type of development must be known in order to determine the quantity of water runoff. Pre-developed is assumed to be that of a non-disturbed location that is common for South Texas, that includes either as a farming or that of natural/grazing lands. Which is connected to that of an imperviousness of 0.5 %. Post-development is that of land use that varies between the low of residential plots (about ¼ of an acre) to a high density of that of 1/3 of an acre. The hydrologic soil group used for the study is that of Group

A (30%) and Group B (50%) with the type of land use found around South Texas is that of a cultivated agricultural land/barren agriculture type, and that of developed areas with vegetation. The Figure 20 shows a part of the Cameron County watershed and its drain lines and soil types.

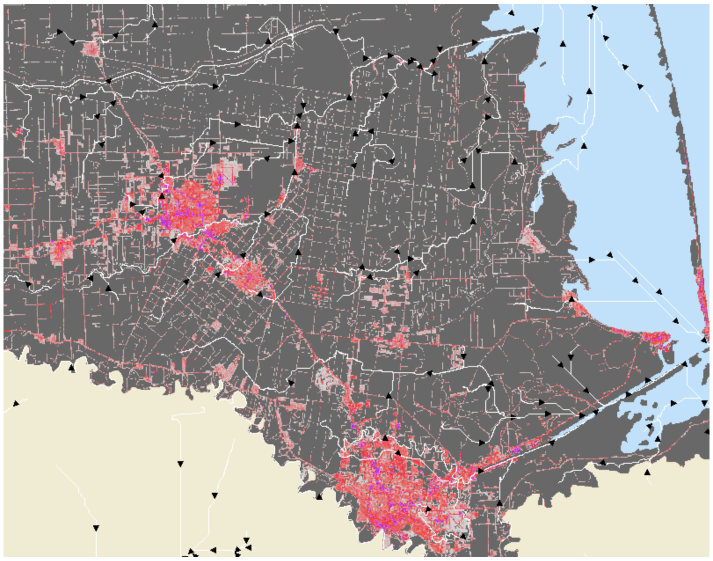
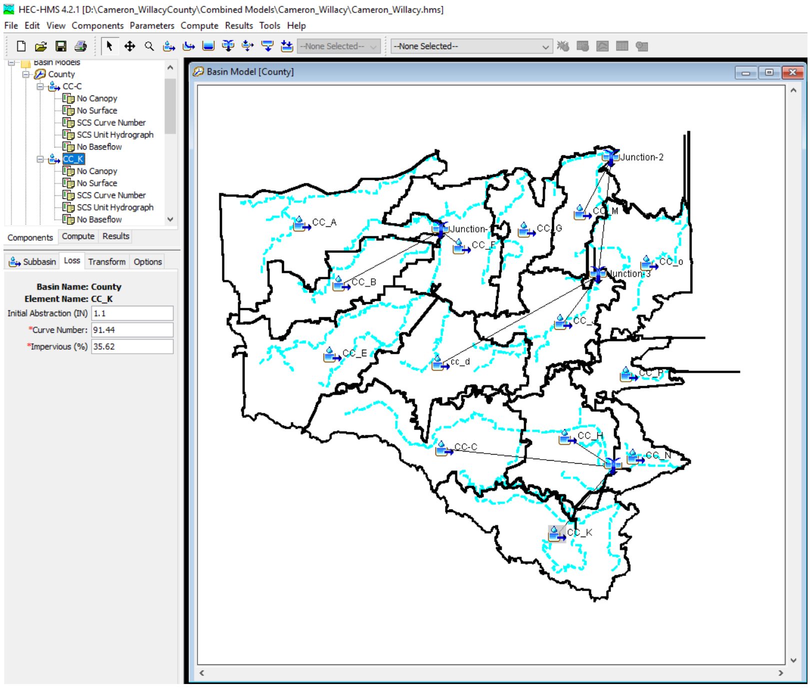


Figure 20. Drain lines and soil types within Cameron County watershed

The SCS-CN (Soil Conservation Service curve number) flood routing methodology was used computing the volume of surface runoff in catchments for a given rainfall event uses an empirical where the analysis of storm event rainfall and runoff. The analysis of a storm event's effects must overcome the interception, depression storage, and infiltration volume before the run-off is to occur. The curve number can be determined from empirical information. The SCS has developed the runoff hydrographs can be accomplished through the creation of the basins and catchments in ArcGIS and Imported to HEC-HMS for calculations as shown in Figure 21. The definition of soils type, imperviousness, and land use are also necessary factors in order to calculate the land's permeability due to water. These factors are included in the calculation of the curve number.

The result is that water flows along a defined path with no possibility of dispersing over the landscape that allows for dispersal of the drainage by proportioning water to the outlet grid cells. Once that flow-paths are defined, basins can also be defined and formulated to obtain the necessary information (soil type, area, land use, imperviousness) that can be easily researched and obtained from various governmental department such as appraisal district office and USGS.

Runoff hydrographs can be accomplished through the program HEC-HMS that develop peer accepted flow versus time hydrographs. In designing a pond using the Volume Time methodology, the biggest point of interest lays within the outflow of various frequency storm events up to 500-year post-developed storm hydrograph output.



Basin Name: County
Element Name: CC_K
Initial Abstraction (IN) 1.1
*Curve Number: 91.44
*Impervious (%) 35.62

Figure 21. HEC-HMS modeling for the Cameron County showcases the watersheds and drain lines

3.1.4 Watershed Compositions and Hypothetical Storm Events

Sixteen and thirty-five watersheds were composed for the Cameron and the Willacy County, respectively as shown in Figures 22 and 23. The Cameron County is composed of three major drainages: Brownsville Ship Channel, Arroyo Colorado, and North Floodway. Table 6 summaries the subbasins, size in unit of square miles, and the associated drainage. In the same way, the Willacy County subbasin watersheds information was listed in Table 7. Three major drain channels were assigned in the Willacy County watershed.

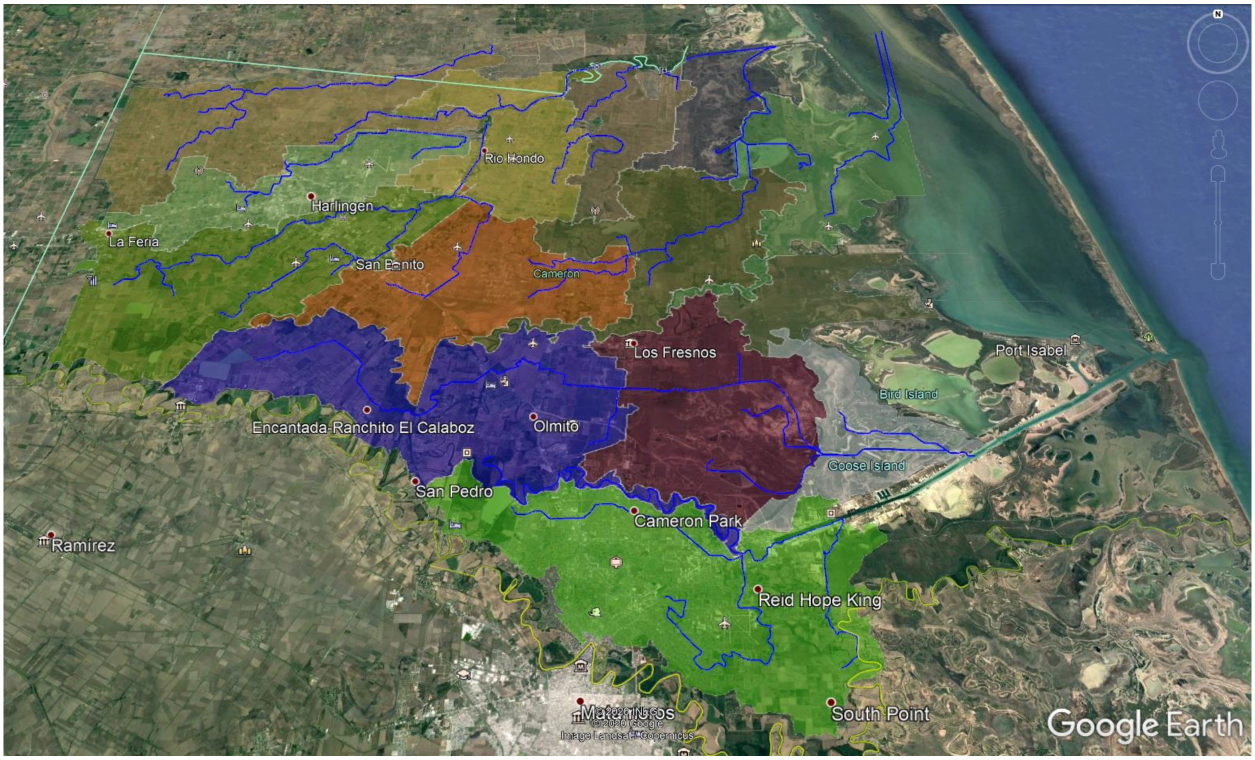


Figure 22. Cameron County sub-basin watersheds and major drain channels

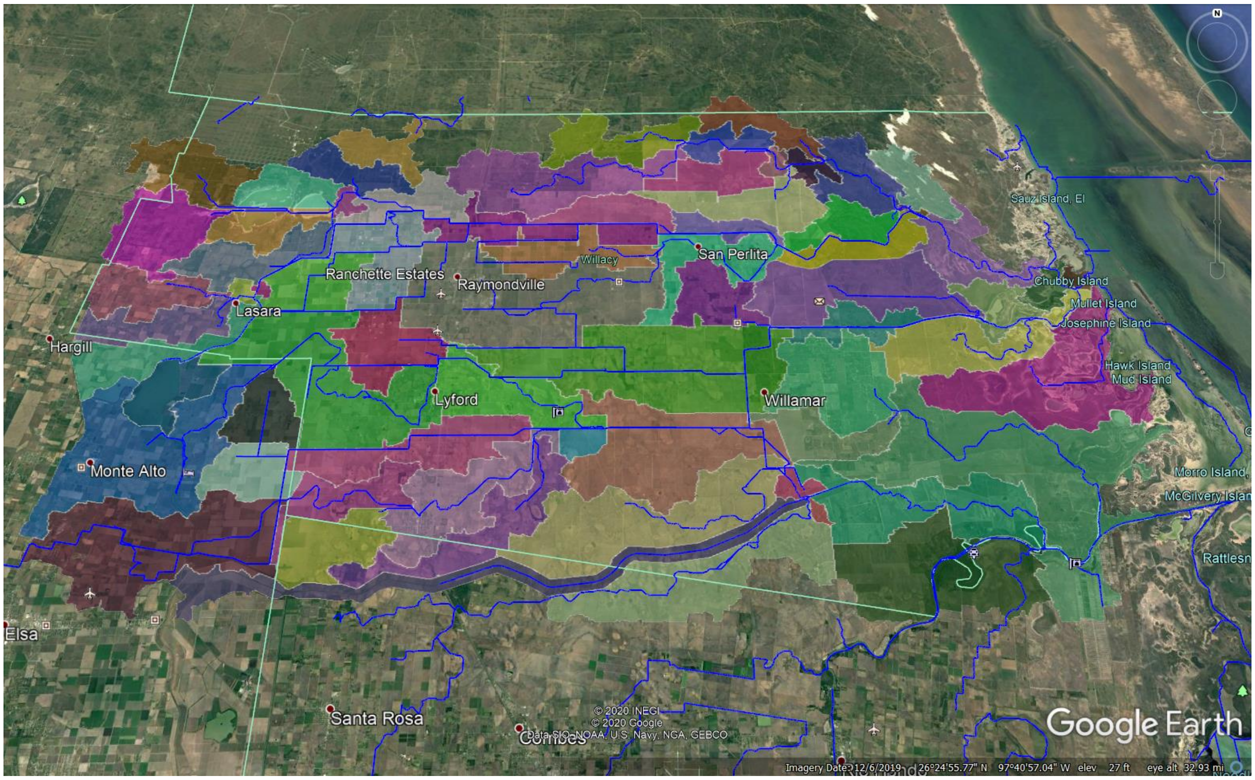


Figure 23. Willacy County sub-basin watershed and major drain channels

Table 6. Cameron County sub-basin watersheds and drainages

Sub-basin	**Area (mi^2)**	**Drainage**
CC-C	39.55	Brownsville drainage
CC_H	38.7	Brownsville drainage
CC_K	29.05	Brownsville drainage
CC_J	37.72	Arroyo Colorado drainage
CC_M	19.89	Floodway drainage
CC_E	57.49	Arroyo Colorado drainage
38088	16.94	Brownsville drainage
CC_F	41.99	Floodway drainage
CC_B	37.67	Floodway drainage
41721	19.39	Brownsville drainage
CC_D	43.39	Arroyo Colorado drainage
CC_O	26.31	Arroyo Colorado drainage
CC_P	26.31	Arroyo Colorado drainage
CC_G	24.49	Floodway drainage
CC_N	16.72	Brownsville drainage
CC_A	57.67	Floodway drainage

Table 7. Willacy County sub-basin watersheds and drainages

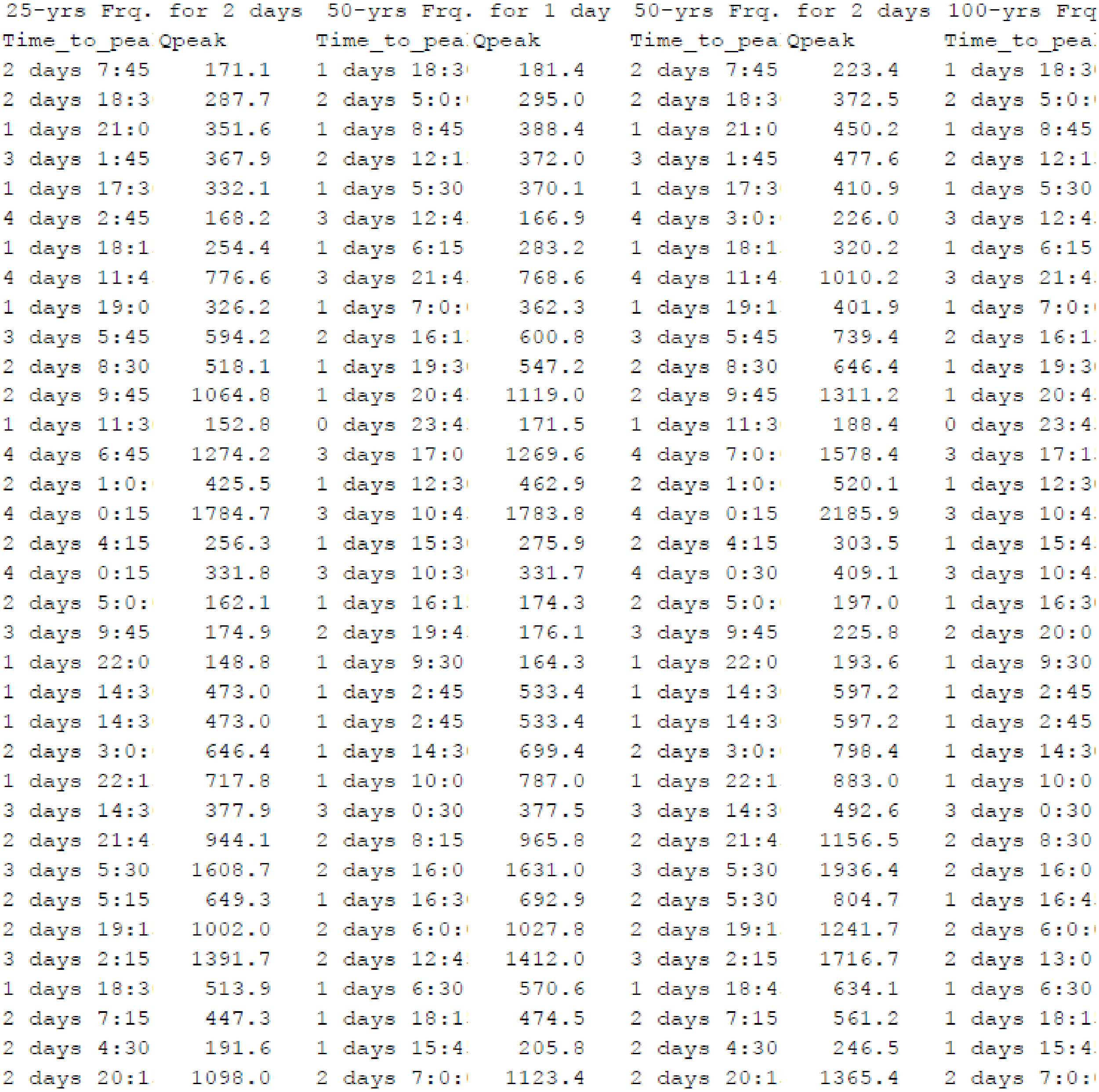
Sub-basins	**Area (mi^2)**	**Drainage**
Basin-H	8.41	Raymondville Drainage
Basin-B	8.31	Raymondville Drainage
Basin A	7.60	Raymondville Drainage
Basin-E	5.53	Raymondville Drainage
Basin-C	5.38	Raymondville Drainage
Basin-D	4.95	Raymondville Drainage
Basin-J	4.47	Raymondville Drainage
Basin-K	4.14	Raymondville Drainage
Basin-N'	7.21	Raymondville Drainage

Basin-M	7.21	Raymondville Drainage
Basin-L	4.51	Raymondville Drainage
Basin-S	51.55	Raymondville Drainage
Basin-T	15.83	Raymondville Drainage
Basin-W	8.33	Raymondville Drainage
Basin-Z	39.60	Raymondville Drainage
Basin-X	13.24	Raymondville Drainage
Basin-Y	6.86	Raymondville Drainage
Basin-C1	25.14	Raymondville Drainage
Basin-B1	23.19	Raymondville Drainage
Basin-G1	84.10	Hidalgo Main Drainage
Basin-D1	81.32	Raymondville Drainage
Basin-V	52.90	Hidalgo Main Drainage
Basin-A1	15.33	Hidalgo Main Drainage
Basin-U	35.11	Hidalgo Main Drainage
Basin-R	32.03	Hidalgo Main Drainage
Basin-F	15.19	Hidalgo Main Drainage
Basin-G	1.82	Hidalgo Main Drainage
Basin-K1	15.48	Hidalgo Main Drainage
Basin-O	14.33	Hidalgo Main Drainage
Basin-P	12.71	Hidalgo Main Drainage
Basin-H1	92.78	Floodway Drainage
Basin-F1	27.11	Floodway Drainage
Basin-E1	29.34	Floodway Drainage
Basin-J1	20.86	Floodway Drainage
Basin-Q	31.69	Floodway Drainage

These watershed models were executed hydrologic computations with hypothetical storm events of a matrix of five frequency storm events (10, 25, 50, 100, and 500-year) and two precipitation durations (1-day and 2-day). The Precipitation Frequency Data Server (PFDS) https://hdsc.nws.noaa.gov/hdsc/pfds/ developed by Hydrometeorological Design Studies Center, NOAA National Weather Service was adopted for the frequency rainfall depths per duration.

As results, a total of 510 sets of design flowrates, peak discharge and time were computed. Tables 8 shows a part of computation results (25-, 50-, and 100- frequency year storm) of peak discharge and time of the Willacy County watersheds. Figure 24 shows the computed hydrographs of each sub-basin of the Cameron County watershed for the 100-year frequency of 1-day storm duration. A full computation results are attached in Appendix I.

Table 8. Computed peak discharge and time of the Willacy County watershed



25-yrs Frq. for 2 days		50-yrs Frq. for 1 day		50-yrs Frq. for 2 days		100-yrs Frq
Time_to_pea	Qpeak	Time_to_pea	Qpeak	Time_to_pea	Qpeak	Time_to_pea
2 days 7:45	171.1	1 days 18:3	181.4	2 days 7:45	223.4	1 days 18:3
2 days 18:3	287.7	2 days 5:0:	295.0	2 days 18:3	372.5	2 days 5:0:
1 days 21:0	351.6	1 days 8:45	388.4	1 days 21:0	450.2	1 days 8:45
3 days 1:45	367.9	2 days 12:1	372.0	3 days 1:45	477.6	2 days 12:1
1 days 17:3	332.1	1 days 5:30	370.1	1 days 17:3	410.9	1 days 5:30
4 days 2:45	168.2	3 days 12:4	166.9	4 days 3:0:	226.0	3 days 12:4
1 days 18:1	254.4	1 days 6:15	283.2	1 days 18:1	320.2	1 days 6:15
4 days 11:4	776.6	3 days 21:4	768.6	4 days 11:4	1010.2	3 days 21:4
1 days 19:0	326.2	1 days 7:0:	362.3	1 days 19:1	401.9	1 days 7:0:
3 days 5:45	594.2	2 days 16:1	600.8	3 days 5:45	739.4	2 days 16:1
2 days 8:30	518.1	1 days 19:3	547.2	2 days 8:30	646.4	1 days 19:3
2 days 9:45	1064.8	1 days 20:4	1119.0	2 days 9:45	1311.2	1 days 20:4
1 days 11:3	152.8	0 days 23:4	171.5	1 days 11:3	188.4	0 days 23:4
4 days 6:45	1274.2	3 days 17:0	1269.6	4 days 7:0:	1578.4	3 days 17:1
2 days 1:0:	425.5	1 days 12:3	462.9	2 days 1:0:	520.1	1 days 12:3
4 days 0:15	1784.7	3 days 10:4	1783.8	4 days 0:15	2185.9	3 days 10:4
2 days 4:15	256.3	1 days 15:3	275.9	2 days 4:15	303.5	1 days 15:4
4 days 0:15	331.8	3 days 10:3	331.7	4 days 0:30	409.1	3 days 10:4
2 days 5:0:	162.1	1 days 16:1	174.3	2 days 5:0:	197.0	1 days 16:3
3 days 9:45	174.9	2 days 19:4	176.1	3 days 9:45	225.8	2 days 20:0
1 days 22:0	148.8	1 days 9:30	164.3	1 days 22:0	193.6	1 days 9:30
1 days 14:3	473.0	1 days 2:45	533.4	1 days 14:3	597.2	1 days 2:45
1 days 14:3	473.0	1 days 2:45	533.4	1 days 14:3	597.2	1 days 2:45
2 days 3:0:	646.4	1 days 14:3	699.4	2 days 3:0:	798.4	1 days 14:3
1 days 22:1	717.8	1 days 10:0	787.0	1 days 22:1	883.0	1 days 10:0
3 days 14:3	377.9	3 days 0:30	377.5	3 days 14:3	492.6	3 days 0:30
2 days 21:4	944.1	2 days 8:15	965.8	2 days 21:4	1156.5	2 days 8:30
3 days 5:30	1608.7	2 days 16:0	1631.0	3 days 5:30	1936.4	2 days 16:0
2 days 5:15	649.3	1 days 16:3	692.9	2 days 5:30	804.7	1 days 16:4
2 days 19:1	1002.0	2 days 6:0:	1027.8	2 days 19:1	1241.7	2 days 6:0:
3 days 2:15	1391.7	2 days 12:4	1412.0	3 days 2:15	1716.7	2 days 13:0
1 days 18:3	513.9	1 days 6:30	570.6	1 days 18:4	634.1	1 days 6:30
2 days 7:15	447.3	1 days 18:1	474.5	2 days 7:15	561.2	1 days 18:1
2 days 4:30	191.6	1 days 15:4	205.8	2 days 4:30	246.5	1 days 15:4
2 days 20:1	1098.0	2 days 7:0:	1123.4	2 days 20:1	1365.4	2 days 7:0:

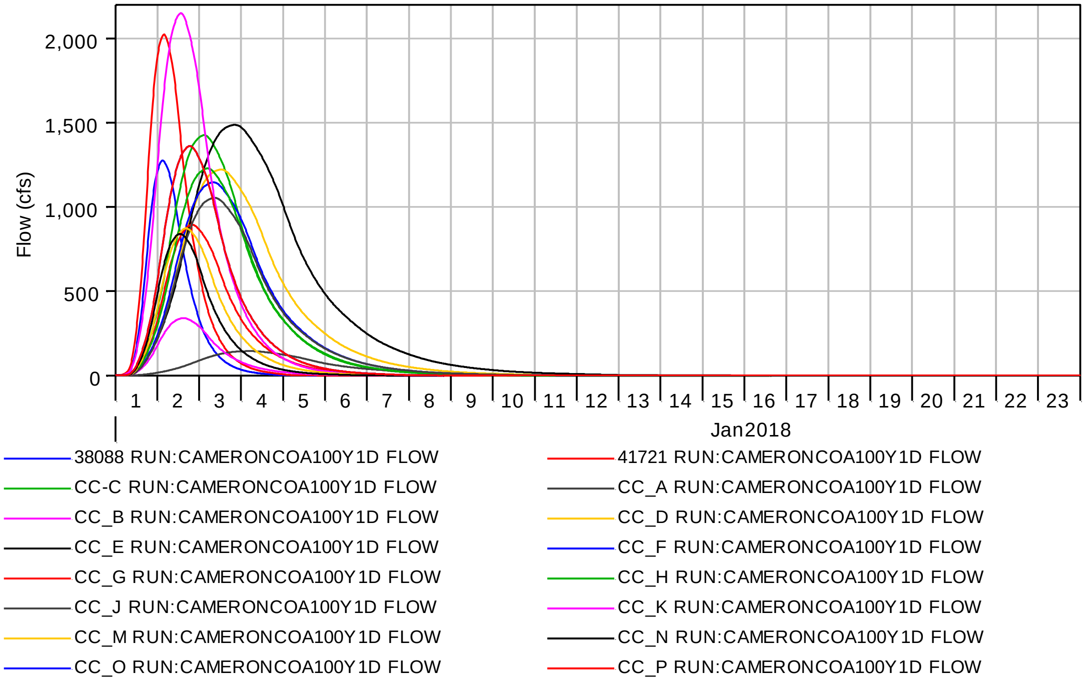


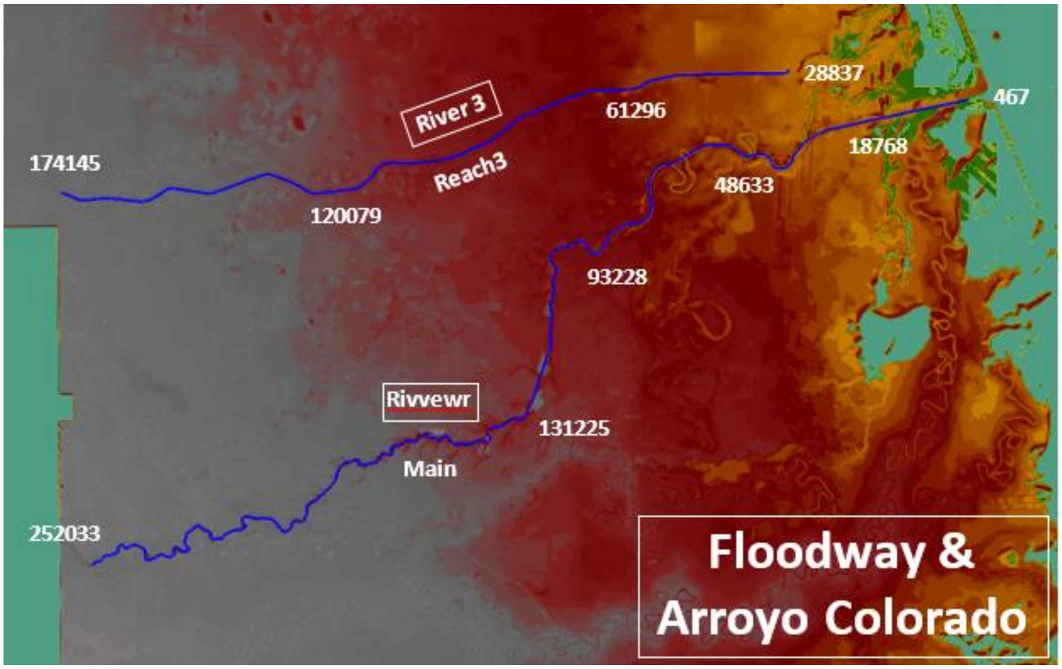
Figure 24. Cameron County hydrographs due to 100-year frequency storm 1-day duration

3.2 Watershed Flood Model

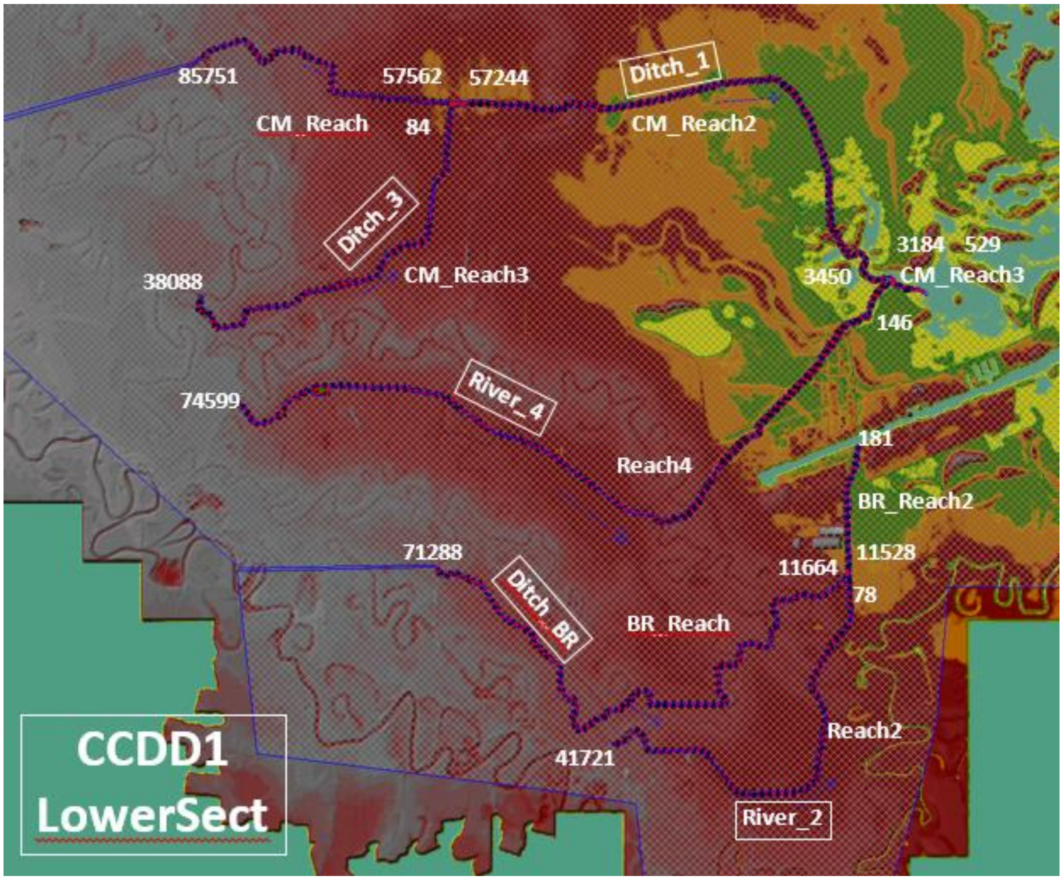
HEC-RAS (Hydrologic Engineering Center River Analysis System) flood routing model was adopted to predict watershed inundation due to excessive channel flow, estimated by the HEC-HMS model. Using the 2-dimensional unsteady flood routing analysis and the RAS Mapper module, lateral inundation boundaries and its flood depths were computed and visualized. HEC-RAS computes the hydraulics of water flow through natural rivers and other artificial waterways using one-dimensional viscous energy equation and momentum equations for hydraulic infrastructure modeling, where the water surface profile is rapidly varied. For unsteady flow, HEC-RAS solves the one-dimensional Saint-Venant equation using an implicit, finite difference method. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities. The program was developed by the United State Army Corps of Engineers (USACE, https://www.hec.usace.army.mil/software/hec-ras/) in order to manage the rivers, harbors, and other public works under their jurisdiction. As described in Introduction of this report, most governmental agencies of the Rio Grande Valley such as Drainage Districts and Cities adopt HEC-RAS program for jurisdiction their stormwater master plan due to its wide applicability and excellent performances.

3.2.1 Drain Network Implementation

The Cameron County watershed geometry is composed of three major drain channels: Brownsville Ship Channel; Arroyo Colorado, and North Floodway. These channels were modeled by five rivers in HEC-RAS geometry. Ditch_BR river is composed of three reaches covering the Cameron County Drainage District 1 jurisdiction over the Brownsville area as shown in Figure 25. The channel is merged to the River_2 channel and discharges to the Brownsville Ship Channel. The River_4 covers the north side of the Brownsville area and merged with the Ditch_1 river at the north of the Brownsville Ship Channel. Ditch_3 is also merged into Ditch_1 at the river station 84. The upstream river from the station is called CM_Reach, while downstream part is CM_Reach2.



(a) North Floodway and Arroyo Colorado drain canal



(b) Cameron County Drainage District 1 and City of Brownsville watershed

Figure 25. Cameron County drain networks modeled in HEC-RAS watershed flood model

The Willacy County watershed geometry is composed of two major drain channels: Hidalgo Main and Raymondville Floodway as shown in Figure 26. We modeled the channels in the HEC-RAS geometry as 13 rivers and 24 reaches. Table 9 lists the Willacy County watershed model drain network and station numbers.

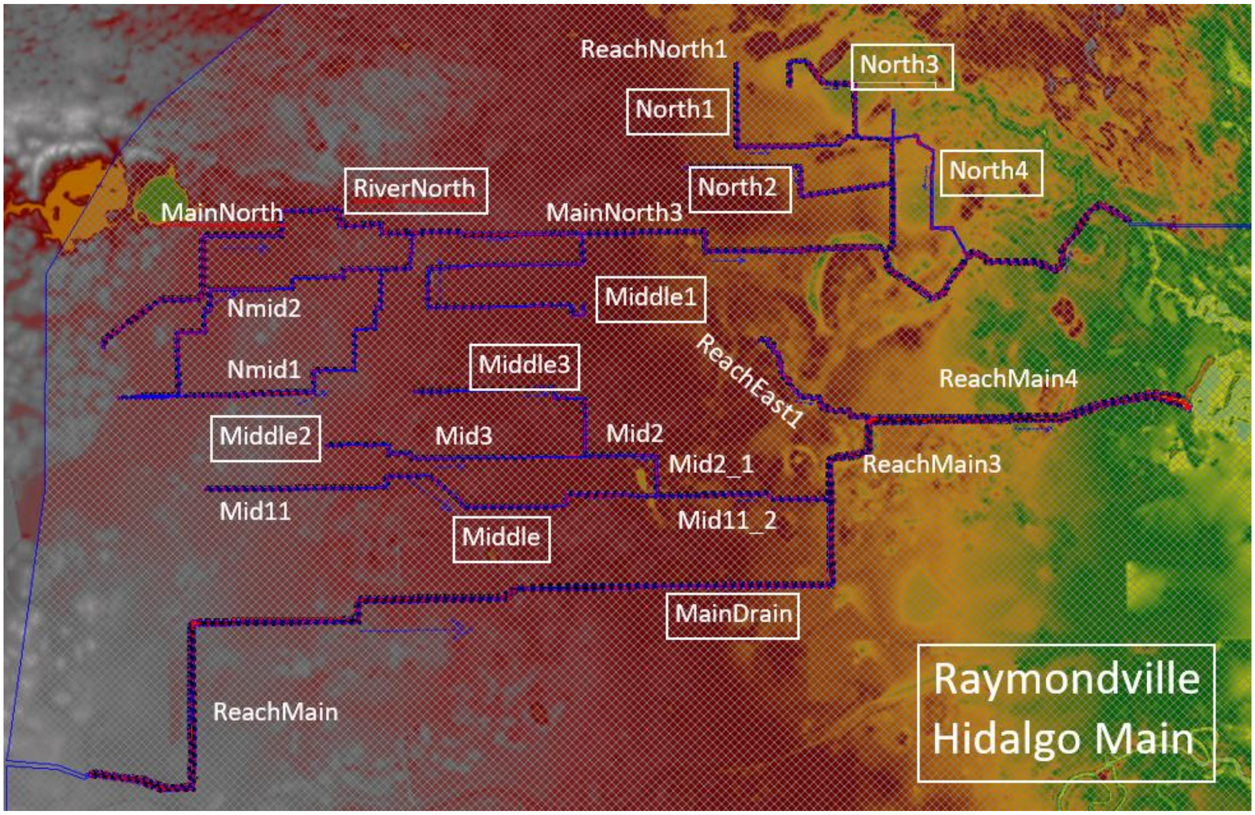


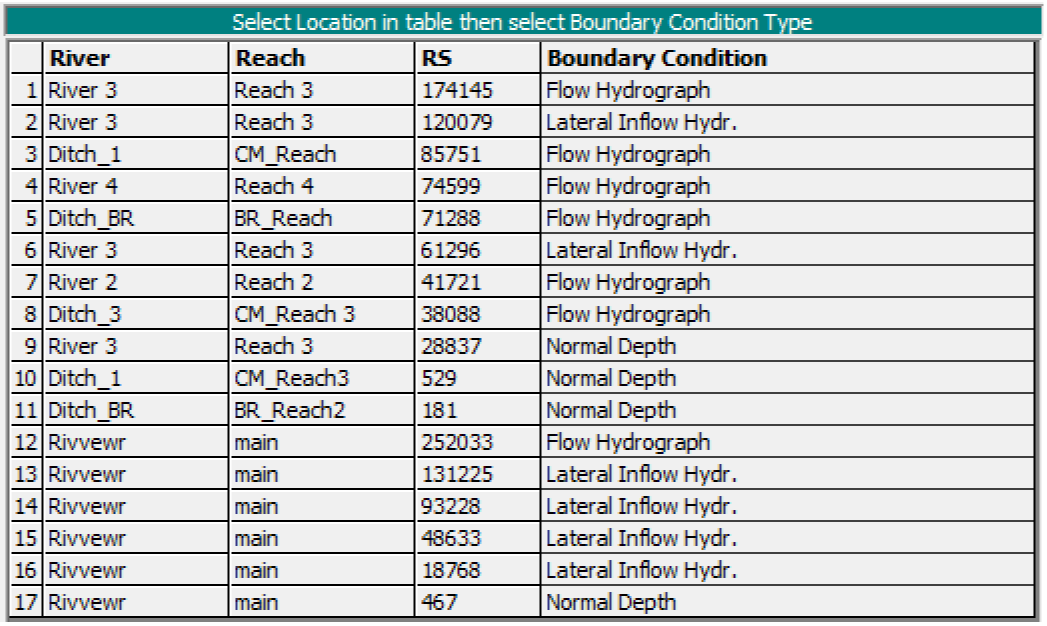
Figure 26. Willacy County drain networks modeled in HEC-RAS watershed flood model

Table 9. Willacy County drain network and river stations modeled

River	Reach	Upstream Station	Downstream Station
East1	ReachEast1	22300.46	62.94243
MainDrain	ReachMain	186637	56588.04
	ReachMain_3	56146.99	42.785.27
	ReachMain_4	42349.86	264.6717
Middle	Mid11	84860.14	22671.05
	Mid11_2	22403.27	203.771
Middle1	MiddleReach	50406.96	72.77344
Middle2	Mid2	49382.32	14539.7
	Mid2_1	14295.33	96.07199
Middle3	Mid3	30241.98	81.40913
North1	ReachNorth1	46043.58	19889.01
	ReachNorth1_1	19644.27	9506.171
	ReachNorth1_2	9215.449	74.41854
North2	ReachNorth2	30291.68	215.6896
North3	ReachNorth3	19339.07	129.7229
North4	ReachNorth4	26634.36	135.7309
NorthMid	Nmid1	57731.99	8674.765
	Nmid1_1	8320.063	28.4919
NorthMid2	NMid2	46878.42	84.991
RiverNorth	MainNorth	162842.5	107437.3
	MainNorth2	107013.4	85956.74
	MainNorth3	84729.33	43899.59
	MainNorth4	43292.51	27966.28
	MainNorth5	28028.53	167.0538

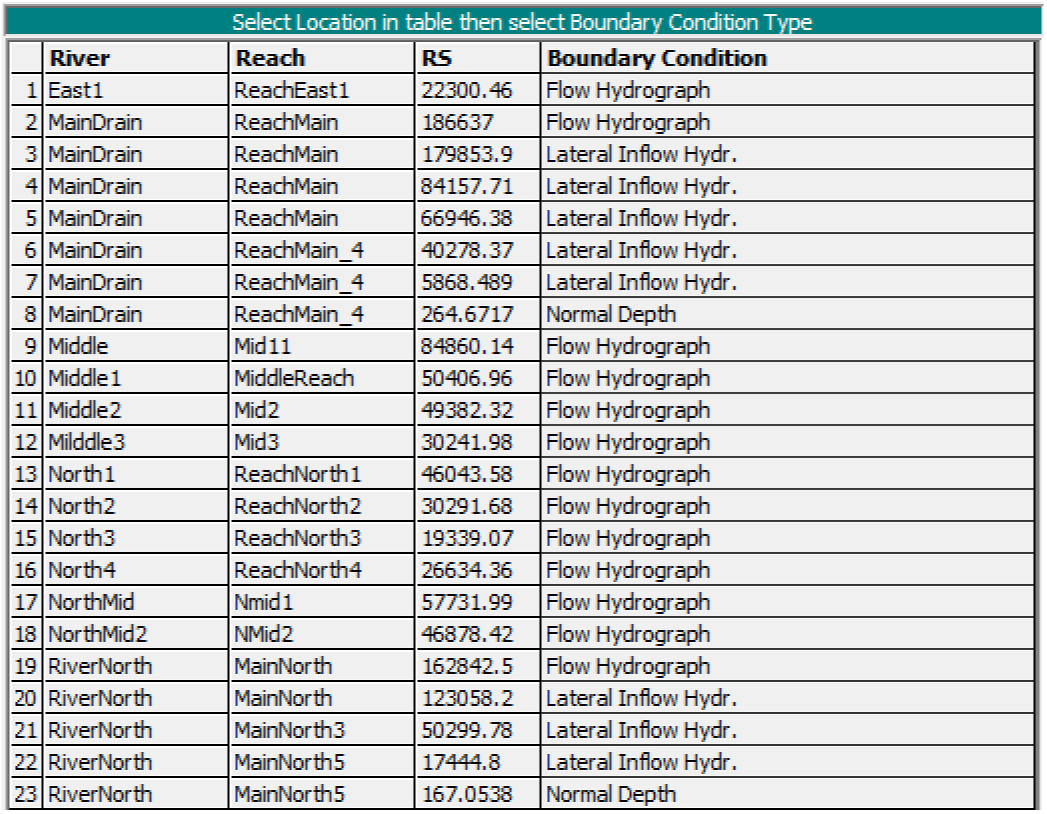
3.2.2 Hydraulic Boundary Conditions

Main hydraulic boundary conditions of the HEC-RAS models were flow hydrograph for the upstream and water depth for the downstream of the channel. In this modeling, the flow hydrograph computation results of HEC-HMS watershed hydrologic model. A normal depth was adopted for the downstream boundary condition. Normal depth is the depth of low in a channel when the slope of the water surface and channel bottom is the same and the water depth remains constant. It occurs when gravitational force of the water is equal to the friction drag along the channel bottom. A channel bed slope was assigned to the model to replace the energy slope along the channel. Beside the upstream and downstream boundary conditions, the model adopts lateral inflow hydrographs, which are outflow hydrographs of sub-basins connected directly to the channel. Figures 27 and 28 depict all boundary conditions and assigned river stations used for the Cameron and Willacy Counties dynamic state simulations.


Select Location in table then select Boundary Condition Type

	River	Reach	RS	Boundary Condition
1	River 3	Reach 3	174145	Flow Hydrograph
2	River 3	Reach 3	120079	Lateral Inflow Hydr.
3	Ditch_1	CM_Reach	85751	Flow Hydrograph
4	River 4	Reach 4	74599	Flow Hydrograph
5	Ditch_BR	BR_Reach	71288	Flow Hydrograph
6	River 3	Reach 3	61296	Lateral Inflow Hydr.
7	River 2	Reach 2	41721	Flow Hydrograph
8	Ditch_3	CM_Reach 3	38088	Flow Hydrograph
9	River 3	Reach 3	28837	Normal Depth
10	Ditch_1	CM_Reach3	529	Normal Depth
11	Ditch_BR	BR_Reach2	181	Normal Depth
12	Rivvewr	main	252033	Flow Hydrograph
13	Rivvewr	main	131225	Lateral Inflow Hydr.
14	Rivvewr	main	93228	Lateral Inflow Hydr.
15	Rivvewr	main	48633	Lateral Inflow Hydr.
16	Rivvewr	main	18768	Lateral Inflow Hydr.
17	Rivvewr	main	467	Normal Depth

Figure 27. Boundary condition used for the Cameron County HEC-RAS model simulation


Select Location in table then select Boundary Condition Type

	River	Reach	RS	Boundary Condition
1	East1	ReachEast1	22300.46	Flow Hydrograph
2	MainDrain	ReachMain	186637	Flow Hydrograph
3	MainDrain	ReachMain	179853.9	Lateral Inflow Hydr.
4	MainDrain	ReachMain	84157.71	Lateral Inflow Hydr.
5	MainDrain	ReachMain	66946.38	Lateral Inflow Hydr.
6	MainDrain	ReachMain_4	40278.37	Lateral Inflow Hydr.
7	MainDrain	ReachMain_4	5868.489	Lateral Inflow Hydr.
8	MainDrain	ReachMain_4	264.6717	Normal Depth
9	Middle	Mid11	84860.14	Flow Hydrograph
10	Middle1	MiddleReach	50406.96	Flow Hydrograph
11	Middle2	Mid2	49382.32	Flow Hydrograph
12	Milddle3	Mid3	30241.98	Flow Hydrograph
13	North1	ReachNorth1	46043.58	Flow Hydrograph
14	North2	ReachNorth2	30291.68	Flow Hydrograph
15	North3	ReachNorth3	19339.07	Flow Hydrograph
16	North4	ReachNorth4	26634.36	Flow Hydrograph
17	NorthMid	Nmid1	57731.99	Flow Hydrograph
18	NorthMid2	NMid2	46878.42	Flow Hydrograph
19	RiverNorth	MainNorth	162842.5	Flow Hydrograph
20	RiverNorth	MainNorth	123058.2	Lateral Inflow Hydr.
21	RiverNorth	MainNorth3	50299.78	Lateral Inflow Hydr.
22	RiverNorth	MainNorth5	17444.8	Lateral Inflow Hydr.
23	RiverNorth	MainNorth5	167.0538	Normal Depth

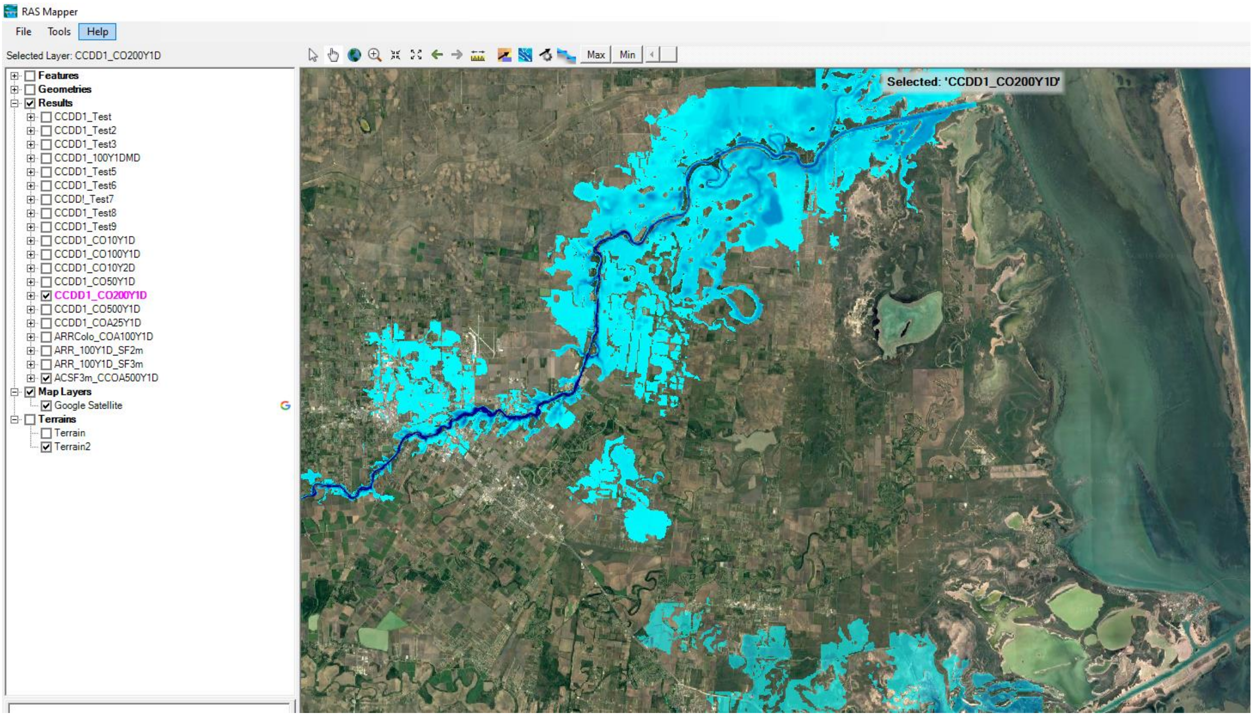
Figure 28. Boundary condition used for the Willacy County HEC-RAS model simulation

HEC-RAS is compatible with different types of input. The most feasible way to input data in this system is using a special database file created by The U.S. Army Corps of Engineers for its use with HEC-RAS and other HEC software. The name of the file type is Database Storage System (DSS) [24]. This file is designed to be used by HEC-RAS and in our assessment, it is the best vector for automated input. The HEC-HMS modeling outputs were stored and adopted in the HEC-RAS model as input data.

3.2.3 Two-Dimensional HEC-RAS Model

Two-dimensional hydrodynamic modeling enables combined 1-D channel/floodplains with 2-D flow areas behind levees. This suits the watershed flood modeling objective. 2-D flow modeling is accomplished by adding 2-D flow area elements into the model in the same manner as adding a storage area. A 2-D flow area is added by drawing a 2-D flow area polygon, developing the 2-D computational mesh, then linking the 2-D flow areas to 1-D model elements [25].

A terrain model was developed by using HEC-RAS Mapper for detailed 2-D hydraulic computations and result visualization. In this study, NAD 1983 State Plane was selected for spatial reference projection. RAS Mapper was also used for visualization of computation results, time series plots, generation of map layers, such as depth of water, water surface elevation, inundation boundary. Figure 29 shows an image copy of RAS Mapper program in application of Cameron County modeling.



Selected Layer: CCDD1_CO200Y1D

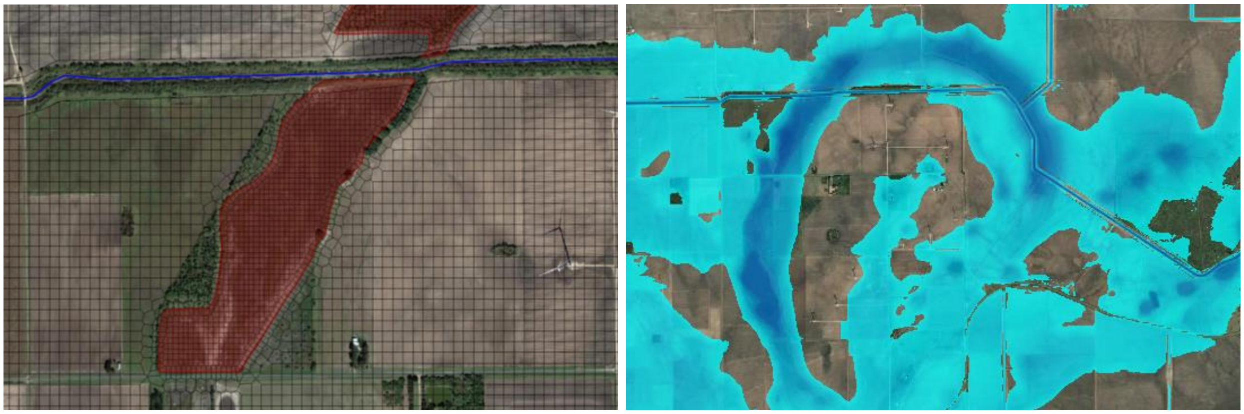
- ☐ Features
- ☐ Geometries
- ☑ Results
  - ☐ CCDD1_Test
  - ☐ CCDD1_Test2
  - ☐ CCDD1_Test3
  - ☐ CCDD1_100Y1DMD
  - ☐ CCDD1_Test5
  - ☐ CCDD1_Test6
  - ☐ CCDD!_Test7
  - ☐ CCDD1_Test8
  - ☐ CCDD1_Test9
  - ☐ CCDD1_CO10Y1D
  - ☐ CCDD1_CO100Y1D
  - ☐ CCDD1_CO10Y2D
  - ☐ CCDD1_CO50Y1D
  - ☑ CCDD1_CO200Y1D
  - ☐ CCDD1_CO500Y1D
  - ☐ CCDD1_COA25Y1D
  - ☐ ARRColo_COA100Y1D
  - ☐ ARR_100Y1D_SF2m
  - ☐ ARR_100Y1D_SF3m
  - ☑ ACSF3m_CCOA500Y1D
- ☑ Map Layers
  - ☑ Google Satellite
- ☐ Terrains
  - ☐ Terrain
  - ☑ Terrain2

Figure 29. RAS Mapper application in 2-D computational results displaying

3.2.4 HEC-RAS 2-D Mesh Refinement

Mesh refinement is an important process for editing finite volume meshes, which is adopted in HEC-RAS 2-D model, in order to increase the accuracy of the solution. A 100 ft by 100 ft cells nominal grid resolution was used to develop an initial mesh build up for the 2-D flow computational mesh. Mesh refinement was conducted by creating break lines and refinement regions of the mesh editing tools. Willacy County HEC-RAS model 2-D mesh refinement was completed to increase computation stability by making finer meshes on flow areas where computational result varies rapidly such as oxbow lakes and shallow channels. Figure 30 shows examples of mesh refinement process and computational results of the oxbow lake near storm drain canal in Willacy County.

(a) Oxbow lake near drain canal **(b) Preliminary mesh**



(c) Refined mesh **(d) Refined mesh computation results**

Figure 30. Two-dimensional mesh refinement: Oxbow lake near drain canal, Willacy County

3.3 Hypothetical Storms Inundation Boundary

To ensure the model computational stability, only one major drain channel of the entire HEC-RAS flood model was simulated at a time. Three and two major drain channels were developed for the Cameron County and Willacy County HEC-RAS model, respectively. Total computational runs were 50 with a matrix of 5 geometries (channel) by 10 hypothetical storms (inland rainfalls). Computational results from each major channel were compiled for displaying the LLM watershed coastal inundation maps (50 maps). Each computation took approximately 1.5 days depending on the scenario size. Figure 31 shows the HEC-RAS simulation results of the five major drain channels over the two Counties for 100-year frequency storm of 1-day rainfall duration.

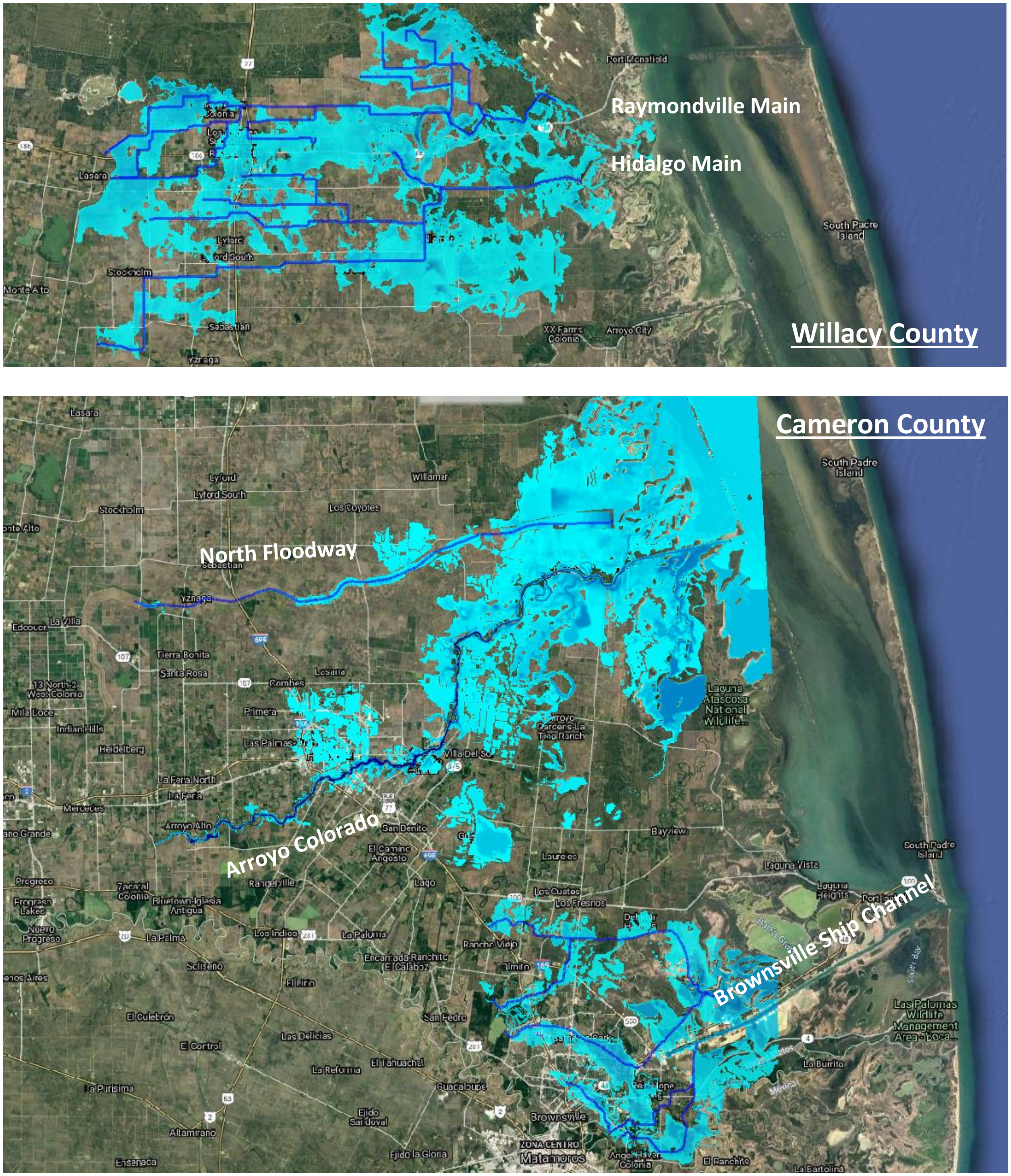


Figure 31. HEC-RAS model simulation results of the five major drain channels for the 100-year frequency storm for 1-day duration

4. COASTAL WATERSHED FLOOD MAPS DEVELOPMENT

South Texas coastal watershed flood maps development is a major goal of this project. This chapter reports the hurricane storm surge model coupling with the 2-D HEC-RAS watershed flood model to produce the watershed flood maps due to hypothetical storm events as well as hurricane storm surge along the coast. We completed 50 modeling scenarios computations using the calibrated coupled model. With the computation results, we created the comprehensive flood maps using GIS. This processing allows an interpolation between the raster surface terrain and the predicted surge height to create the possible inundated grids over the area.

4.1 ADCIRC Coupling/Automation with HEC-RAS Model

This comprehensive coastal watershed flood model is the last model to be executed in the pipeline of events as seen on **Error! Reference source not found.**. This model will execute automatically after a successful run of ADCIRC. HEC-RAS utilizes the water surface elevation output from ADCIRC as a stage hydrograph to initialize the model and to read input at every time step. HEC-RAS can only be executed in a Windows operating system. This adds a layer of complexity to the communication between the models. Having two different operating systems implies the creation of a communication framework for the computers and models.

HEC-RAS users can interact with the model through a Graphical User Interface (GUI) that ships with every installation. The GUI for HEC-RAS represents the main and intended way of interacting with HEC-RAS, situation that represents a problem for its automation. A GUI automation can be reliable but requires extensive testing and error handling, a meticulous work for a non-guaranteed success. It is for this reason that the GUI automation was downgraded to a last resource, and an alternative was researched. In the search of an alternative to the automation of HEC-RAS another method to interact with the model was found. There exists a programmatic way of communicating effectively with HEC-RAS. The logic behind the Python scripts developed to control HEC-RAS can be seen on Figure 32 below.

```
Routine 3: HEC-RAS Automation Routine
eventid ← Unique ID created for ADCIRC is used for the simulation in HEC-RAS
Function prepare_input(eventid):
    if extract_simulation(eventid) is successful then
        Retrieve extract from directory of eventid
        inputdss ← DSS file created that will contain information from extract file
        foreach node ∈ extract do
            Create a DSSrecord with appropriate name based on characteristics of the data
            Write DSSrecord in inputdss
        end foreach
        Write inputdss to disk
return

Function execute_RAS(eventid):
    if inputdss exists then
        HECRASController ← Initialize variable containing an instance of COM that controls RAS
        Use HECRASController to spawn a HEC-RAS project
        Execute HEC-RAS project using inputdss for eventid
        Wait for completion of execution and report return code
return

Function extract_RAS_output(eventid):
    if Return code of RAS simulation with eventid == 0 then
        floodmap ← Output flood map created by RASMapper in a successful execution
        Safely store floodmap classified under eventid name
return
```

Figure 32. Pseudocode representing the Python script developed for the automation of HEC-RAS

4.1.1 Input Data Sharing with HEC-RAS Model

In the ADCIRC Automation section it is explained that the model output from ADCIRC needs to be processed and the relevant information from specified nodes will be stored in a file. The file produced after processing ADCIRC output will be shared with HEC-RAS to start the Model Input process. The file created by the Model Output Handling process of ADCIRC cannot be directly used by HEC-RAS. A processing step is needed before the HEC-RAS input is possible. The file will be sent to the machine running HEC-RAS and a data conversion process will begin. The logic behind this process can be seen in the method called prepare_input(eventid) in Figure 32.

HEC-RAS is compatible with different types of input. The most feasible way to input data in this system is using a special database file created by The U.S. Army Corps of Engineers for its use with HEC-RAS and other HEC software. The name of the file type is Database Storage System (DSS) [24]. This file is designed to be used by HEC-RAS and in our assessment, it is the best vector for automated input. DSS files are a type of database for data that is mostly sequential in nature. A DSS file contains records that can be read and written by HEC-RAS and other HEC applications. DSS files can be constructed and modified by Python with the help of a library called Pydsstools [26]. Utilizing DSS files and the Pydsstools library can ensure the readability of HEC-RAS input and reduce bugs and problems related with other input alternatives for HEC-RAS. A Python script was developed to handle the automatic creation of a DSS file record to serve as input for HEC-RAS. The script is aimed at creating a set of DSS records that come from ADCIRC's output. The DSS file will be shared with HEC-RAS to initialize and perform its simulation. The library Pydsstools allows to perform Create, Read, Update and Delete (CRUD) operations in a DSS database file without major complications. It is worth noting that Pydsstools is in an early development state and only provides CRUD functionality for the most part, however, the library proved to be adequate for the needs of the forecasting system proposed and no further development for the library is required.

The script responsibility is to read the output produced by ADCIRC for water surface elevations and dump the information into various records in a DSS file. The records that are written into the DSS files specifying the type of information as described in the DSS file documentation. The information coming from ADCIRC's output is written to a DSS file as a stage hydrograph that provides information on water elevation in ft for every hour. A record is made for every different location that is stored in the processed ADCIRC's output. The modified DSS file will be saved to disk and will later be used by HEC-RAS as input.

4.1.2 Coupled Model Execution

In the search of an alternative method to GUI for controlling HEC-RAS it was found that every installation comes with a Component Object Model (COM) called HECRAS Controller. For pragmatic purposes this COM interface can be thought of as an Application Programming Interface (API) that allows the user to communicate with HEC-RAS in a programmatic way. This COM interface provides a set of predefined methods to control certain characteristics of HEC-RAS. It is important to note that not every function of HEC-RAS can be reached with this COM interface, but the functionality it provides covers all the needs of the forecasting system developed. As suggested by [27] a COM interface could be accessed through Visual Basic for Applications (VBA). The first attempt at automating the execution of a HEC-RAS utilized the VBA functionality available in Microsoft Excel. The automation of a HEC-RAS execution proved to be successful, and the COM interface use was adopted as the main methodology for automating HEC-RAS.

In order to create a Python script capable of communicating effectively with the COM interface that HEC-RAS ships with it was necessary to spawn an instance of the COM controller itself. The library Pywin32 [28] for Python provides access to a great part of the WIN32 API, which is a Microsoft Windows API that, among other things, allows for the use of COM objects. Using this library, Python can spawn an instance of HECRAS Controller, therefore it is possible to access HECRAS Controller methods through Python. It was possible to reproduce the first attempt of automating HEC-RAS using only a Python script. Python can load a HEC-RAS project and perform computations, the method execute_RAS(eventid) in

Figure 32 showcases the Python routine for executing the model. HEC-RAS execution is the only use in this system for the HECRAS Controller, other functionality such as output handling was implemented in Python separately.

4.1.3 Model Output Handling

The output that is expected from HEC-RAS is a flooding map. This map is created thanks to a HEC-RAS feature called RAS Mapper. HECRAS Controller doesn't provide a set of methods for interacting with this mapping functionality, fortunately accessing RAS Mapper is not necessary when performing a forecasting run. This is because HEC-RAS and RAS Mapper can be set to produce flooding maps before running a simulation. The model that is already set up can be reused with new input data to perform another simulation and get another set of flood map. The maps produced by HEC-RAS cannot be directly posted in our delivery website for the public. This step is only responsible of saving the output map into a safe and labeled location to be later pre-processed and uploaded into the delivery website for the public.

4.1.4 Model Output Delivery System

The simulation run generates a forecasted flood map that needs to be distributed to the end users, to accomplish this, an online delivery system was created. The delivery system must be accessible to any device capable of browsing the internet. In the same manner, the delivery system must be lightweight enough to work on slow connections. The characteristics of the delivery system are intended to widen the accessibility of any prospective user trying to reference the flood forecasts.

The forecasted flooding maps produced need to be handled and processed before being posted in the delivery system. This pre-processing step is aimed at extracting shape information out of the raster flooding maps produced by HEC-RAS. The resulting shape information needs to be cleaned and simplified to reduce its size, thereby reducing loading times on slow connections.

The pre-processing step is accomplished using 2 libraries for manipulating geospatial data. The Geospatial Data Abstraction Library (GDAL) [29] is used in conjunction with the JavaScript library called Mapshaper [30]. These libraries allow for the conversion of the original raster into a different geospatial file format. The libraries are also capable of reducing the size of the shape file by eliminating redundant shape information. A script was created to use both libraries and simplify all flooding maps before being posted in the delivery system. The raster files are converted to a GeoJSON format for its display in the interactive web map. GeoJSON is a data format used to represent geographic elements that uses a JavaScript Object Notation (JSON) style formatting. The reason to use a shapefile like GeoJSON is to allow compatibility with future features that require shape information such as the implementation of a routing engine to help users navigate safely around the flood zone.

4.2 Coupled Model Boundary Condition Changes

The Cameron County HEC-RAS model is composed of three major drain channels (Main Floodway, Arroyo Colorado, and Brownsville Ship Channel), which has downstream stations near the Laguna Madre shoreline. The ocean water surface fluctuations due to hurricane storm surges will be adopted as the downstream boundary conditions to the HEC-RAS model to estimate the storm surge impact on the coastal flood. Five different hurricane scenarios were developed. Each of the five hurricane scenarios consist of different categories, and those categories are determined by the Saffir Simpson Scale.

The five representing hurricanes were assigned to ADCIRC model to compute abnormal ocean water surface level changes, which are assigned to Cameron County HEC-RAS model as the downstream boundary conditions. Figures 33, 34, 35, 35, and 37 depict the downstream boundary conditions assigned to the HEC-RAS model for five hurricanes. The coupled indicates downstream boundary condition with hurricane storm surge, while the uncoupled shows the normal tidal level variation without consideration of storm surge.

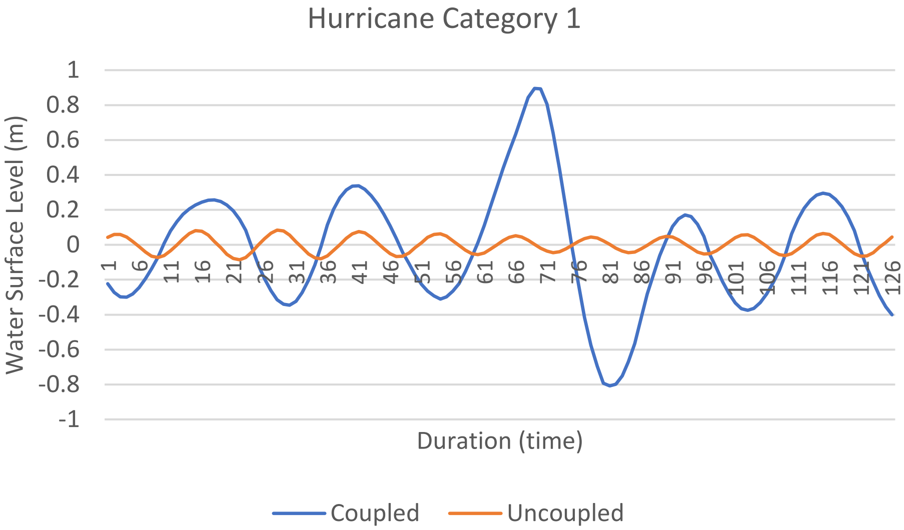


Figure 33. Cameron County HEC-RAS downstream boundary conditions for category 1 hurricane

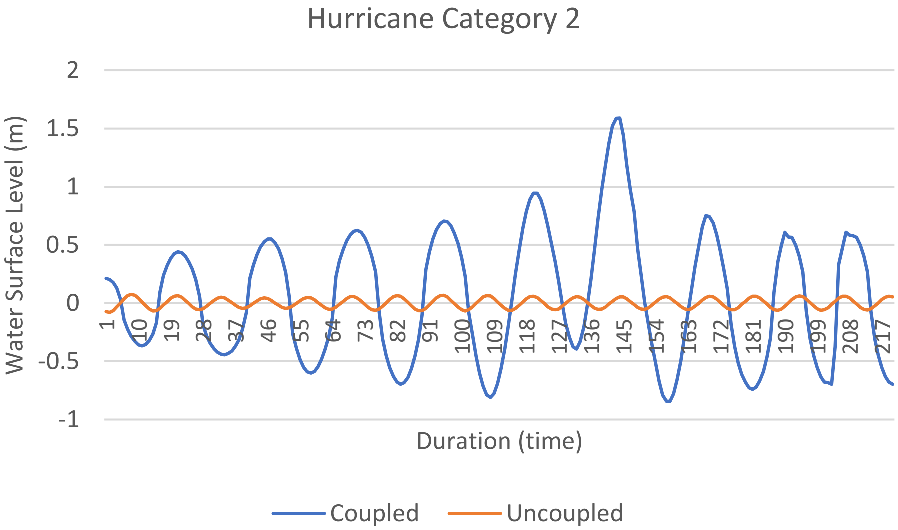


Figure 34. Cameron County HEC-RAS downstream boundary conditions for category 2 hurricane

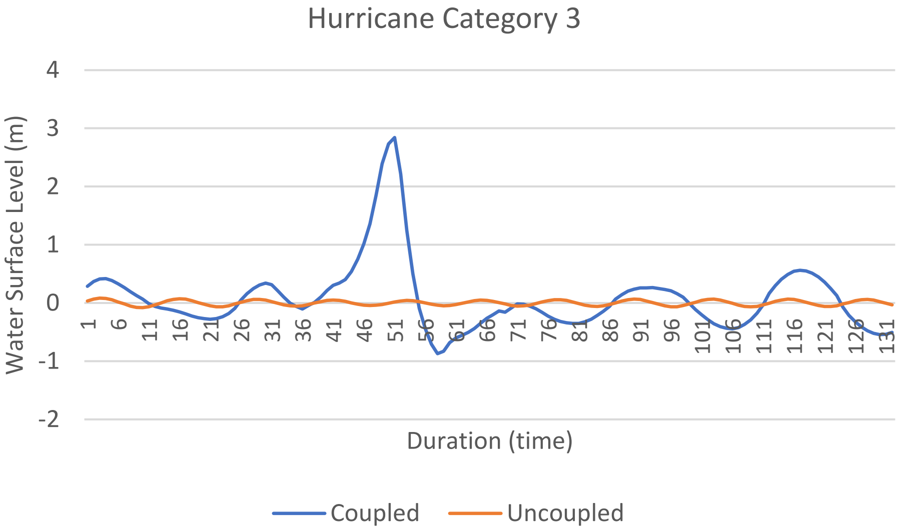


Figure 35. Cameron County HEC-RAS downstream boundary conditions for category 3 hurricane

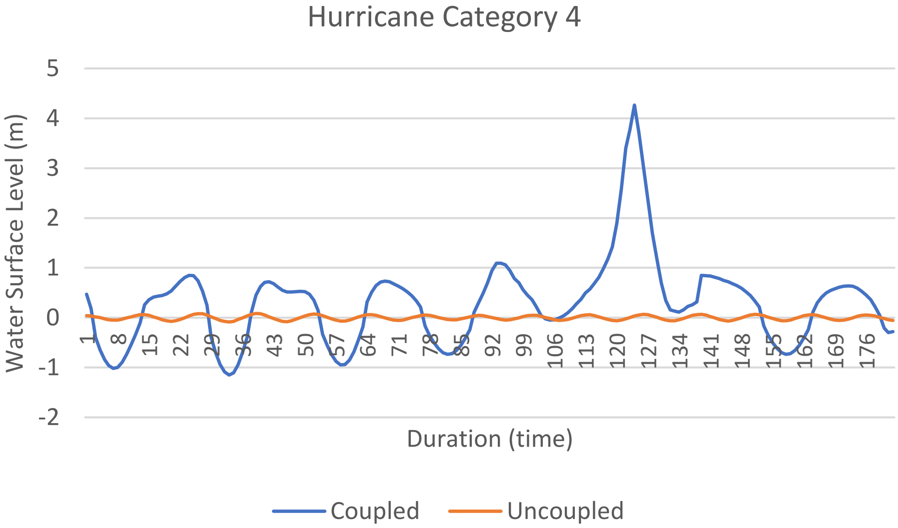


Figure 36. Cameron County HEC-RAS downstream boundary conditions for category 4 hurricane

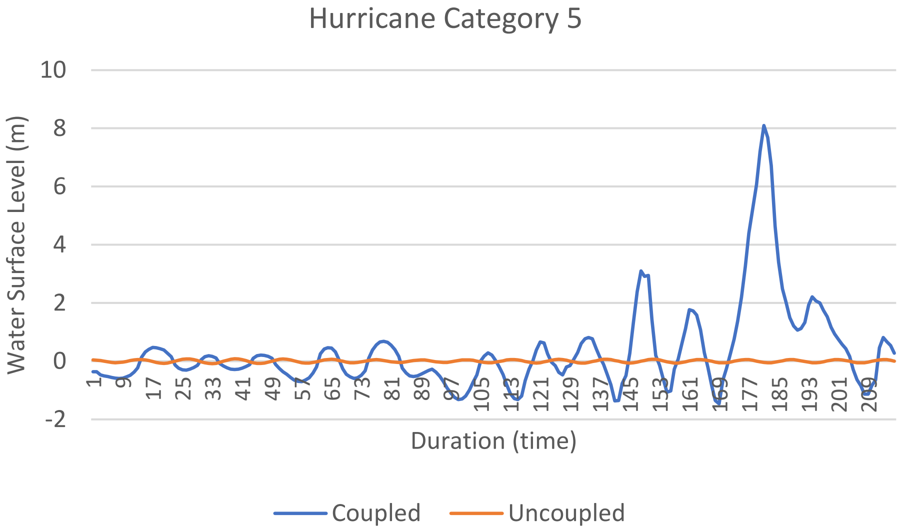


Figure 37. Cameron County HEC-RAS downstream boundary conditions for category 5 hurricane

The Willacy County HEC-RAS model is composed of two major drain channels, which has downstream stations near the Laguna Madre shoreline. The ocean water surface fluctuations due to hurricane storm surges will be adopted as the downstream boundary conditions to the HEC-RAS model to estimate the storm surge impact on the coastal flood. In the same way with the Cameron County, each of the five hurricane scenarios consist of different categories, and those categories are determined by the Saffir Simpson Scale. Figures 38, 39, 40, 41, and 42 depict the downstream boundary conditions assigned to the HEC-RAS model for five hurricanes. The coupled indicates downstream boundary condition with hurricane storm surge, while the uncoupled shows the normal tidal level variation without consideration of storm surge.

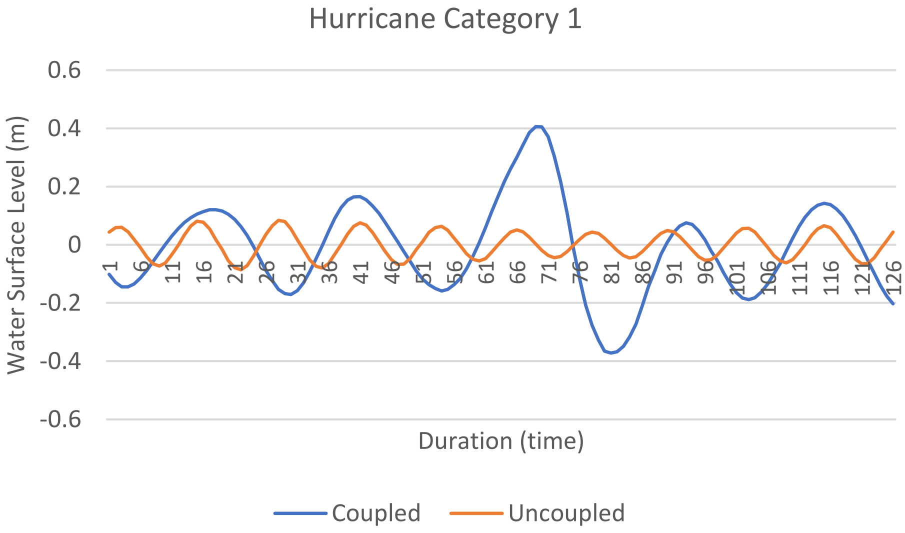


Figure 38. Willacy County HEC-RAS downstream boundary conditions for category 1 hurricane

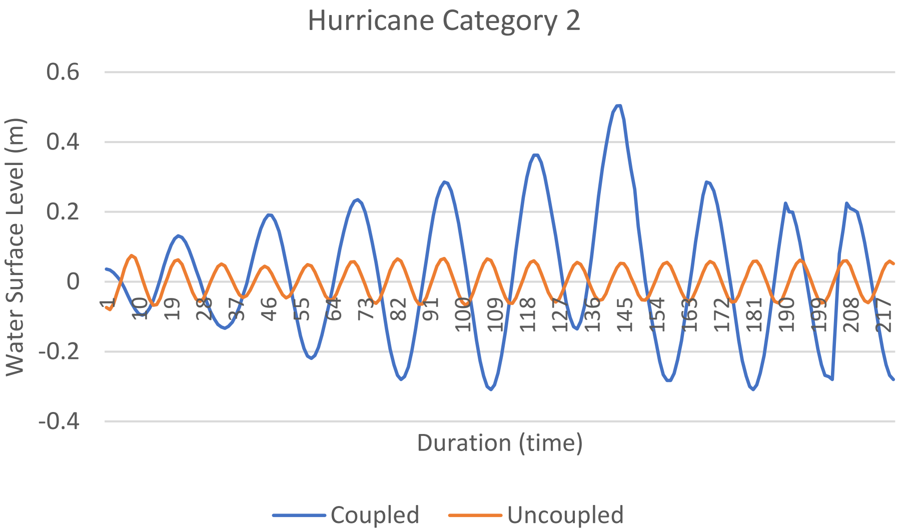


Figure 39. Willacy County HEC-RAS downstream boundary conditions for category 2 hurricane

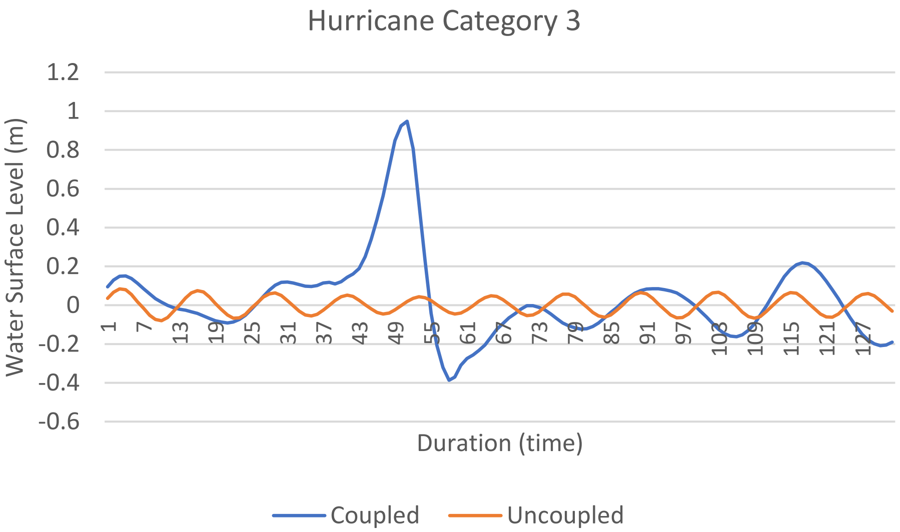


Figure 40. Willacy County HEC-RAS downstream boundary conditions for category 2 hurricane

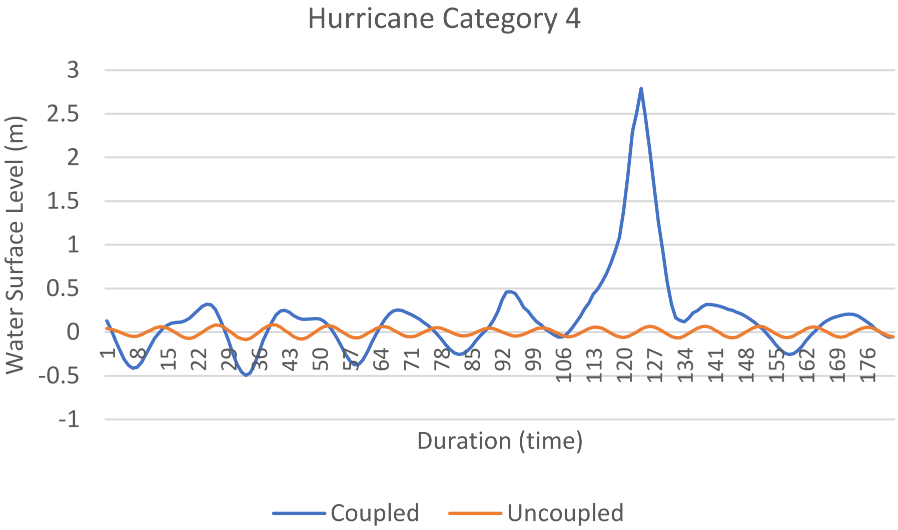


Figure 41. Willacy County HEC-RAS downstream boundary conditions for category 4 hurricane

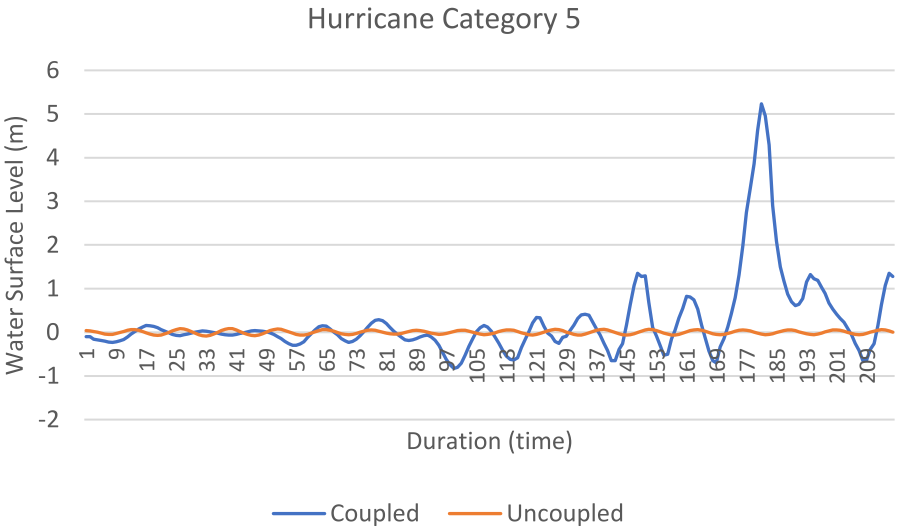


Figure 42. Willacy County HEC-RAS downstream boundary conditions for category 5 hurricane

4.3 A Test Run of ADCIRC-RAS Coupled Model

The costal flood coupled model (ADCIRC and HEC-RAS) was successfully tested for the Willacy County coastal watershed. The coupled model executes automatically after a successful run of ADCIRC model. HEC-RAS utilizes the water surface elevation output from ADCIRC as a stage hydrograph to initialize the model and to read input at every time step. The coastal watershed to be simulated in this test-run belongs to Willacy County, which was modeled in HEC-RAS. For ADCIRC a model of the Gulf of Mexico and the Lower Laguna Madre was used. Figure 43 shows the costal water surface profiles computed by ADCIRC model. This profile was transferred to HEC-RAS model as a DSS file format, which is a databased system designed to efficiently store and retrieve time series data used in HEC program, such as HEC-RAS and HEC-HMS. Figure 44 show differences between un-coupled model computations and the coupled model computations.

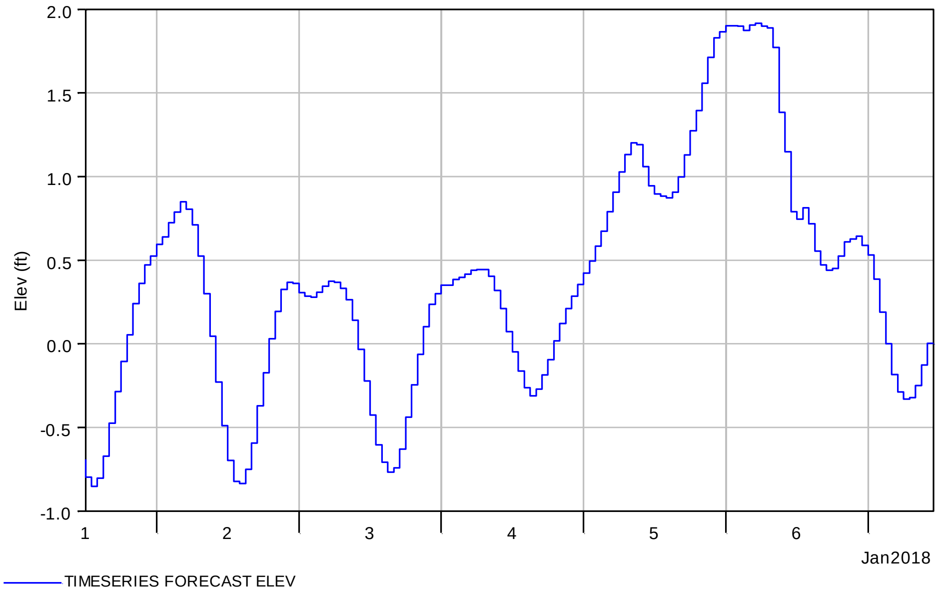


Figure 43. Coupled ADCIRC-RAS model computation result of water surface elevation profile

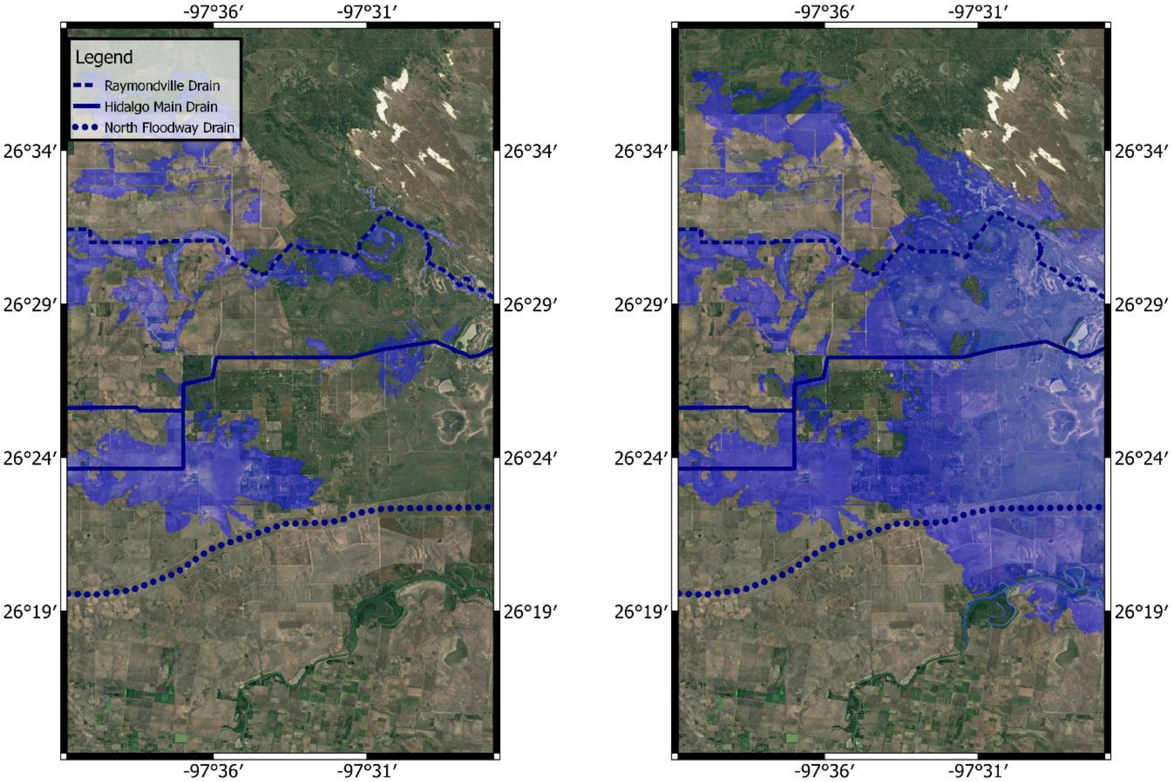


Figure 44. Predicted flood maps over the City of San Perlita, Willacy County. The left-side map shows flooding area computed by the un-coupled model, while the right-side map depicts the coupled model result.

4.4 Computation Result GIS Mapping and Maximum Hypothetical Flood Maps

ArcMap, which is part of the ArcGIS software package was used to showcase the severity of flooding in the Cameron and Willacy County based on the intensity of a possible hurricane or specific storm scenario. Fifty flood maps were developed, showcasing the following storm scenarios: 10 Year frequency storm for 1 and 2 days; 25 Year frequency storm for 1 and 2 days; 50 Year frequency storm for 1 and 2 days; 100 Year frequency storm for 1 and 2 days; and 500 Year frequency storm for 1 and 2 days. These scenarios were then combined with the coastal flooding predictions based on hurricanes of category 1 through 5 to obtain the priorly mentioned number of maps. The maps developed required the use of different geographical sources in order to develop the most accurate elements possible. The sources used were the following:

- Texas Department of Transportation (TxDOT) – Country Boundaries, Evacuation Routes
- U.S. International Boundary and Water Commission – Digital Elevation Models of the specified regions.
- Esri, Gamin, GEBCO, NOAA NGDC, etc. – Global base map.

The mapping process initiated with use of the mosaic tool to unify the raster digital elevation models into a single file which was then modified with the use of the raster calculator tool to showcase the elevation of water in each area according to the hurricane model predictions. This raster file was clipped with the use of the extraction by mask tool to only show the hurricane area water elevations; the mask used was a previously developed shapefile highlighting the contour of the hurricane flooding area. Next, the storm scenario raster TIFF files which showcase the water elevation according to the model simulations were added to the hurricane flooding with the use of the raster calculator tool to highlight the ultimate water elevation. This process was repeated with each storm scenario – hurricane category combination and was concluded with the modification of symbology to denote a clearer and visually pleasing map before exporting into a jpeg and pdf format as shown in Figure 45 below. The entire 50 maps also have been posted in the project website: https://vcore.utrgv.edu/ as well as Appendix III.

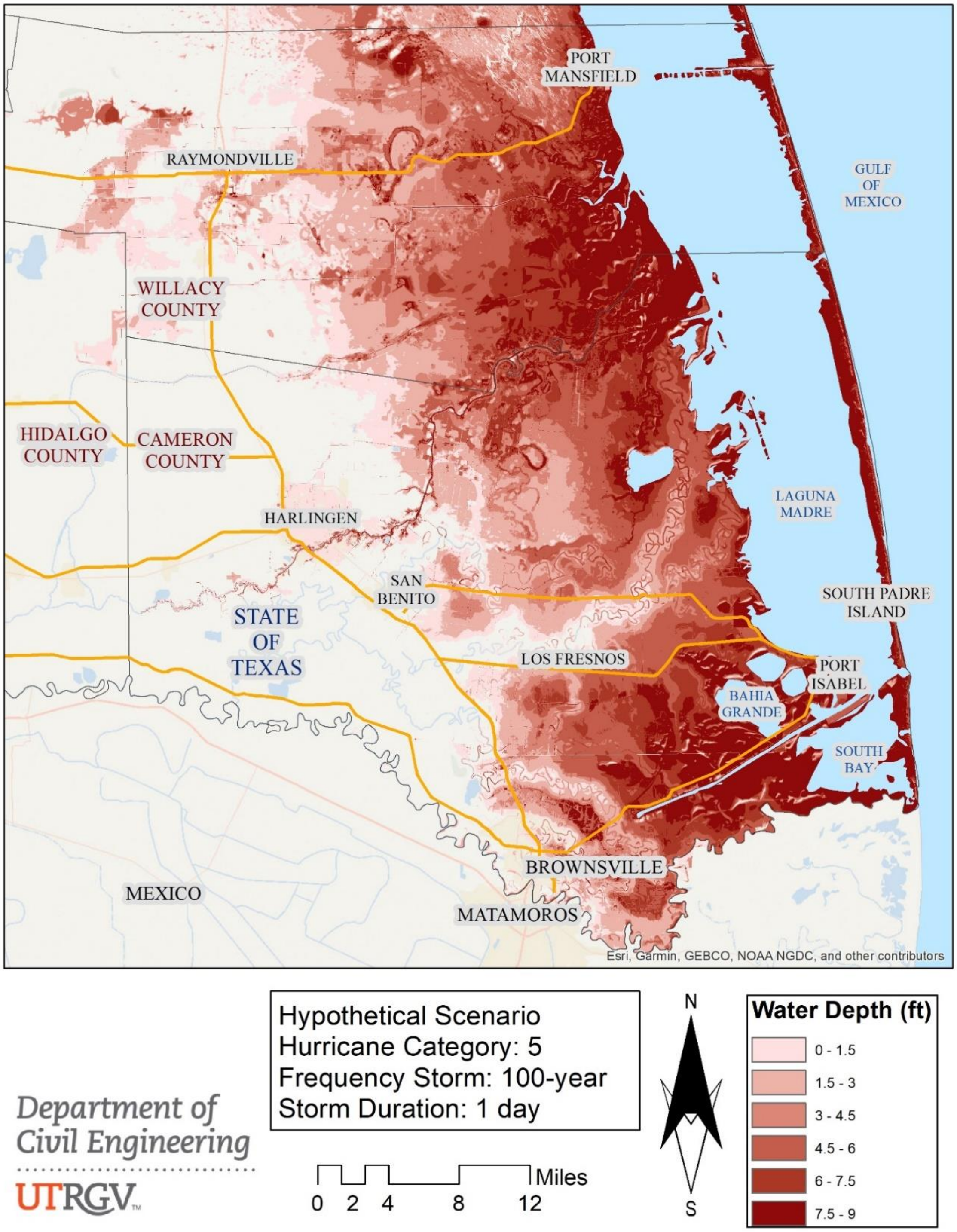


Figure 45. Hypothetical flood map due to 100-year frequency storm for 1-day duration and category 5 hurricne storm surge

5. EMERGENCY EVACUATION ROUTE MODEL DEVELOPMENT

In recent years, the advent of floods has left a noticeable impact in many communities. In just the past two years alone, there have been two major flooding events in the Rio Grande Valley. Both of these events were called “great floods”, with damage estimates up to $100 million. The purpose of this project is to create a web-based tool that will give first responders the ability to navigate flooded areas safely.

In order to achieve the goal of creating the web-based tool, a pipeline capable of rapid processing and visualization of data is required. The beginning of the pipeline will receive the results of a hurricane simulation model as input. Thereafter, the data, which the pipeline has the just received, is then processed on the servers.

Potential water depths and areas with high likelihood of flooding, information on roadway conditions, and existing emergency evacuation routes and shelters were incorporated into the web-based navigation system in the LLM. This work produced an emergency route navigation indicating fastest route avoiding coastal flood areas from the current location to the existing emergency evacuation route and public shelters operated by the County emergency management offices. This navigation system provides a vital information to coastal communities assisting their safer evacuation. In addition, it will allow local agencies to better distribute information about alternative routes and target potential evacuees to spread out along the network.

5.1 South Texas Emergency Evacuation Routes

Current resources on emergency evacuation routing in the state of Texas are static maps, available online [31]. Figure 46 shows a part of the Texas Department of Transportation (TxDOT) emergency evacuation routes for the Rio Grande Valley region. Although comprehensive, the website redirects towards other sites such as the National Weather Service (NWS) and Texas.gov Emergency Portal, which has links redirecting back to the hurricane evacuation routes along as well as the NWS. Preliminary recommended evacuation routes in cases of hurricane events are:

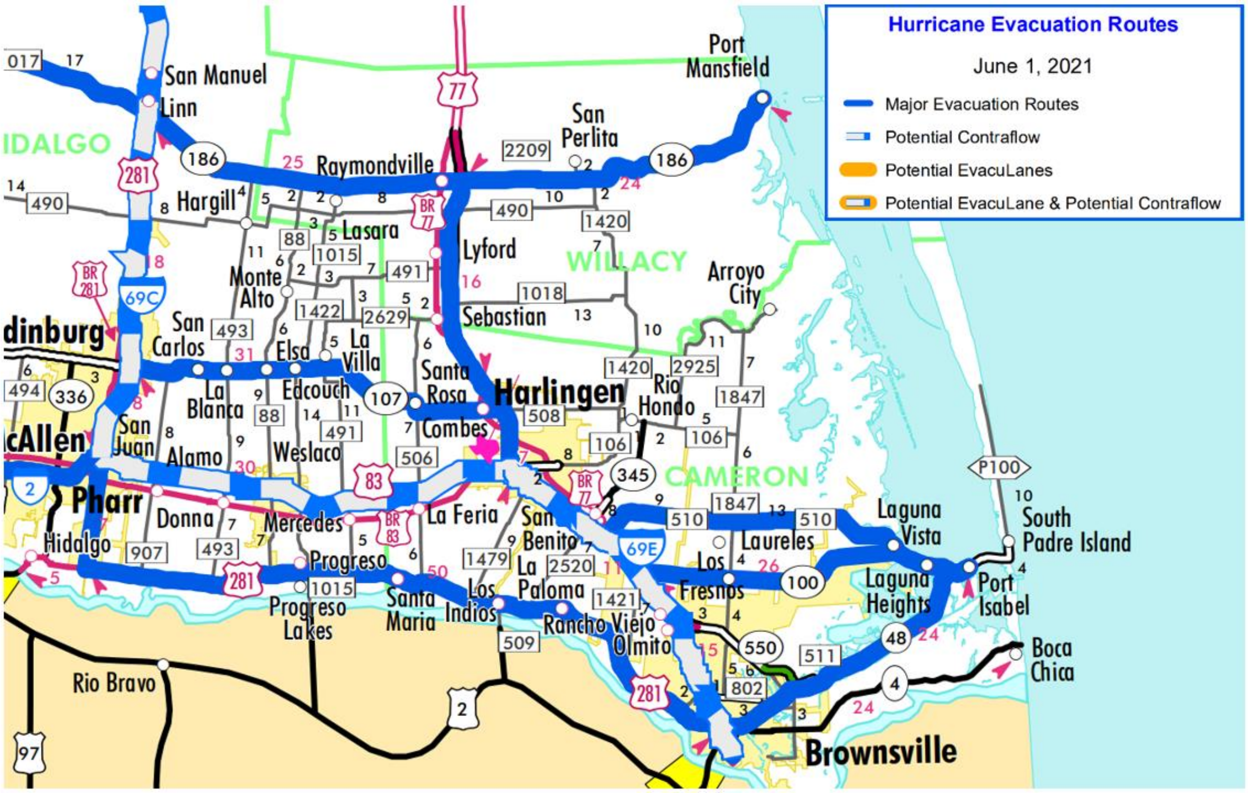


Figure 46. TxDOT evacuation routes of the Rio Grande Valley updated on June 1st, 2021

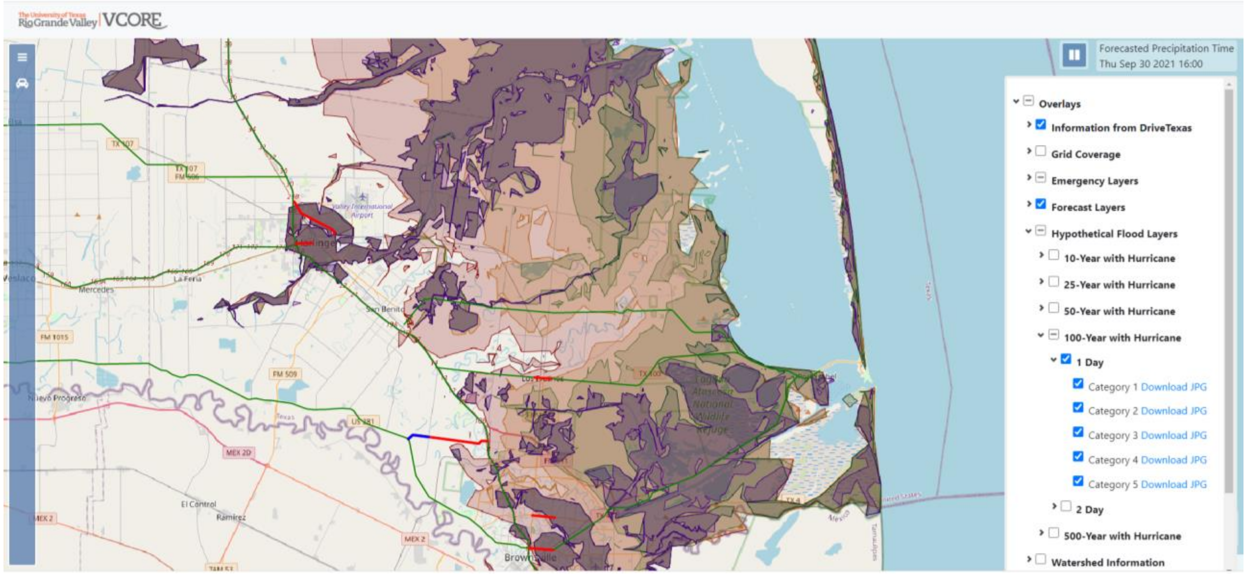
- SH 100 from South Padre Island/Port Isabel travel to US 77/83 northbound, then to US 77 to Raymondville, continue north on US 77 to I-37 in Corpus Christi.
- SH 48 from South Padre Island/Port Isabel west to US 281 (Military Highway) in Brownsville and continue west on US 281 to San Antonio or Laredo.
- US 83 northbound from Brownsville to Harlingen then west on US 83 to the Pharr Interchange then North on US 281 to San Antonio or Laredo.
- SH 186 from Port Mansfield/Raymondville travel west to US 281 to San Antonio or Laredo.

Also of interest is the web application DriveTexas https://drivetexas.org/, located at drivetexas.org and provided by the TxDOT. The web application provides up-to-date travel related information about the current status of Texas roadway including road closure, damage, construction, and current traffic. However, the website doesn't provide any information on emergency routes, opting to link to a separate website which shows the maps in a PDF format. Furthermore, it does not provide any sort of navigation or routing capabilities.

5.2 A Web-Based Navigation System

5.2.1 Project Website Development

The preliminary goal of this project website, VCORE (**V**alley **CO**astal disaster **RE**siliency system) website: https://vcore.utrgv.edu/ is to host and display the GIS maps from HEC-RAS and ADCIRC models. The website gives the user the option to display the various hypothetical storm event flood layers from the Overlays menu as shown in Figure 47. Each storm flood layer covers an area larger than 7.7 mi^2 covering most of Brownsville and Los Fresnos Texas. This created an obstacle for the website development, since the Openrouteservice (ORS) public API (Application Programming Interface) we had been using could not find routes avoiding polygons covering an area larger than 7.7 mi^2. This is due to restrictions set by the ORS API to prevent any single user from making the API unstable to others by taking up most of its resources.



Forecasted Precipitation Time
Thu Sep 30 2021 16:00

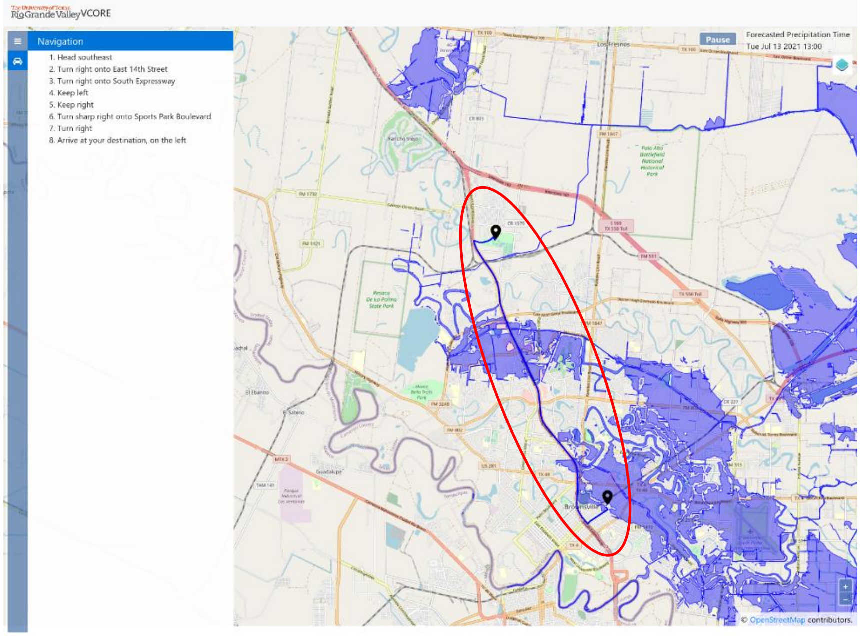
☐ Overlays
- ☑ Information from DriveTexas
- ☐ Grid Coverage
- ☐ Emergency Layers
- ☑ Forecast Layers
- ☐ Hypothetical Flood Layers
  - ☐ 10-Year with Hurricane
  - ☐ 25-Year with Hurricane
  - ☐ 50-Year with Hurricane
  - ☐ 100-Year with Hurricane
    - ☑ 1 Day
      - ☑ Category 1 Download JPG
      - ☑ Category 2 Download JPG
      - ☑ Category 3 Download JPG
      - ☑ Category 4 Download JPG
      - ☑ Category 5 Download JPG
    - ☐ 2 Day
  - ☐ 500-Year with Hurricane
- ☐ Watershed Information

Figure 47. VCORE website hosting hypothetical flood simulation results

5.2.2 Navigation Algorithm Determination

Although there are several navigation algorithms currently available, such as algorithms developed for emergency services [32] as well as routing tools for the general public [33], there is a lack of a general-purpose emergency navigation algorithms.

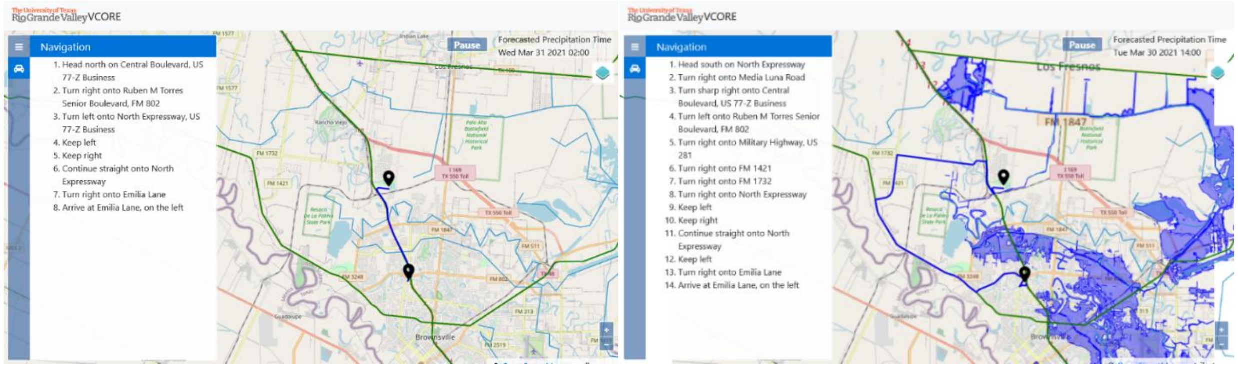
After having gone over the implementation of the navigation program, seeing the product in action would help to cement the utility of the program. The following section will cover two small scenarios that demonstrate the utility of the program. Also discussed will be the several details into the maintenance of the program and servers. As a brief demonstration of the navigation application, a scenario showing simulated 100-year flood event in the Brownsville area. Images will be show of the safe routing as well as how routing would have proceeded without the save routing algorithm. For the purpose of making the routing differences clear, minimal UI will be displayed. Along with this, the UI elements displayed will be consistent throughout each of the respective flooding cases. In this scenario, routing is done from the edge of a flooded area to a park North of the starting point. The scenario presented is to demonstrate the ability to navigate from areas near flooded areas as well as to navigate around flooded routes. Figure 48 shows how routing would have occurred without the flood avoidance algorithm. A traditional route like this would have taken the user through flooded areas, as it is not configured to handle such information. It would be up to the user, or more specifically the driver, to determine whether or not it would be safe to continue. Seeing that humans are not that great at gauging risk, it makes sense to develop applications where risk wouldn't have to be considered.



1. Head southeast
2. Turn right onto East 14th Street
3. Turn right onto South Expressway
4. Keep left
5. Keep right
6. Turn sharp right onto Sports Park Boulevard
7. Turn right
8. Arrive at your destination, on the left

Figure 48. Traditional navigation tool performance on flood zone

To overcome this obstacle, we created our own custom ORS API by cloning ORS's git repository and downloading the Texas OpenStreetMap (OSM) pbf file from their website. By creating our own custom API, we were able configure features and resources to fit our needs. The ORS API consumes a large number of resources, an estimated 3.4GB of RAM was used to create and maintain the container holding the mapped graphs of the OSM file. The large memory consumption is the result of ORS API creating a single large graph of with each address within the OSM file as a node that can be mapped from point A to point B using Dijkstra's algorithm [32] to find the optimal path. This is due to the simplicity and utility of the algorithm, which many other navigation algorithms including [35]. Attempting to limit the API's resources to 2GB or less resulted in out of bounds memory. The website is currently hosted on a Virtual Machine (VM) with a 2GB RAM, thus preventing us from hosting our ORS API in the same VM. Figure 49 illustrates the performances of the navigation tool to avoid the flooded area filled with blue polygon. The detour route directions are displayed in the left section of the website.



1. Head north on Central Boulevard, US 77-Z Business
2. Turn right onto Ruben M Torres Senior Boulevard, FM 802
3. Turn left onto North Expressway, US 77-Z Business
4. Keep left
5. Keep right
6. Continue straight onto North Expressway
7. Turn right onto Emilia Lane
8. Arrive at Emilia Lane, on the left

(a) Point A to Point B without polygon (flood)

1. Head south on North Expressway
2. Turn right onto Media Luna Road
3. Turn sharp right onto Central Boulevard, US 77-Z Business
4. Turn left onto Ruben M Torres Senior Boulevard, FM 802
5. Turn right onto Military Highway, US 281
6. Turn right onto FM 1421
7. Turn right onto FM 1732
8. Turn right onto North Expressway
9. Keep left
10. Keep right
11. Continue straight onto North Expressway
12. Keep left
13. Turn right onto Emilia Lane
14. Arrive at Emilia Lane, on the left

(b) Point A to Point B avoiding polygon (flood)

Figure 49. Navigation tool performance test

In response to the large consumption of memory we customized our own OSM pbf file to cover only the Rio Grande Valley. A smaller OSM file requires less memory consumption from the CPU, we were able to reduce our file size from 500mb to 8mb and our RAM usage from 3.4GB to 1.5GB. This leaves only 0.5GB for GeoServer and NGINX to compete over. Our best option is to acquire a second VM to host the navigation. A secondary VM will give us more freedom to expand our navigation beyond the Rio Grande Valley to the rest of Texas.

The following is a snippet of code, shown in Figure 50, used to query our ORS API for a route from point A to point B, whose coordinates are stored in ‘info.coordinates’. If either the 25-year or 100-year storm layers are being displayed, the code retrieves the polygon’s coordinates from its GeoJson file using the ‘get_polygon’ function and sends them to the ORS API using the ‘orsDirections’ function.

```
router.post('/ors', async function(req, res, next){
  let info = req.body;
  if (info.twentyFiveYearStorm) {
    const body = await get_polygon('25-year.geojson').then(data => {
      let params = {
        coordinates: info.coordinates,
        options: {
          avoid_polygons: JSON.parse(data).geometries[0]
        }
      };
      return params;
    });
    res.send(await orsDirections(body));
  }
  else if (info.oneHundredYearStorm) {
    const body = await get_polygon('100-year.geojson').then(data => {
      let params = {
        coordinates: info.coordinates,
        options: {
```

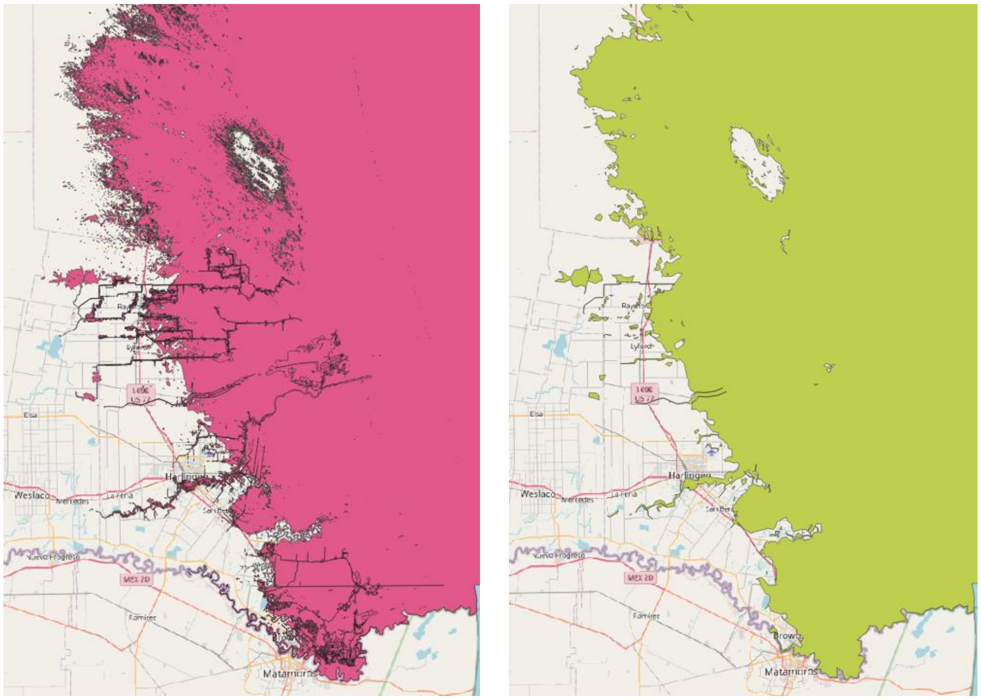
```
        avoid_polygons: JSON.parse(data).geometries[0]
```

Figure 50. Part of code used to query ORS API for the navigation tool

5.2.3 Shapefile Polygon Simplification

It is important to simplify our shapefiles since large shapefiles can slow down the VCORE website and cause errors within GeoServer. Before simplifying the shapefiles, it should be checked that they were all using the same coordinate system: "EPSG:4326". VCORE website uses GeoServer to share geospatial data (shapefiles) online. When uploading shapefiles to VCORE's GeoServer, it is needed to specify their coordinate system, if the wrong coordinate system is specified the shapefile polygon may not show at all. Having all the shapefiles use the same coordinate system is more convenient and efficient. Ogr2ogr was adopted to format all shapefiles' coordinate systems, Ogr2ogr is a software that converts simple geospatial data features between file formats and edits attributes, such as coordinate systems.

Mapshaper was used to simplify the shapefiles. Mapshaper is a software based on JavaScript used for editing geospatial data (shapefiles, GeoJSON, CSV, etc.). We used Mapshaper to simplify our shapefiles to 0.15% its original size. Figure 51 shows the original shapefile of size 9.4MB (a) and the simplified shapefile of size 54KB (b). Although Figure 49 (a) is more detailed, it puts excess strain on GeoServer and the web browser. Figure 49 (b) on the other hand is easier to share and loads faster on user's web browser.



(a) Original shapefile (b) Simplified shapefile

Figure 51. Comparison of polygon shapefile simplification results

Once all the shapefiles had been simplified and stored in our "Simplified" directory, the areas covering the ocean should be removed or clipped. This step was done after the simplification, since clipping an un-simplified shapefile took considerably longer due to the much larger file size. To clip the shapefiles at the coastline we needed another shapefile that covered the continent and was outlined by the coastline. The Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) https://www.soest.hawaii.edu/pwessel/gshhg/ was adopted for the shapefile. Ogr2ogr software was used to clip our shapefiles. Figure 52 shows Python script developed for clipping the shapefiles in our "Simplified" directory using Ogr2ogr and store them in our new "Clipped" directory.

```
import os
import time

category = ['1H','2H','3H','4H','5H']
year = ['10Y', '25Y', '50Y', '100Y', '500Y']
day = ['1D', '2D']

for y in year:
   for d in day:
         os.system("mkdir -p Clipped/" + y + d + "/")
       for c in category:
           os.system("ogr2ogr -skipfailures -clipsrc " +
        "gshhg-shp-2.3.7/GSHHS_shp/f/GSHHS_f_L1.shp Clipped/" +
        y + d + "/" + c + y + d + ".shp Simplified/" + y + d + "/" +
        c + y + d + ".shp")
           time.sleep(5)
```

Figure 52. Python script for clipping shapefiles

5.2.4 System Maintenance

Developing such a system isn’t without its dues. The navigation system does require a degree of maintenance even with a great deal of the work done to retrieve data being automated. As the navigation tool is expanded into further areas, consideration is needed to be placed in the amount of memory that both GeoServer takes as well as the mount of memory that Openrouteservice takes. Given that Openrouteservice takes a great deal of data to generate routes, the amount of memory it requires increases as they are of interest also increases.

Further complicating the fact is that the generation of navigation paths can be parallelized. While this is of great use for small areas to help multiple users get routes quickly, this leads to slow processing of responses in larger areas. Currently, the most effective method for mitigating the time it takes to generate a route is to minimize the coverage area. This limits the overall time it takes to compute data. Other methods would be to maximize the processing capability of the computer that the server is running on and simplify the flood avoidance layer, though the latter could have a negative impact on safety.

Of consideration is also the storage of the data on the servers. Although keeping historical forecasts for the area would be of use in both tuning the flood forecast model, it is too costly to keep the data on the server accessible to the public. Therefore, model forecast results are keep locally, on the forecasting device, with the data either manual backed up for future reference or removed for more storage space for future forecasts.

5.3 Evacuation Capacity and Recommendations

5.3.1 Emergency Evacuation Routes Scenarios Development

A total of eight scenarios for the emergency evacuation routes were determined to test performance of the emergency navigation system. The main goal of the emergency tool is to provide alternate route to the destination to evade flooded area. As the destinations, TxDOT emergency evacuation routes, emergency shelters, and medical service centers were selected. A full list of the TxDOT evacuation routes and emergency shelters and medical services are provided. Table 10 lists the navigation route scenarios determined in this test. The mileage indicates normal closest path travel mileage from the departures to the destinations.

Table 10. Evacuation route scenarios selection for navigation system performance test

Departures	Destinations	Mileage
Arroyo City, Cameron County	TxDOT evacuation route SH 510	15.2
Rio Hondo, Cameron County	American Red Cross 6914 W Expressway 83, Harlingen, TX 78552	13.4
Hubert R. Hudson Elementary School, Cameron County	Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520	4.4
South Padre Island, Cameron County	TxDOT evacuation route SH 100	4.9
Los Fresnos, Cameron County	TxDOT evacuation route US 83	6.4
Rancho Viejo, Cameron County	South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550	13.4
Port Mansfield, Willacy County	Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580	25.4
Brownsville International Airport	US 281 Military Highway	5.6

<u>Emergency Shelters and Medical Services</u>

- South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550
- American Red Cross 6914 W Expressway 83, Harlingen, TX 78552
- Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520
- Cameron County Department of Health, 711 N L St., Harlingen, TX 78550
- Cameron County Health Department, 1390 W Expy 83, Harlingen, TX 78550
- Cameron County Sheriff Department, 7300 Old Alice Rd. Olmito, TX 78575
- Cameron County Sheriff Office, 3302 Wilson Rd, Harlingen, TX 78552
- La Feria Police Department, 115 E Commercial Ave. La Feria, TX 78559
- Port Isabel Police Department, 110 W Hickman Ave. Port Isabel, TX 78578
- Harlingen Police Department,1018 Fair Park Blvd. Harlingen, TX 78550
- South Padre Island Police Department, 4601 Padre Blvd, South Padre Island, TX 78597
- City of Los Fresnos, 520 E Ocean Blvd. Los Fresnos, TX 78566
- Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580
- Willacy County Sheriff's Department 1371 Industrial Dr. Raymondville, TX 78580
- Port Mansfield Post Office, 800 Mansfield Dr. Port Mansfield, TX 78598
- Sebastian Municipal Utilities, 13343 W 2nd St, Lyford, TX 78569

5.3.2 Performance Tests for Evacuation Navigation System

The navigation tool capacity test results of the 8 evacuation route scenarios are presented in Tables 11 through 15. Table 11 lists the performances in an event of the category 1 hurricane storm surge with the 100-year 1 day duration frequency storm. The mileage and travel time indicate normal closest path travel mileage and its travel time from the departure to the destination. The "alternate" (columns 4 and 6) depicts the mileage and travel time along the detoured path predicted by the navigation tool. For example, the first scenario of Table 11 is navigation from Arroyo City, Cameron County (departure) to TxDOT evacuation route SH 510 (destination). The closest mileage and travel time in a normal situation are 15.2 miles and 19 minutes. However, the watershed flood forecasting model predicted a potential flooding along the path. The emergency navigation tool estimated a detour path to evade the flood area. The alternate mileage and travel time in the emergency are 22.8 miles and 55.5 minutes. The predicted flood area and alternate path line of this scenario also illustrated in Figure 53. Table 15 shows the comparisons between a normal situation and the emergency of the event of the category 5 hurricane storm surge with the 100-year 1 day duration frequency storm. In this case, the considerable range of the path from the departure to the destination have been inundated as shown in Figure 56, 58, and 62. No alternate route is predicted.

<u>General Recommendation for the category 1 hurricane with 100-year 1 day duration frequency storm</u>
Three out of eight departure points (Arroyo Colorado drain channel estuary, Brownsville International Airport, and Port Mansfield) will be already flooded in this storm event. One of destinations, the south Texas Emergency Care near the Valley Baptist Medical Center in the City of Harlingen will be flooded partially.

No flood along the route was predicted for three route scenarios:

- From the Hubert R. Hudson Elementary School to the Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville as shown in Figure 6
- From South Padre Island, Cameron County to TxDOT evacuation route SH 100 as shown in Figure 8
- From Los Fresnos, Cameron County to TxDOT evacuation route US 83 as shown in Figure 10

Significant increasement of travel time (greater than 50%) will be expected in routes of:

- From Arroyo City, Cameron County to TxDOT evacuation route SH 510 as shown in Figure 2
- From Brownsville International Airport to US 281 Military Highway as shown in Figure 14

The route from Port Mansfield, Willacy County to the Willacy County Emergency Medical Services, 693 S 7th St. Raymondville is not recommended during this storm event as shown in Figure 13.

<u>General Recommendation for the category 2 hurricane with 100-year 1 day duration frequency storm</u>
Four out of eight departure points (Arroyo Colorado drain channel estuary, Brownsville International Airport, Port Mansfield, and South Padre Island) will be already flooded in this storm event. Two destinations: TxDOT evacuation route SH 100 and the Emergency Medical Services, 693 S 7th St. Raymondville will be flooded. The south Texas Emergency Care near the Valley Baptist Medical Center in the City of Harlingen and will be flooded partially.

No flood along the route was predicted for two route scenarios:

- From the Hubert R. Hudson Elementary School to the Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville
- From Los Fresnos, Cameron County to TxDOT evacuation route US 83

Significant increasement of travel time (greater than 50%) will be expected in routes of:

- From Arroyo City, Cameron County to TxDOT evacuation route SH 510
- From Brownsville International Airport to US 281 Military Highway

Two out of eight routes are not recommended during this storm event:

- From Port Mansfield, Willacy County to the Willacy County Emergency Medical Services, 693 S 7th St. Raymondville
- From South Padre Island, Cameron County to TxDOT evacuation route SH 100 as shown in Figure 9

General Recommendation for the category 3 hurricane with 100-year 1 day duration frequency storm

Five out of eight departure points (Arroyo Colorado drain channel estuary, Brownsville International Airport, Port Mansfield, and South Padre Island) will be already flooded in this storm event. One of destinations, the south Texas Emergency Care near the Valley Baptist Medical Center in the City of Harlingen will be flooded partially.

No flood along the route was predicted for two route scenarios:

- From the Hubert R. Hudson Elementary School to the Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville
- From Los Fresnos, Cameron County to TxDOT evacuation route US 83

Significant increasement of travel time (greater than 50%) will be expected in a route of Brownsville International Airport to US 281 Military Highway.

Three out of eight routes are not recommended during this storm event:

- From Port Mansfield, Willacy County to the Willacy County Emergency Medical Services, 693 S 7th St. Raymondville
- From South Padre Island, Cameron County to TxDOT evacuation route SH 100
- From Arroyo City, Cameron County to TxDOT evacuation route SH 510 as shown in Figure 3

General Recommendation for the category 4 hurricane with 100-year 1 day duration frequency storm

Five out of eight departure points (Arroyo Colorado drain channel estuary, Brownsville International Airport, Port Mansfield, and South Padre Island) will be already flooded in this storm event. One of destinations, the south Texas Emergency Care near the Valley Baptist Medical Center in the City of Harlingen will be flooded partially.

No flood along the route was predicted for two route scenarios:

- From the Hubert R. Hudson Elementary School to the Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville
- From Los Fresnos, Cameron County to TxDOT evacuation route US 83

Significant increasement of travel time (greater than 50%) will be expected in a route of Brownsville International Airport to US 281 Military Highway.

Four out of eight routes are not recommended during this storm event:

- From Port Mansfield, Willacy County to the Willacy County Emergency Medical Services, 693 S 7th St. Raymondville
- From South Padre Island, Cameron County to TxDOT evacuation route SH 100
- From Arroyo City, Cameron County to TxDOT evacuation route SH 510
- From Brownsville International Airport to US 281 Military Highway as shown in Figure 15

General Recommendation for the category 5 hurricane with 100-year 1 day duration frequency storm

Seven out of eight departure points (Arroyo Colorado drain channel estuary, Brownsville city boundary including the International Airport, and Port Mansfield, and South Padre Island) will be already flooded in this storm event. One of destinations, the south Texas Emergency Care near the Valley Baptist Medical Center in the City of Harlingen will be flooded partially. Only the Rancho Viejo, about 10 miles north of the City of Brownsville along the US 83, is predicted not to be flooded in this storm event.

Seven out of eight routes are not recommended during this storm event:

- From Port Mansfield, Willacy County to the Willacy County Emergency Medical Services, 693 S 7th St. Raymondville
- From South Padre Island, Cameron County to TxDOT evacuation route SH 100
- From Arroyo City, Cameron County to TxDOT evacuation route SH 510
- From Brownsville International Airport to US 281 Military Highway
- From Rio Hondo, Cameron County to American Red Cross 6914 W Expressway 83, Harlingen as shown in Figure 8
- From Hubert R. Hudson Elementary School, Cameron County to Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville as shown in Figure 7
- From Los Fresnos, Cameron County to TxDOT evacuation route US 83 as shown in Figure 11

Only one alternate route from Rancho Viejo, Cameron County to South Texas Emergency Care, 1705 Vermont, Harlingen will not be flooded during the storm.

Table 11. Navigation route scenarios (Category 1 hurricane with 100-year 1 day duration frequency storm)

Departure	**Destination**	**Mileage**		**Travel time (min)**		**Flooded**
		Closest	**Alternate**	**Fastest**	**Alternate**	
Arroyo City, Cameron County (26.337815, -97.434142)	TxDOT evacuation route SH 510 (26.129407, -97.471143)	15.2	22.8	19.0	55.5	At Departure
Rio Hondo, Cameron County (26.241018, -97.581345)	American Red Cross 6914 W Expressway 83, Harlingen, TX 78552	13.8	15.6	21.0	27.5	At departure
Hubert R. Hudson Elementary School, Cameron County	Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520	4.3	4.3	7.8	7.8	No flood along the route
South Padre Island, Cameron County (26.118582, -97.169844)	TxDOT evacuation route SH 100 (26.075269, -97.210177)	5.4	5.7	9.0	9.8	No flood along the route
Los Fresnos, Cameron County (26.071657, -97.476260)	TxDOT evacuation route US 83 (26.084624, -97.582287)	6.6	6.6	8.0	8.0	No flood along the route
Rancho Viejo, Cameron County (26.045327, -97.552306)	South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550	12.1	13.1	14.0	15.5	At destination partially
Port Mansfield, Willacy County (26.550473, -97.434574)	Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580	24.6	No alternate	27.0	No alternate	Along the route
Brownsville International Airport (25.906355, -97.435264)	US 281 Military Highway (25.925879, -97.511383)	5.2	20.0	11.0	29.3	At departure

Table 12. Navigation route scenarios (Category 2 hurricane with 100-year 1 day duration frequency storm)

Departure	**Destination**	**Mileage**		**Travel time (min)**		**Flooded**
		Closest	**Alternate**	**Fastest**	**Alternate**	
Arroyo City, Cameron County (26.337815, -97.434142)	TxDOT evacuation route SH 510 (26.129407, -97.471143)	15.2	22.8	19.0	55.5	at Departure
Rio Hondo, Cameron County (26.241018, -97.581345)	American Red Cross 6914 W Expressway 83, Harlingen, TX 78552	13.8	15.6	21.0	27.5	No flood along the route
Hubert R. Hudson Elementary School, Cameron County	Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520	4.3	4.3	7.8	7.8	No flood along the route
South Padre Island, Cameron County (26.118582, -97.169844)	TxDOT evacuation route SH 100 (26.075269, -97.210177)	5.4	No alternate	9.0	No alternate	At departure
Los Fresnos, Cameron County (26.071657, -97.476260)	TxDOT evacuation route US 83 (26.084624, -97.582287)	6.6	6.6	8.0	8.0	No flood along the route
Rancho Viejo, Cameron County (26.045327, -97.552306)	South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550	12.1	13.1	14.0	15.5	At destination partially
Port Mansfield, Willacy County (26.550473, -97.434574)	Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580	24.6	No alternate	27.0	No alternate	Along the route
Brownsville International Airport (25.906355, -97.435264)	US 281 Military Highway (25.925879, -97.511383)	5.2	20.0	11.0	29.3	At departure

Table 13. Navigation route scenarios (Category 3 hurricane with 100-year 1 day duration frequency storm)

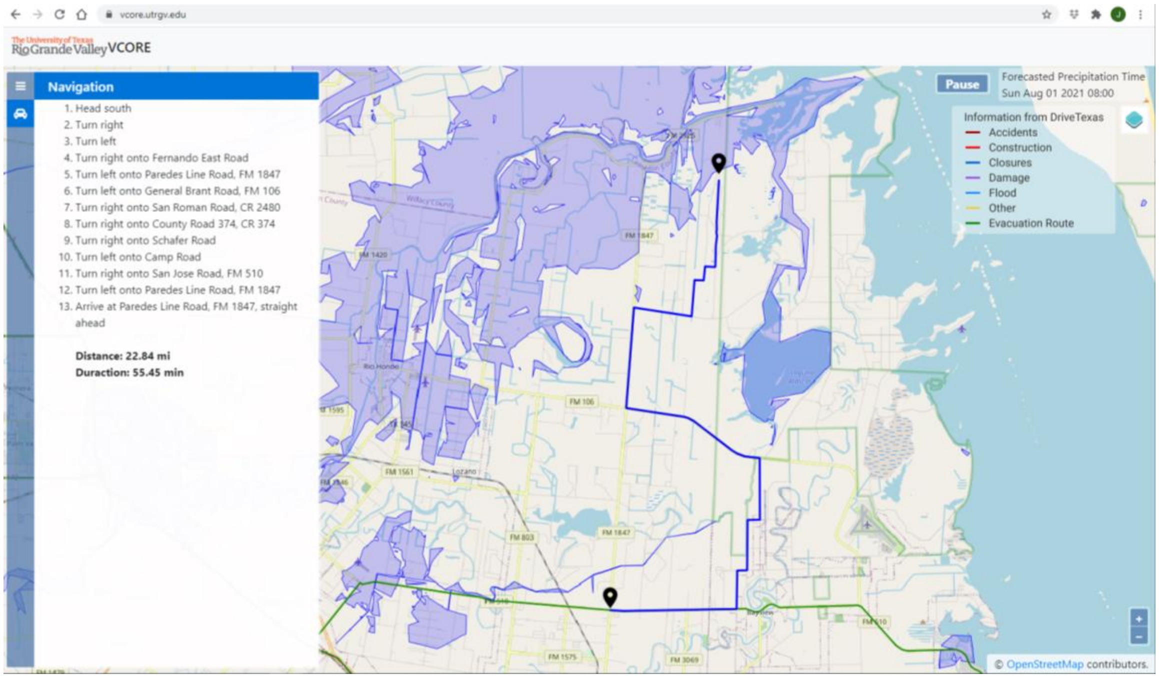
Departure	Destination	Mileage		Travel time (min)		Flooded
		Closest	Alternate	Fastest	Alternate	
Arroyo City, Cameron County (26.337815, -97.434142)	TxDOT evacuation route SH 510 (26.129407, -97.471143)	15.2	No alternate	19.0	No alternate	Along the route
Rio Hondo, Cameron County (26.241018, -97.581345)	American Red Cross 6914 W Expressway 83, Harlingen, TX 78552	13.8	15.6	21.0	27.5	No flood along the route
Hubert R. Hudson Elementary School, Cameron County	Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520	4.3	4.3	7.8	7.8	No flood along the route
South Padre Island, Cameron County (26.118582, -97.169844)	TxDOT evacuation route SH 100 (26.075269, -97.210177)	5.4	No alternate	9.0	No alternate	At departure
Los Fresnos, Cameron County (26.071657, -97.476260)	TxDOT evacuation route US 83 (26.084624, -97.582287)	6.6	6.6	8.0	8.0	No flood along the route
Rancho Viejo, Cameron County (26.045327, -97.552306)	South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550	12.1	13.1	14.0	15.5	At destination partially
Port Mansfield, Willacy County (26.550473, -97.434574)	Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580	24.6	No alternate	27.0	No alternate	Along the route
Brownsville International Airport (25.906355, -97.435264)	US 281 Military Highway (25.925879, -97.511383)	5.2	20.0	11.0	29.3	At departure

Table 14. Navigation route scenarios (Category 4 hurricane with 100-year 1 day duration frequency storm)

Departure	Destination	Mileage		Travel time (min)		Flooded
		Closest	Alternate	Fastest	Alternate	
Arroyo City, Cameron County (26.337815, -97.434142)	TxDOT evacuation route SH 510 (26.129407, -97.471143)	15.2	No alternate	19.0	No alternate	Along the route
Rio Hondo, Cameron County (26.241018, -97.581345)	American Red Cross 6914 W Expressway 83, Harlingen, TX 78552	13.8	15.6	21.0	27.5	No flood along the route
Hubert R. Hudson Elementary School, Cameron County	Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520	4.3	4.3	7.8	7.8	No flood along the route
South Padre Island, Cameron County (26.118582, -97.169844)	TxDOT evacuation route SH 100 (26.075269, -97.210177)	5.4	No alternate	9.0	No alternate	At departure
Los Fresnos, Cameron County (26.071657, -97.476260)	TxDOT evacuation route US 83 (26.084624, -97.582287)	6.6	6.6	8.0	8.0	No flood along the route
Rancho Viejo, Cameron County (26.045327, -97.552306)	South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550	12.1	13.1	14.0	15.5	At destination partially
Port Mansfield, Willacy County (26.550473, -97.434574)	Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580	24.6	No alternate	27.0	No alternate	Along the route
Brownsville International Airport (25.906355, -97.435264)	US 281 Military Highway (25.925879, -97.511383)	5.2	No alternate	11.0	No alternate	Along the route

Table 15. Navigation route scenarios (Category 5 hurricane with 100-year 1 day duration frequency storm)

Departure	Destination	Mileage		Travel time (min)		Flooded
		Closest	Alternate	Fastest	Alternate	
Arroyo City, Cameron County (26.337815, -97.434142)	TxDOT evacuation route SH 510 (26.129407, -97.471143)	15.2	No alternate	19.0	No alternate	along the route
Rio Hondo, Cameron County (26.241018, -97.581345)	American Red Cross 6914 W Expressway 83, Harlingen, TX 78552	13.8	No alternate	21.0	No alternate	At departure
Hubert R. Hudson Elementary School, Cameron County	Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520	4.3	No alternate	7.8	No alternate	At departure
South Padre Island, Cameron County (26.118582, -97.169844)	TxDOT evacuation route SH 100 (26.075269, -97.210177)	5.4	No alternate	9.0	No alternate	At departure
Los Fresnos, Cameron County (26.071657, -97.476260)	TxDOT evacuation route US 83 (26.084624, -97.582287)	6.6	No alternate	8.0	No alternate	At departure
Rancho Viejo, Cameron County (26.045327, -97.552306)	South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550	12.9	13.1	14.0	15.5	At destination partially
Port Mansfield, Willacy County (26.550473, -97.434574)	Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580	24.6	No alternate	27.0	No alternate	Along the route
Brownsville International Airport (25.906355, -97.435264)	US 281 Military Highway (25.925879, -97.511383)	5.2	No alternate	11.0	No alternate	Along the route

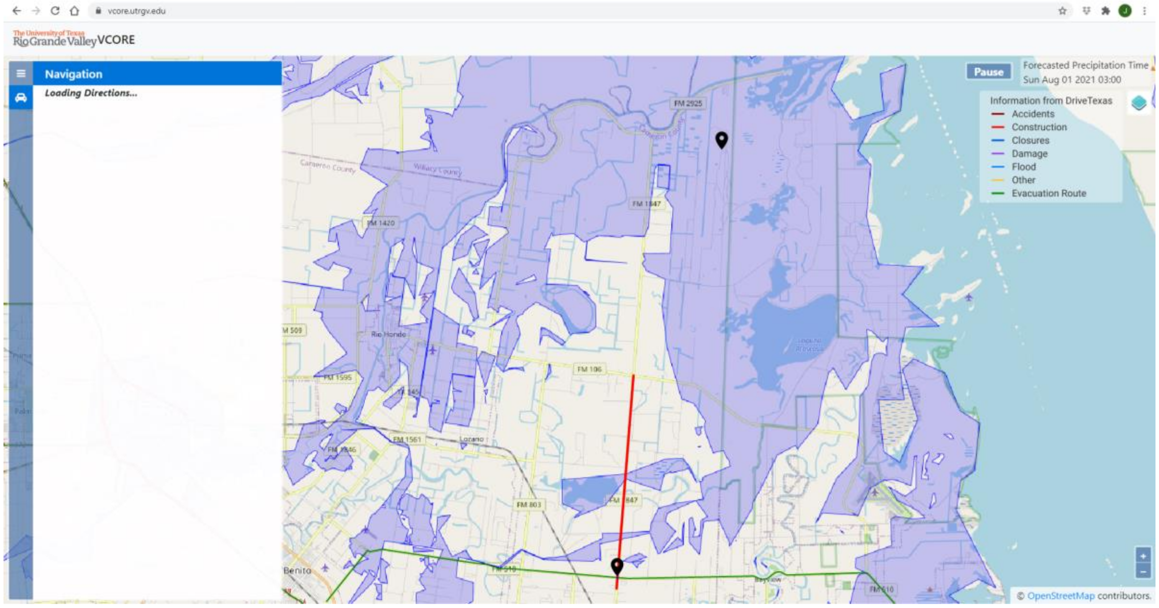


Navigation

1. Head south
2. Turn right
3. Turn left
4. Turn right onto Fernando East Road
5. Turn left onto Paredes Line Road, FM 1847
6. Turn left onto General Brant Road, FM 106
7. Turn right onto San Roman Road, CR 2480
8. Turn right onto County Road 374, CR 374
9. Turn right onto Schafer Road
10. Turn left onto Camp Road
11. Turn right onto San Jose Road, FM 510
12. Turn left onto Paredes Line Road, FM 1847
13. Arrive at Paredes Line Road, FM 1847, straight ahead

Distance: 22.84 mi
Duraction: 55.45 min

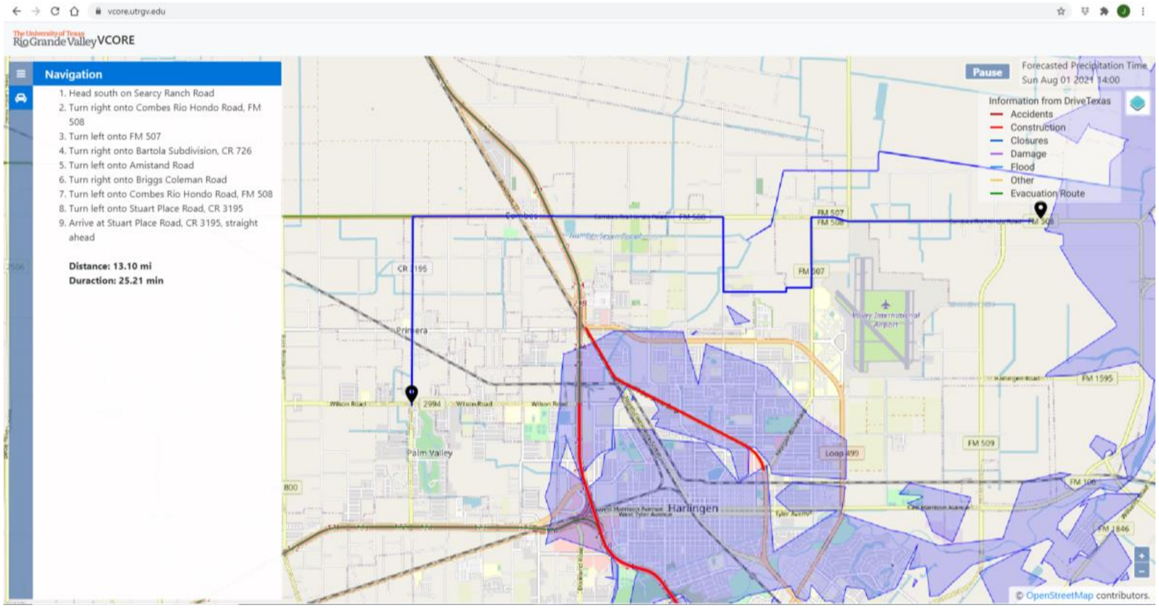
Figure 53. [From Arroyo City, Cameron County to TxDOT evacuation route SH 510] in 100-year 1 day duration storm with category 1 hurricane storm surge



Navigation

Loading Directions...

Figure 54. [From Arroyo City, Cameron County to TxDOT evacuation route SH 510] in 100-year 1 day duration storm with category 3 hurricane storm surge

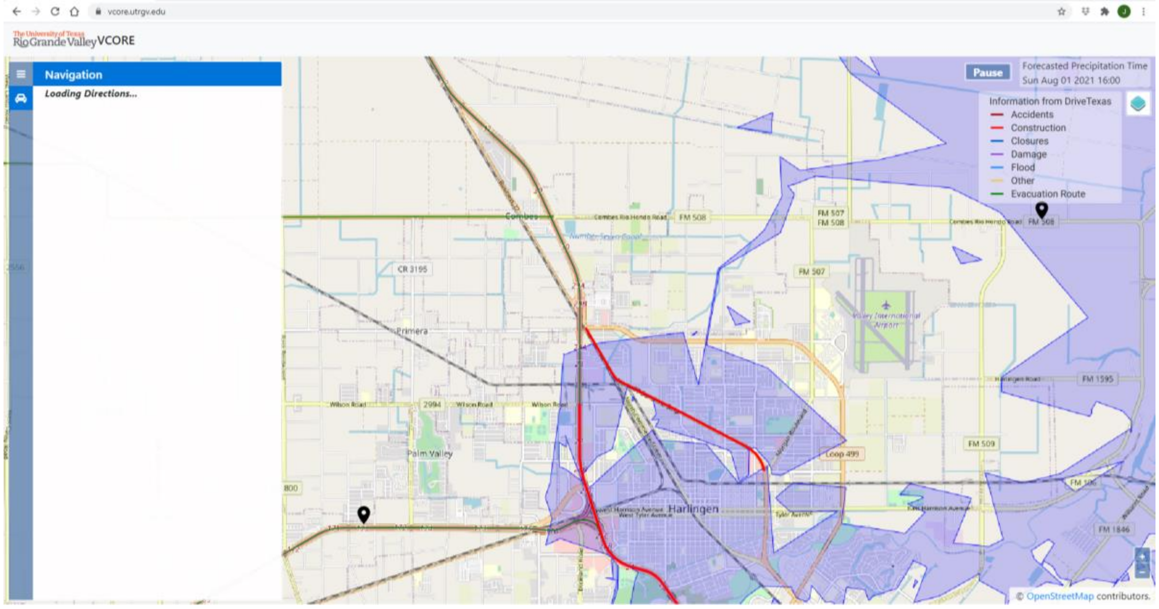


Navigation

1. Head south on Searcy Ranch Road
2. Turn right onto Combes Rio Hondo Road, FM 508
3. Turn left onto FM 507
4. Turn right onto Bartola Subdivision, CR 726
5. Turn left onto Amistand Road
6. Turn right onto Briggs Coleman Road
7. Turn left onto Combes Rio Hondo Road, FM 508
8. Turn left onto Stuart Place Road, CR 3195
9. Arrive at Stuart Place Road, CR 3195, straight ahead

Distance: 13.10 mi
Duraction: 25.21 min

Figure 55. [From Rio Hondo, Cameron County to American Red Cross 6914 W Expressway 83, Harlingen, TX 78552] in 100-year 1 day duration storm with category 1 hurricane storm surge



Navigation

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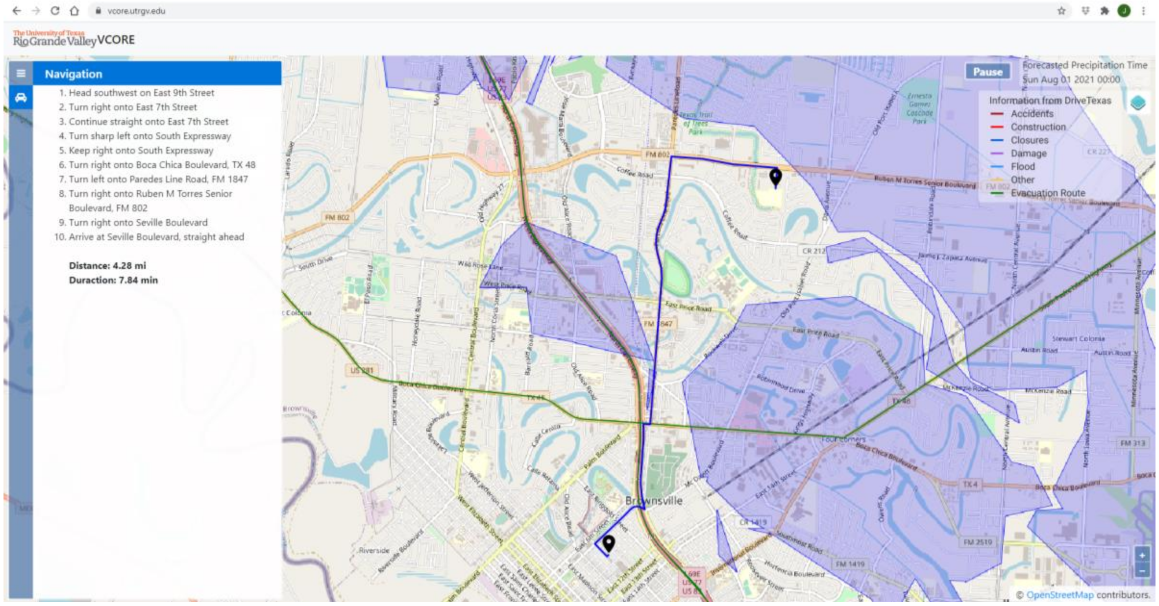
Figure 56. [From Rio Hondo, Cameron County to American Red Cross 6914 W Expressway 83, Harlingen, TX 78552] in 100-year 1 day duration storm with category 5 hurricane storm surge

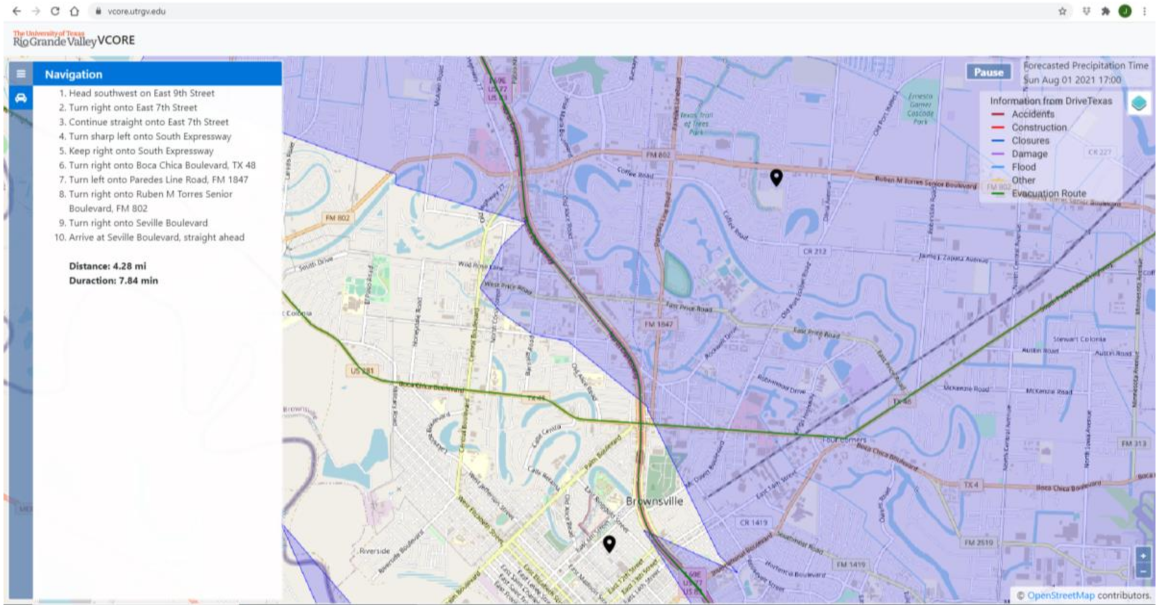


Navigation

1. Head southwest on East 9th Street
2. Turn right onto East 7th Street
3. Continue straight onto East 7th Street
4. Turn sharp left onto South Expressway
5. Keep right onto South Expressway
6. Turn right onto Boca Chica Boulevard, TX 48
7. Turn left onto Paredes Line Road, FM 1847
8. Turn right onto Ruben M Torres Senior Boulevard, FM 802
9. Turn right onto Seville Boulevard
10. Arrive at Seville Boulevard, straight ahead

Distance: 4.28 mi
Duraction: 7.84 min

Figure 57. [From Hubert R. Hudson Elementary School, Cameron County to Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520] in 100-year 1 day duration storm with category 1 hurricane storm surge

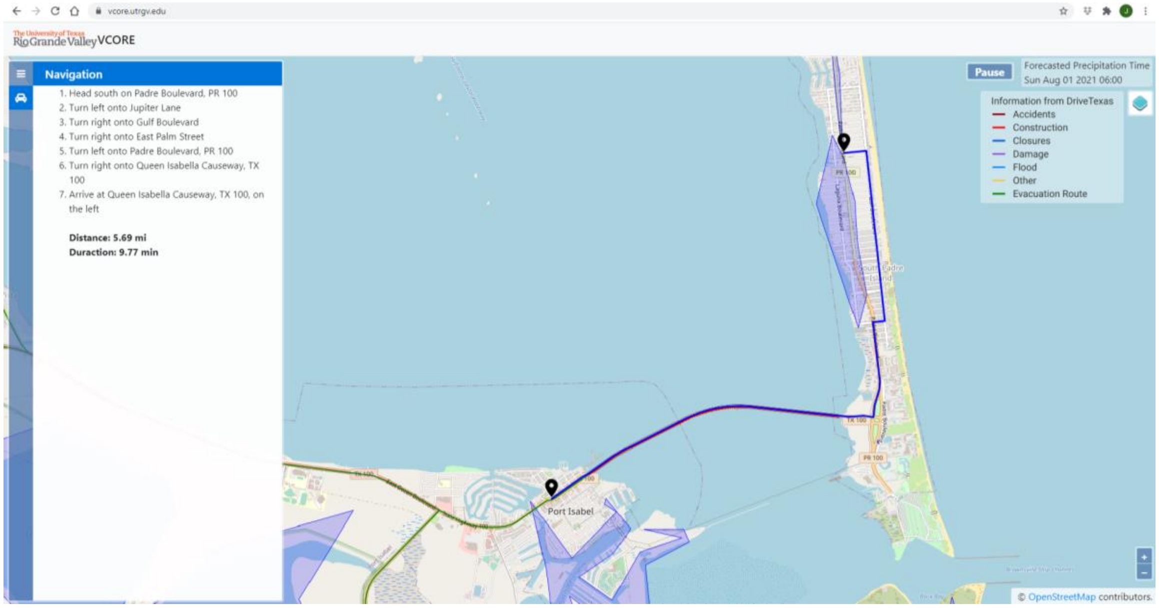


Navigation

1. Head southwest on East 9th Street
2. Turn right onto East 7th Street
3. Continue straight onto East 7th Street
4. Turn sharp left onto South Expressway
5. Keep right onto South Expressway
6. Turn right onto Boca Chica Boulevard, TX 48
7. Turn left onto Paredes Line Road, FM 1847
8. Turn right onto Ruben M Torres Senior Boulevard, FM 802
9. Turn right onto Seville Boulevard
10. Arrive at Seville Boulevard, straight ahead

Distance: 4.28 mi
Duraction: 7.84 min

Figure 58. [From Hubert R. Hudson Elementary School, Cameron County to Cameron County Emergency Management Services, 964 E. Harrison St., Brownsville, TX 78520] in 100-year 1 day duration storm with category 5 hurricane storm surge

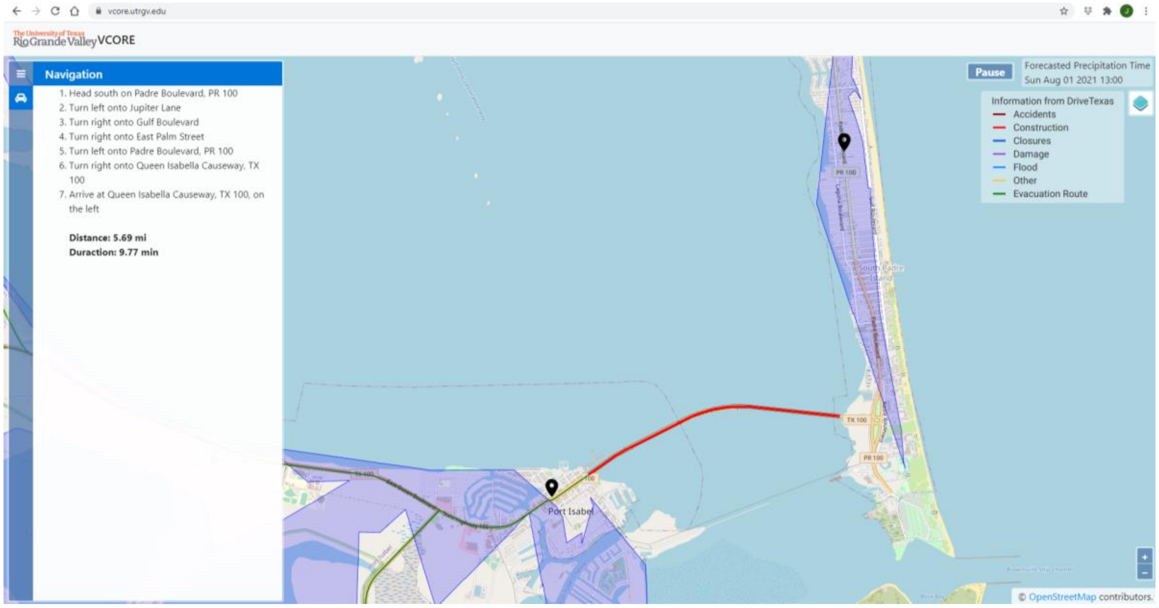


Forecasted Precipitation Time Sun Aug 01 2021 06:00

1. Head south on Padre Boulevard, PR 100
2. Turn left onto Jupiter Lane
3. Turn right onto Gulf Boulevard
4. Turn right onto East Palm Street
5. Turn left onto Padre Boulevard, PR 100
6. Turn right onto Queen Isabella Causeway, TX 100
7. Arrive at Queen Isabella Causeway, TX 100, on the left

Distance: 5.69 mi
Duraction: 9.77 min

Figure 59. [From South Padre Island, Cameron County to TxDOT evacuation route SH 100] in 100-year 1 day duration storm with category 1 hurricane storm surge

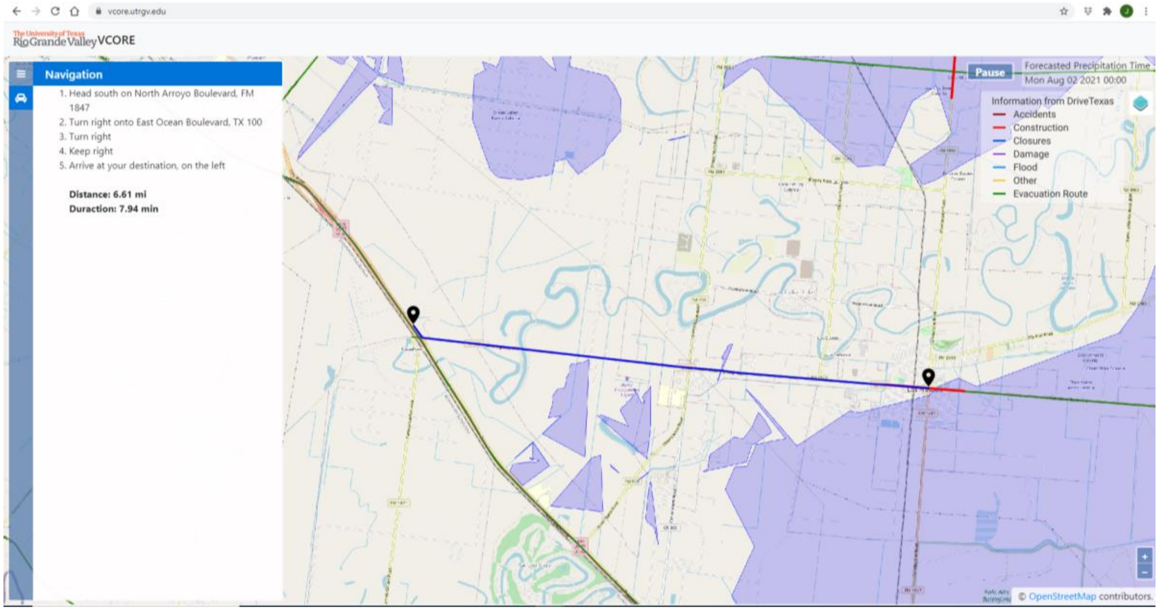


Forecasted Precipitation Time Sun Aug 01 2021 13:00

1. Head south on Padre Boulevard, PR 100
2. Turn left onto Jupiter Lane
3. Turn right onto Gulf Boulevard
4. Turn right onto East Palm Street
5. Turn left onto Padre Boulevard, PR 100
6. Turn right onto Queen Isabella Causeway, TX 100
7. Arrive at Queen Isabella Causeway, TX 100, on the left

Distance: 5.69 mi
Duraction: 9.77 min

Figure 60. [From South Padre Island, Cameron County to TxDOT evacuation route SH 100] in 100-year 1 day duration storm with category 2 hurricane storm surge

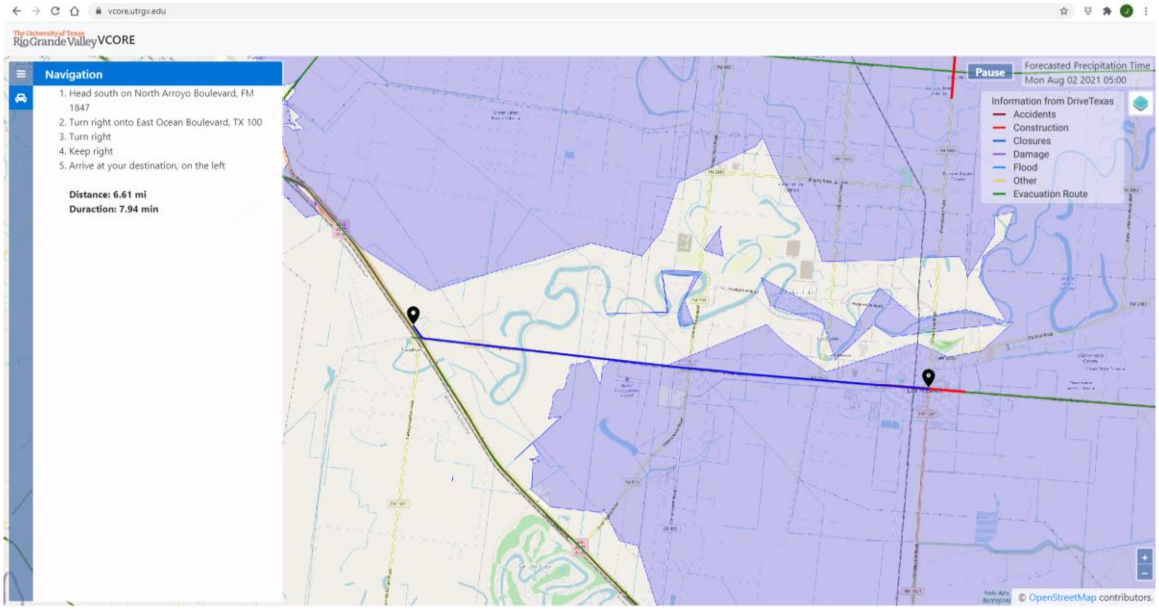


Navigation

1. Head south on North Arroyo Boulevard, FM 1847
2. Turn right onto East Ocean Boulevard, TX 100
3. Turn right
4. Keep right
5. Arrive at your destination, on the left

Distance: 6.61 mi
Duraction: 7.94 min

Figure 61. [From Los Fresnos, Cameron County to TxDOT evacuation route US 83] in 100-year 1 day duration storm with category 1 hurricane storm surge

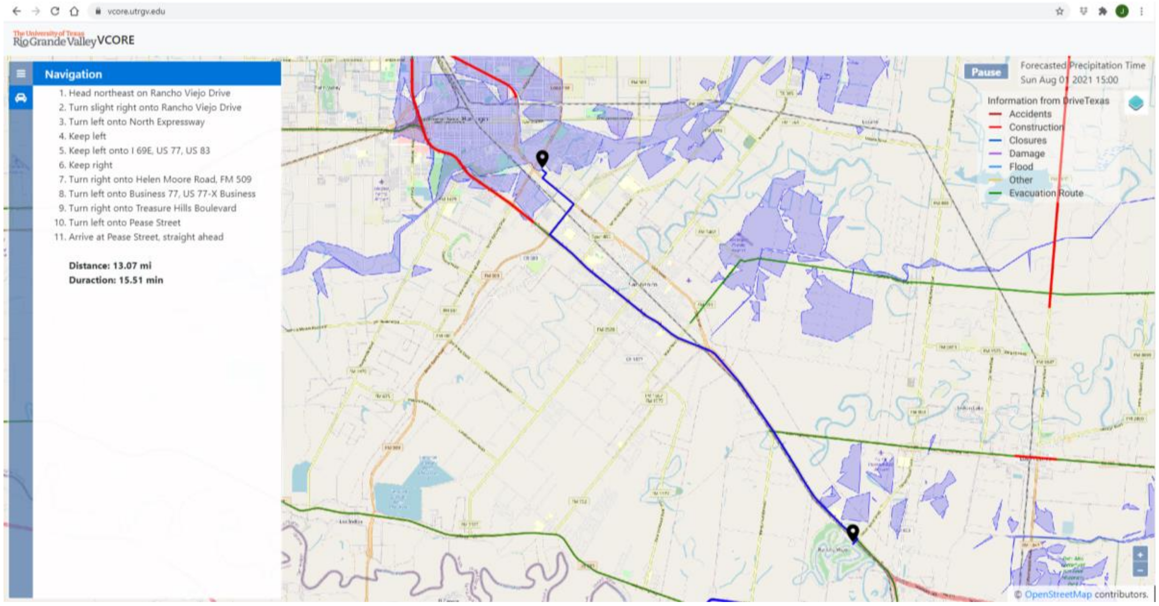


Navigation

1. Head south on North Arroyo Boulevard, FM 1847
2. Turn right onto East Ocean Boulevard, TX 100
3. Turn right
4. Keep right
5. Arrive at your destination, on the left

Distance: 6.61 mi
Duraction: 7.94 min

Figure 62. [From Los Fresnos, Cameron County to TxDOT evacuation route US 83] in 100-year 1 day duration storm with category 5 hurricane storm surge



1. Head northeast on Rancho Viejo Drive
2. Turn slight right onto Rancho Viejo Drive
3. Turn left onto North Expressway
4. Keep left
5. Keep left onto I 69E, US 77, US 83
6. Keep right
7. Turn right onto Helen Moore Road, FM 509
8. Turn left onto Business 77, US 77-X Business
9. Turn right onto Treasure Hills Boulevard
10. Turn left onto Pease Street
11. Arrive at Pease Street, straight ahead

Distance: 13.07 mi
Duraction: 15.51 min

Figure 63. [From Rancho Viejo, Cameron County to South Texas Emergency Care, 1705 Vermont, Harlingen, TX 78550] in 100-year 1 day duration storm with category 1 hurricane storm surge

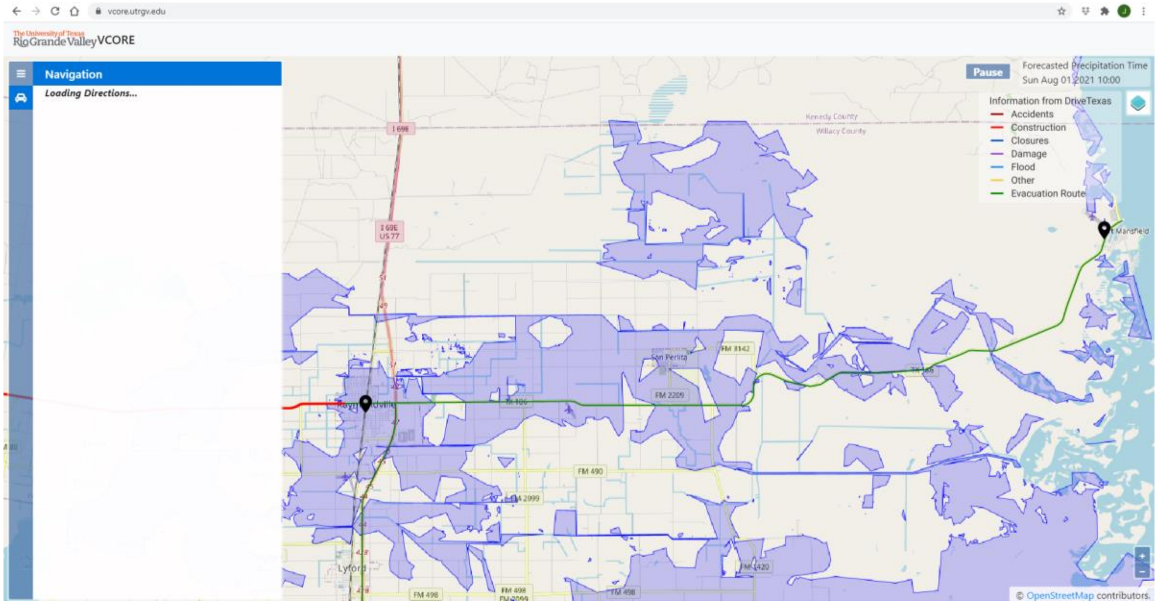


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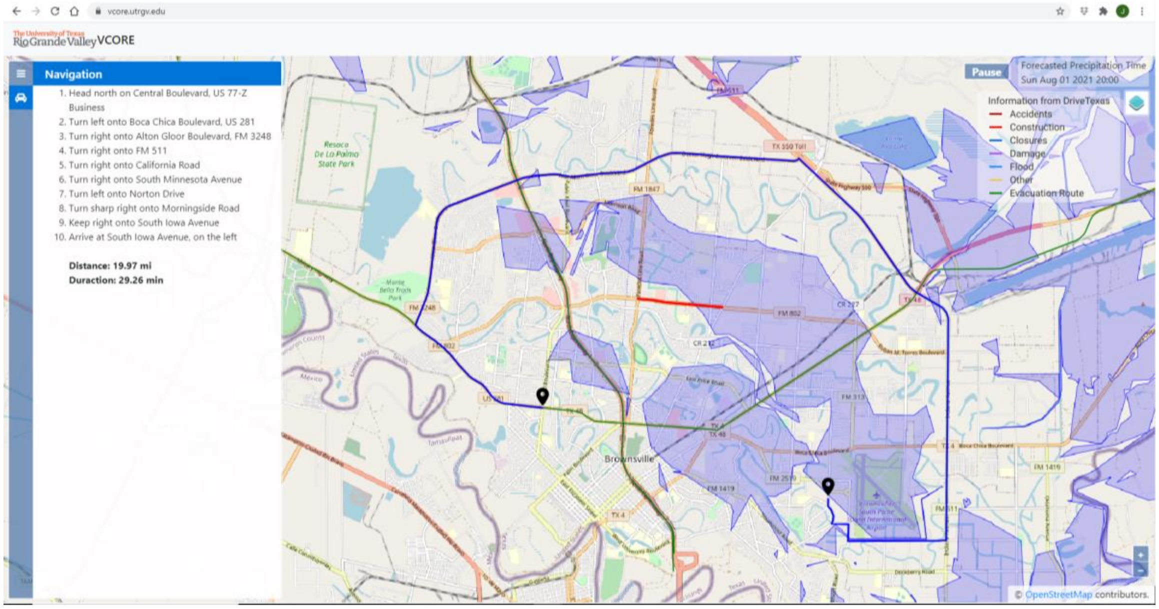
Figure 64. [From Port Mansfield, Willacy County to Emergency Medical Services, 693 S 7th St. Raymondville, TX 78580] in 100-year 1 day duration storm with category 1 hurricane storm surge

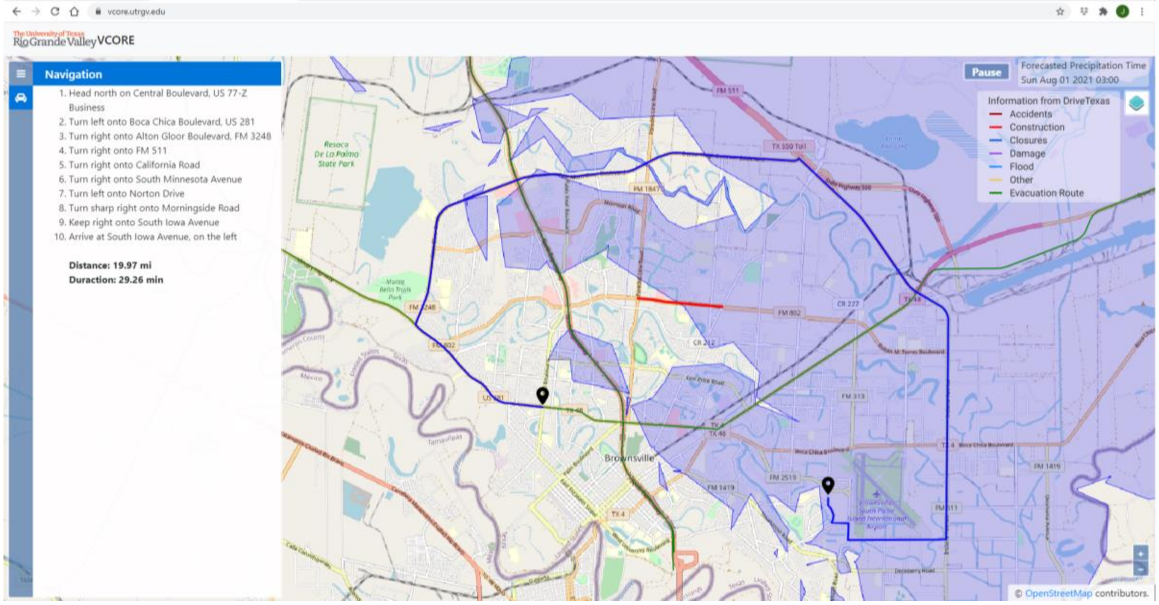


Navigation

1. Head north on Central Boulevard, US 77-Z Business
2. Turn left onto Boca Chica Boulevard, US 281
3. Turn right onto Alton Gloor Boulevard, FM 3248
4. Turn right onto FM 511
5. Turn right onto California Road
6. Turn right onto South Minnesota Avenue
7. Turn left onto Norton Drive
8. Turn sharp right onto Morningside Road
9. Keep right onto South Iowa Avenue
10. Arrive at South Iowa Avenue, on the left

Distance: 19.97 mi
Duraction: 29.26 min

Figure 65. [From Brownsville International Airport, Cameron County to US 281 Military Highway] in 100-year 1 day duration storm with category 1 hurricane storm surge



Navigation

1. Head north on Central Boulevard, US 77-Z Business
2. Turn left onto Boca Chica Boulevard, US 281
3. Turn right onto Alton Gloor Boulevard, FM 3248
4. Turn right onto FM 511
5. Turn right onto California Road
6. Turn right onto South Minnesota Avenue
7. Turn left onto Norton Drive
8. Turn sharp right onto Morningside Road
9. Keep right onto South Iowa Avenue
10. Arrive at South Iowa Avenue, on the left

Distance: 19.97 mi
Duraction: 29.26 min

Figure 66. [From Brownsville International Airport, Cameron County to US 281 Military Highway] in 100-year 1 day duration storm with category 4 hurricane storm surge

6. PROJECT DISSEMINATION AND OUTREACH

The VCORE website: https://vcore.utrgv.edu/ works as the major dissemination tool for this project. Retrieved input data for the numerical models used, supplemental modeling information, computation results, hypothetical coastal flood maps, and emergency evacuation navigation system are available through the website. In additions, two vital input parameters for the hydrodynamic modeling: precipitations and wind speed/magnitude are continuously updated on the website. Hydrologic engineers, community residences, governmental agencies as well as emergency first responders can easily access the vital information without limitation. This chapter depicts the information provided through website and project outreach activities conducted in the project duration.

6.1 Dissemination of Results through Project Website

The website provides user-interactive GIS format information on the OpenStreatMap https://www.openstreetmap.org/. The platform includes general menu options and legends in the right side and a navigation toolbox and website information in the left side of the website. Users can choose multiple overlays such as, Information from DriveTexas, Grid Coverage, Emergency Layers, Forecasting Data Layers, Hypothetical Flood Layers, Watershed Information.

6.1.1 Hypothetical Flood Layers

The hypothetical flood layer feature of VCORE shows users the predicted flooding areas for 2 days in the event of a hurricane of different category over the span of 10 to 500 years. VCORE gives the user the option to view each individual predicted flooded area at a time or all at once as shown in Figure 67. The hypothetical flood layer feature is divided into multiple groups and subgroups as seen on the right-side of the figure. The first group is divided into 5 layers according to their prediction year: 10, 25, 50, 100, and 500. Each individual year layer has 2 subgroup layers of 1 Day and 2 Day. Each day layer holds 5 layers for the 5 different hurricane categories. The user can select the hurricane category they wish to see to view its representation on the website's map or they can download a JPG image of the hurricane flood area to keep for their own record.

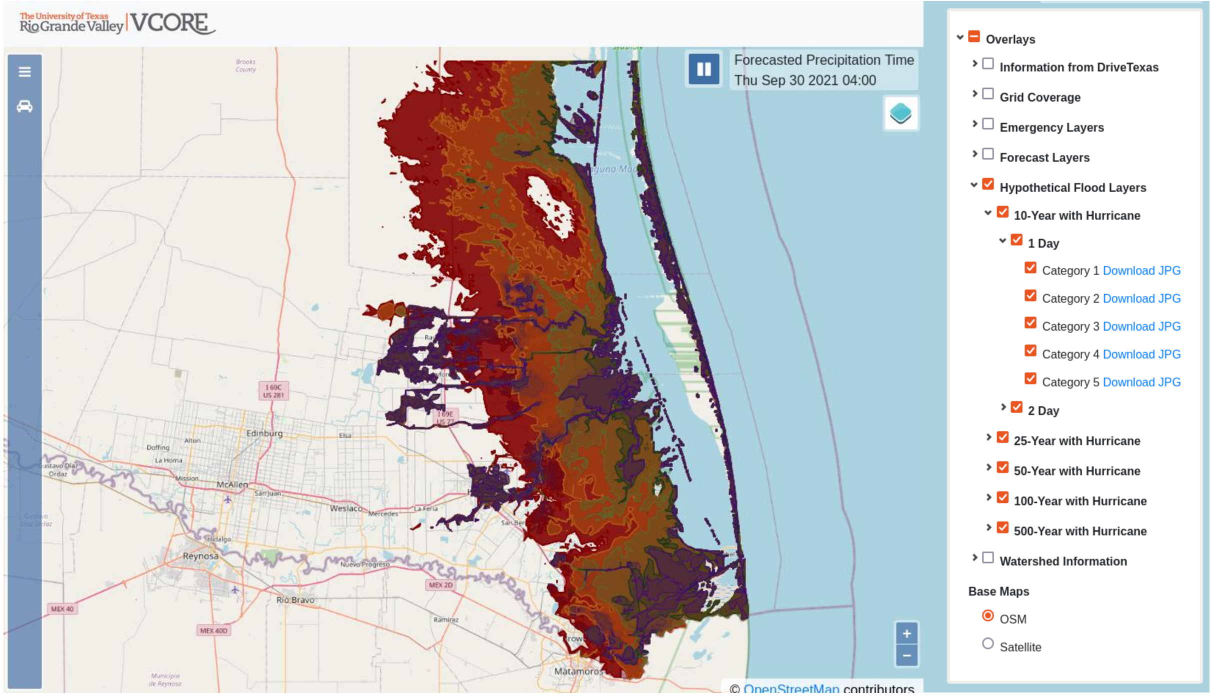


Figure 67. Hypothetical flood layers of the five frequency storms for 1- and 2-day with 5 category hurricanes

6.1.2 Evacuation Navigation Tool

The routing feature of VCORE gives users directions from any two points in the Rio Grande Valley, so long as those points are not near an area with no visible roads on the map. The starting point is represented by a black pin and the destination by a red pin. Once a route is found, VCORE displays the directions on the left panel step by step along with the distance and estimated time of arrival and visually displays the path in a blue line. To calculate a route, we constructed our own OpenRouteService (ORS) API on a separate server. VCORE sends the ORS API the coordinates of the two starting points and the ORS API calculates a path using graphs to find the shortest path and returns the line coordinates and text directions in geoJSON format back to VCORE. The routing feature can also avoid flooded areas from the Hypothetical Flood Layer. Each flood layer has an assigned geoJSON coordinate file of the area it covers. When a flood layer is selected the geoJSON file is also sent to the ORS API to find a path avoiding the flooded areas.

<u>Information from DriveTexas</u>

The information from DriveTexas feature of VCORE shows the user all the current road obstructions in Texas resulting from accidents, construction, closure, damage, floods, and others. VCORE obtains the current road obstructions using the Drive Texas API. Every time the VCORE website is opened or is reloaded a new GET request is made to the Drive Texas API to retrieve the latest road obstruction data. VCORE receives the data in geoJSON format containing the line coordinates of the obstructed roads and the type of obstruction. VCORE parses the data and displays it on the map for users to see as shown in Figure 68. Each different obstruction type is assigned a color, accidents are maroon, constructions are red, closures are blue, damages are purple, floods are light blue, and others are yellow. Each obstruction type is assigned a layer that users can view individually or all at once as shown in the figure.

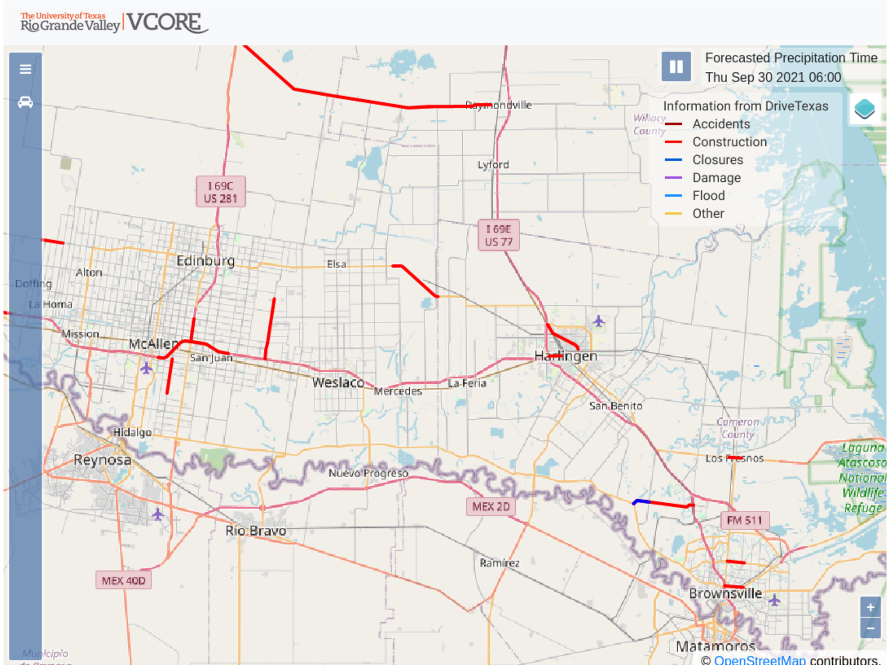


Figure 68. Information from DriveTexas shows current construction and road closures

<u>Emergency Layers</u>

The emergency layers feature of VCORE shows users all the necessary emergency buildings in the Rio Grande Valley and escape routes in Texas in the event of a hurricane as shown in Figure 69. The green routes are the emergency evacuation routes in the event of a hurricane, the evacuation route coordinates are from the Texas Department of Transportation. The yellow markers are the shelters put in place by Hidalgo

County in 2008 in preparation for Hurricane Dolly. The red markers are the emergency management offices in Cameron and Willacy County including the American Red Cross offices. The blue markers are the major hospitals in Cameron and Willacy County including the two Valley Baptist Medical Centers, the Harlingen Medical Center, and the Valley Regional Medical Center. VCORE separates its emergency features into three layers: Evacuation Routes, Shelters, and Emergency & Medical Services (emergency management office and hospitals). The user can view each layer individually or at the same time as shown in Figure 69. Each marker is located on the exact coordinate position of the building it represents. Upon clicking on a marker, VCORE shows the user the name of the emergency service and its address. The user can copy the address to use their default navigation service, or they can use VCORE's own routing feature.

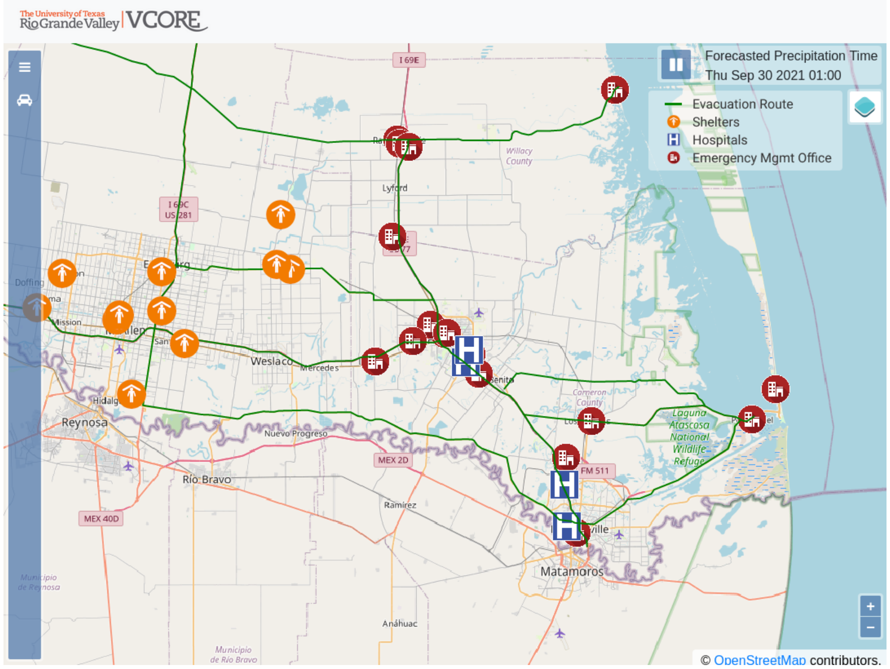
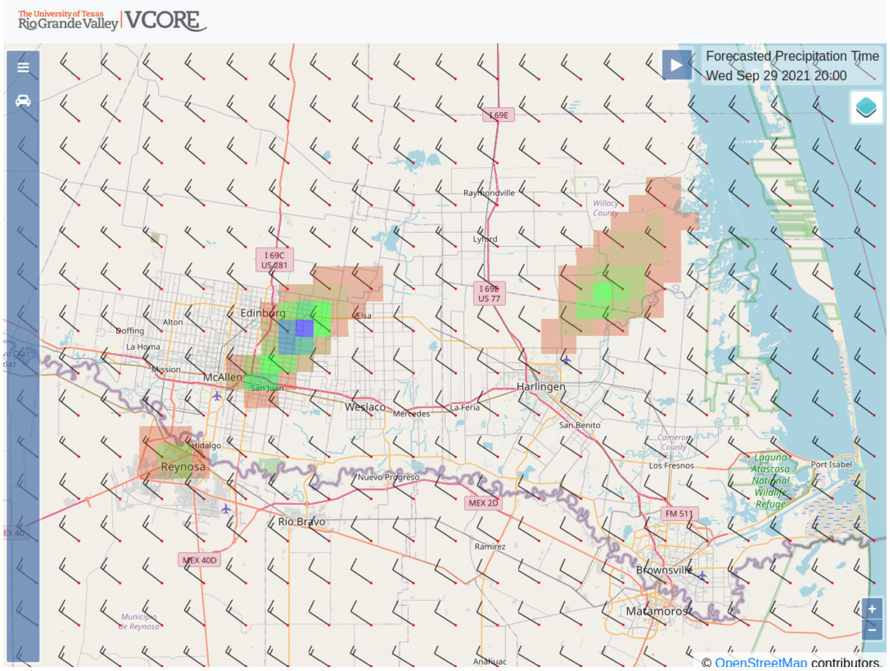


Figure 69. Displaying evacuation routes, shelters, hospitals, and emergency management offices

6.1.3 Watershed Modeling Information Layers

Forecast Layer

The forecast layer feature of VCORE shows users the forecasted precipitation and wind of the Conterminous United States (CONUS) area for the next 36 hours. VCORE retrieves the latest precipitation and wind forecasts every 6 hours. Both forecasts are retrieved from the National Oceanic and Atmospheric Administration's (NOAA's) Operational Model Archive and Distribution System (NOMADS) website in GRIB2 format. The GRIB2 format allows the data to be shown in an animation-like type form. The precipitation forecast is represented in NOAAs HRRR atmospheric model using red, green, and blue colors as shown in Figure 70. The wind forecast is represented in NAM model using wind barbs to represent the wind direction and speed. The forecast layer has two sub-categories precipitation and wind layer, and each can be viewed individually or at the same time. On the top right-hand corner of the VCORE website there is a Forecast Precipitation Time timer that shows the user the exact time the visual forecast is representing during the animation. The animation restarts every 3 minutes during which it displays the forecast for each hour every 5 seconds. VCORE gives the user the option to pause the forecast animation at any time to further analyze the forecast.

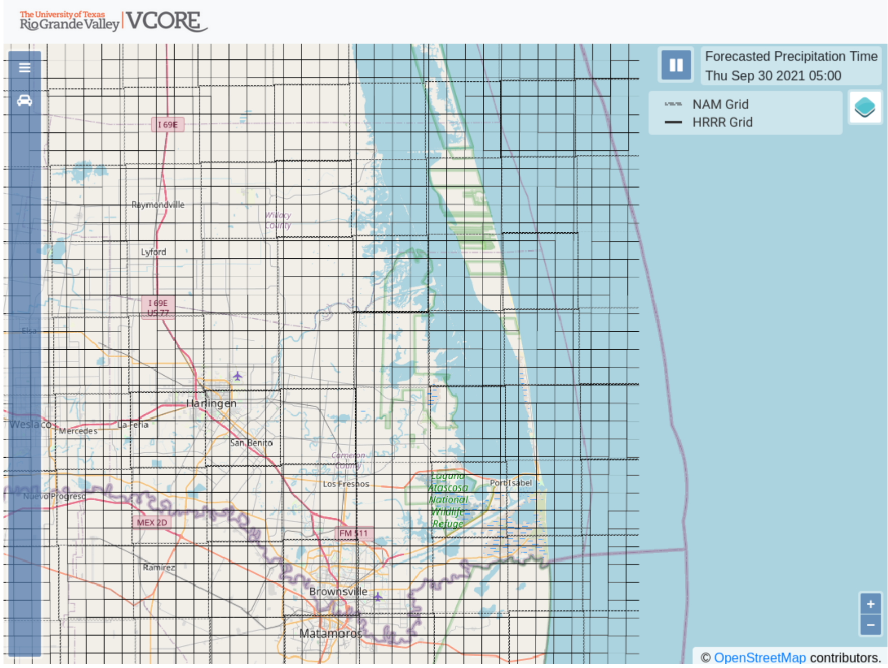


Forecasted Precipitation Time
Wed Sep 29 2021 20:00

Figure 70. Forecast layer displays precipitation and wind forecasts for the next 36 hours

<u>Grid Coverages</u>

The grid coverages feature of VCORE covers the Rio Grande Valley and Laguna Madre area with two grids one for the North American Mesoscale (NAM) https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00630 weather forecast and the other for the High-Resolution Rapid Refresh (HRRR) https://rapidrefresh.noaa.gov/hrrr/ forecast data. The NAM grid is represented by a grid using dotted lines, while the HRRR grid is represented by a grid using straight lines. A user can view each grid individually or at the same time as shown in Figure 71.



Forecasted Precipitation Time
Thu Sep 30 2021 05:00

Figure 71. NAM and FRRR grid coverage of the LLM in Grid Coverages

Watershed Information Layer

The watershed information feature of VCORE shows users the basin areas and drain lines for Cameron and Willacy County. The watershed information feature is divided into 2 subgroups one for Cameron County and the other for Willacy County. Each group holds the watershed information for their county and is divided into 3 layers: gage-stations, sub-basin layer, and drains layer. The user can view each layer individually or all at once as shown in Figure 7. There is a gage station for each individual sub-basin as shown in Figure 72. Each gage station holds the waterfall information for their sub-basin according to the precipitation forecast from the NOMADS HRRR model. When a user clicks on a gage station marker, they are given the option to download the forecasted HRRR model for that sub-basin in DSS format.

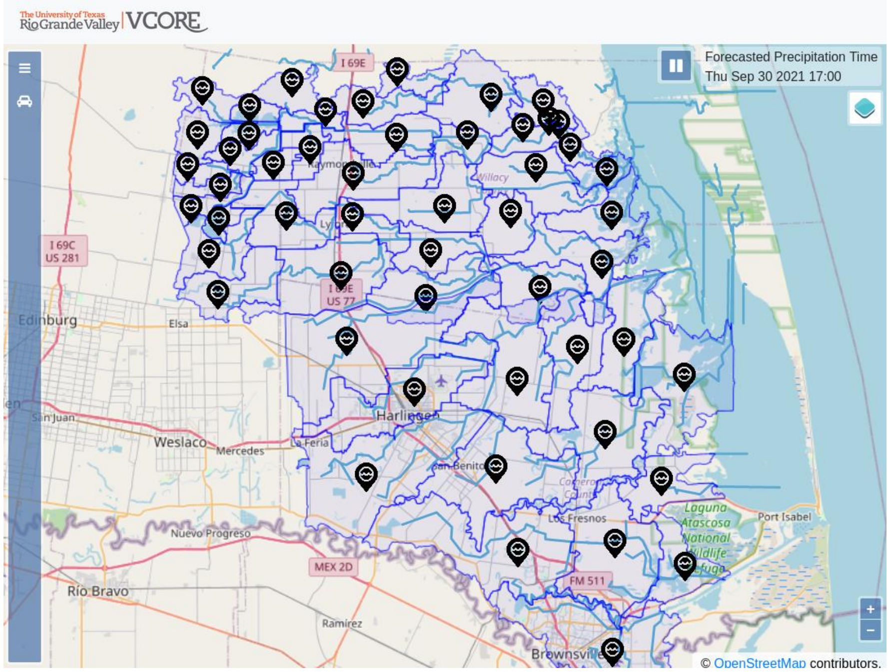


Figure 72. Cameron and Willacy County sub-basin layers, drain layers, and gage stations

6.2 Project Outreach

The following table is a summary of project outreach activities including meetings with local governmental agencies and technical conference to present the CMP project outcome during the project period. Three meetings with the product end-users of the local governmental agencies of County emergency management office and engineering/transportation departments were proposed to discuss ideal modeling scenarios including hypothetical storm events and local drain channels determination. The meeting agenda/minutes and conference schedule were attached in Appendix II.

Table 16. List of meetings and presentation with the project end-users conducted

Date	Agency/conference	Agenda	Location
11/16/2018	Cameroon County Emergency Management Office	Coastal flood model feedback	Brownsville, Cameron County

03/28/2019	2019 South Texas All-Hazards Conference, State of Texas	Hurricane storm surge modeling result presentation	McAllen, Hidalgo County
04/10/2019	Willacy County Emergency Management Office	Coastal flood model feedback	Raymondville, Willacy County
04/15/2019	Cameroon County Emergency Management Office	Coastal flood model feedback/modeling scenario	Brownsville, Cameron County
04/24/2019	Cameroon County Engineering/ transportation department	Coastal flood model feedback	Brownsville, Cameron County
05/20/2021	2021 Water Quality Management Conf., RGV Stormwater Taskforce	Coastal flood modeling result update	South Padre Island, Cameron County
05/20/2021	2021 Water Quality Management Conf., RGV Stormwater Taskforce	Emergency evacuation navigation system development	South Padre Island, Cameron County

In addition, two local TV media interviews for weather and flood prevention were conducted.

- KVEO media request in February 2021: The interview was focused on the history of flooding in RGV and infrastructure to improve against the flood threat. I demonstrated the hurricane storm surge model and website developed in the CMP project as the engineering tool.
  RGV municipalities work to prepare for future flooding | KVEO-TV (valleycentral.com)

- KRGV Channel 5 interview in October 2019: The interview was focused on the hurricane storm surge and occurrence interval. I introduced the CMP project as the scientific and engineering study for the coastal flood preparation and management. The interview was aired on November 16th at 10 pm news.

CONCLUSIONS

One of the two major contributions of the CMP Cycle 23 funded project, Storm Surge Flood Maps Development for the Lower Laguna Madre Coastal Emergency Management is the LLM coastal flood depth maps due to 50 hypothetical storm events. Each hypothetical storm is a matrix of five frequency storm events (10, 25, 50, 100, and 500-year), two precipitation durations (1 and 2-day), and five categories of hurricane based on the wind speed. These frequency storms were modified from the originally proposed values (25, 50, 100-year for a duration of 12-hour, 1, and 2-day) to adjust the modeling scenarios to more realistic hydrologic circumstances. The ADCIRC computation results of five representing hurricanes storm surge is an average 8.8 ft (in a range of 1.1 to 26.2 ft) along the LLM watershed (Cameron and Willacy County) costal line. These predicted ocean water surface elevations were assigned to the HEC-RAS watershed flood model downstream boundary conditions through the DSS format files by the coupled model between ADCIRC and HEC-RAS.

The coupled model predicted that the LLM coastal watershed flood zone water depth will be up to 9 ft around the Brownsville Ship Channel area, the low-lying area south of the Arroyo Colorado, if a 500-year frequency rainfall event is continued 2 days and a category 5 hurricane strikes the coast. In this scenario, most of Brownsville area will be submerged, and the City of Harlingen will also be flooded mostly by the backwater from the storm surge filled along the Arroyo Colorado. By a hypothetical storm of category 3 hurricane, 100-year frequency for 1 day rainfall duration, some locations of the Brownsville area will be flooded by up to 4.5 ft, but most coast area including the Port Mansfield, South Padre Island, and Arroyo City will be flooded, therefore early evacuations from the impacted areas should be recommended.

The evacuation navigation tool is the other major output of this project. Based on the navigation capacity analysis, the scenario makes a significant increasement of travel time in a route of Brownsville Airport to US 281 Military Highway, one of the TxDOT evacuation routes. Evacuations from the coastline are not available during the storm event. However, the evacuation navigation tool successfully finds alternative path avoiding the flooded areas. The interactive GIS maps presenting coastal flood areas and the evacuation navigation tool are accessible at the project website: https://vcore.utrgv.edu/. Besides these main deliverables, the project is able to provide robust coupled hydrodynamic model for hurricane storms surge and ocean flow circulation prediction.

The immediate benefit of these outcomes to the end-users are high fidelity coastal flood geospatial information that will serve as an effective tool for local emergency management and planning. However, the models can be always improved/localized by model calibration with observation data. The ADCIRC model was calibrated/validated with multiple set-ups of tidal constituents and surface roughness values of the ocean bathymetry. The 2-dimensional finite element meshes covering the computational domain can be improved/updated to predict more accurate results and with new coastal infrastructures. Numerical instability is another weakness of the model simulation. Rapid changes of the wind forcing data causes the issue, but it is inevitable for hurricane storm surge prediction. Finer mesh along the given hurricane tracks can reduce the occurrence of the stability.

The watershed rainfall-runoff and flood model improvement can be discussed with the local drainage engineers. The subbasin delineation was conducted by using ArcHydro tool in HEC-HMS model with DEM data. Resolution of DEM data is an important factor, the local engineers and manager’s decision on land cover and soil types would be a significant contributor of the model accuracy improvement. Based on network and density of subbasins of the watershed, the HEC-RAS flood model can be updated by assigning future flood management plans such as drain channel and stormwater detention fond operations. Several Drainage Districts maintenances rainfall and drainage flow gage stations. These observation data can serve as the flood model calibration. In this way, a forecasting system for coastal food will give explicit solution to the emergency management and coastal disaster prevention. Executing the coupled hydrodynamic model was already automated in this project. Retrieving external climate data also should be incorporated into the system for predominant flood forecasting. The forecasting system has not developed in this phase, however, the retrieve forecasted data (precipitation and wind) are available through the project website. This will be extra outcome of this project.

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APPENDIX I. CAMERON COUNTY HYDROLOGIC MODELING RESULTS

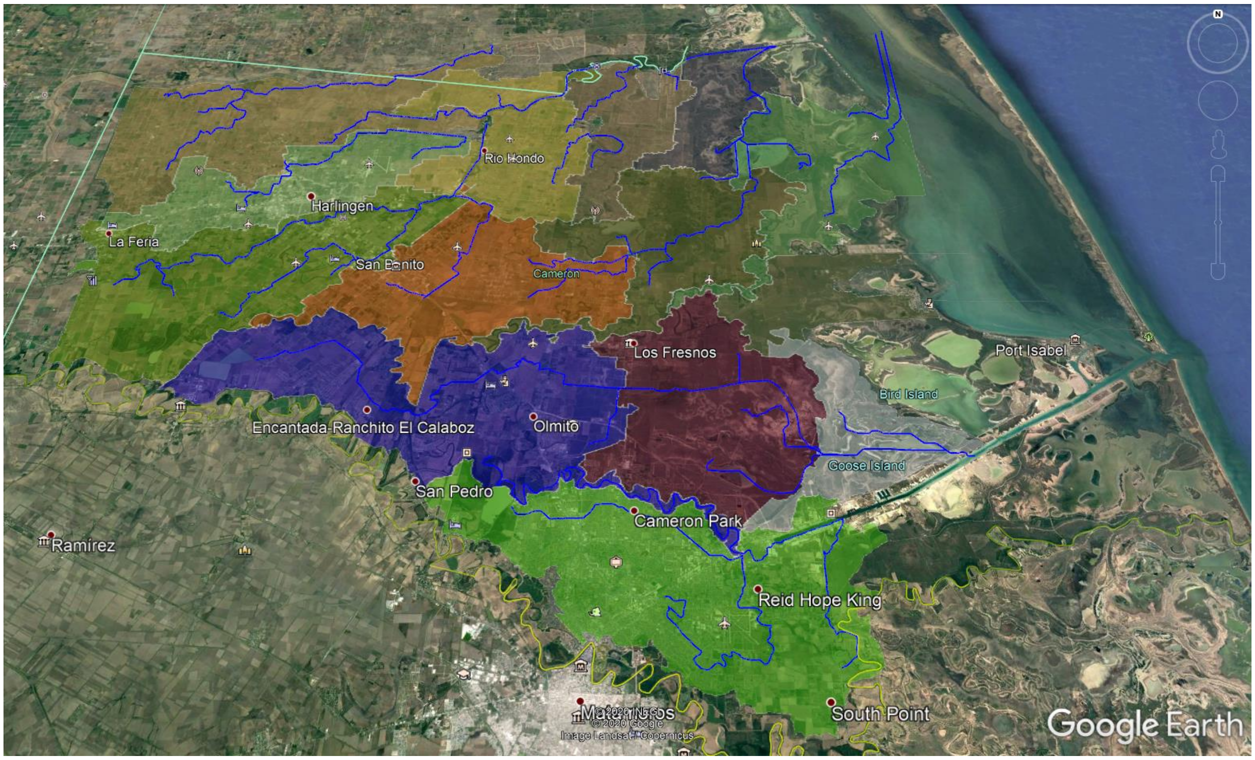


Figure AI-1. Cameron County Sub-basin Watershed

Sub-basin	Area (mi^2)	Drainage
CC-C	39.55	Brownsville drainage
CC_H	38.7	Brownsville drainage
CC_K	29.05	Brownsville drainage
CC_J	37.72	Arroyo Colorado drainage
CC_M	19.89	Floodway drainage
CC_E	57.49	Arroyo Colorado drainage
38088	16.94	Brownsville drainage
CC_F	41.99	Floodway drainage
CC_B	37.67	Floodway drainage
41721	19.39	Brownsville drainage
CC_D	43.39	Arroyo Colorado drainage
CC_O	26.31	Arroyo Colorado drainage
CC_P	26.31	Arroyo Colorado drainage
CC_G	24.49	Floodway drainage
CC_N	16.72	Brownsville drainage
CC_A	57.67	Floodway drainage

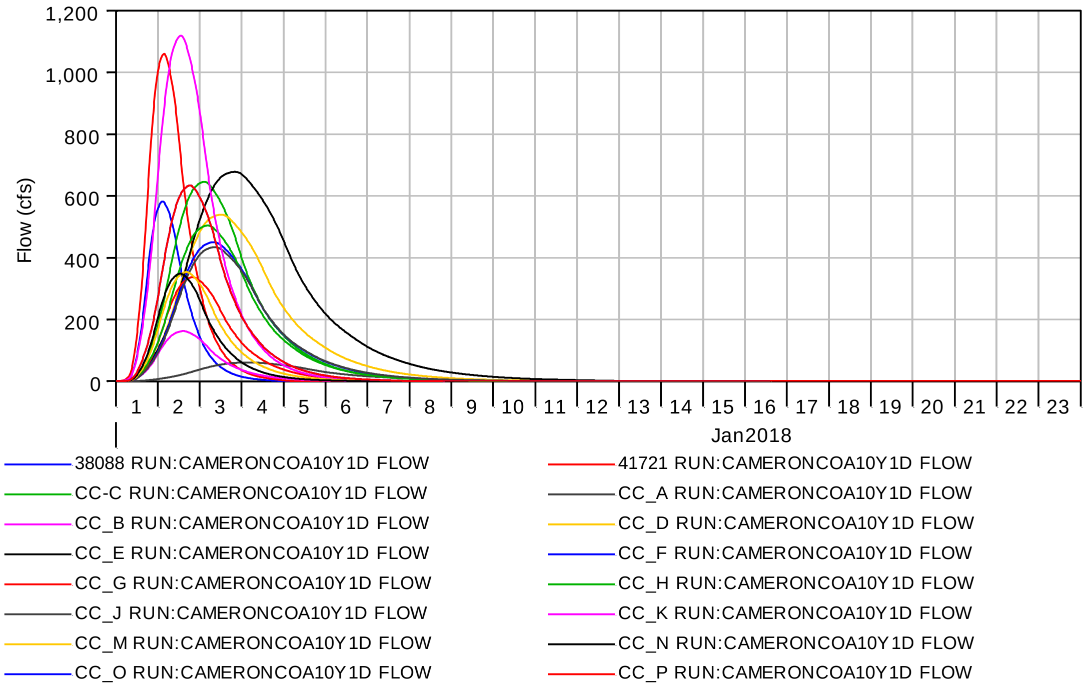


Figure AI-2. Watershed Hydrographs due to 10-year frequency storm 1-day precipitation duration

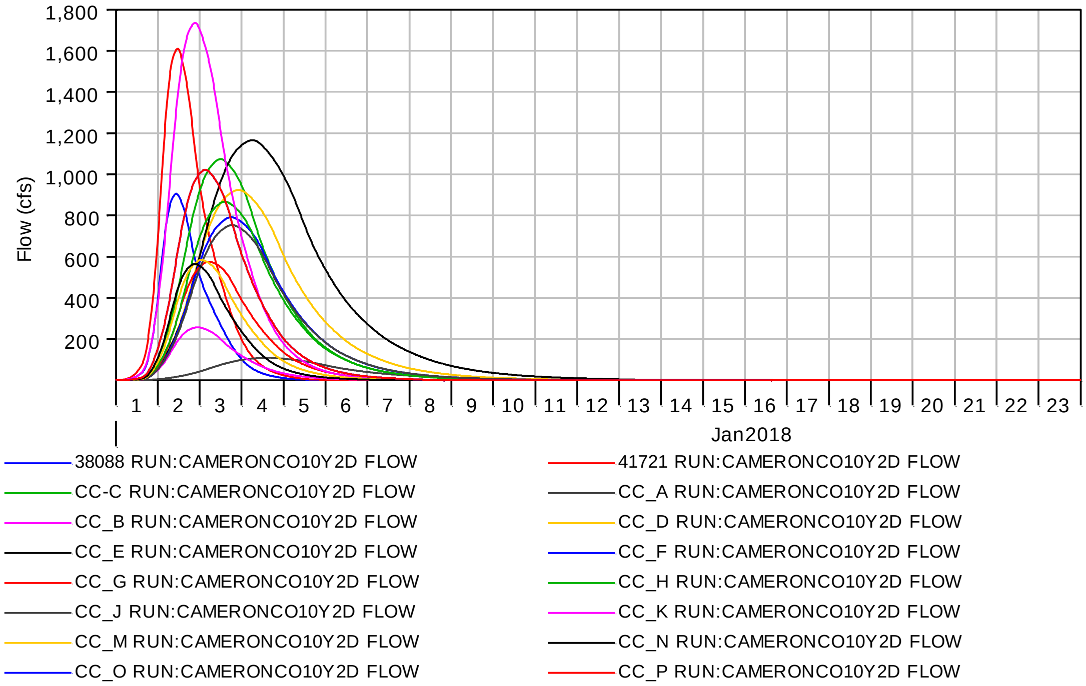


Figure AI-3. Watershed Hydrographs due to 10-year frequency storm 2-day precipitation duration

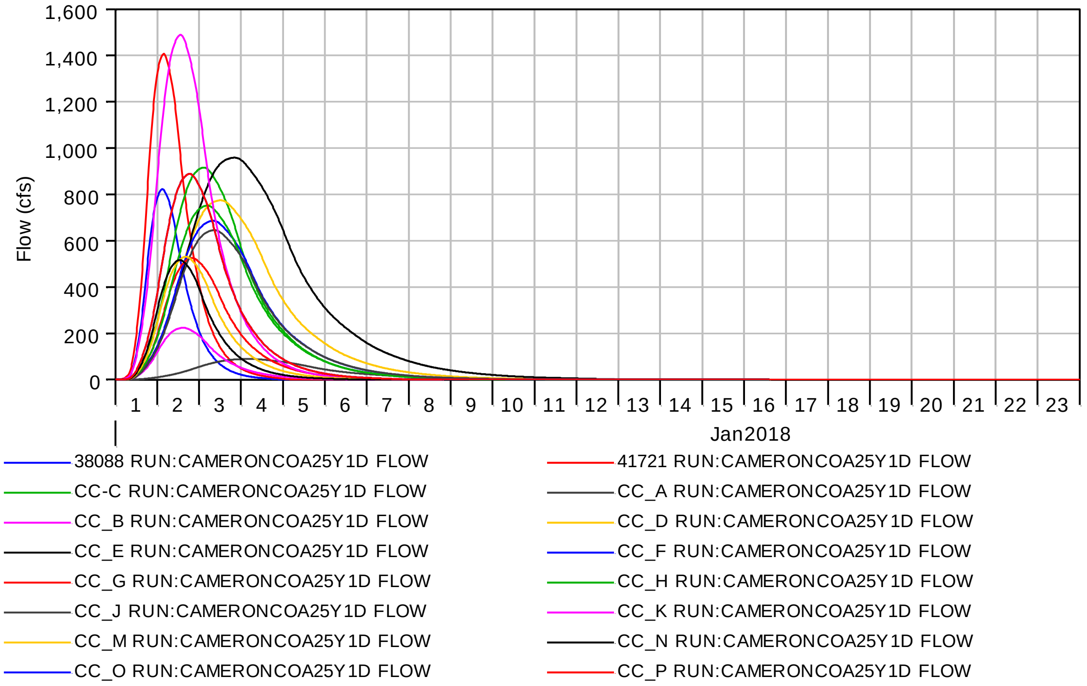


Figure AI-4. Watershed Hydrographs due to 25-year frequency storm 1-day precipitation duration

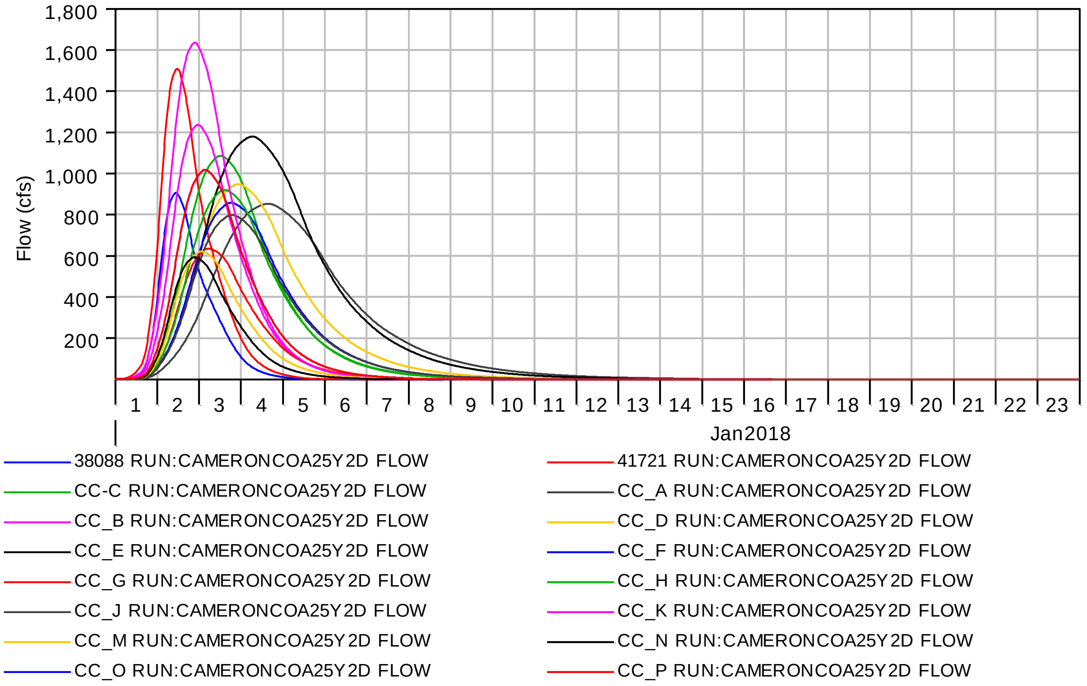


Figure AI-5. Watershed Hydrographs due to 25-year frequency storm 2-day precipitation duration

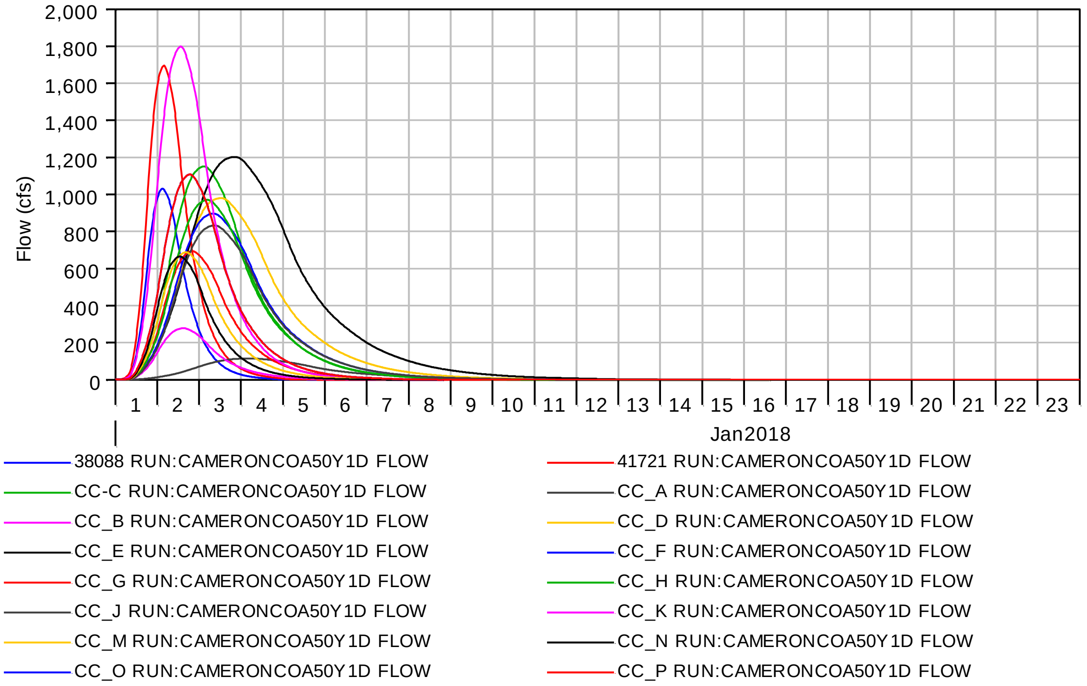


Figure AI-6. Watershed Hydrographs due to 50-year frequency storm 1-day precipitation duration

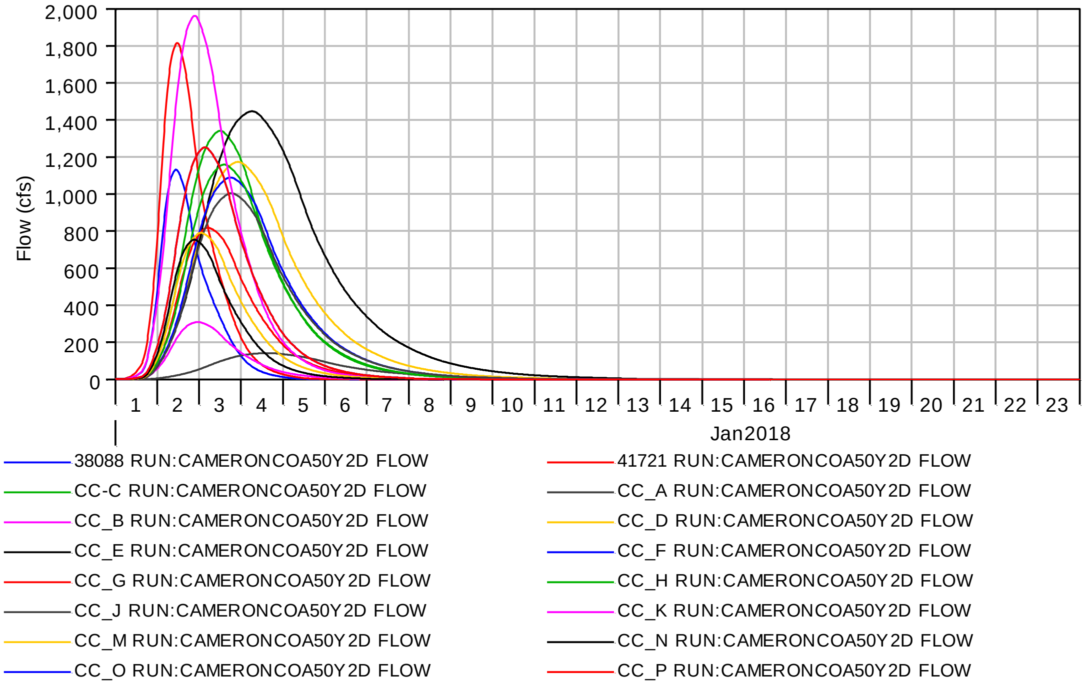


Figure AI-7. Watershed Hydrographs due to 50-year frequency storm 2-day precipitation duration

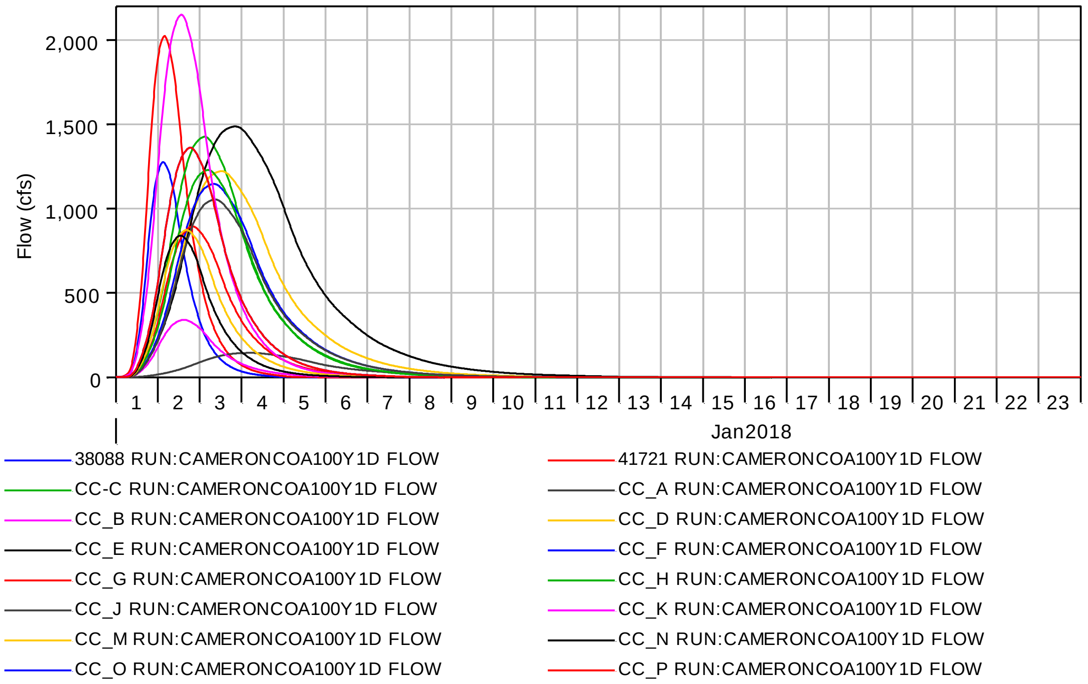


Figure AI-8. Watershed Hydrographs due to 100-year frequency storm 1-day precipitation duration

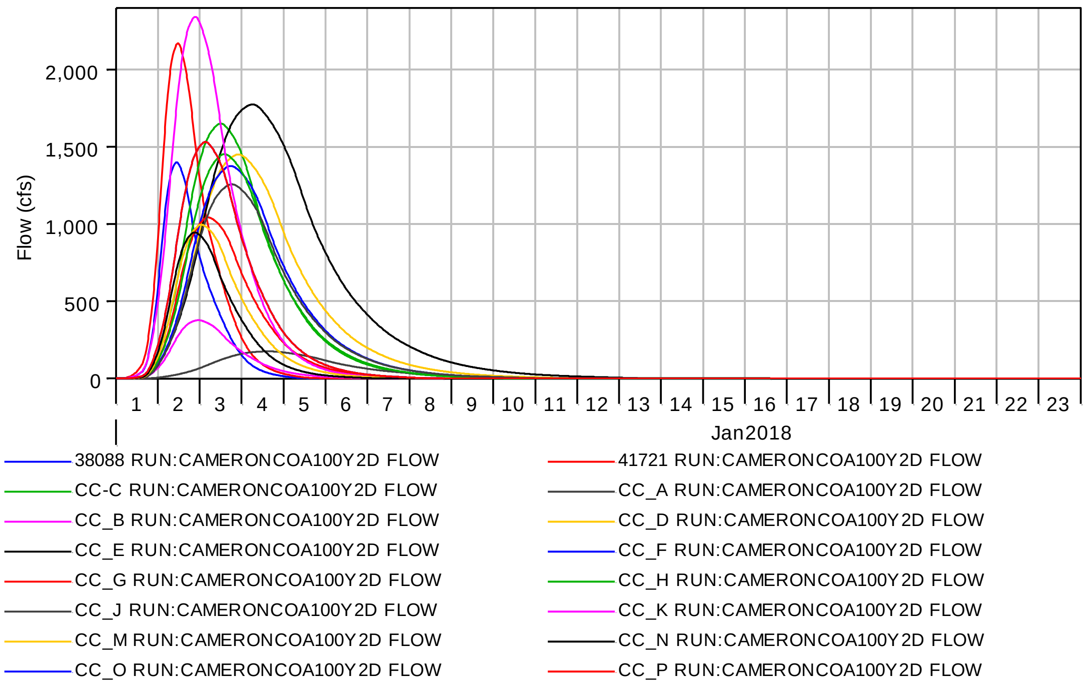


Figure AI-9. Watershed Hydrographs due to 100-year frequency storm 2-day precipitation duration

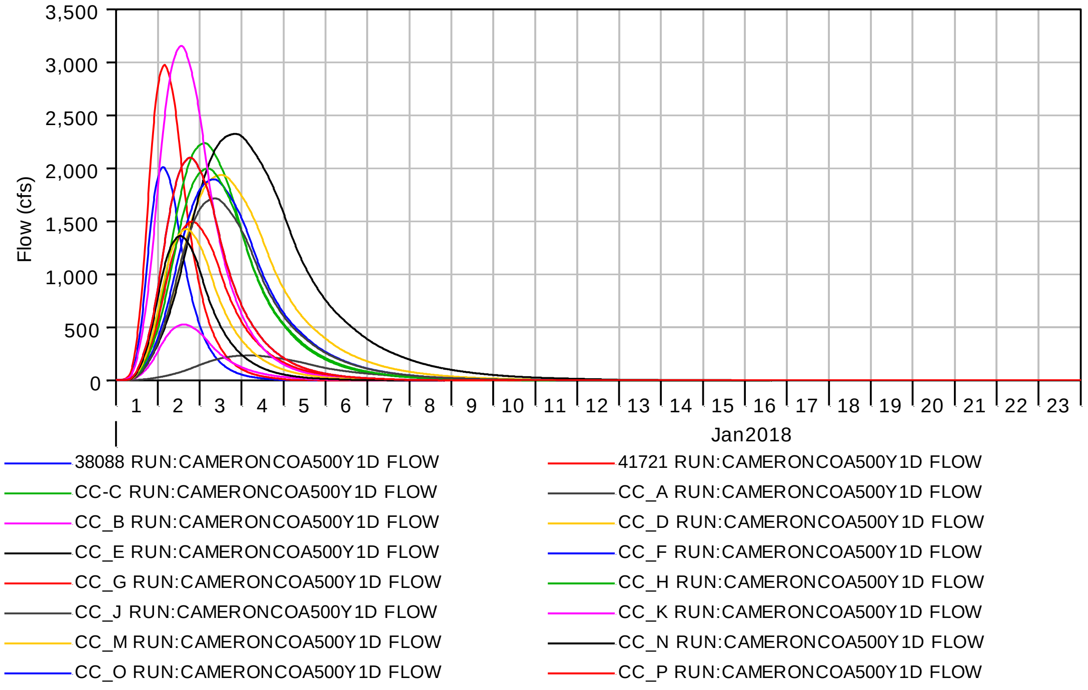


Figure AI-10. Watershed Hydrographs due to 500-year frequency storm 1-day precipitation duration

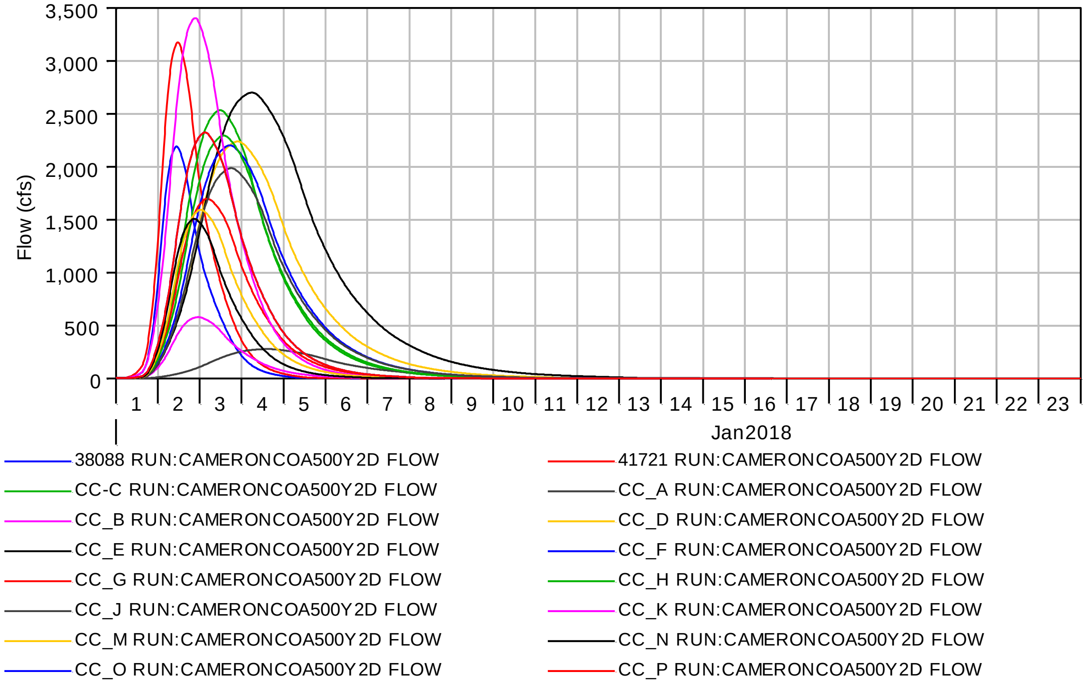


Figure AI-11. Watershed Hydrographs due to 500-year frequency storm 2-day precipitation duration

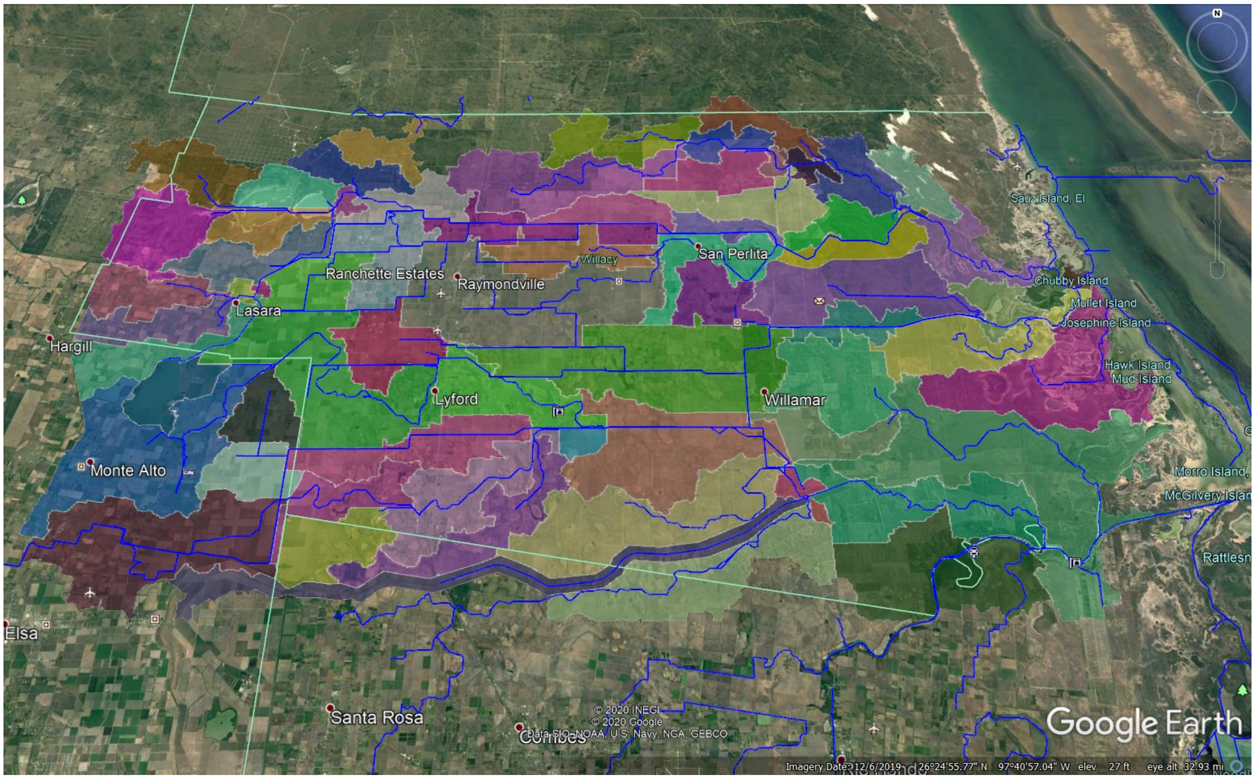


Figure AI-12. Willacy County Sub-basin Watershed

Sub-basins	Area (mi^2)	Drainage
Basin-H	8.41	Raymondville Drainage
Basin-B	8.31	Raymondville Drainage
Basin A	7.60	Raymondville Drainage
Basin-E	5.53	Raymondville Drainage
Basin-C	5.38	Raymondville Drainage
Basin-D	4.95	Raymondville Drainage
Basin-J	4.47	Raymondville Drainage
Basin-K	4.14	Raymondville Drainage
Basin-N'	7.21	Raymondville Drainage
Basin-M	7.21	Raymondville Drainage
Basin-L	4.51	Raymondville Drainage
Basin-S	51.55	Raymondville Drainage
Basin-T	15.83	Raymondville Drainage
Basin-W	8.33	Raymondville Drainage
Basin-Z	39.60	Raymondville Drainage
Basin-X	13.24	Raymondville Drainage
Basin-Y	6.86	Raymondville Drainage
Basin-C1	25.14	Raymondville Drainage
Basin-B1	23.19	Raymondville Drainage

Basin-G1	84.10	Hidalgo Main Drainage
Basin-D1	81.32	Raymondville Drainage
Basin-V	52.90	Hidalgo Main Drainage
Basin-A1	15.33	Hidalgo Main Drainage
Basin-U	35.11	Hidalgo Main Drainage
Basin-R	32.03	Hidalgo Main Drainage
Basin-F	15.19	Hidalgo Main Drainage
Basin-G	1.82	Hidalgo Main Drainage
Basin-K1	15.48	Hidalgo Main Drainage
Basin-O	14.33	Hidalgo Main Drainage
Basin-P	12.71	Hidalgo Main Drainage
Basin-H1	92.78	Floodway Drainage
Basin-F1	27.11	Floodway Drainage
Basin-E1	29.34	Floodway Drainage
Basin-J1	20.86	Floodway Drainage
Basin-Q	31.69	Floodway Drainage

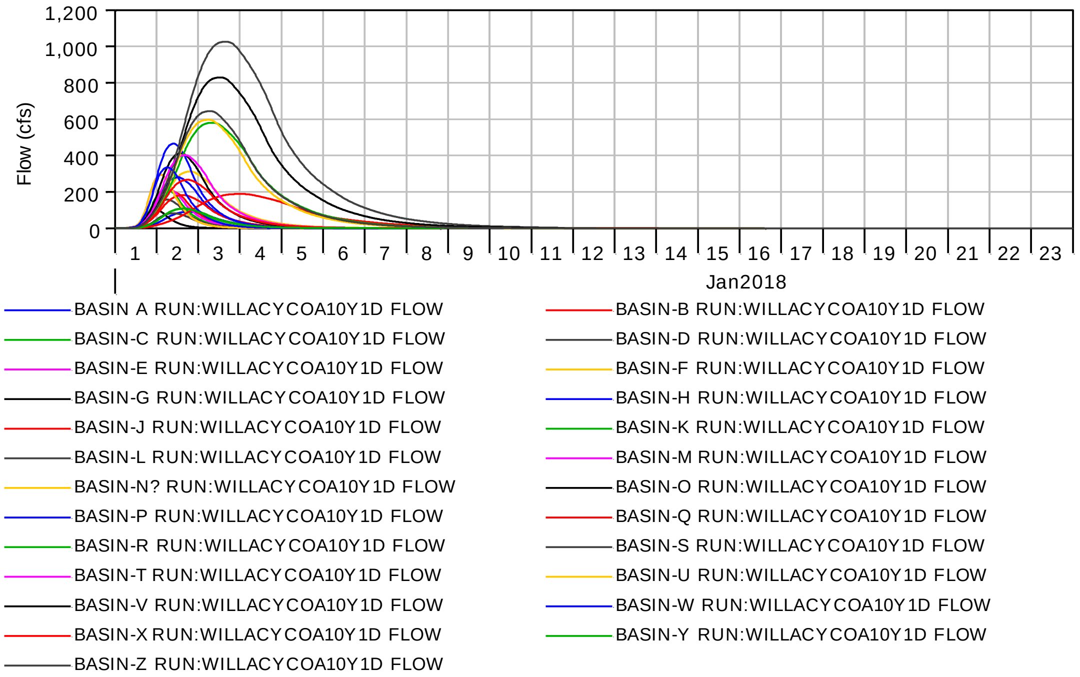


Figure AI-13. Watershed Hydrographs due to 10-year frequency storm 1-day precipitation duration

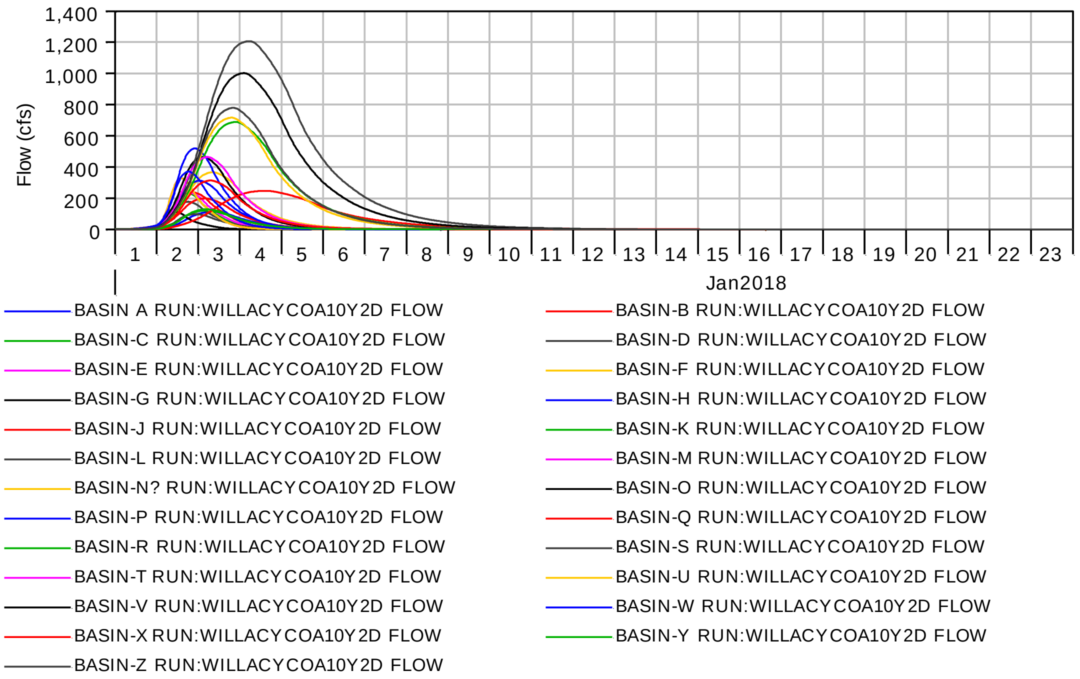


Figure AI-14. Watershed Hydrographs due to 10-year frequency storm 2-day precipitation duration

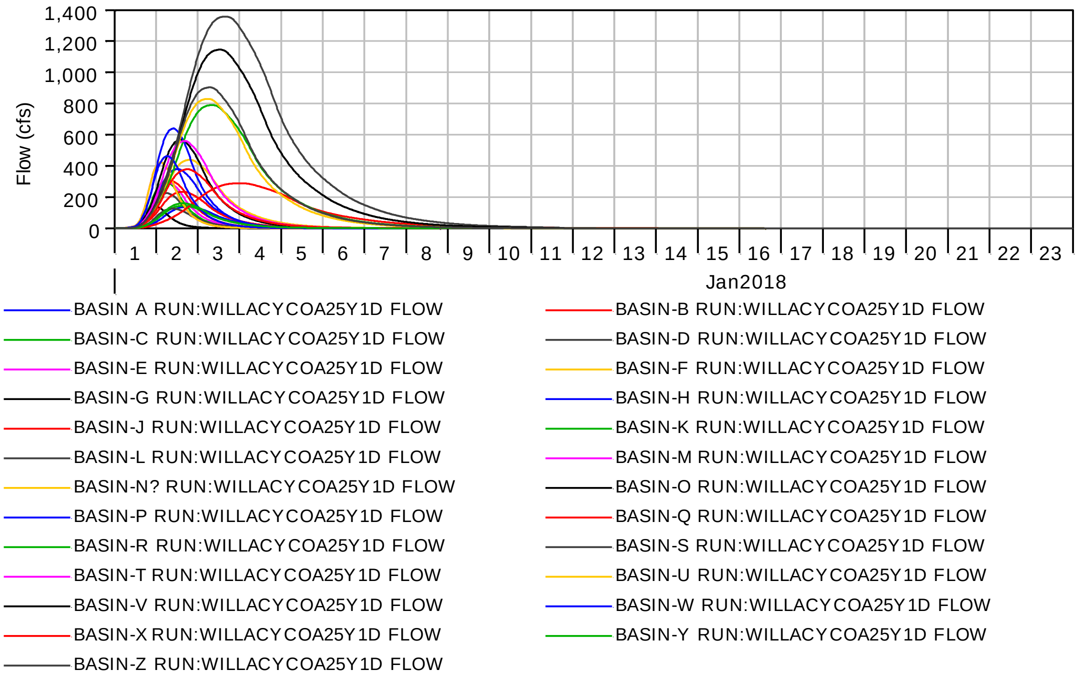


Figure AI-15. Watershed Hydrographs due to 25-year frequency storm 1-day precipitation duration

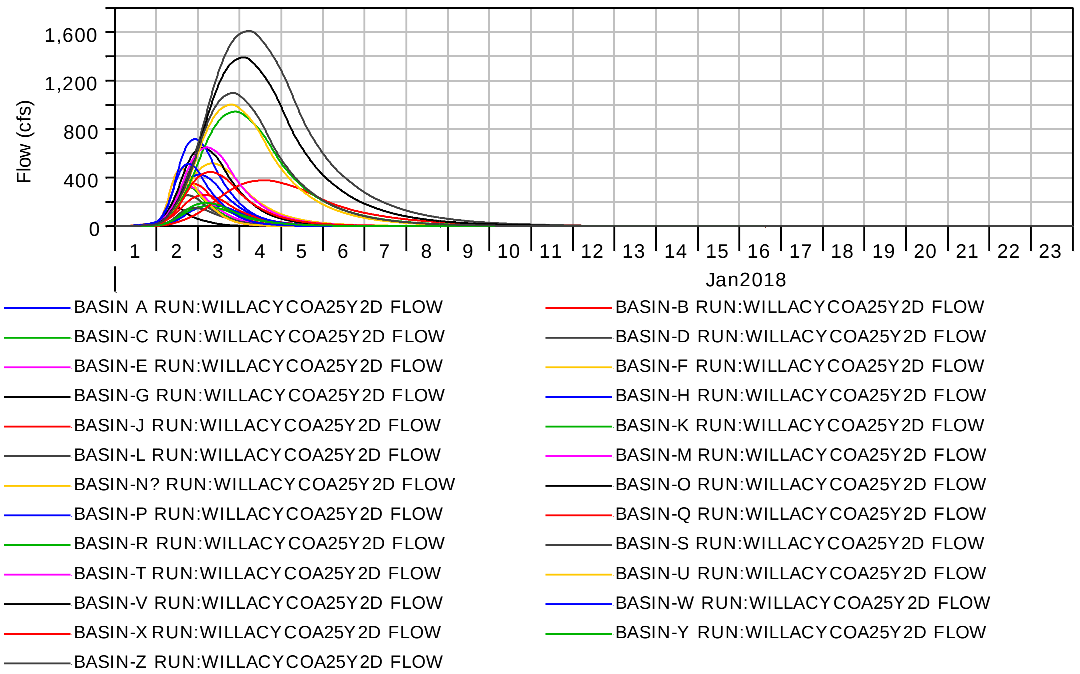


Figure AI-16. Watershed Hydrographs due to 25-year frequency storm 2-day precipitation duration

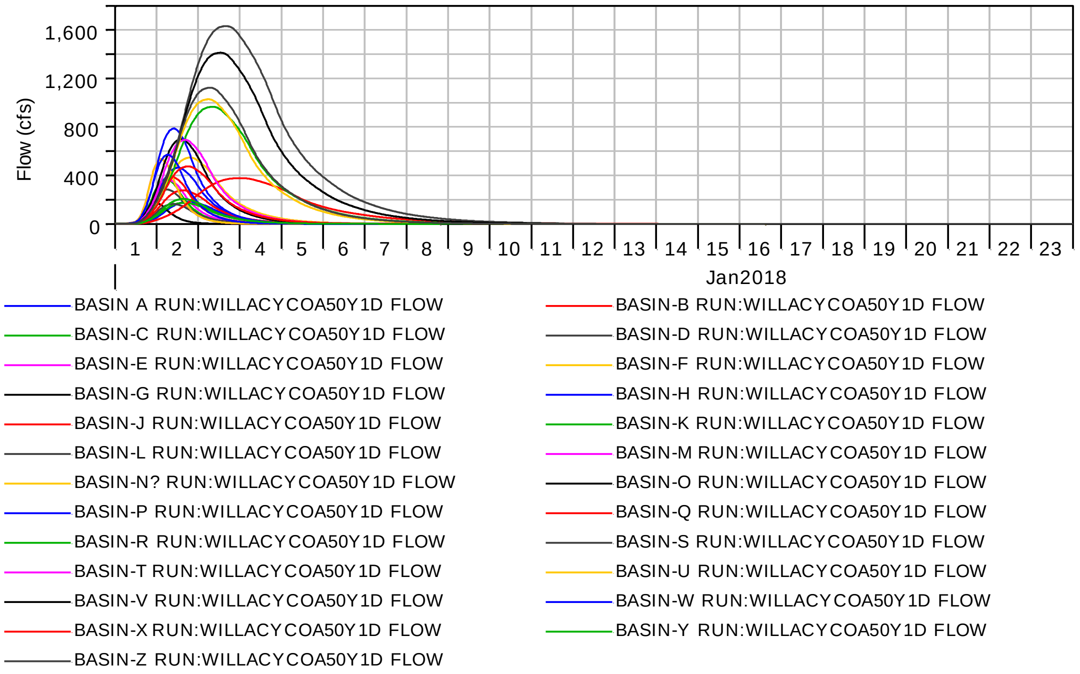


Figure AI-17. Watershed Hydrographs due to 50-year frequency storm 1-day precipitation duration

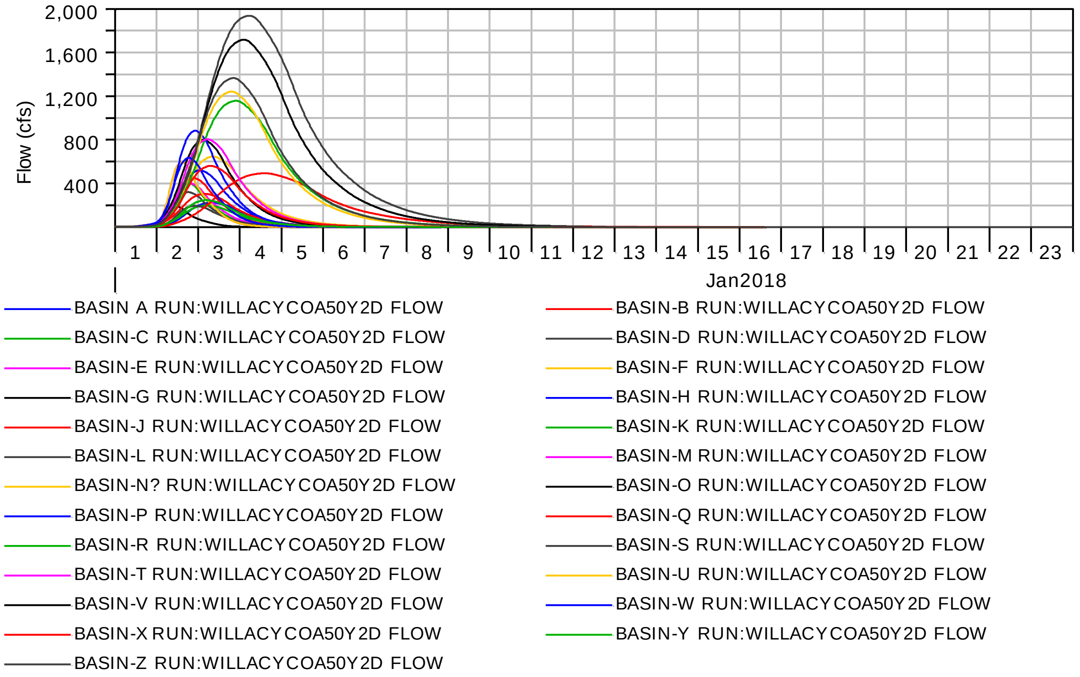


Figure AI-18. Watershed Hydrographs due to 50-year frequency storm 2-day precipitation duration

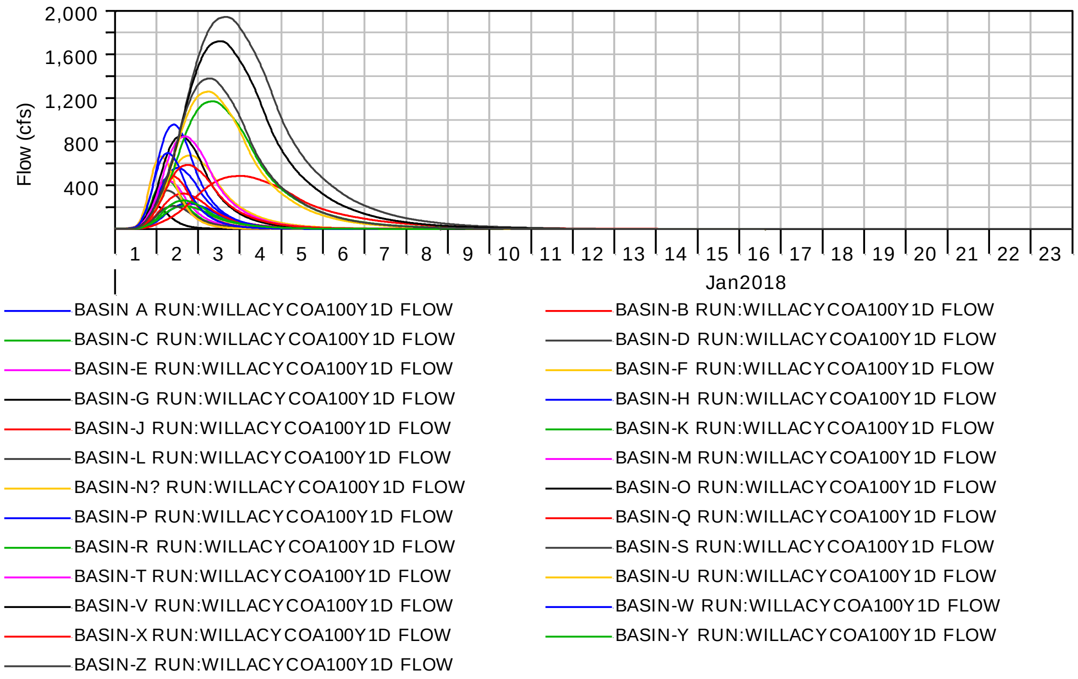


Figure AI-19. Watershed Hydrographs due to 100-year frequency storm 1-day precipitation duration

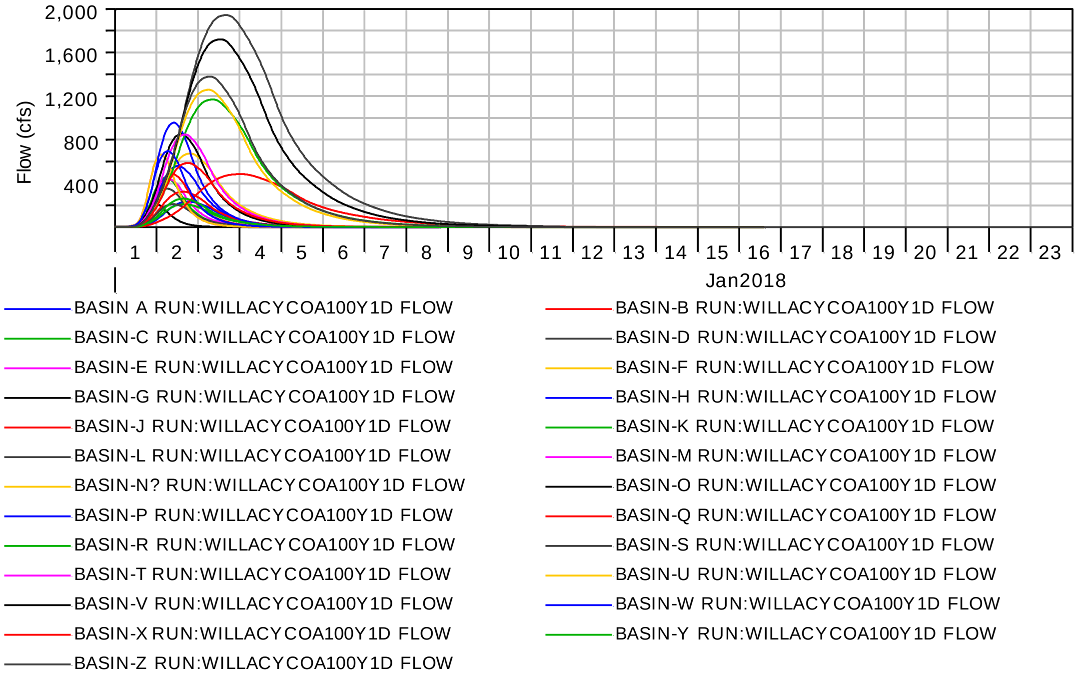


Figure AI-20. Watershed Hydrographs due to 100-year frequency storm 2-day precipitation duration

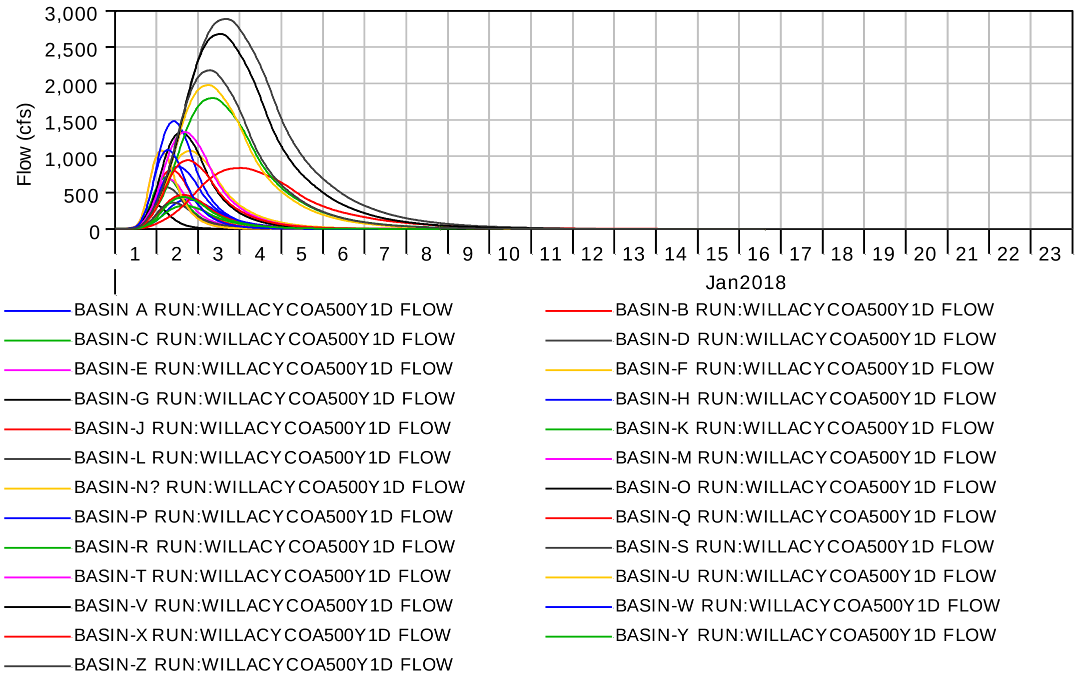


Figure AI-21. Watershed Hydrographs due to 500-year frequency storm 1-day precipitation duration

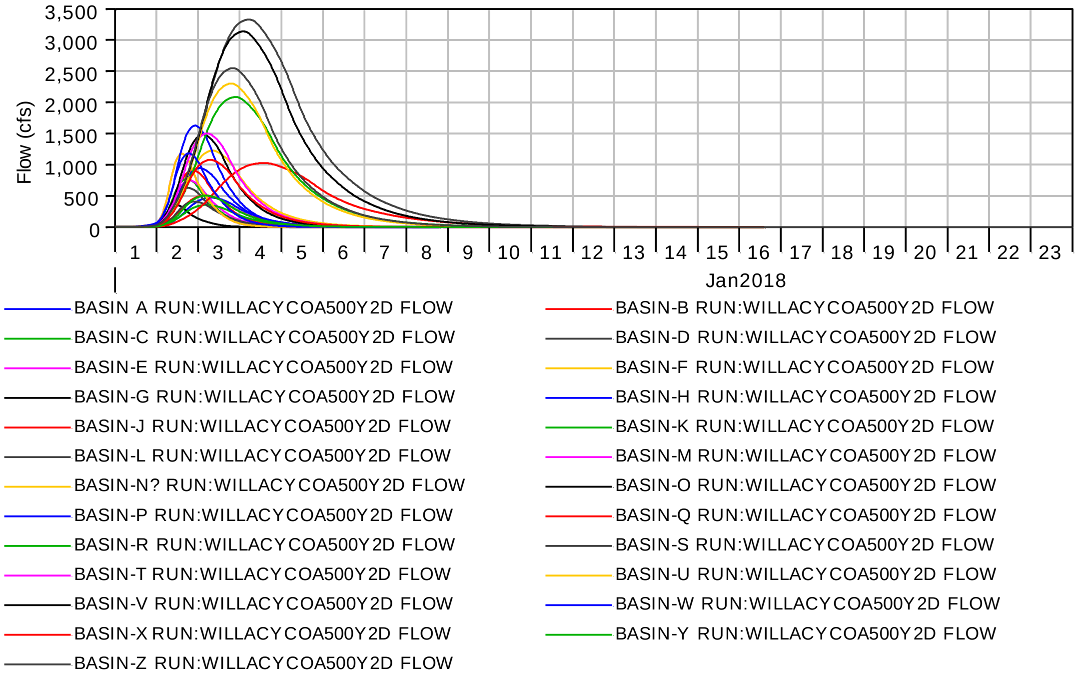


Figure AI-22. Watershed Hydrographs due to 500-year frequency storm 2-day precipitation duration

APPENDIX II. MEETING AGENDA/MINUTES AND PRESENTATION WITH THE PROJECT END-USERS

MEETING AGENDA AND MINUTES

Project Name: CMP23 Storm Surge Flood Maps Development for the Lower Laguna Madre
Event name: Project meeting with Cameron County Emergency Management Office
Event date and time: 11/16/2018, 1:00 to 2:00 pm
Location: Cameron County Emergency Management Office, 964 E. Harrison St., Brownsville, Cameron County
Attendees: Tom Hushen, Nathan Flores, and Jungseok Ho
Agenda:

1. Review of the CMP project deliverables
    a. Ho presented the project task and deliverable plan/schedule.
    b. Flores briefly re-introduced the Cameron County Emergency Management Office's needs and current resources.
2. Hurricane storm surge model draft results review
    a. The ADCIRC hurricane storm surge model capability and preliminary modeling results of LLM water circulation, hurricane tracking, and storm surge of Hurricane Dolly (2008) were discussed (Ho).
    b. Hushen introduced current Cameron County emergency evacuation routes and hazard reduction and recovery map determined in 2016 and related best management plans.
3. Coastal flood model modeling scenarios
    a. Ho presented preliminary modeling scenarios based on the hypothetical frequency storm and hurricane categories due to wind speed.
    b. Flores suggested a forecasting model development, which enable flood forecasting in several days before the real storm event.
    c. Discussion of major two factors of inland rainfall runoff and hurricane storm surge along the coastal area.
4. Next task/deliverable preview
    a. Model progress will be updated in April 2019
    b. ADCIRC model mesh will be updated with new geometric data (Ho).

5. Adjourn

Meeting Agenda: Lower Laguna Madre Watershed Hurricane Flood Map Development
Sponsored by TGLO Coastal Management Project (CMP)

Project outcome:

1. Forty-five flood maps of the Lower Laguna Madre (LLM) watershed due to hurricane storm surge (5 categories) and inland rainfall runoff (9 frequency storms). See the preliminary map.
2. Forty-five local emergency evacuation routes to the TxDOT evacuation highway and emergency shelters by avoiding the flooding areas.
3. The flood maps and related emergency evacuation routes will be posted at the project website, VCORE (Valley COastal disaster REsilient) and these can be embedded and linked to any governmental agencies websites.
4. Watershed flood models (HEC-HMS and HEC-RAS) for the Cameron County and Willacy County.
5. Hurricane storm surge model (ADCIRC) covering most of the LLM and Gulf of Mexico.

Meeting questions:

- Any major update of flood protection AND/OR emergency evacuation plan and strategy
- Specific areas to watch over – we can make finer computational mesh for more accurate result.

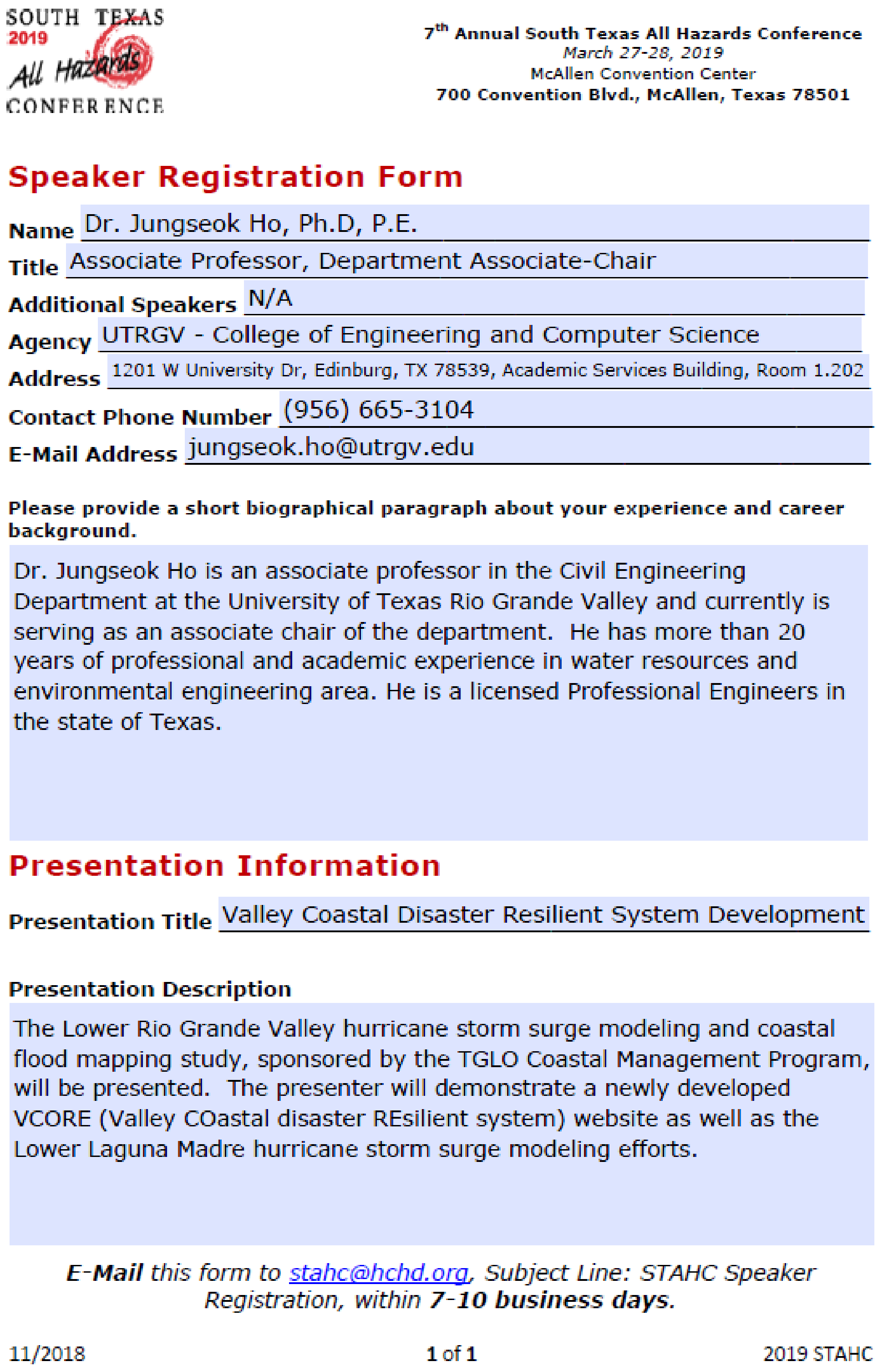
- Primary flood control infrastructures (floodways, canal, diversion, levee, major outfall, sluice gate, etc.) in your district and its' operation plan/guideline – this can be an important input data
- Your gage stations data of rainfall and stream flow

- How these coastal flood maps can be useful on your work?

- Level of referencing the flood maps and the local evacuation routes – how to use them for your work? How significantly?

- Any specific flood/emergency scenarios you want to simulate with this model.
- Any other comments and insight regarding flood management and emergency evacuation.

2019 South Texas All-Hazards Conference presentation to the County emergency management officer and other first responders. The CMP project and draft results were introduced and discussed.



SOUTH TEXAS 2019 All Hazards CONFERENCE

7th Annual South Texas All Hazards Conference
March 27-28, 2019
McAllen Convention Center
700 Convention Blvd., McAllen, Texas 78501

Speaker Registration Form

Name Dr. Jungseok Ho, Ph.D, P.E.
Title Associate Professor, Department Associate-Chair
Additional Speakers N/A
Agency UTRGV - College of Engineering and Computer Science
Address 1201 W University Dr, Edinburg, TX 78539, Academic Services Building, Room 1.202
Contact Phone Number (956) 665-3104
E-Mail Address jungseok.ho@utrgv.edu

Please provide a short biographical paragraph about your experience and career background.

Dr. Jungseok Ho is an associate professor in the Civil Engineering Department at the University of Texas Rio Grande Valley and currently is serving as an associate chair of the department. He has more than 20 years of professional and academic experience in water resources and environmental engineering area. He is a licensed Professional Engineers in the state of Texas.

Presentation Information

Presentation Title Valley Coastal Disaster Resilient System Development

Presentation Description

The Lower Rio Grande Valley hurricane storm surge modeling and coastal flood mapping study, sponsored by the TGLO Coastal Management Program, will be presented. The presenter will demonstrate a newly developed VCORE (Valley COastal disaster REsilient system) website as well as the Lower Laguna Madre hurricane storm surge modeling efforts.

***E-Mail** this form to stahc@hchd.org, Subject Line: STAHC Speaker Registration, within **7-10 business days**.*

11/2018 **1 of 1** 2019 STAHC

Day 1 – Wednesday, March 27, 2019

OPENING CEREMONIES – McALLEN PERFORMING ARTS CENTER - MAIN AUDITORIUM		
★ ★ ★ EXHIBIT HALL OPEN 9:00a-5:00p ★ ★ ★		
8:45a–10:00a	**Introduction - Master of Ceremonies**	Tim Smith, Chief Meteorologist, Channel 5 News
	Presentation of Colors	McAllen Fire Honor Guard
	National Anthem	Pentecostals of Weslaco
	Invocation	Jim Darling, Mayor of the City of McAllen
	Opening Welcome	The Honorable Greg Abbott, Governor of Texas
	Welcome	On behalf of the Honorable Richard F. Cortez, Hidalgo County Judge
		Commissioner David Fuentes, Hidalgo County Precinct 1
	Opening Speaker	David Gruber, Associate Commissioner for Regional and Local Health Operations, Department of State Health Services
	Guest Speaker	W. Nim Kidd, Vice Chancellor for Disaster and Emergency Services, Texas A&M; Chief of Texas Emergency Management
	Special Guest Speaker	Introduction of new USCBP Sector Chief, Rodolfo Karisch
10:00a-10:30a	**BREAK – PERFORMING ARTS CENTER**	
PLENARY SESSIONS – McALLEN PERFORMING ARTS CENTER – MAIN AUDITORIUM		
10:30a-11:10a	**ASPR Priorities**	**Kevin Yeskey, M.D.** Principal Deputy Assistant Secretary for Preparedness & Response
11:10a-11:30a	**★PRESS CONFERENCE★**	**McALLEN PERFORMING ARTS CENTER - MULTI-PURPOSE ROOM** **★INVITATION ONLY★**
11:20a-12:00p	**In Honor of The Charleston 9: A Study of Change Following Tragedy**	**Dr. David Griffin** On A Mission – Find Your Mission Tour
12:00p-1:30p	**★COLLABOR-EAT★**	**LUNCH – ON YOUR OWN** **★COLLABOR-EAT★**

KEYNOTE SESSION – McALLEN CONVENTION CENTER - GRAND BALLROOM (LIMITED SEATING)		
1:30p-3:30p	**Turn PTSD in PTG: It Will Change Your Life**	**Dr. David Griffin** On A Mission–Find Your Mission Tour

BREAKOUT SESSIONS – McALLEN CONVENTION CENTER

	101 A	101 BC	102 A	102 BC	103 B	103 CD
1:30p-2:30p	**Garrett Hagood** *Hospital Preparedness Program, TSA-V* **Cybersecurity is Everyone's Responsibility**	**Dee Grimm** *BCFS* **2017-2018 Disaster Seasons** Are We Getting Better or Just Trying to Keep Up?	**William Mangieri** *US Dept. of Health & Human Services* **National Health Security Strategy**	**Linley Boone-Almaguer** *Texas Rural Legal Authority* **Disaster Legal Needs 101**	**Jack Cress & Valerie Blanton** *Federal Emergency Management Agency & Texas DPS* **Disaster Debris Management**	**Chief Maryanne Denner** *Hidalgo County Juvenile Justice Department* **What We Have Here is a Failure to Communicate**
2:30p-3:00p	**BREAK – EXHIBIT HALL**					
	Mike Bricker *Palm Valley Animal*	**Stephen Robertson &**	**Norma Villanueva &**	**Fidel Calvillo** *South East Texas*	**Martin Chavez** *United States*	**Daniel D. Vlaisavljevic**

Day 2 – Thursday, March 28, 2019

★ ★ ★ EXHIBIT HALL OPEN 9:00a-5:00p ★ ★ ★

BREAKOUT SESSIONS – McALLEN CONVENTION CENTER

	101 A (90)	101 BC (180)	102 A (104)	102 BC (96)	103 B (72)	103 CD (198)
8:15a-9:15a	**Cesar Rodriguez & Arcelia Canales** *City of McAllen - Health & Code Enforcement* **City of McAllen: Illegal Dumping & Cleanups**	**Joshua Carrillo & Michael Moore** *Union Pacific Railroad* **Critical Rail Hazmat Awareness for Responders**	**Nathanael Flores** *Cameron County Judge's Office - Division of Emergency Management* **Strengthening Social Media Community Outreach During Emergency Management**	**Dr. Jungseok Ho** *University of Texas – Rio Grande Valley* **Valley Coastal Disaster Resilient System Development**	**Danella Hughes** *American Red Cross* **Maintaining a Relationship Matrix in a Disaster**	**Antonio Zarzoza** *University of Texas – Rio Grande Valley Police Department* **Processing Under Pressure:** Human Factors Affecting First Responders
9:25a-10:25a	**Dr. Ronald Tyler** *DSHS, R-11* **Capt. James Dunks** *Texas Parks & Wildlife Div.* ***Animal Control CEU*** **Animal Control Officer Continuing Education Seminar**	**Bill Long & Tony Crites** *Texas A&M Engineering Extension Service* **Incident Management & Public Works**	**Eugene Hileman** *United Methodist Church* **United Methodist Disaster Response Ministry**	**Jeff Newbold** *Texas DPS/TDEM* **TDEM CIS Tech Update**	**VIP Special Meeting** **10:00a-12:00p** *Hidalgo County District Attorney's Office* ***INVITATION ONLY***	**Judy Lucio** *Texas Division of Emergency Management* **Getting Ahead… Completing the Disaster Summary Outline**
10:25a-10:50a						
10:50a-11:50a	**Dr. Thomas deMarr** *Gladys Porter Zoo*	**Bill Long & Tony Crites** *Texas A&M Engineering Extension Service*	**Lidia Fonseca & Brooke Hernandez** *Valley Association for Independent Living*	**Pablo Mendez** *University of Texas – Rio Grande Valley*	**VIP Special Meeting** **10:00a-12:00p**	**Chief Antonio Lopez** *Weslaco Fire Department & Office of Emergency Management*

MEETING AGENDA AND MINUTES

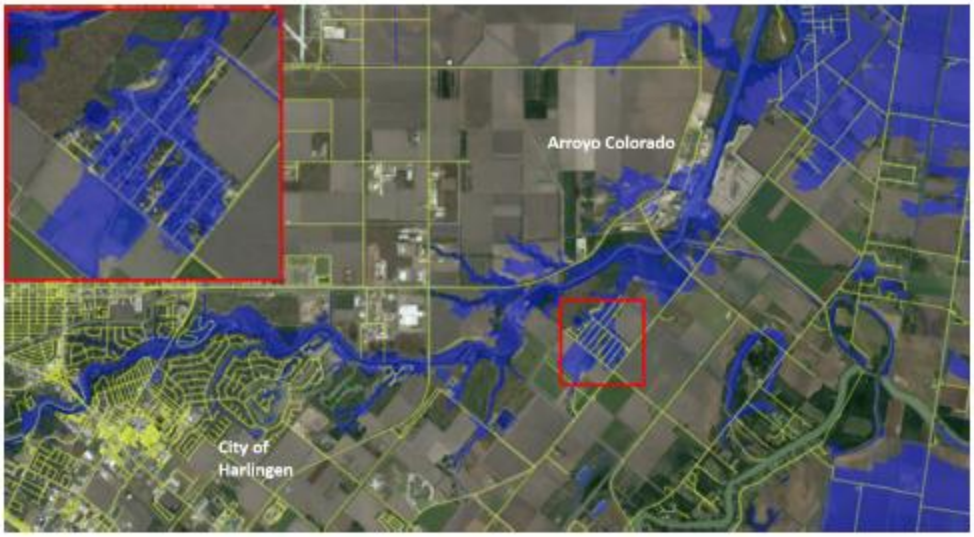
Project Name: CMP23 Storm Surge Flood Maps Development for the Lower Laguna Madre
Event name: Project meeting with Willacy County Emergency Management Office
Event date and time: 11/16/2018, 1:00 to 2:00 pm
Location: Willacy County Judge Office, 576 W. Main Ave., Raymondville, Willacy County
Attendees: Troy Allen, Henry Gonzalez, Frances Salazar, Eliberto Guerra, Jessica Garcia, Frank Torres, Raul Torres, and Jungseok Ho
Agenda:

1. Review of the CMP project deliverables
    a. J Garcia started the meeting with brief introduction of this CMP project and engagement with the Willacy County.
    b. Ho presented the project task and deliverable plan/schedule and required geometric
    c. data acquisition.
    d. F Torres briefly introduced the Willacy County Emergency Management Office's needs and current resources.
    e. H Gonzalez mentioned his CMP project management regarding the natural resources project in the Willacy County.
2. Hurricane storm surge model draft results review
    a. The ADCIRC hurricane storm surge model capability and preliminary modeling results of LLM water circulation, hurricane tracking, and storm surge of Hurricane Dolly (2008) were discussed (Ho).
    b. T Allen pointed out the coast shoreline of the Willacy County are vulnerable for hurricane storm surge due to no protection of shoreline erosion, however, there is no development, which does not provide significant property damage.
3. Coastal flood model modeling scenarios
    a. Ho presented preliminary modeling scenarios based on the hypothetical frequency storm and hurricane categories due to wind speed.
    b. T Allen answered E Guerra 's question on the Willacy County's major issue of flood prevention and management plan.
    c. Discussion of major two factors of inland rainfall runoff and hurricane storm surge along the coastal area.
    d. F Salazar pointed out the Hidalgo Main drainage channel and its impact on the Willacy County watershed flood. Another discussion followed on this topic. It is concluded that the flood model would be discussed also with the Hidalgo County Drainage District.
    e. T Allen briefly updated the Raymondville Main drainage channel. Its modeling and geometric/surveying data applicability were discussed.
4. Next task/deliverable preview
    a. Modeling progress will be updated in September 2019
    b. ADCIRC model mesh will be updated with new geometric data (Ho).
    c. Modeling scenarios will be finalized by September 2019 (Ho).
5. Adjourn

Meeting Agenda: Lower Laguna Madre Watershed Hurricane Flood Map Development
Sponsored by TGLO Coastal Management Project (CMP), October 2018 – March 2020
Jungseok Ho, jungseok.ho@utrgv.edu, Civil Engineering, UTRGV

Project Outcome:

1. Forty-five flood maps of the Lower Laguna Madre (LLM) watershed due to hurricane storm surge (5 categories) and inland rainfall runoff (9 frequency storms). See the preliminary result map.
2. Forty-five local emergency evacuation routes to the TxDOT evacuation highway and emergency shelters by avoiding the flooding areas.
3. The flood maps and related emergency evacuation routes will be posted at the project website, VCORE (Valley COastal disaster REsilient) and these can be embedded and linked to any governmental agencies websites.
4. Watershed hydrologic models (HEC-HMS and HEC-RAS) covering the Cameron County and the Willacy County.
5. Hurricane storm surge model (ADCIRC) covering the LLM with the Gulf of Mexico.



Meeting Questions:

- Any major update of flood protection AND/OR emergency evacuation plan and strategy
- Any specific areas to watch over and modeling scenarios to simulate – we can make finer computational mesh for more accurate result and useful predictions
- Primary flood control infrastructures (floodways, canal, diversion, levee, major outfall, sluice gate, etc.) in your district and its' operation plan/guideline – this can be an important input data of the flood computer model
- Your gage station data of rainfall and stream flow – this can be critical for the model calibration
- How these coastal flood maps can be useful to your work?
- Level of reference of the flood maps and the local evacuation routes? How significantly? Can it be viewed as supplemental information?
- Any other comments and insight regarding flood management and emergency evacuation.

MEETING AGENDA AND MINUTES

Project Name: CMP23 Storm Surge Flood Maps Development for the Lower Laguna Madre
Event name: Project meeting with Cameron County Emergency Management Office
Event date and time: 4/15/2019, 1:00 to 2:30 pm
Location: Cameron County Emergency Management Office, 964 E. Harrison St., Brownsville, Cameron County
Attendees: Santiago Ramos, Lucio Grecia, Maggie Perkild, Juan Martinez, Tom Hushen, Nathan Flores, and Jungseok Ho
Agenda:

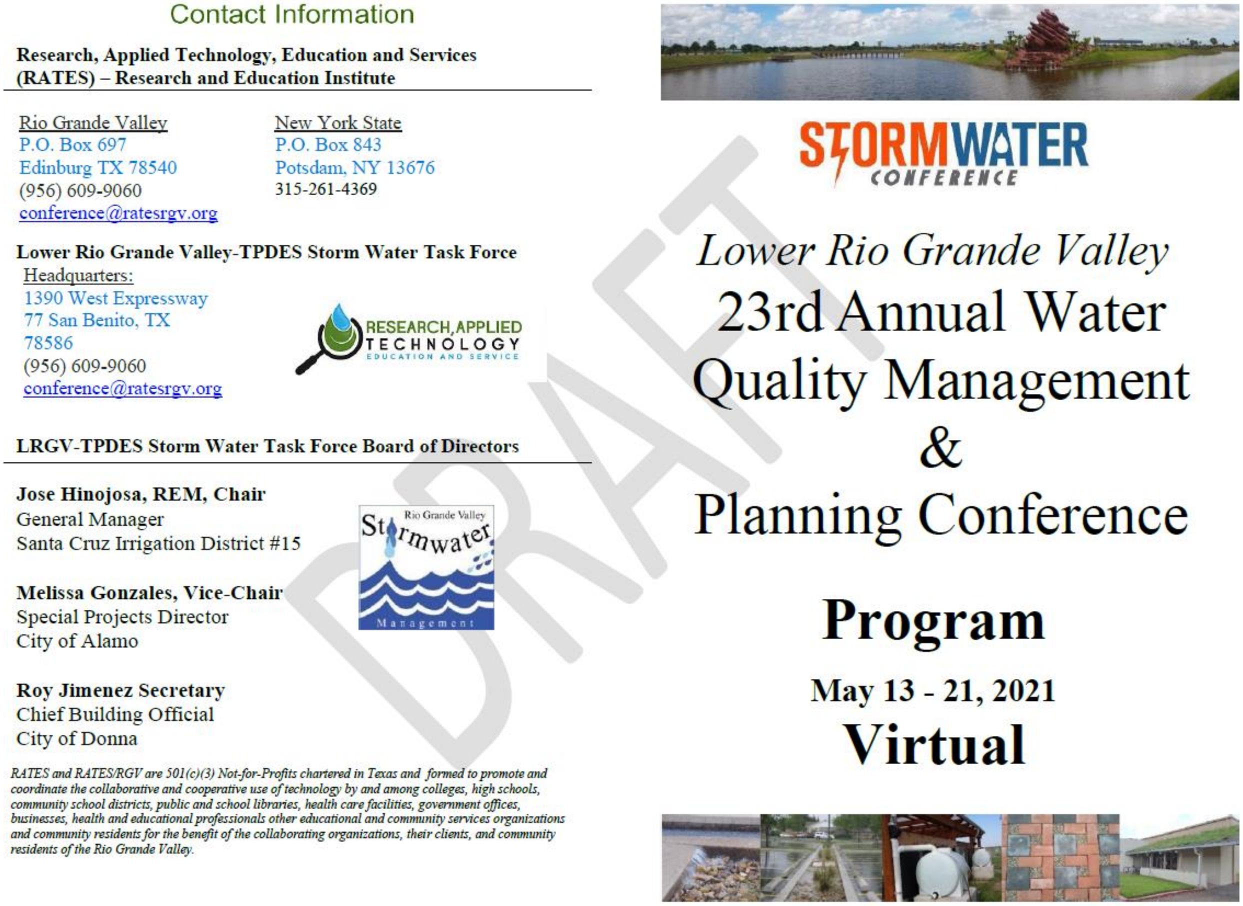
1. Review of the CMP project deliverables in focusing of emergency navigation system
    a. Ho presented the project task and deliverable plan/schedule including emergency evacuation navigation tool
    b. Flores briefly re-introduced the Cameron County Emergency Management Office's emergency evacuation operation and management plan.
2. Coastal flood model expected output and deliverables
    a. Ho presented preliminary modeling scenarios based on the 9 hypothetical frequency storm and 5 hurricane categories. Total 45 hypothetical flood events will be prepared.
    b. The model coupling between the hurricane storm surge model and inland rainfall flood model was explained (Ho) and the un-couple model simulation results (Hurricane Dolly storm surge and the 100-year frequency storm for 1 day duration flood event) were presented (Ho).
    c. Flores briefly explained how emergency evacuation is determined and delivered to the local first responders.
    d. Logistics of the navigation tool applications and level of usage were discussed. It was discussed that dissemination of the tool to the community can cause unexpected confusion. At least the navigation accuracy should be significantly verified.
3. Next task/deliverable preview
    a. Model progress will be updated in September 2019.
    b. Modeling scenarios will be finalized by November 2019.
    c. The navigation tool dissemination plan such as posting through website will be discussed.
4. Adjourn

MEETING AGENDA AND MINUTES

Project Name: CMP23 Storm Surge Flood Maps Development for the Lower Laguna Madre
Event name: Project meeting with Cameron County Transportation/Engineering Department
Event date and time: 4/24/2019, 11:00 to 12:00 pm
Location: Cameron County Transportation/Engineering Department, 26945, San Benito, Cameron County
Attendees: Paolina Vega and Jungseok Ho
Agenda:

1. Review of the CMP project deliverables
    a. Ho presented the project task and deliverable plan/schedule in focusing on model applicability for flood control/management.
    b. Vega briefly re-introduced the Cameron County's flood control infrastructure.
2. Coastal flood model modeling scenarios
    a. Ho presented preliminary modeling scenarios based on the 9 hypothetical frequency storm and 5 hurricane categories. Total 45 hypothetical flood events will be prepared.
    b. The model coupling between the hurricane storm surge model and inland rainfall flood model was explained (Ho) and the un-couple model simulation results (Hurricane Dolly storm surge and the 100-year frequency storm for 1 day duration flood event) were presented (Ho).
    c. Vega brought hydrologic impact of resaca to the local watershed, especially as a drainage waterway to the Lower Laguna Madre. It was discussed that resaca can be assigned into the model geometry, but any hydrologic boundary condition can be given to the model due to uncertainty of the hydrologic impact and observation/measurement.
3. Next task/deliverable preview
    a. A meeting with Transportation/Engineering Department staff and County Drainage District staff will be arranged to discuss local flood issues and local areas prone to floods.
    b. Modeling scenarios will be finalized by November 2019 (Ho).
4. Adjourn

2021 Water Quality Management & Planning Conference presentation to the County emergency management officers and city/county engineers, managers. The CMP project and draft results were introduced and discussed.



Contact Information

Research, Applied Technology, Education and Services (RATES) – Research and Education Institute

Rio Grande Valley
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Edinburg TX 78540
(956) 609-9060
conference@ratesrgv.org

New York State
P.O. Box 843
Potsdam, NY 13676
315-261-4369

Lower Rio Grande Valley-TPDES Storm Water Task Force

Headquarters:
1390 West Expressway
77 San Benito, TX
78586
(956) 609-9060
conference@ratesrgv.org

LRGV-TPDES Storm Water Task Force Board of Directors

Jose Hinojosa, REM, Chair
General Manager
Santa Cruz Irrigation District #15

Melissa Gonzales, Vice-Chair
Special Projects Director
City of Alamo

Roy Jimenez Secretary
Chief Building Official
City of Donna

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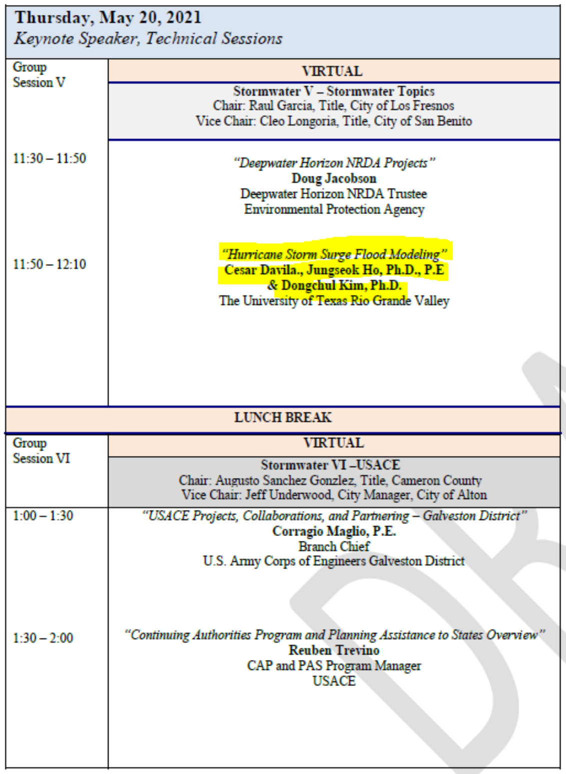
Lower Rio Grande Valley

23rd Annual Water Quality Management & Planning Conference

Program

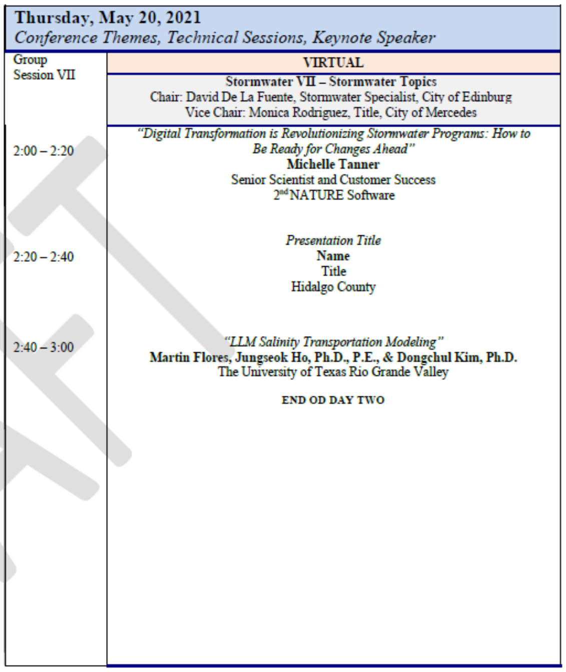
May 13 - 21, 2021

Virtual



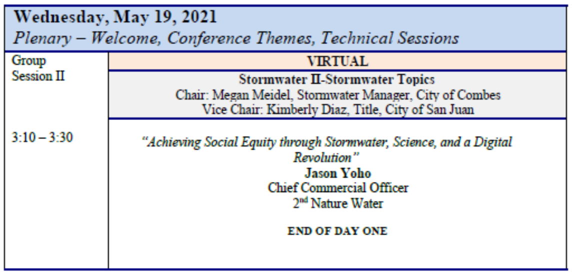
Thursday, May 20, 2021
Keynote Speaker, Technical Sessions

Group Session V	**VIRTUAL**
	Stormwater V – Stormwater Topics Chair: Raul Garcia, Title, City of Los Fresnos Vice Chair: Cleo Longoria, Title, City of San Benito
11:30 – 11:50	*"Deepwater Horizon NRDA Projects"* **Doug Jacobson** Deepwater Horizon NRDA Trustee Environmental Protection Agency
11:50 – 12:10	*"Hurricane Storm Surge Flood Modeling"* **Cesar Davila., Jungseok Ho, Ph.D., P.E & Dongchul Kim, Ph.D.** The University of Texas Rio Grande Valley
LUNCH BREAK	
Group Session VI	**VIRTUAL**
	Stormwater VI –USACE Chair: Augusto Sanchez Gonzlez, Title, Cameron County Vice Chair: Jeff Underwood, City Manager, City of Alton
1:00 – 1:30	*"USACE Projects, Collaborations, and Partnering – Galveston District"* **Corragio Maglio, P.E.** Branch Chief U.S. Army Corps of Engineers Galveston District
1:30 – 2:00	*"Continuing Authorities Program and Planning Assistance to States Overview"* **Reuben Trevino** CAP and PAS Program Manager USACE



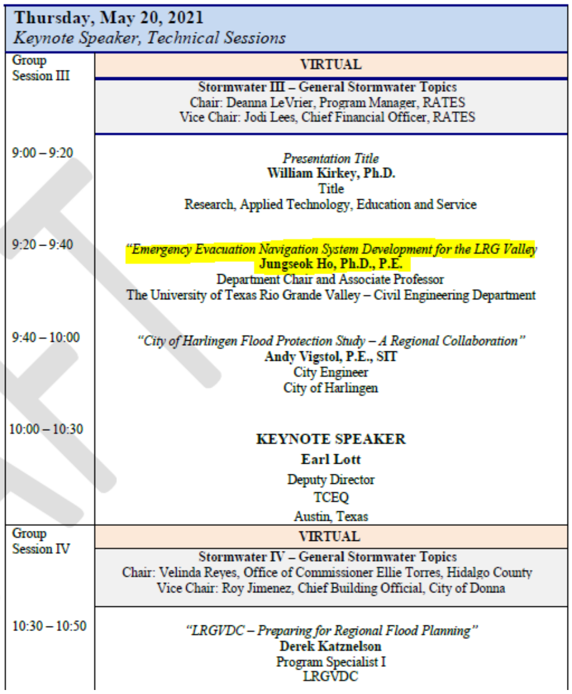
Thursday, May 20, 2021
Conference Themes, Technical Sessions, Keynote Speaker

Group Session VII	**VIRTUAL**
	Stormwater VII – Stormwater Topics Chair: David De La Fuente, Stormwater Specialist, City of Edinburg Vice Chair: Monica Rodriguez, Title, City of Mercedes
2:00 – 2:20	*"Digital Transformation is Revolutionizing Stormwater Programs: How to Be Ready for Changes Ahead"* **Michelle Tanner** Senior Scientist and Customer Success 2nd NATURE Software
2:20 – 2:40	*Presentation Title* **Name** Title Hidalgo County
2:40 – 3:00	*"LLM Salinity Transportation Modeling"* **Martin Flores, Jungseok Ho, Ph.D., P.E., & Dongchul Kim, Ph.D.** The University of Texas Rio Grande Valley **END OD DAY TWO**



Wednesday, May 19, 2021
Plenary – Welcome, Conference Themes, Technical Sessions

Group Session II	**VIRTUAL**
	Stormwater II-Stormwater Topics Chair: Megan Meidel, Stormwater Manager, City of Combes Vice Chair: Kimberly Diaz, Title, City of San Juan
3:10 – 3:30	*"Achieving Social Equity through Stormwater, Science, and a Digital Revolution"* **Jason Yoho** Chief Commercial Officer 2nd Nature Water **END OF DAY ONE**



Thursday, May 20, 2021
Keynote Speaker, Technical Sessions

Group Session III	**VIRTUAL**
	Stormwater III – General Stormwater Topics Chair: Deanna LeVrier, Program Manager, RATES Vice Chair: Jodi Lees, Chief Financial Officer, RATES
9:00 – 9:20	*Presentation Title* **William Kirkey, Ph.D.** Title Research, Applied Technology, Education and Service
9:20 – 9:40	*"Emergency Evacuation Navigation System Development for the LRG Valley* **Jungseok Ho, Ph.D., P.E.** Department Chair and Associate Professor The University of Texas Rio Grande Valley – Civil Engineering Department
9:40 – 10:00	*"City of Harlingen Flood Protection Study – A Regional Collaboration"* **Andy Vigstol, P.E., SIT** City Engineer City of Harlingen
10:00 – 10:30	**KEYNOTE SPEAKER** **Earl Lott** Deputy Director TCEQ Austin, Texas
Group Session IV	**VIRTUAL**
	Stormwater IV – General Stormwater Topics Chair: Velinda Reyes, Office of Commissioner Ellie Torres, Hidalgo County Vice Chair: Roy Jimenez, Chief Building Official, City of Donna
10:30 – 10:50	*"LRGVDC – Preparing for Regional Flood Planning"* **Derek Katznelson** Program Specialist I LRGVDC

APPENDIX III. HYPOTHETICAL STORM SURG FLOOD MAPS OF LOWER LAGUNA MADRE

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 10-year
Storm Duration: 1 day

N
S

0 2 4 8 12 Miles

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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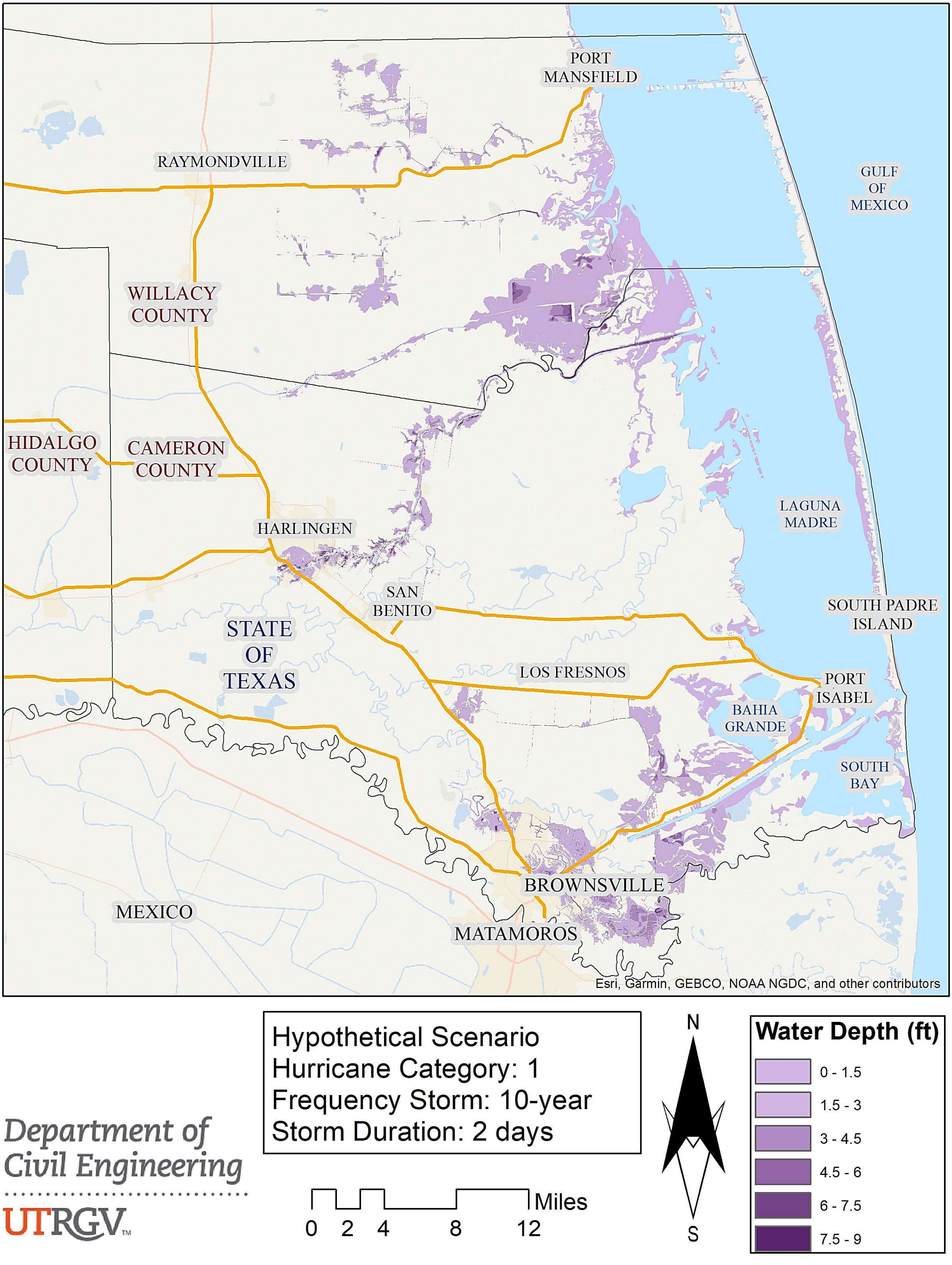

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 10-year
Storm Duration: 2 days

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Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 25-year
Storm Duration: 1 day

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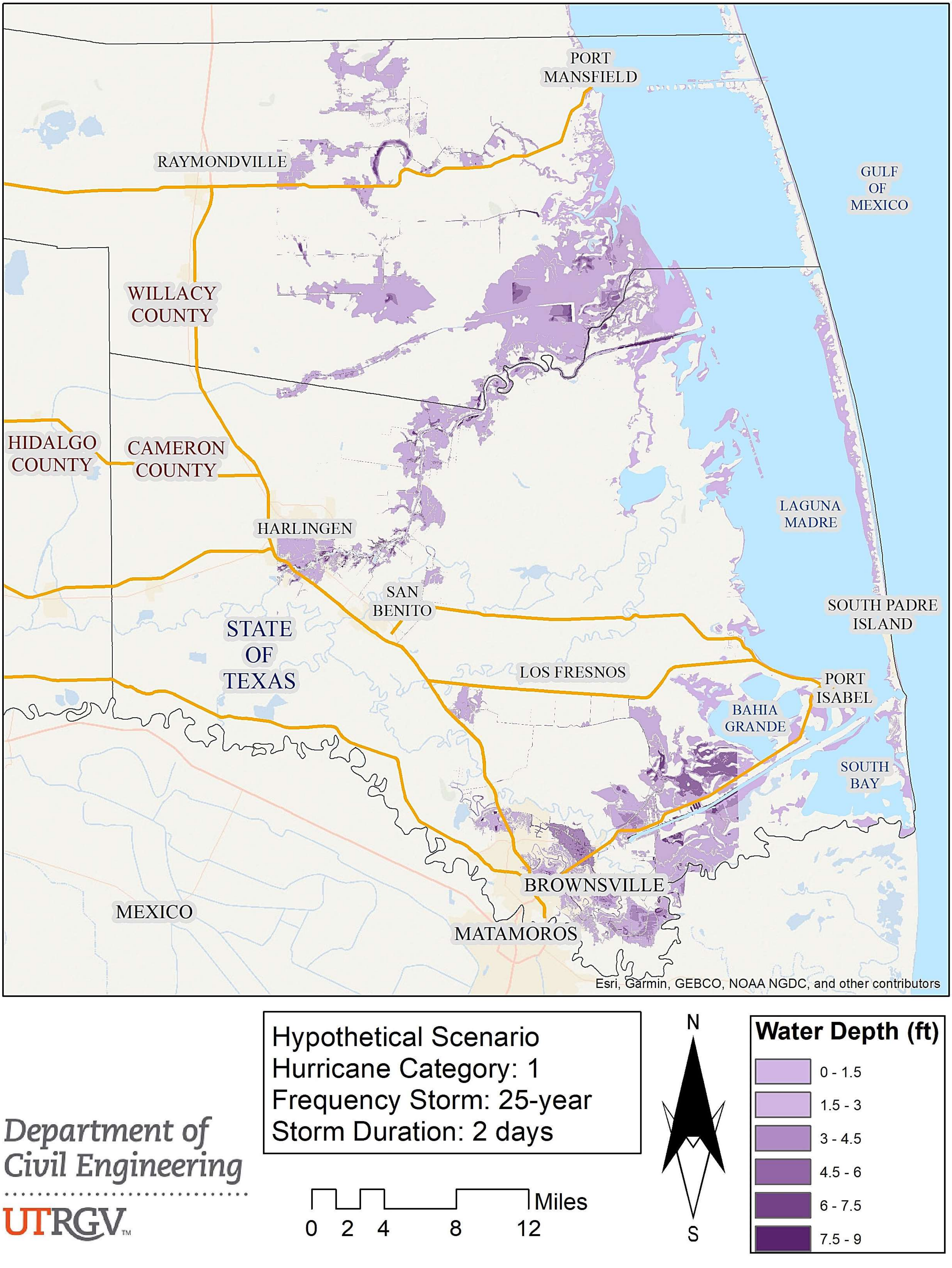

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 25-year
Storm Duration: 2 days

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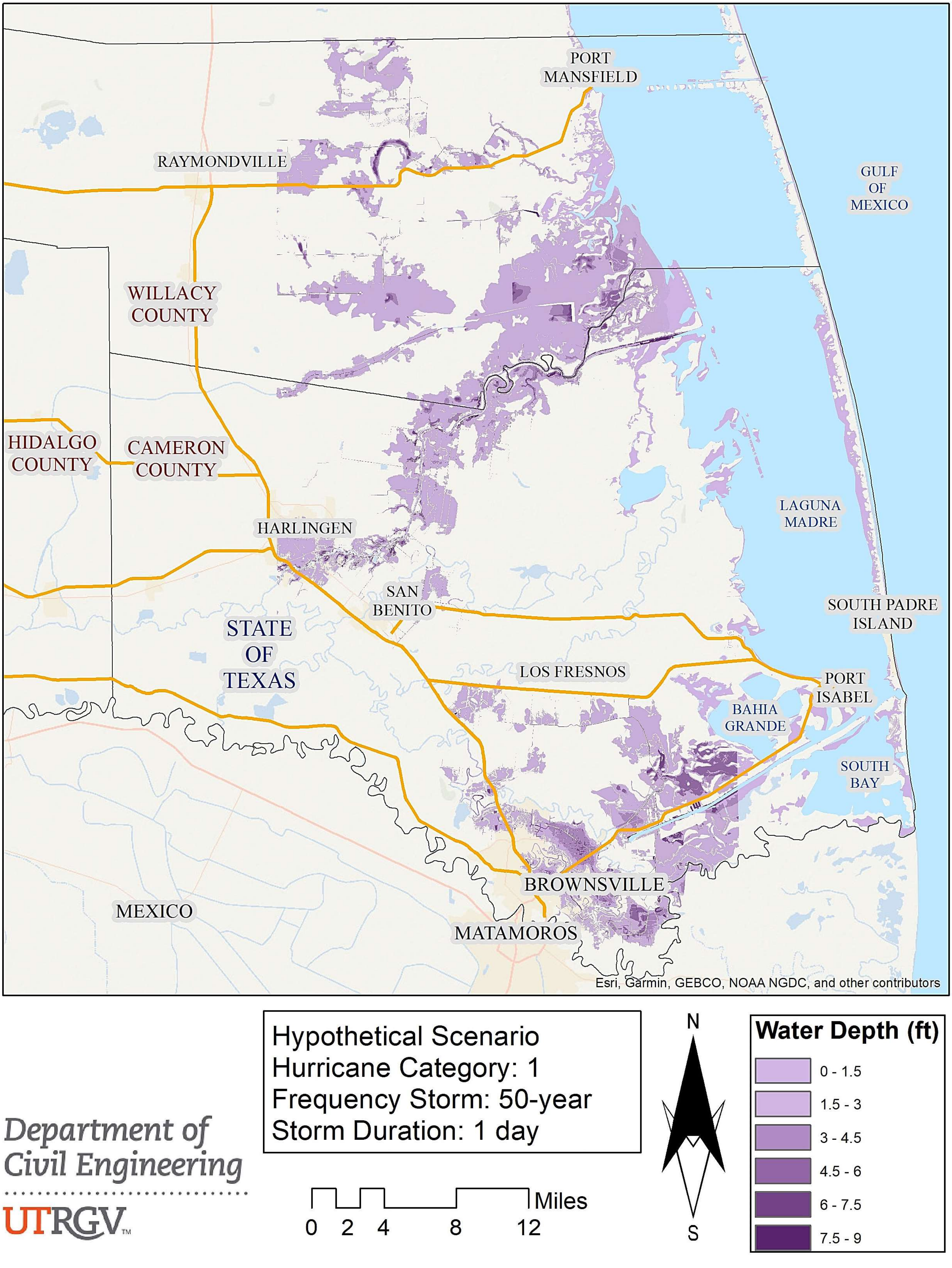

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 50-year
Storm Duration: 1 day

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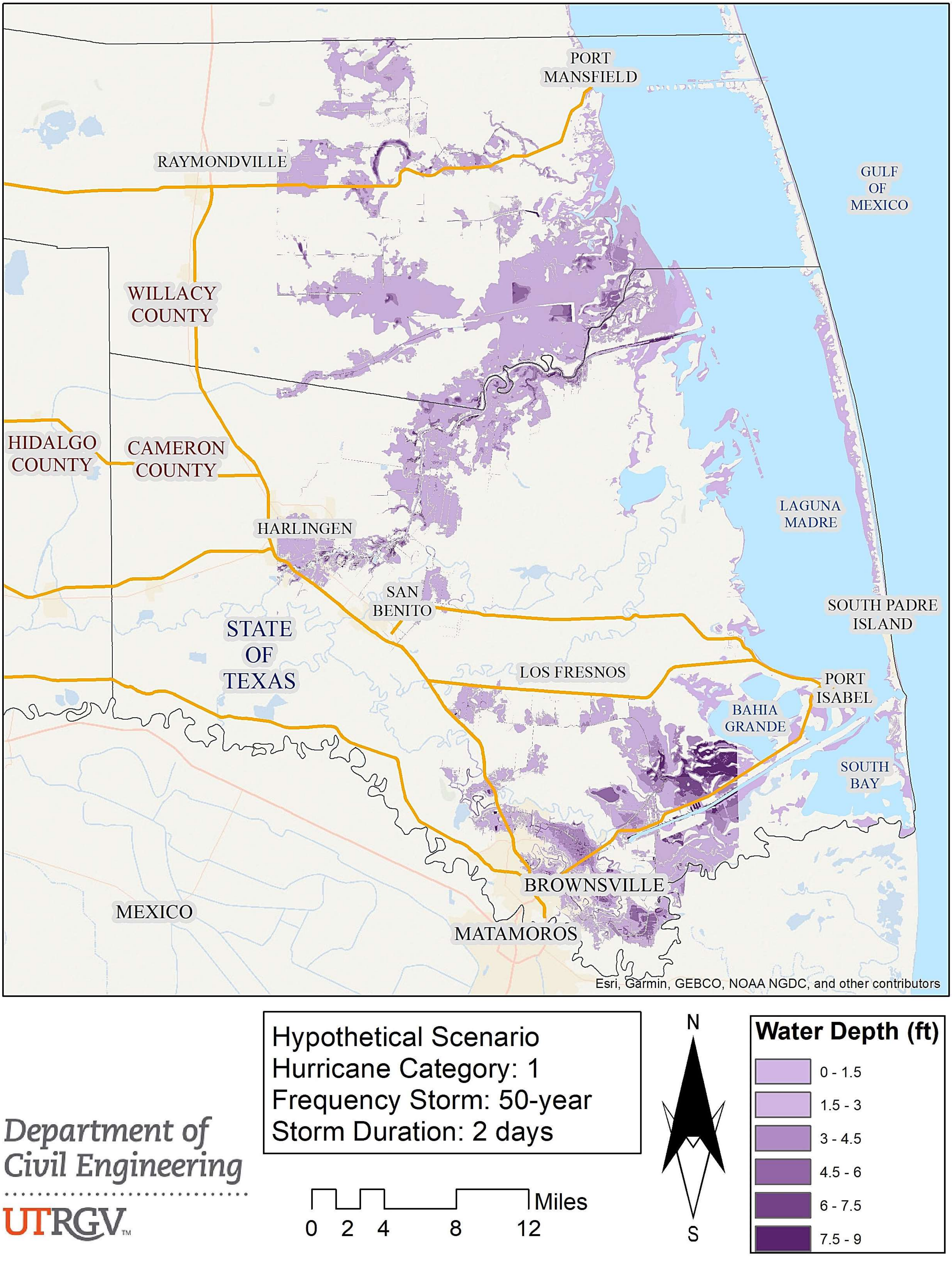

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 50-year
Storm Duration: 2 days

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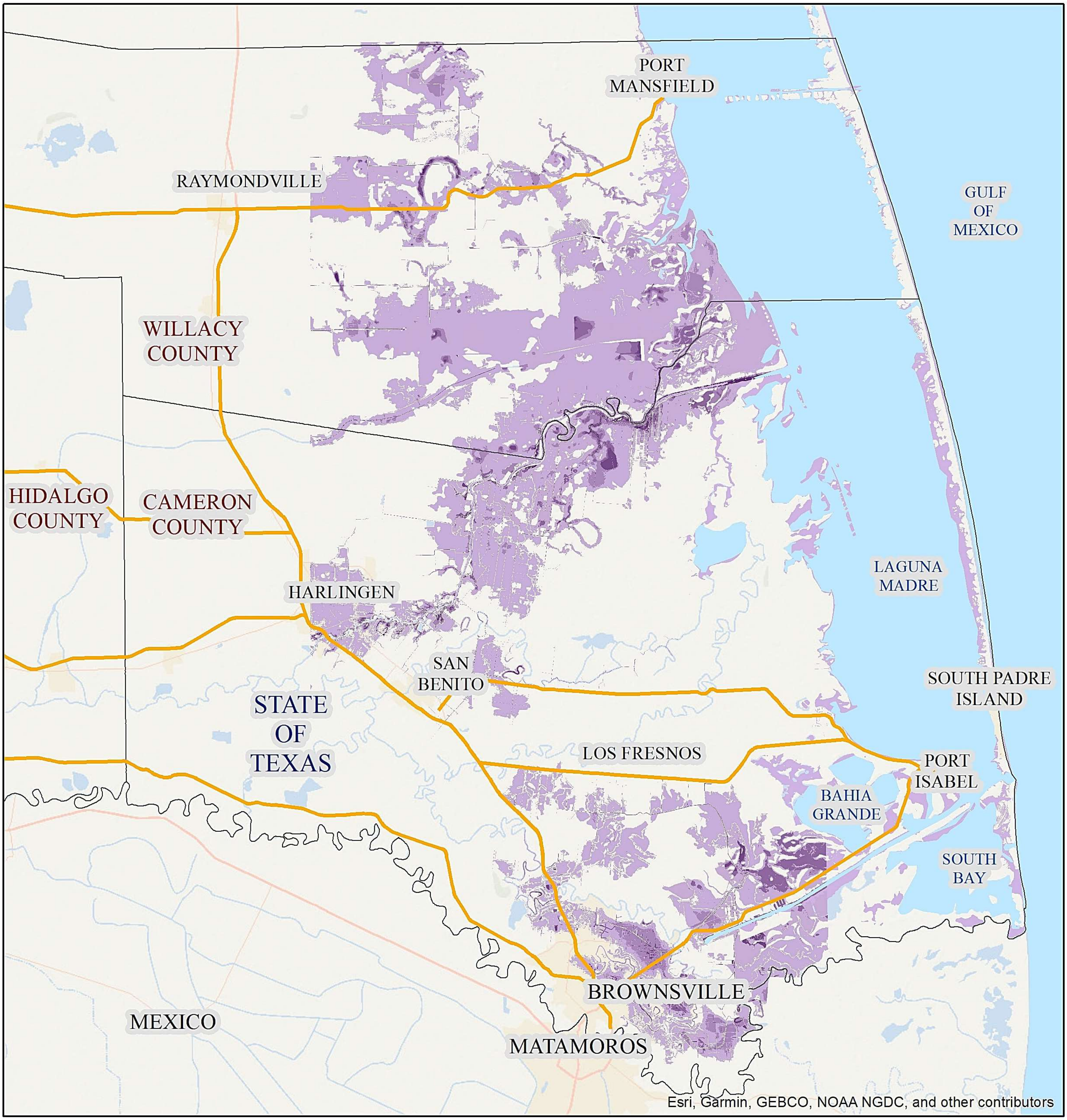

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 100-year
Storm Duration: 1 day

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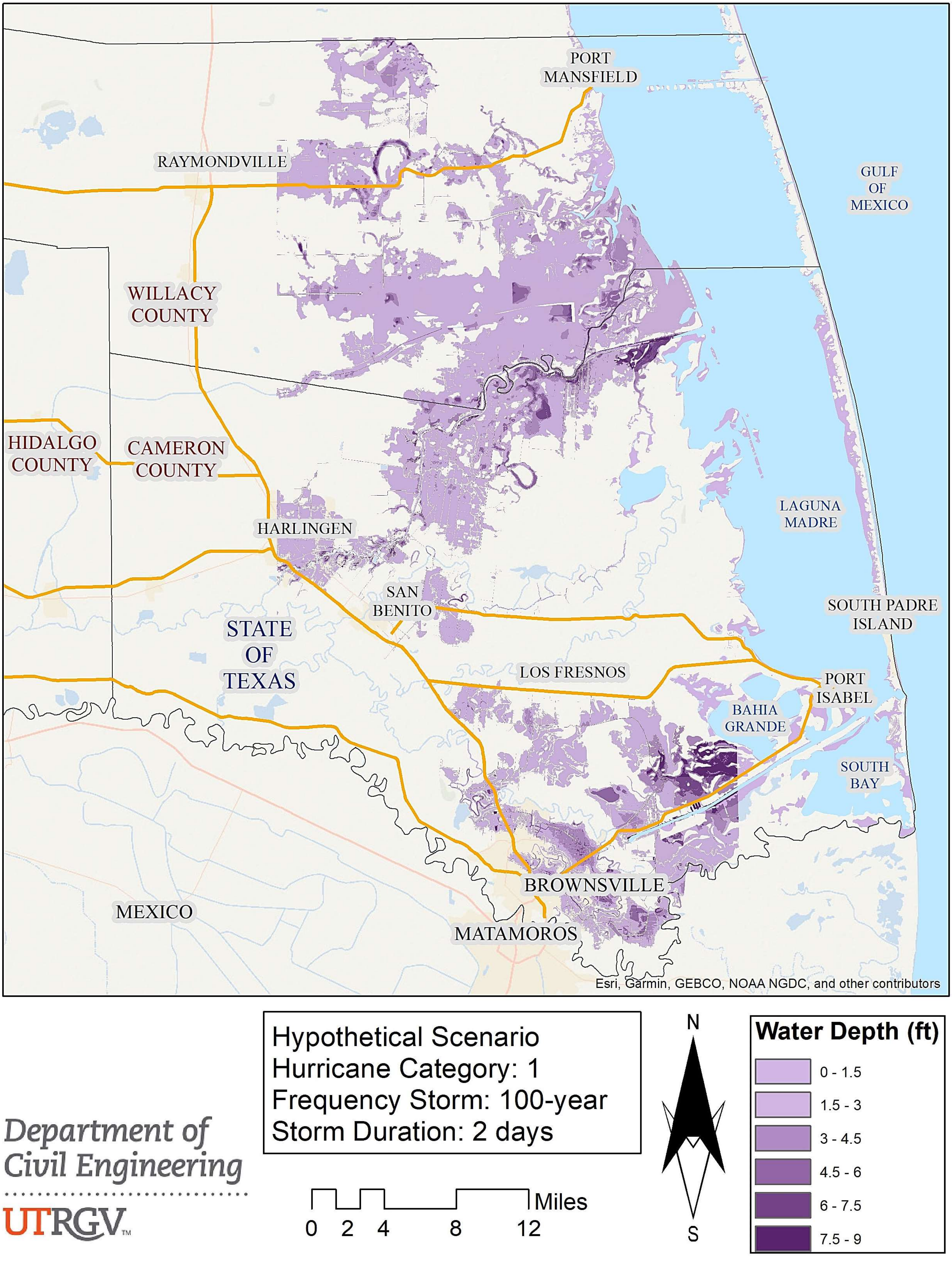

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 100-year
Storm Duration: 2 days

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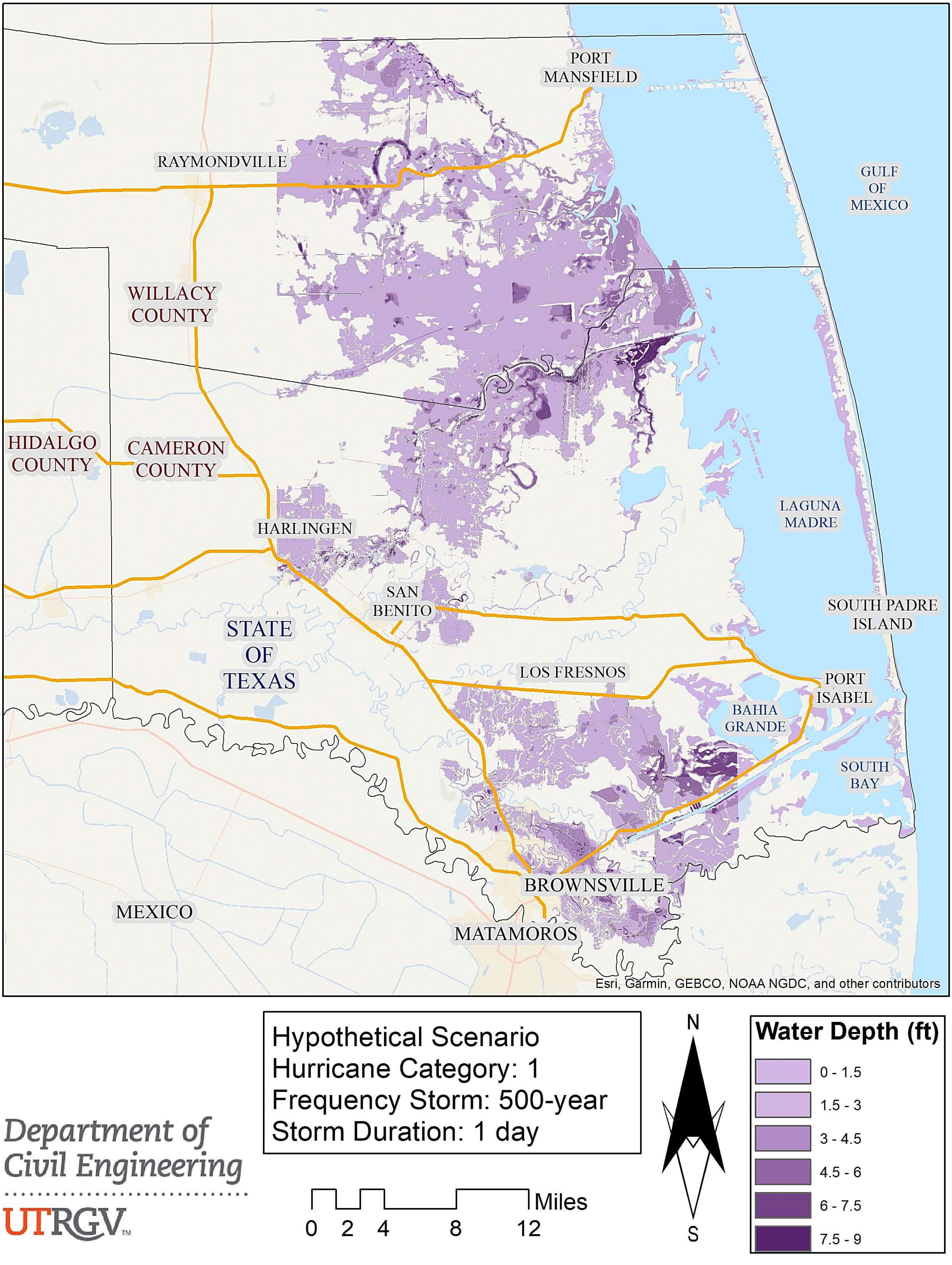

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 500-year
Storm Duration: 1 day

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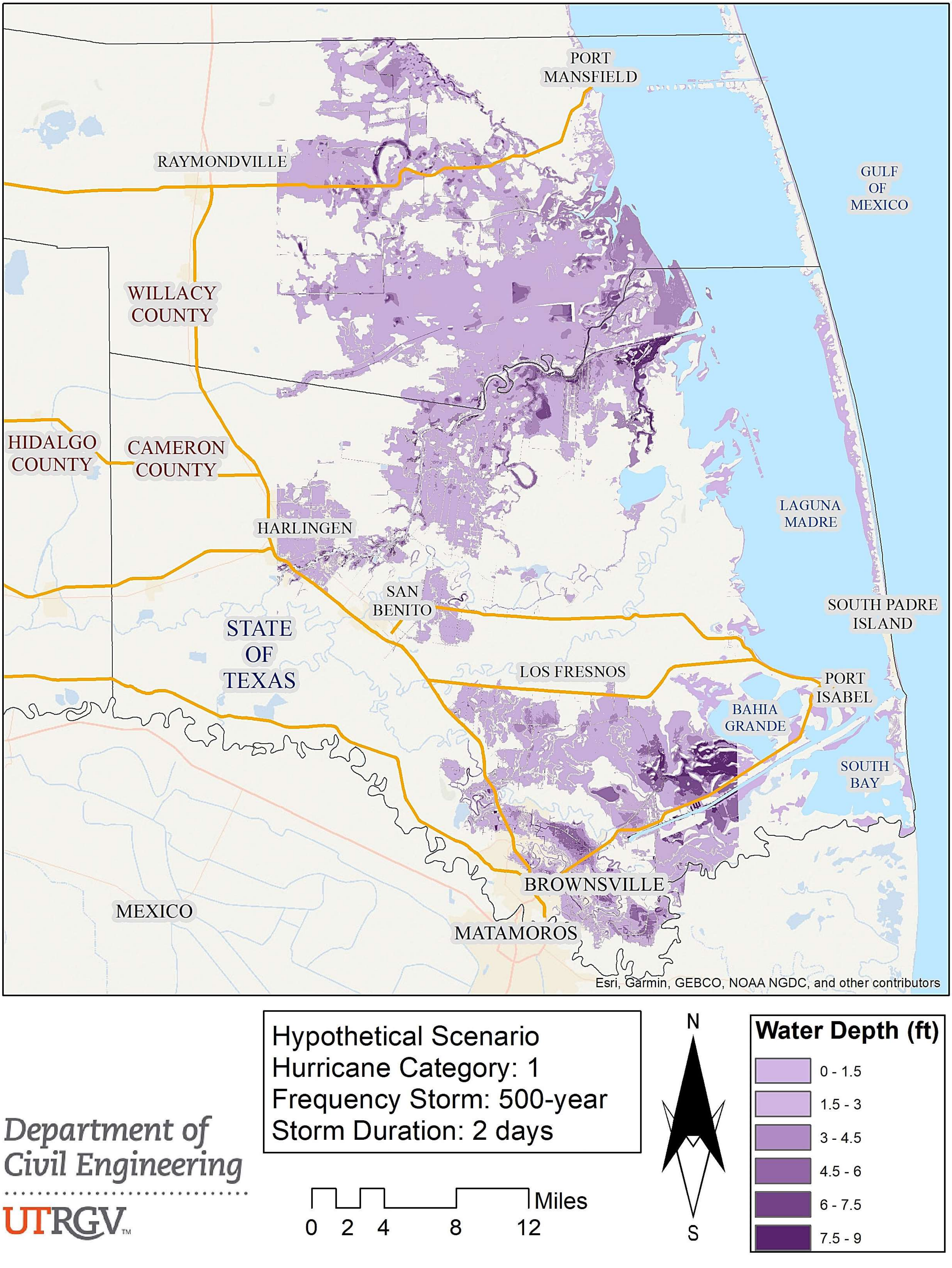

Hypothetical Scenario
Hurricane Category: 1
Frequency Storm: 500-year
Storm Duration: 2 days

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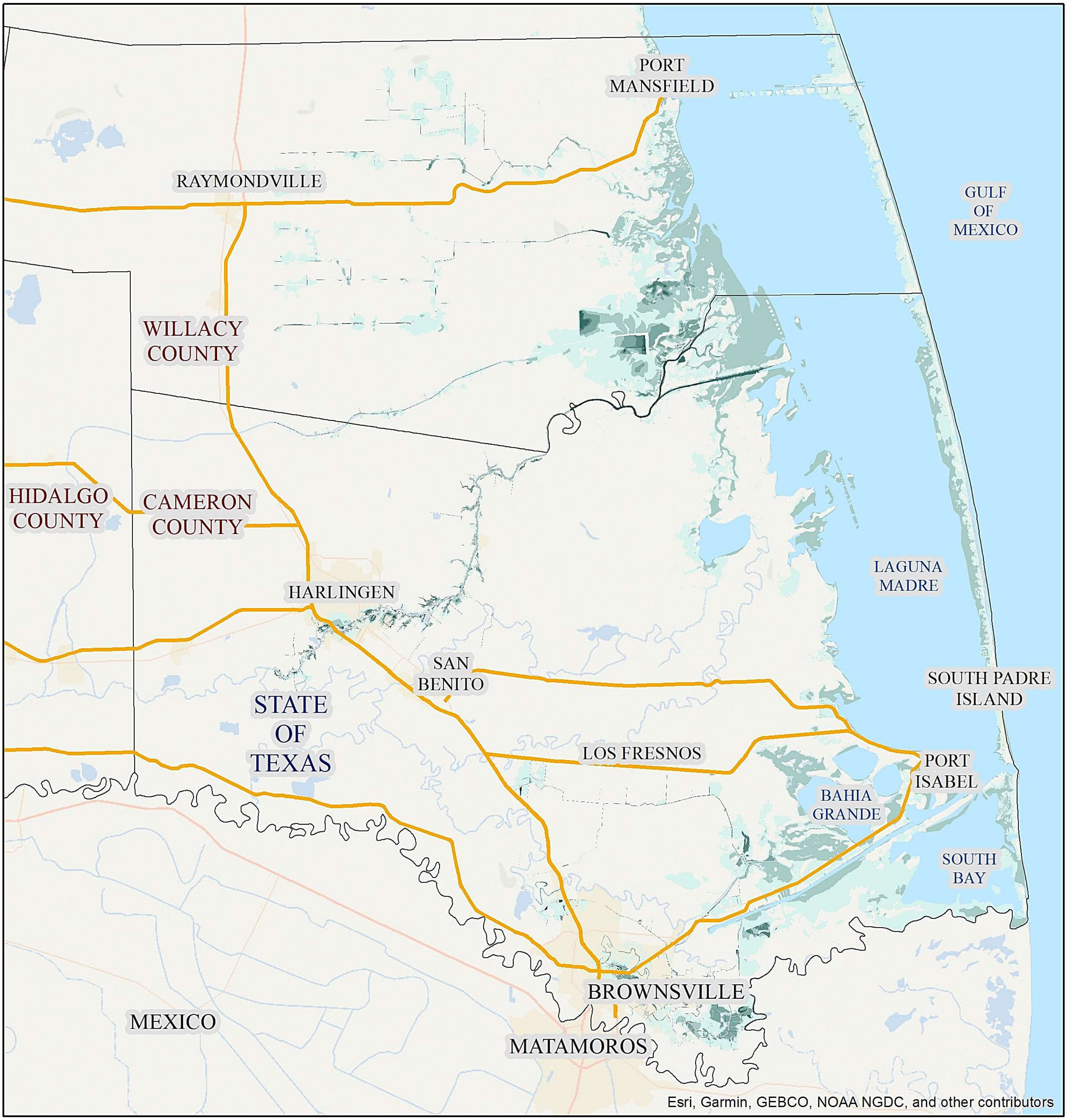

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 10-year
Storm Duration: 1 day

0 2 4 8 12 Miles

N
S

Water Depth (ft)

- 0 - 1.5
- 1.5 - 3
- 3 - 4.5
- 4.5 - 6
- 6 - 7.5
- 7.5 - 9

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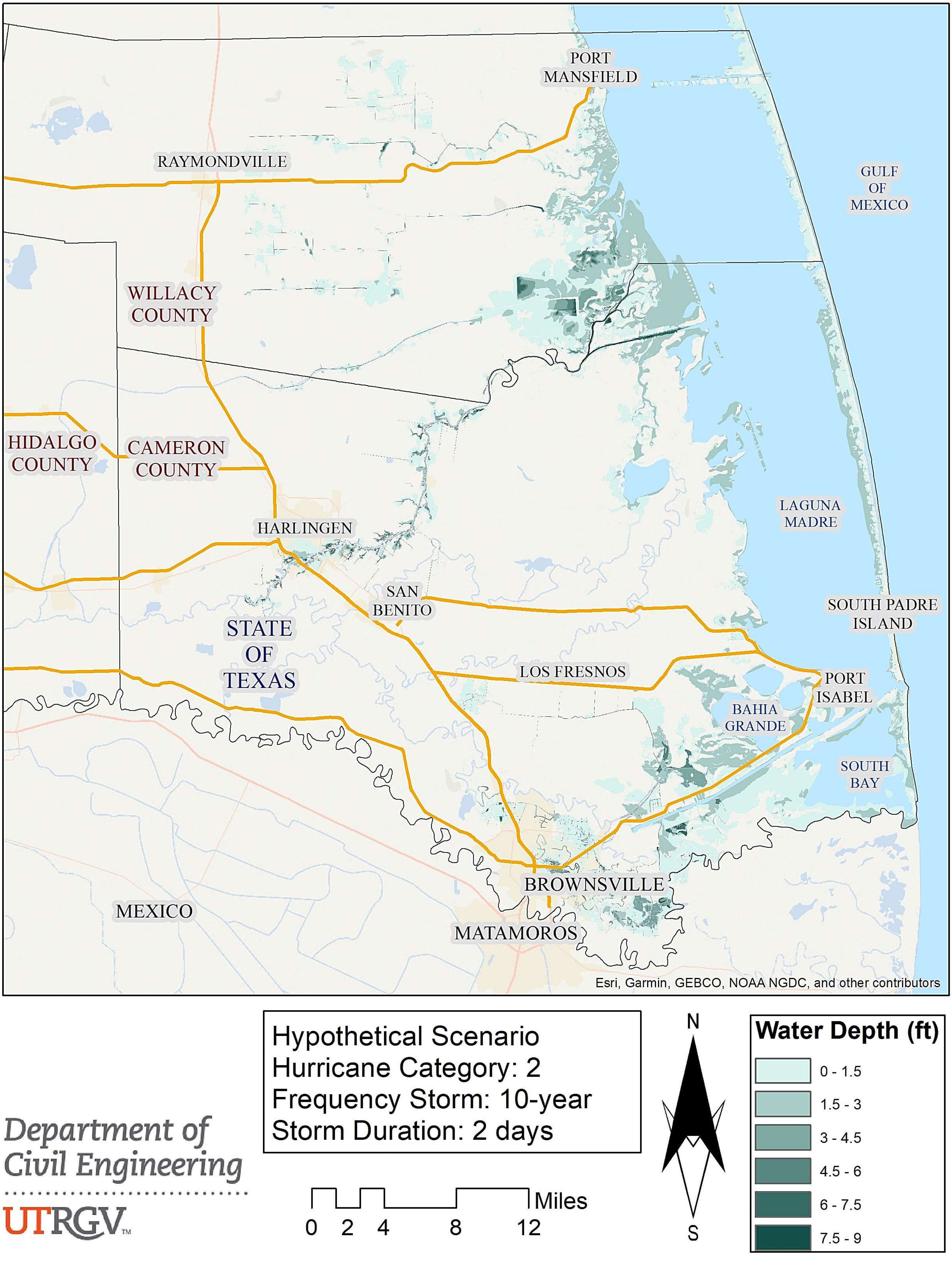

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 10-year
Storm Duration: 2 days

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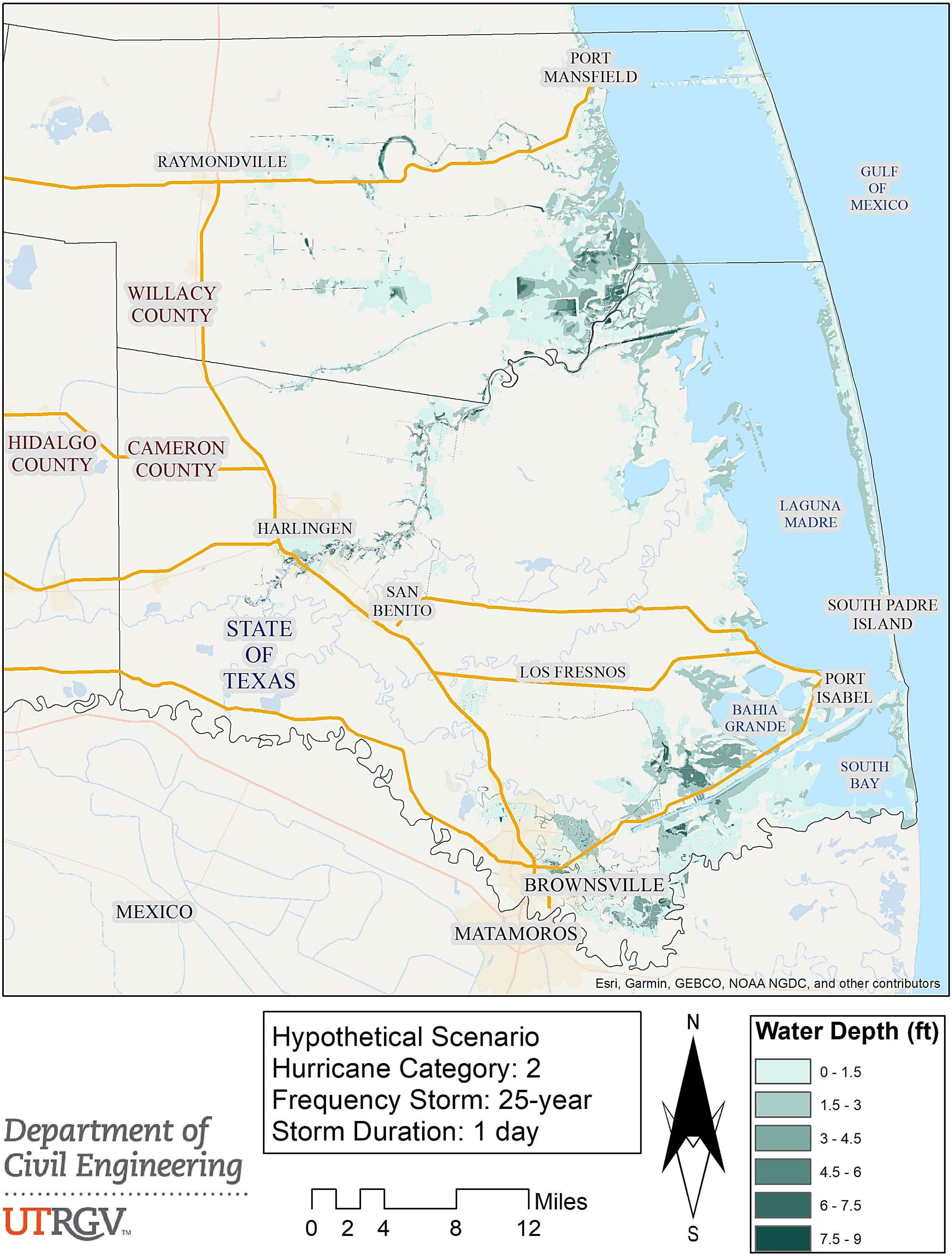
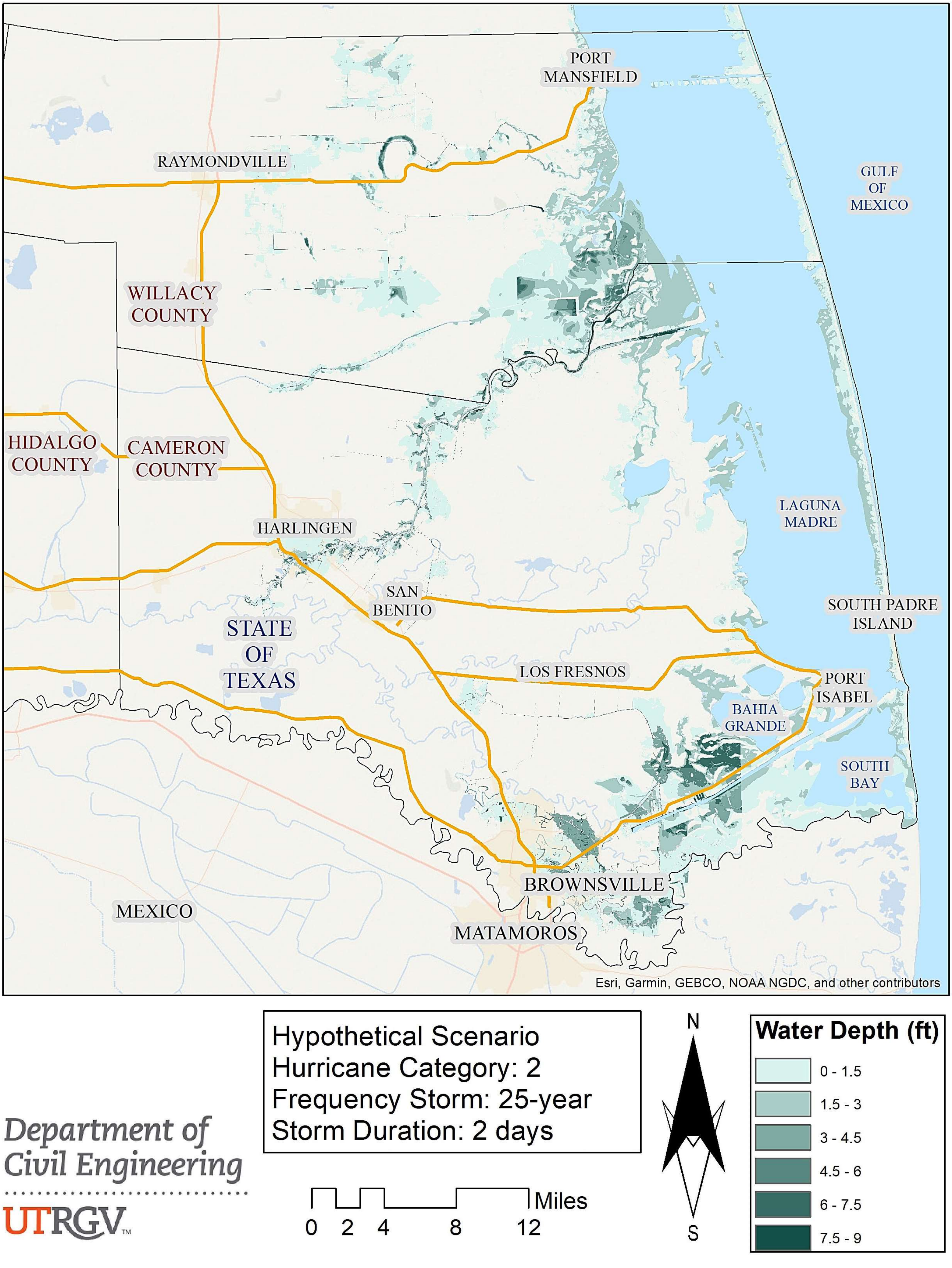


Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 25-year
Storm Duration: 1 day

Department of
Civil Engineering

UTRGV™



Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 25-year
Storm Duration: 2 days

Department of Civil Engineering

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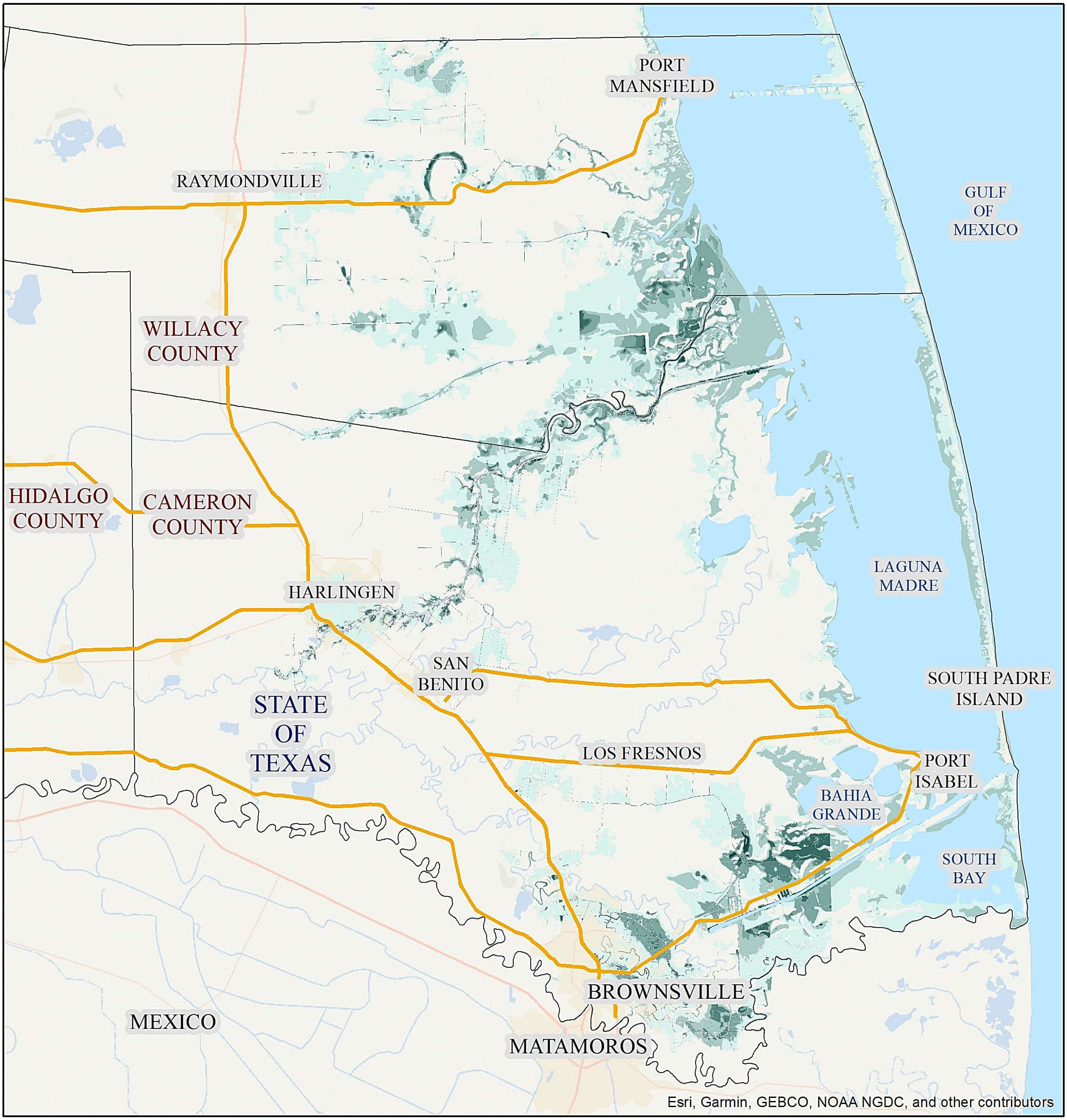

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 50-year
Storm Duration: 1 day

0 2 4 8 12 Miles

N
S

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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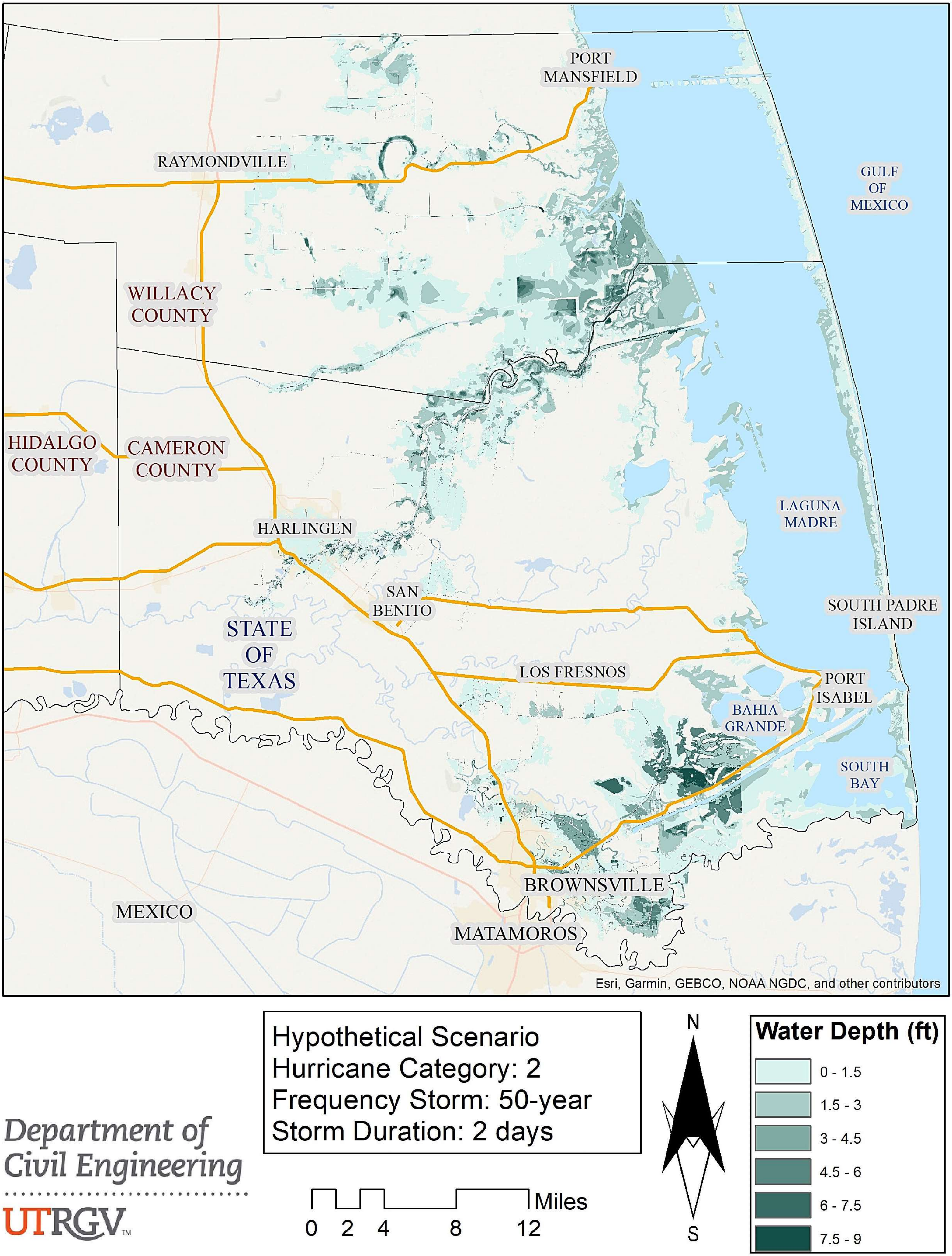

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 50-year
Storm Duration: 2 days

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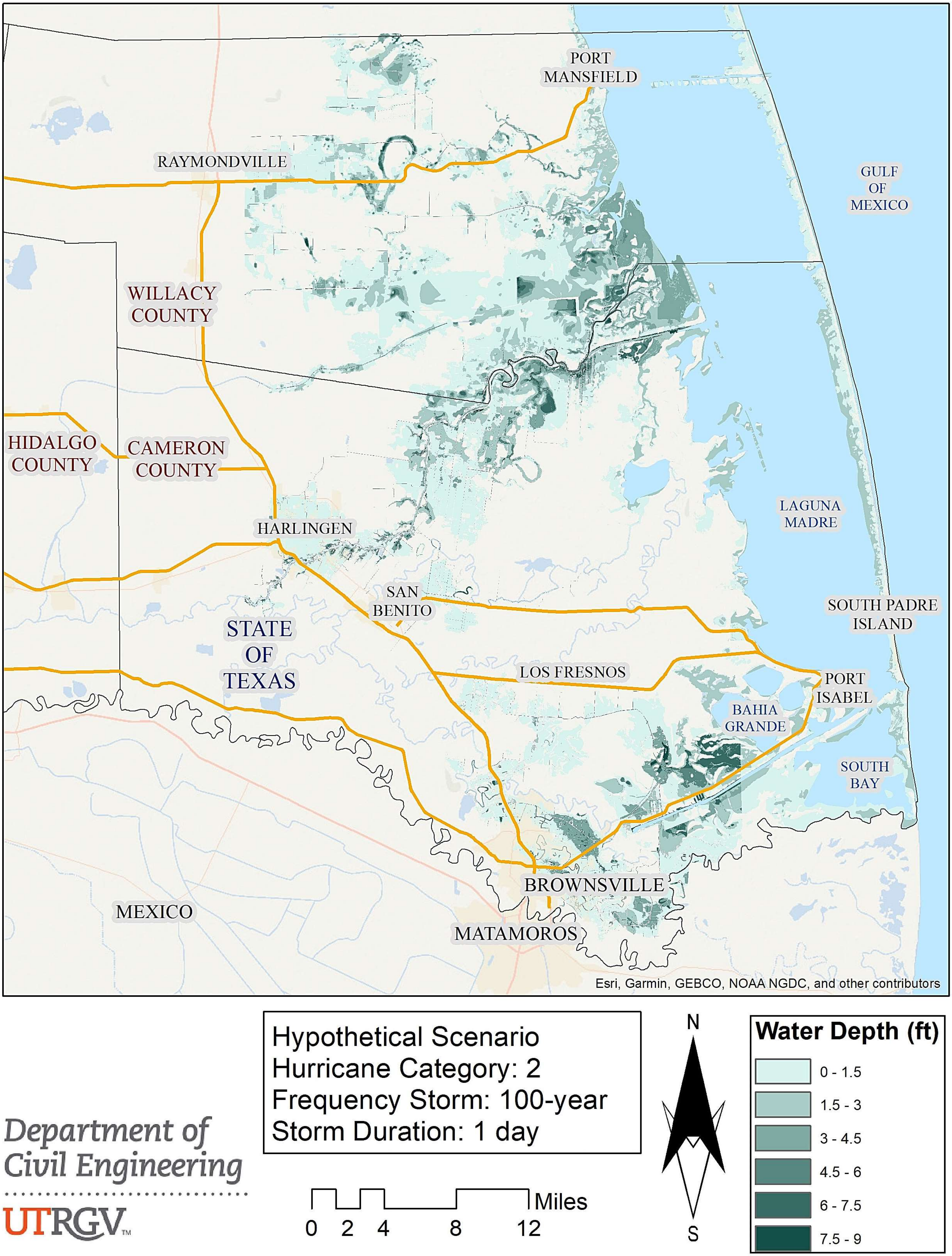

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 100-year
Storm Duration: 1 day

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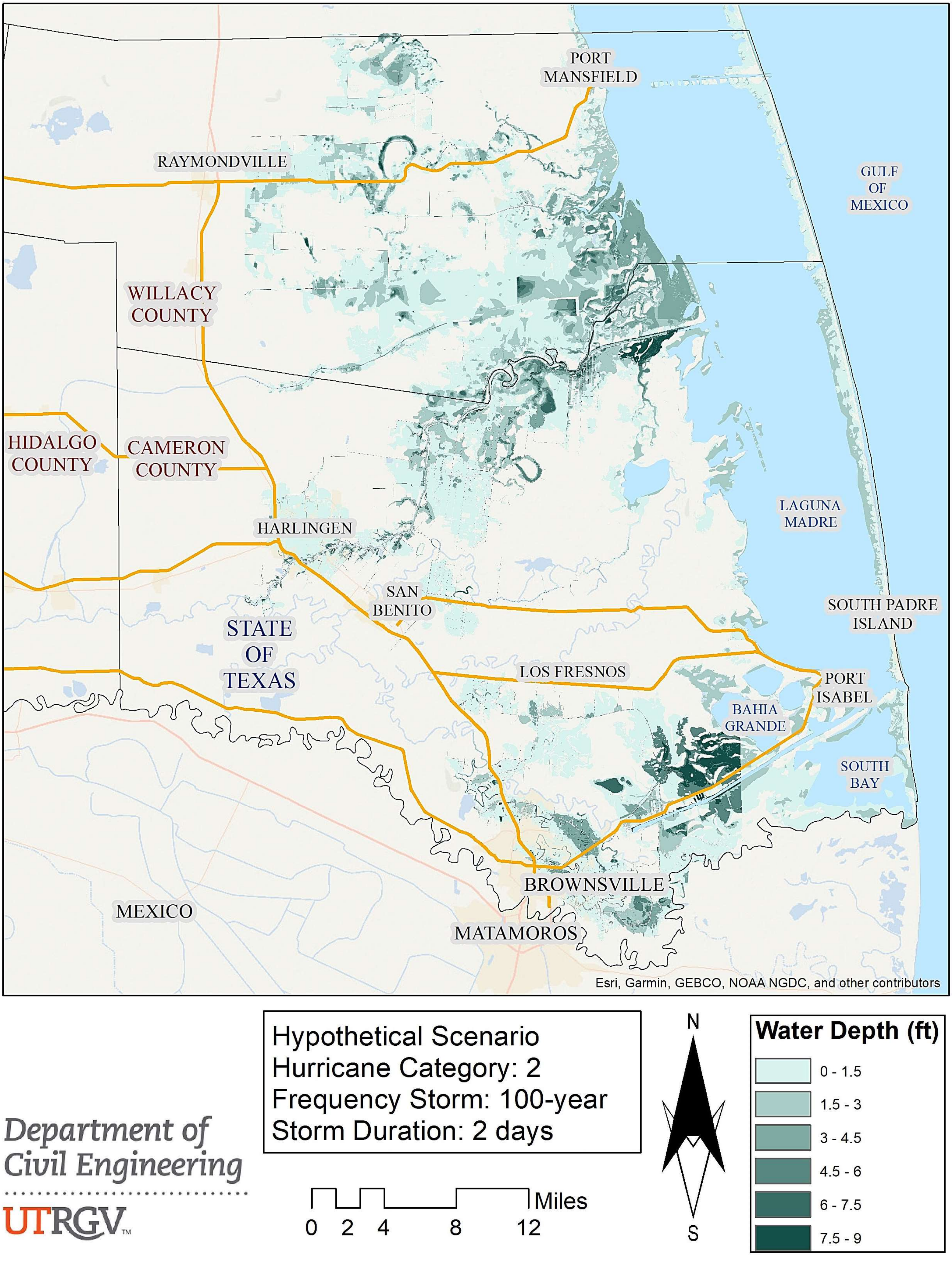

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 100-year
Storm Duration: 2 days

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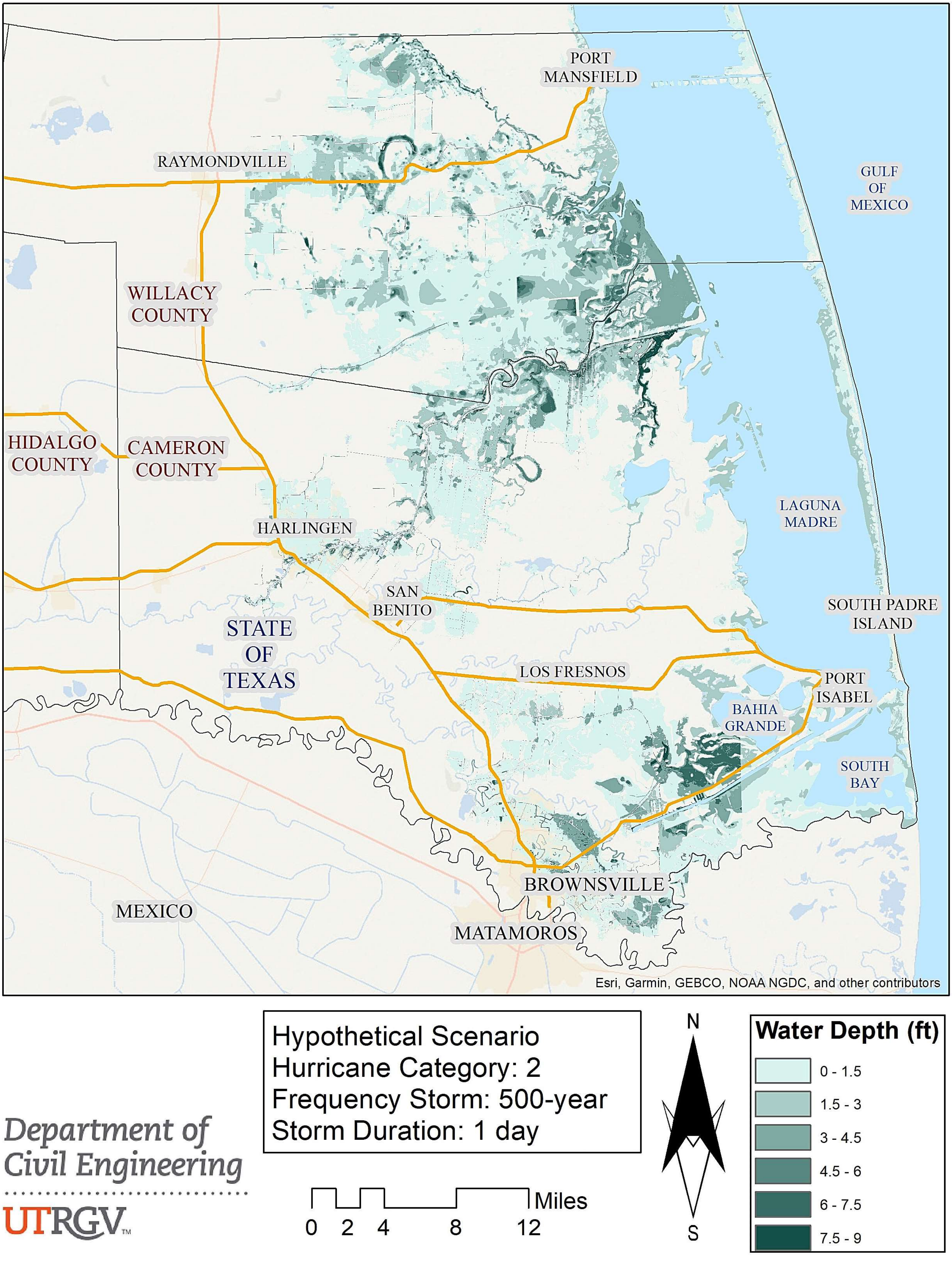

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 500-year
Storm Duration: 1 day

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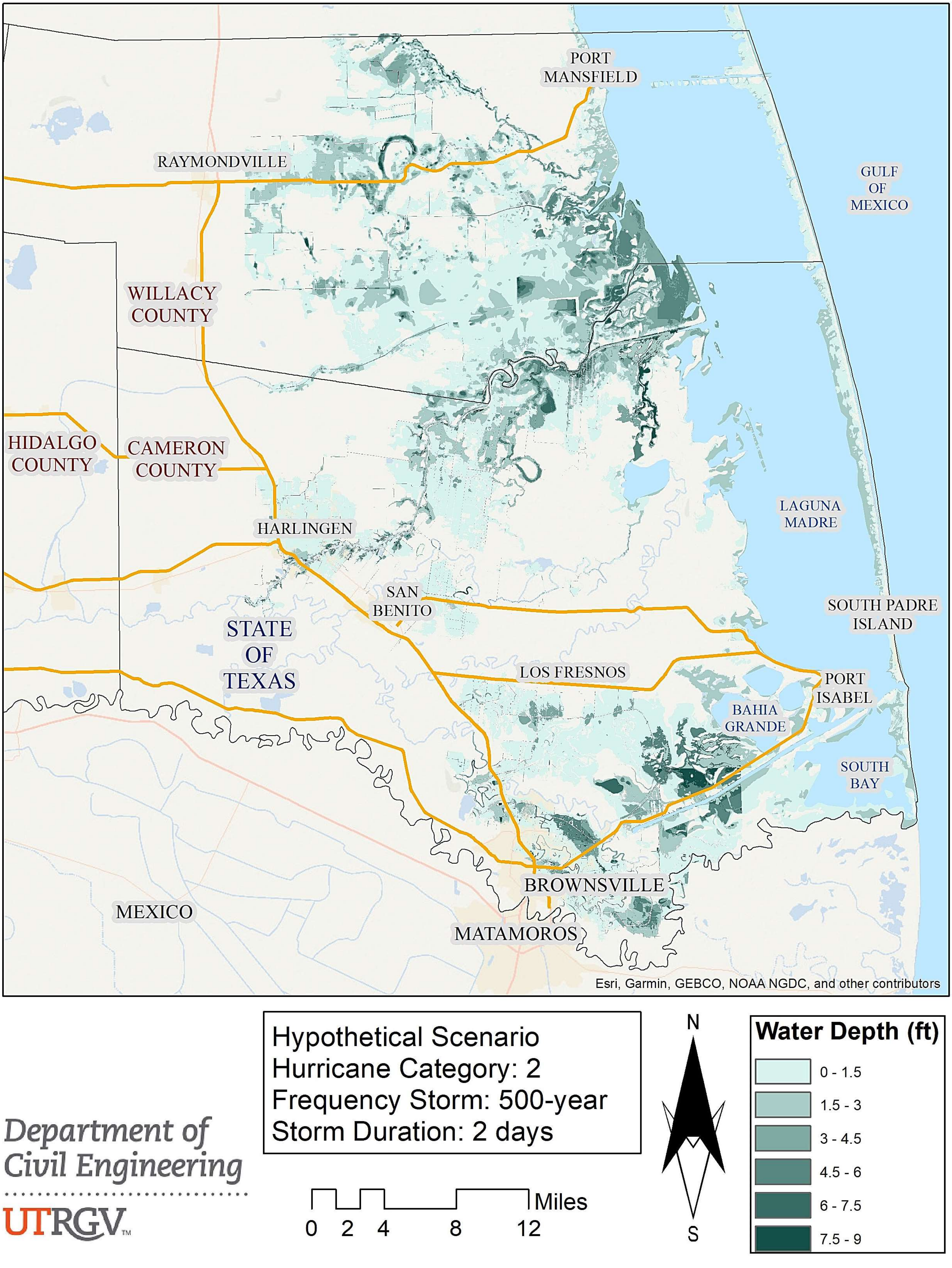

Hypothetical Scenario
Hurricane Category: 2
Frequency Storm: 500-year
Storm Duration: 2 days

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Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 10-year
Storm Duration: 1 day

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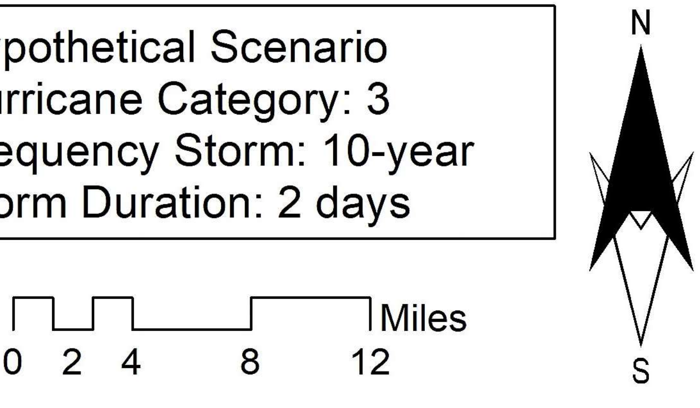
Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 10-year
Storm Duration: 2 days



Water Depth (ft)

🟩	0 - 1.5
🟩	1.5 - 3
🟩	3 - 4.5
🟩	4.5 - 6
🟩	6 - 7.5
🟩	7.5 - 9

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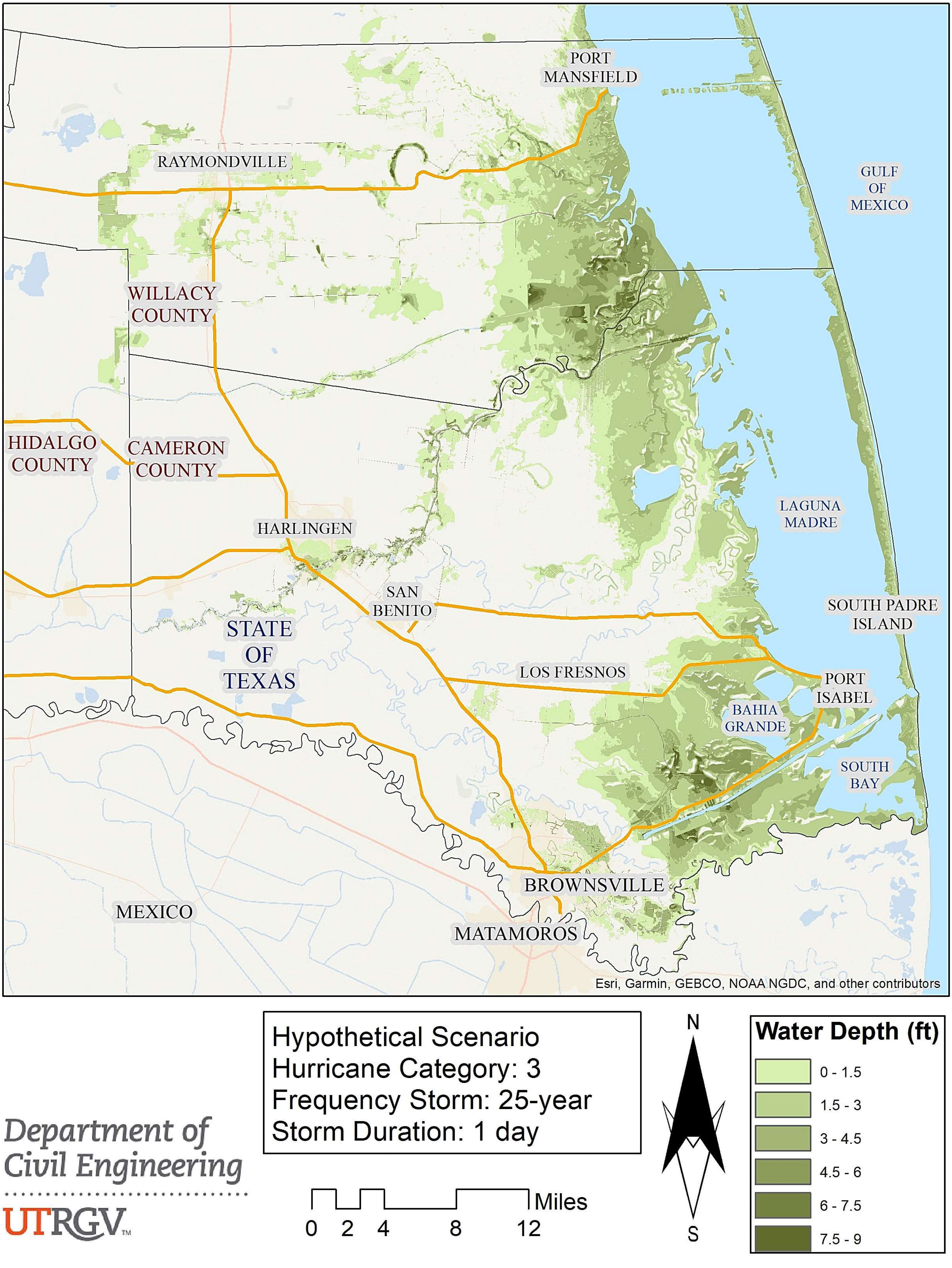

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 25-year
Storm Duration: 1 day

Water Depth (ft)

🟩	0 - 1.5
🟩	1.5 - 3
🟩	3 - 4.5
🟩	4.5 - 6
🟩	6 - 7.5
🟩	7.5 - 9

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Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 25-year
Storm Duration: 2 days

Water Depth (ft)

🟩	0 - 1.5
🟩	1.5 - 3
🟩	3 - 4.5
🟩	4.5 - 6
🟩	6 - 7.5
🟩	7.5 - 9

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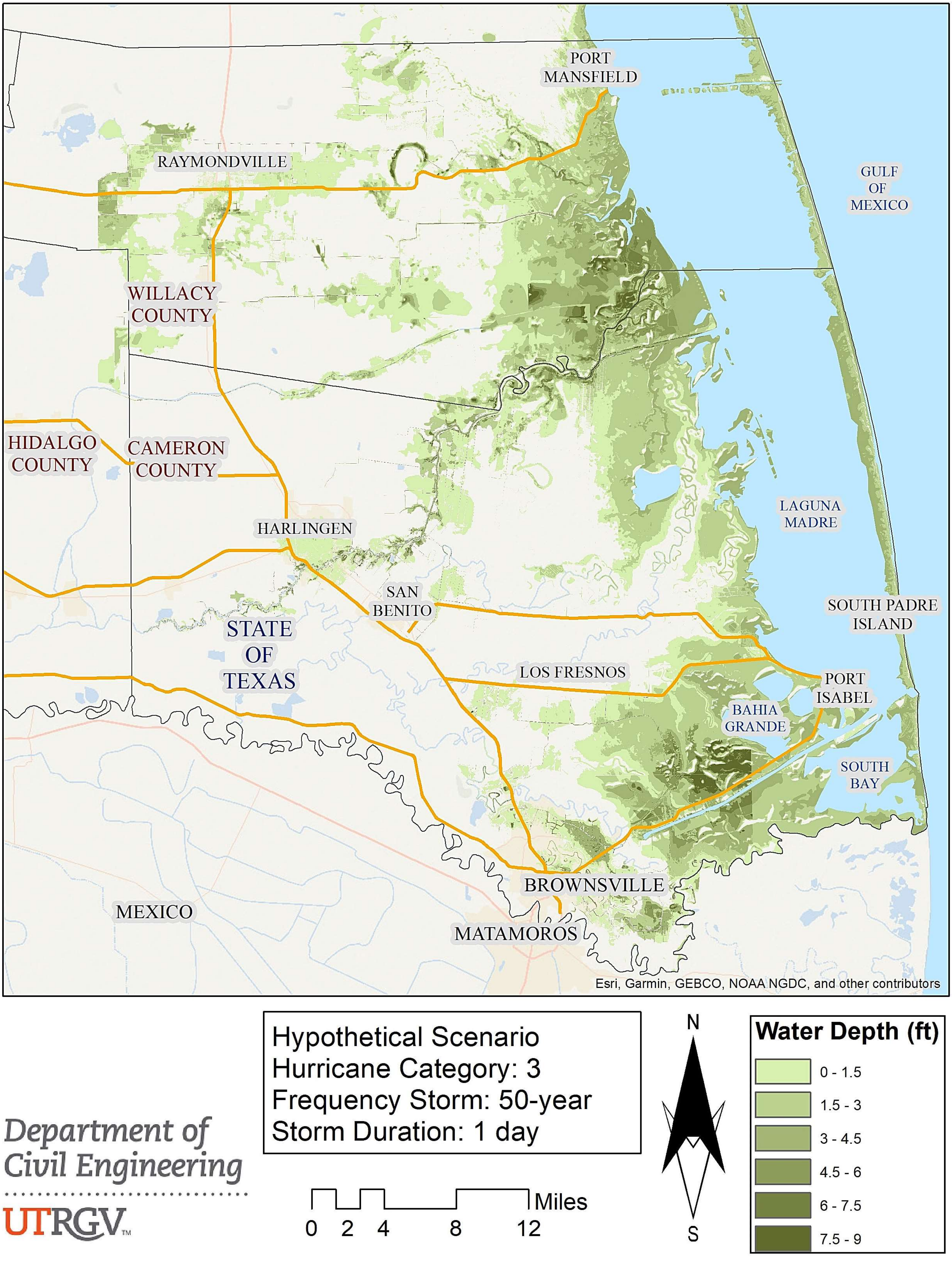

Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 50-year
Storm Duration: 1 day

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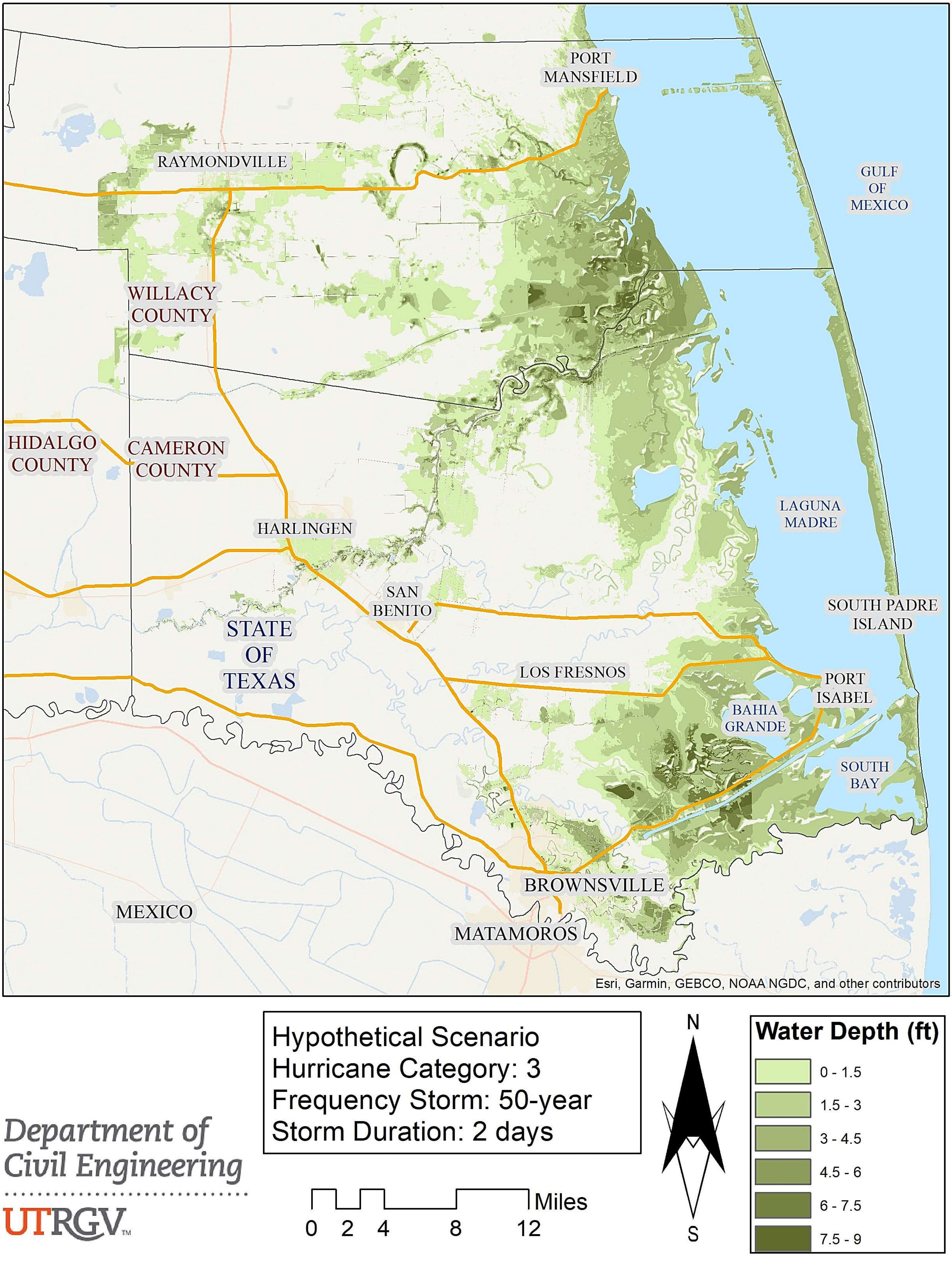

Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 50-year
Storm Duration: 2 days

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Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 100-year
Storm Duration: 1 day

Water Depth (ft)

🟩	0 - 1.5
🟩	1.5 - 3
🟩	3 - 4.5
🟩	4.5 - 6
🟩	6 - 7.5
🟩	7.5 - 9

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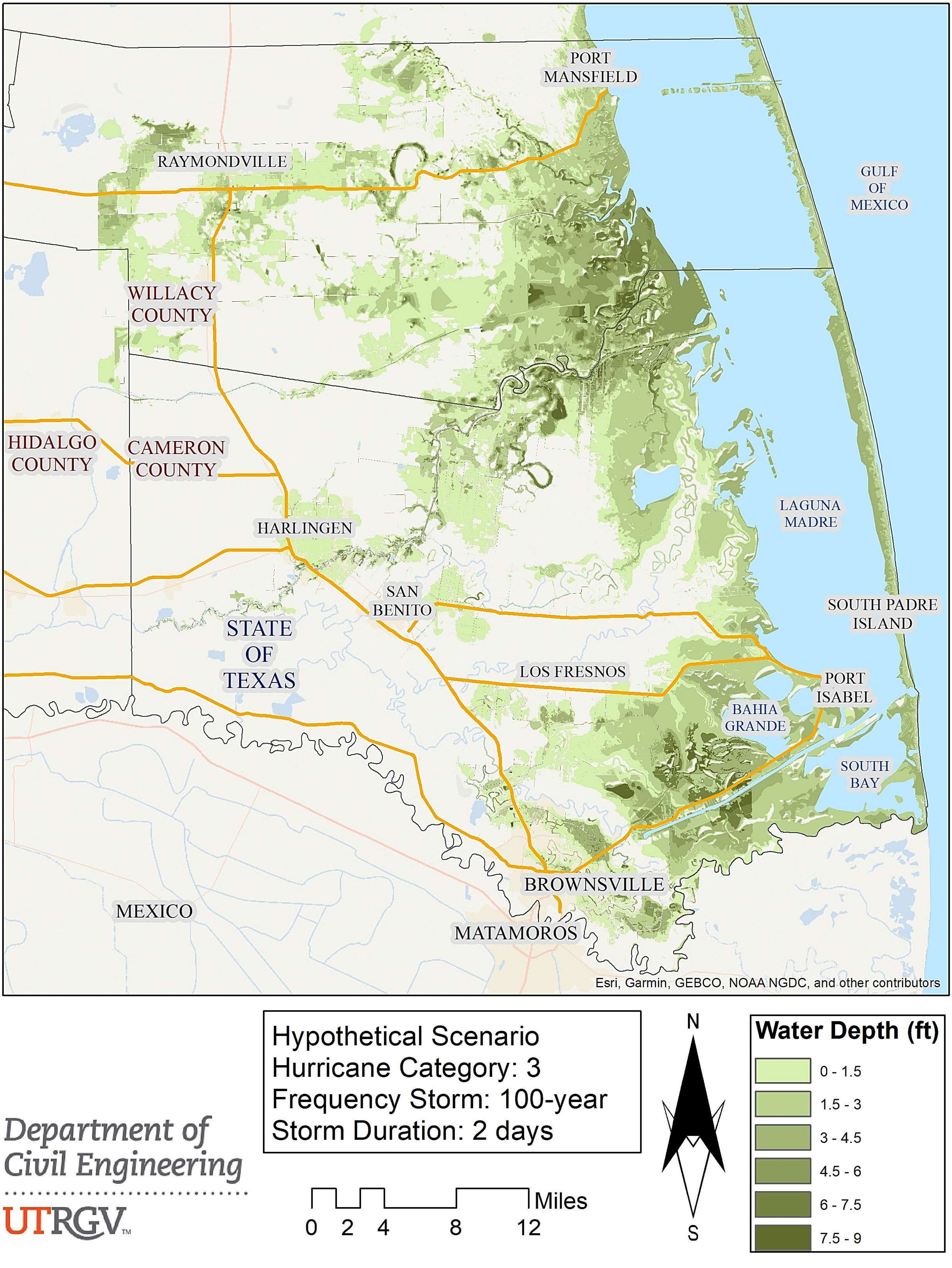

Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 100-year
Storm Duration: 2 days

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Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 500-year
Storm Duration: 1 day

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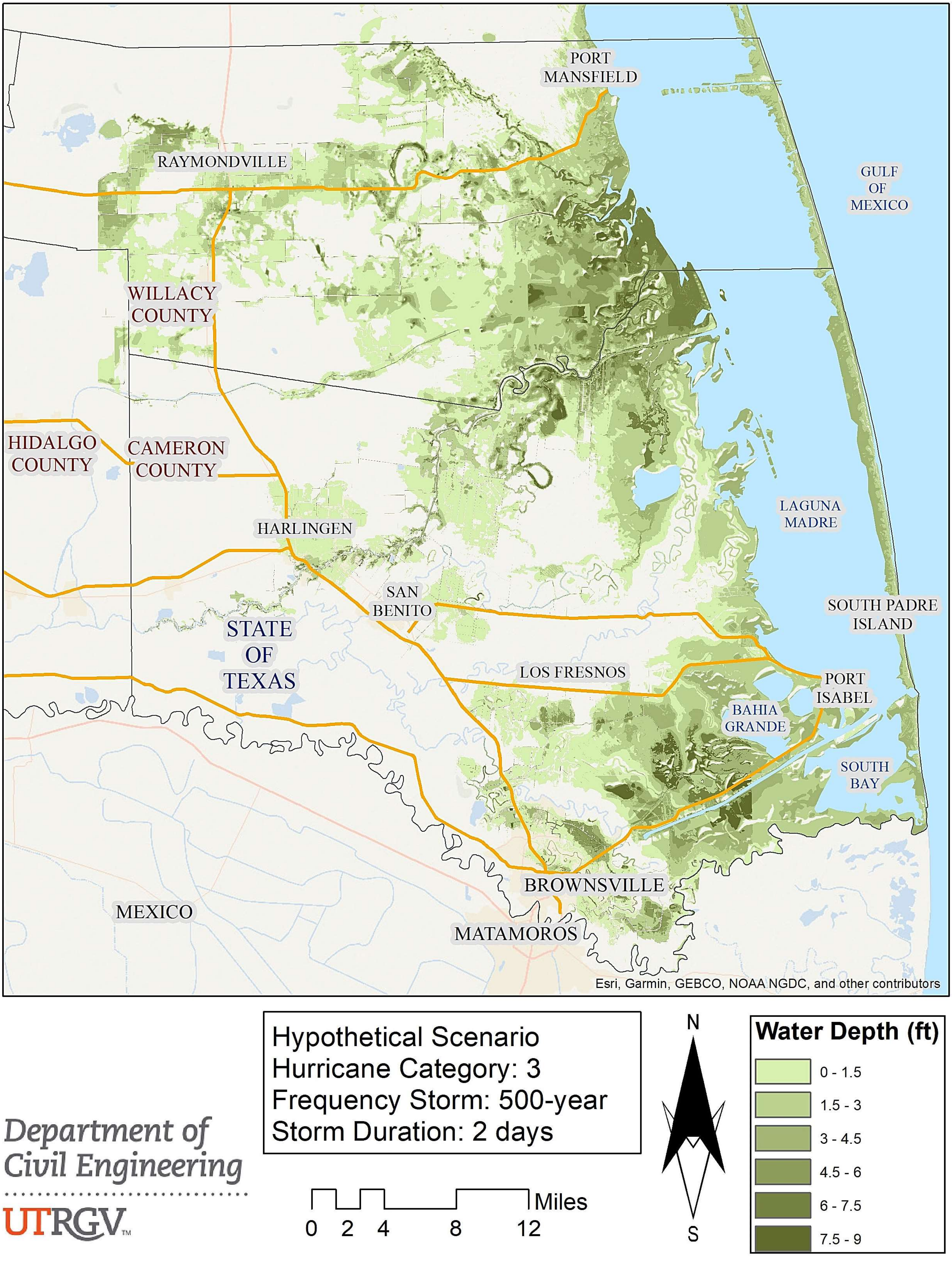

Hypothetical Scenario
Hurricane Category: 3
Frequency Storm: 500-year
Storm Duration: 2 days

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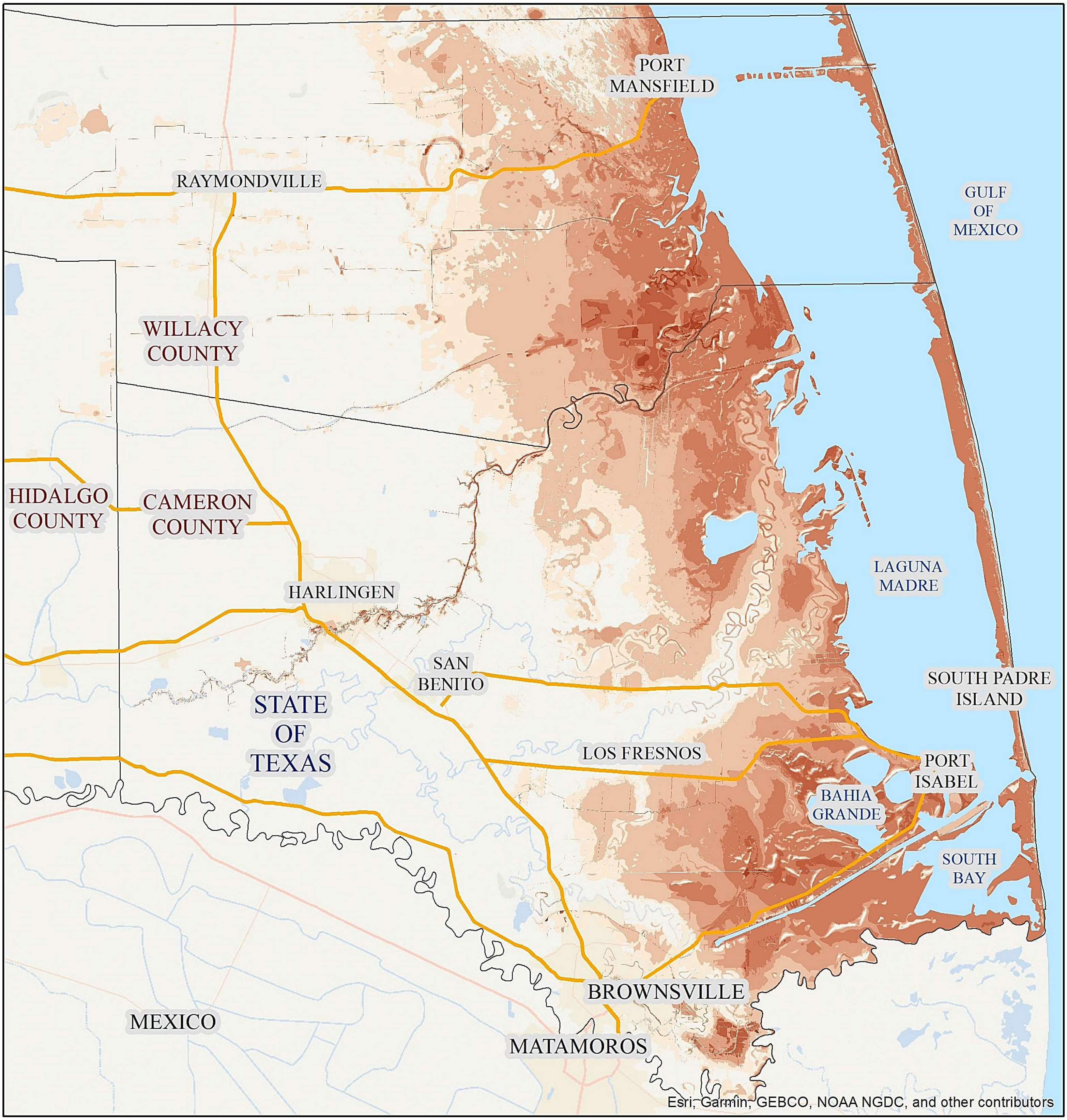

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 10-year
Storm Duration: 1 day

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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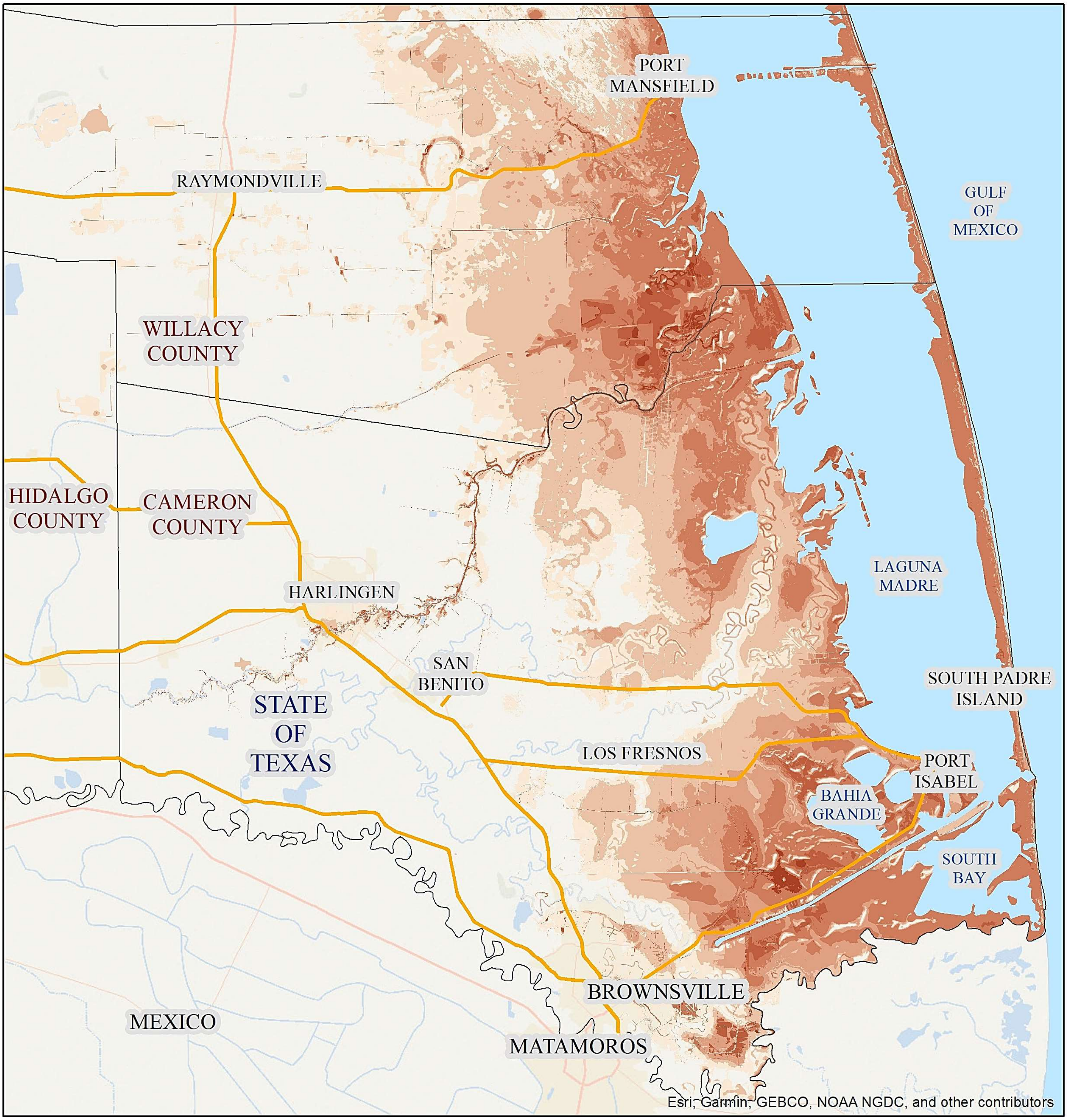

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 10-year
Storm Duration: 2 days

0 2 4 8 12 Miles

N
S

Water Depth (ft)

- 0 - 1.5
- 1.5 - 3
- 3 - 4.5
- 4.5 - 6
- 6 - 7.5
- 7.5 - 9

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Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 25-year
Storm Duration: 1 day

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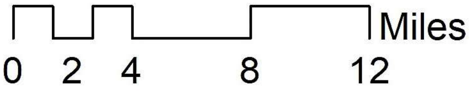
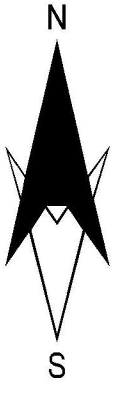
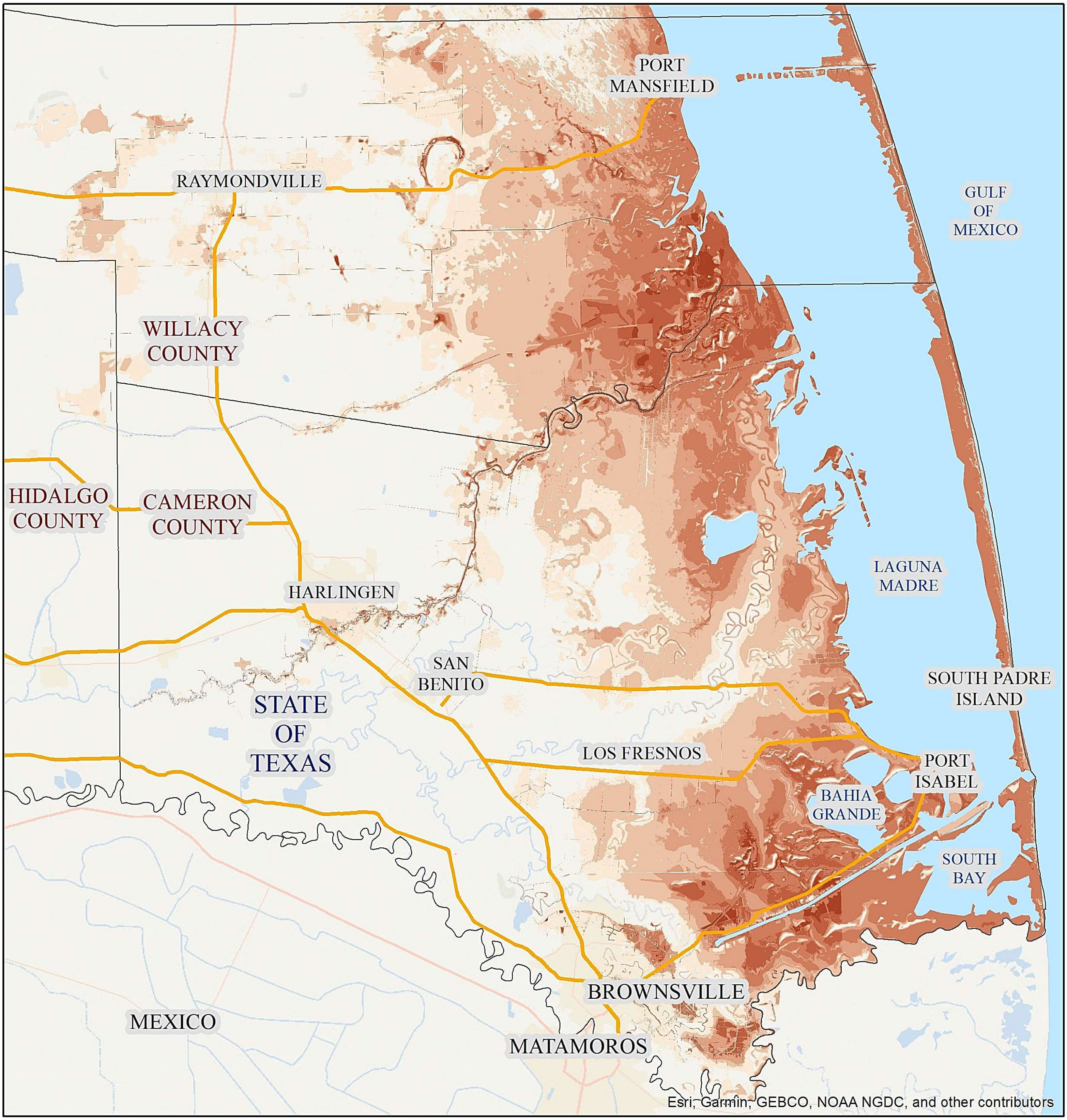




Water Depth (ft)	
▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9



Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 25-year
Storm Duration: 2 days

0 2 4 8 12 Miles

N
S

Water Depth (ft)

- ▨ 0 - 1.5
- ▨ 1.5 - 3
- ▨ 3 - 4.5
- ▨ 4.5 - 6
- ▨ 6 - 7.5
- ▨ 7.5 - 9

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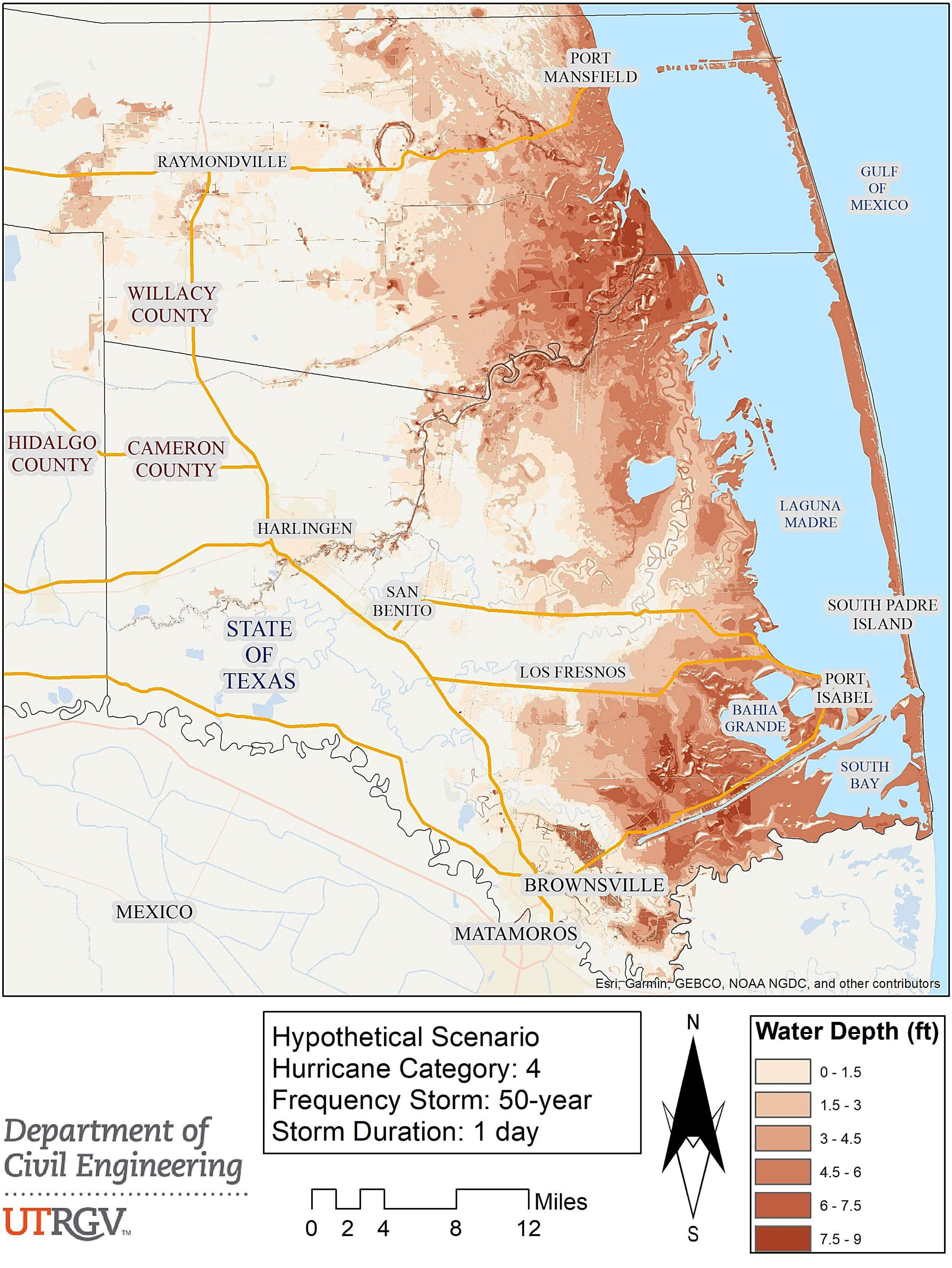

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 50-year
Storm Duration: 1 day

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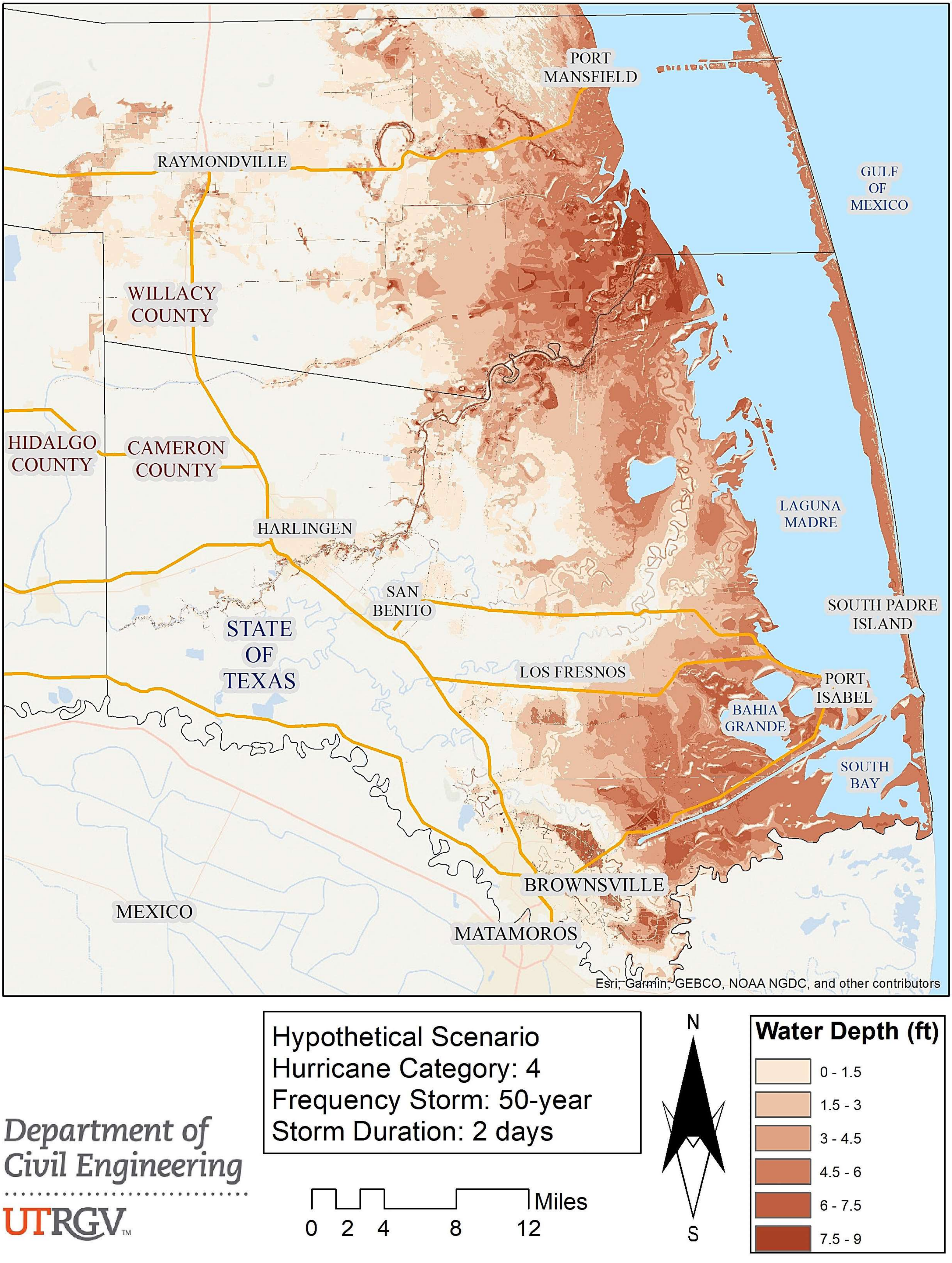

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 50-year
Storm Duration: 2 days

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Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 100-year
Storm Duration: 1 day

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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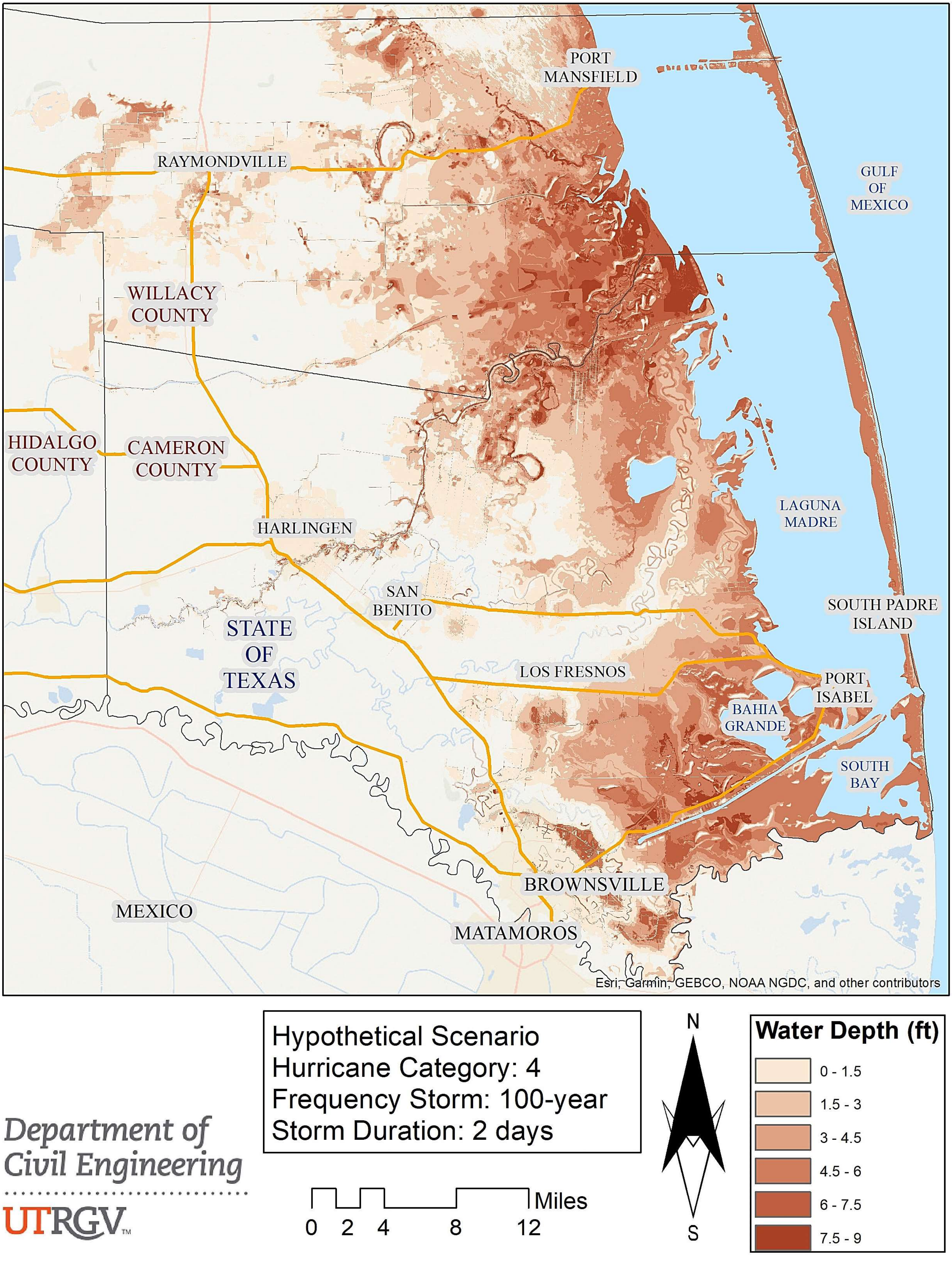

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 100-year
Storm Duration: 2 days

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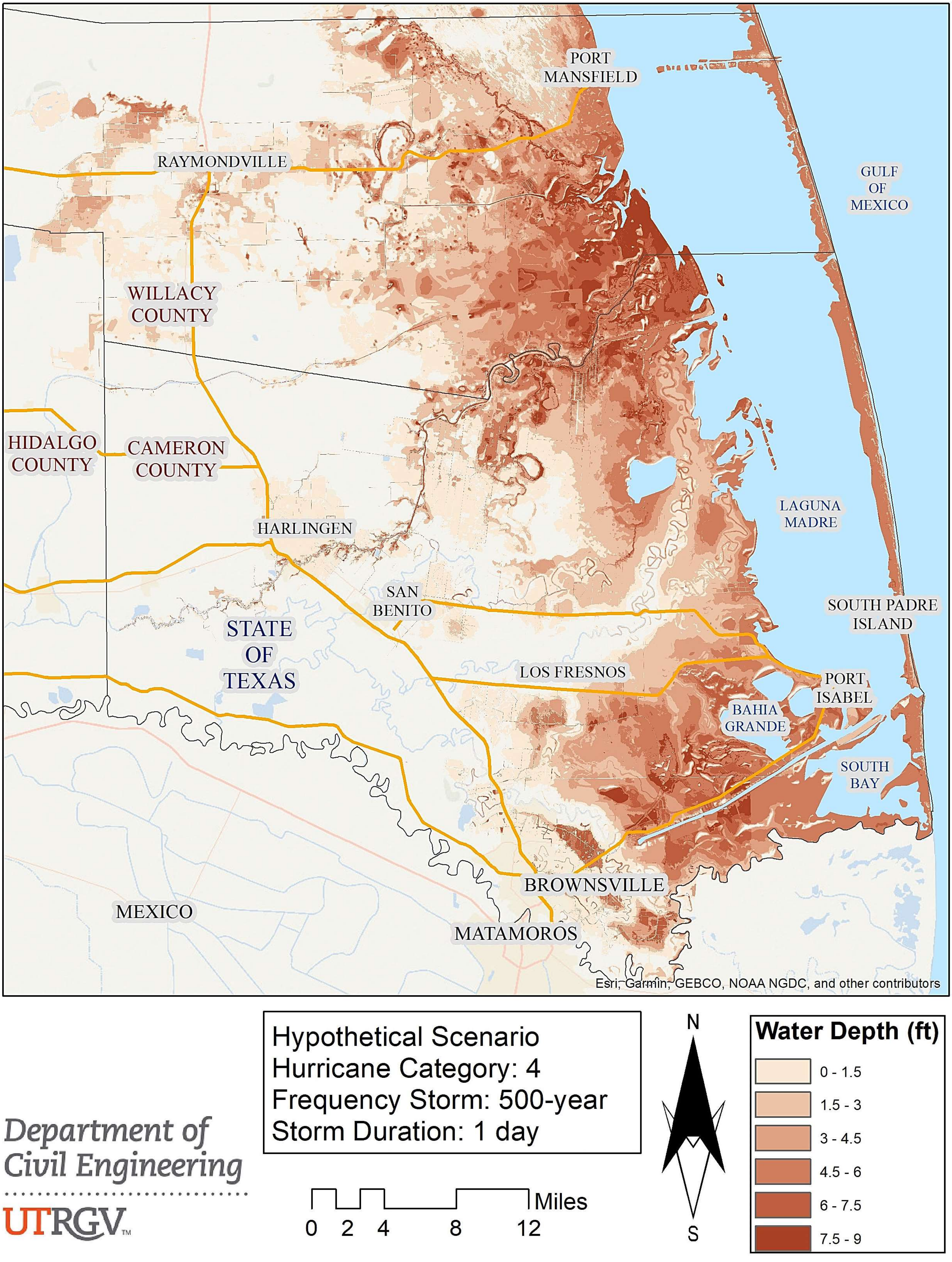

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 500-year
Storm Duration: 1 day

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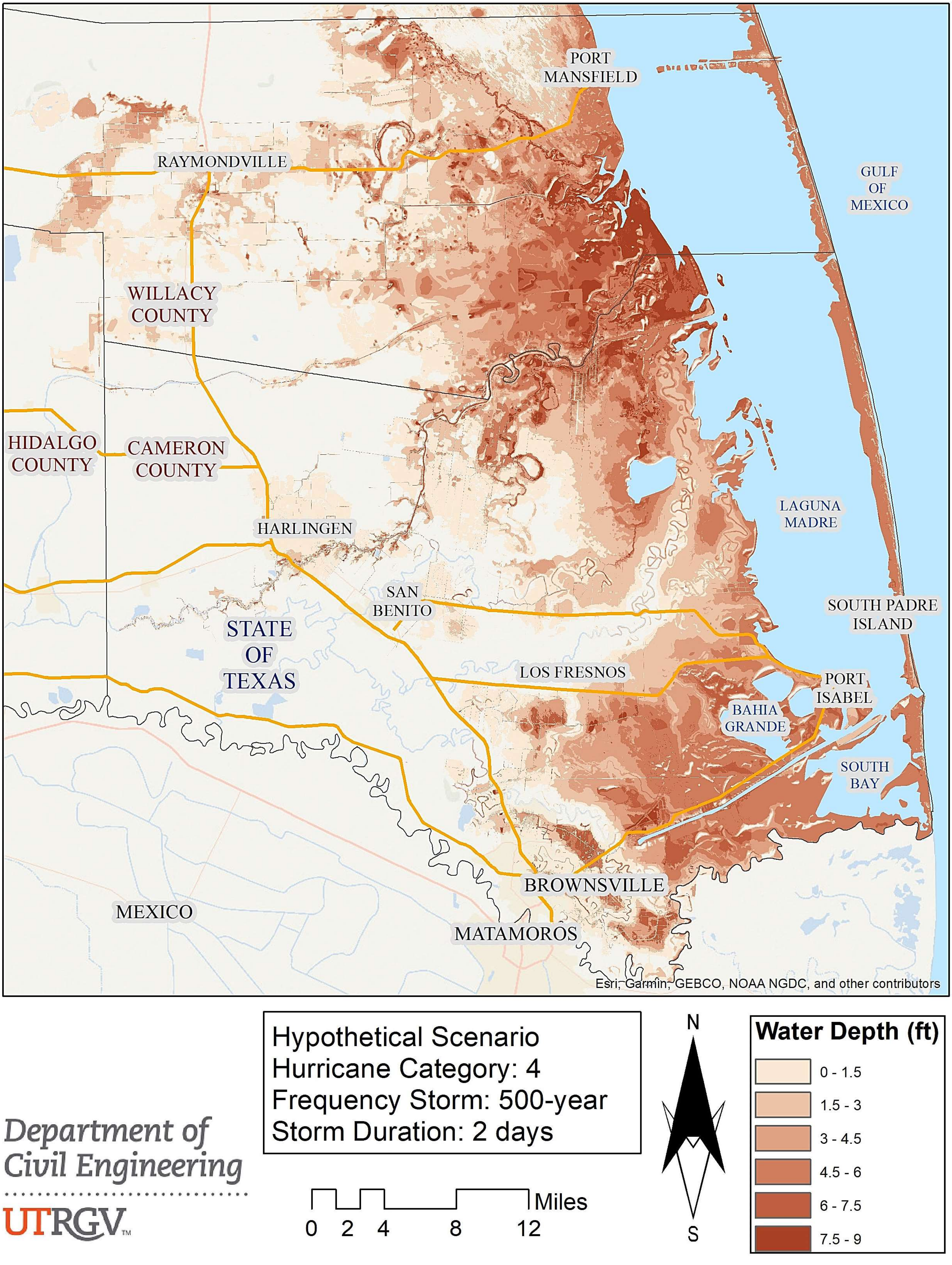

Hypothetical Scenario
Hurricane Category: 4
Frequency Storm: 500-year
Storm Duration: 2 days

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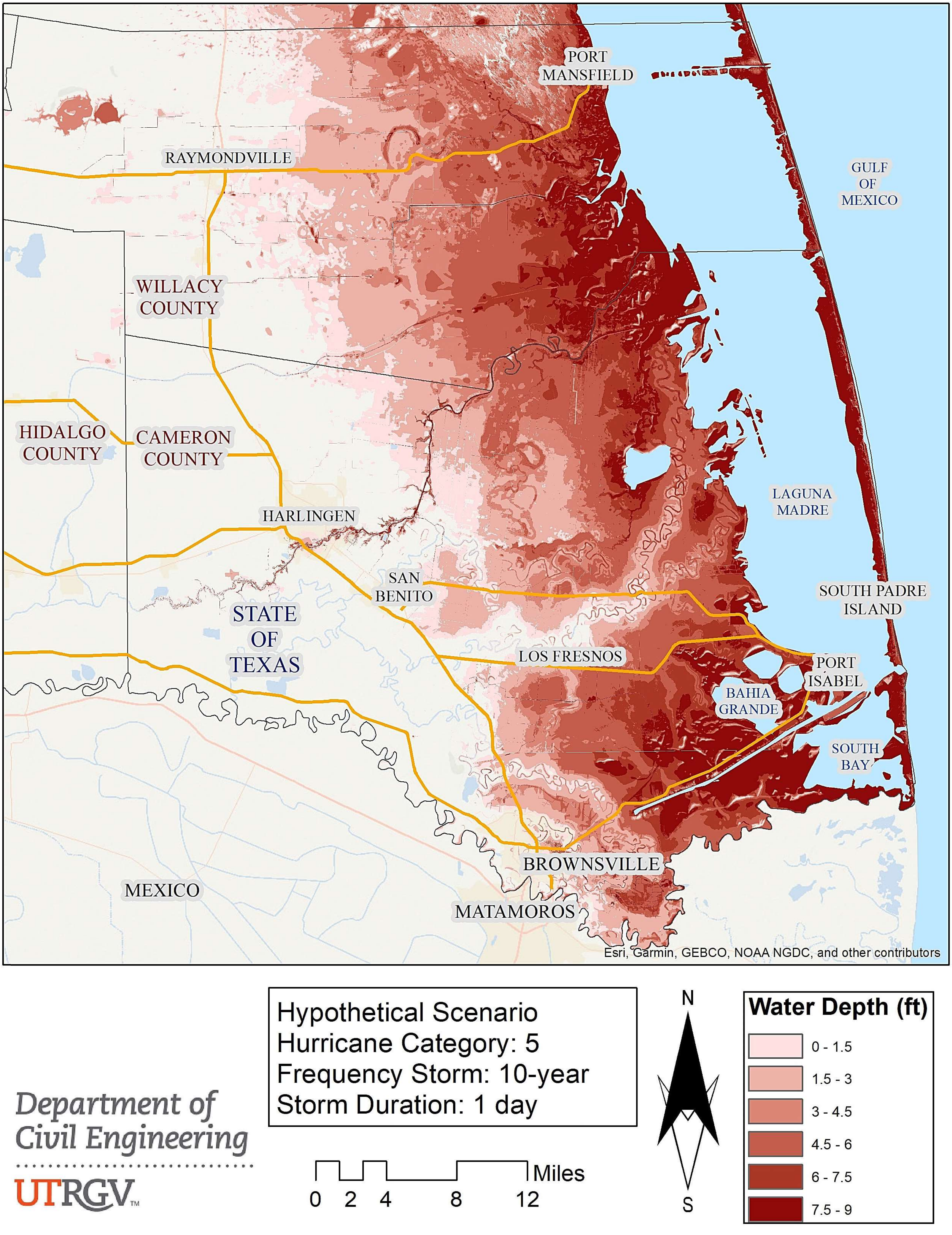

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 10-year
Storm Duration: 1 day

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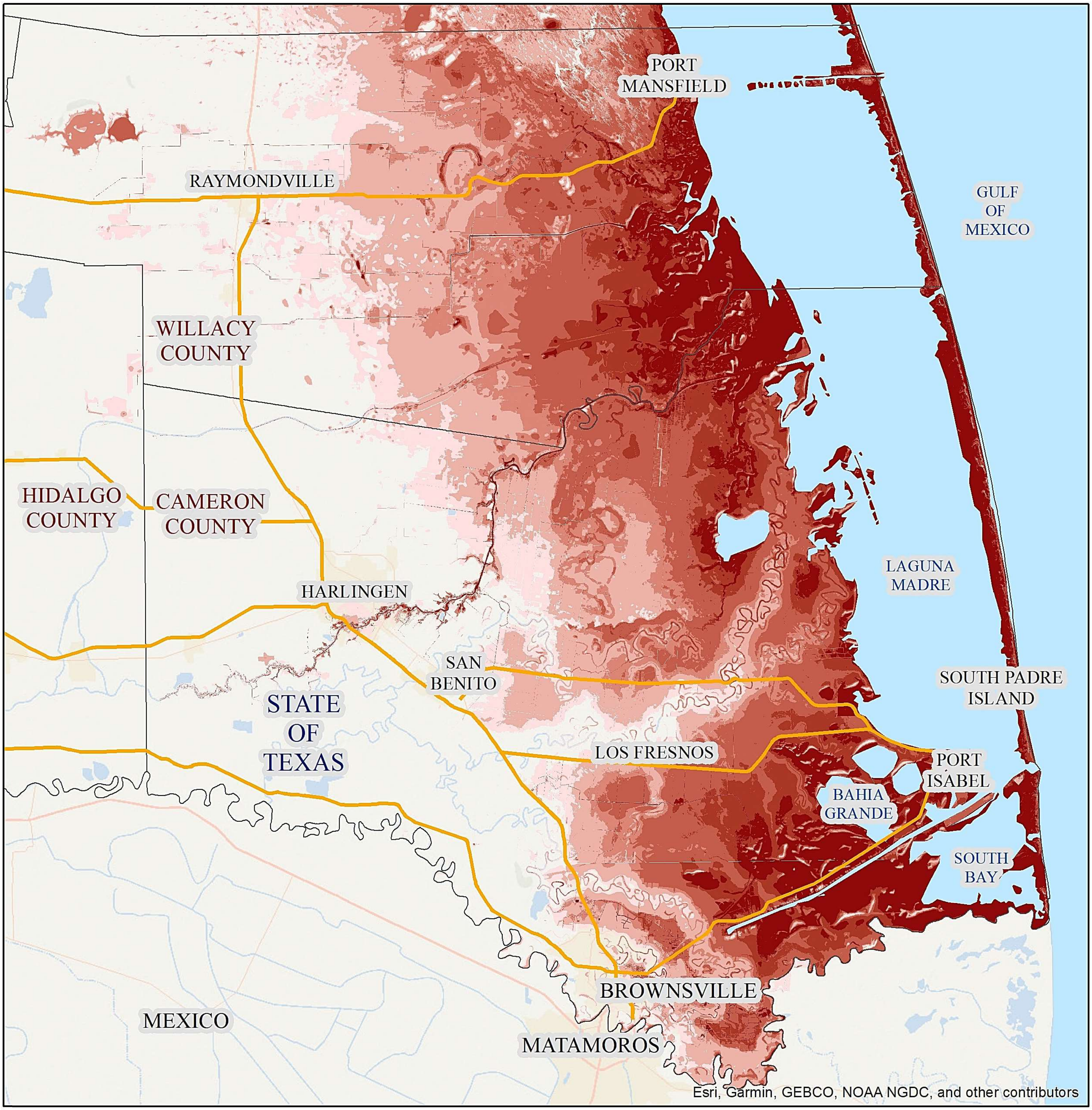

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 10-year
Storm Duration: 2 days

0 2 4 8 12 Miles

N
S

Water Depth (ft)	
🟥	0 - 1.5
🟥	1.5 - 3
🟥	3 - 4.5
🟥	4.5 - 6
🟥	6 - 7.5
🟥	7.5 - 9

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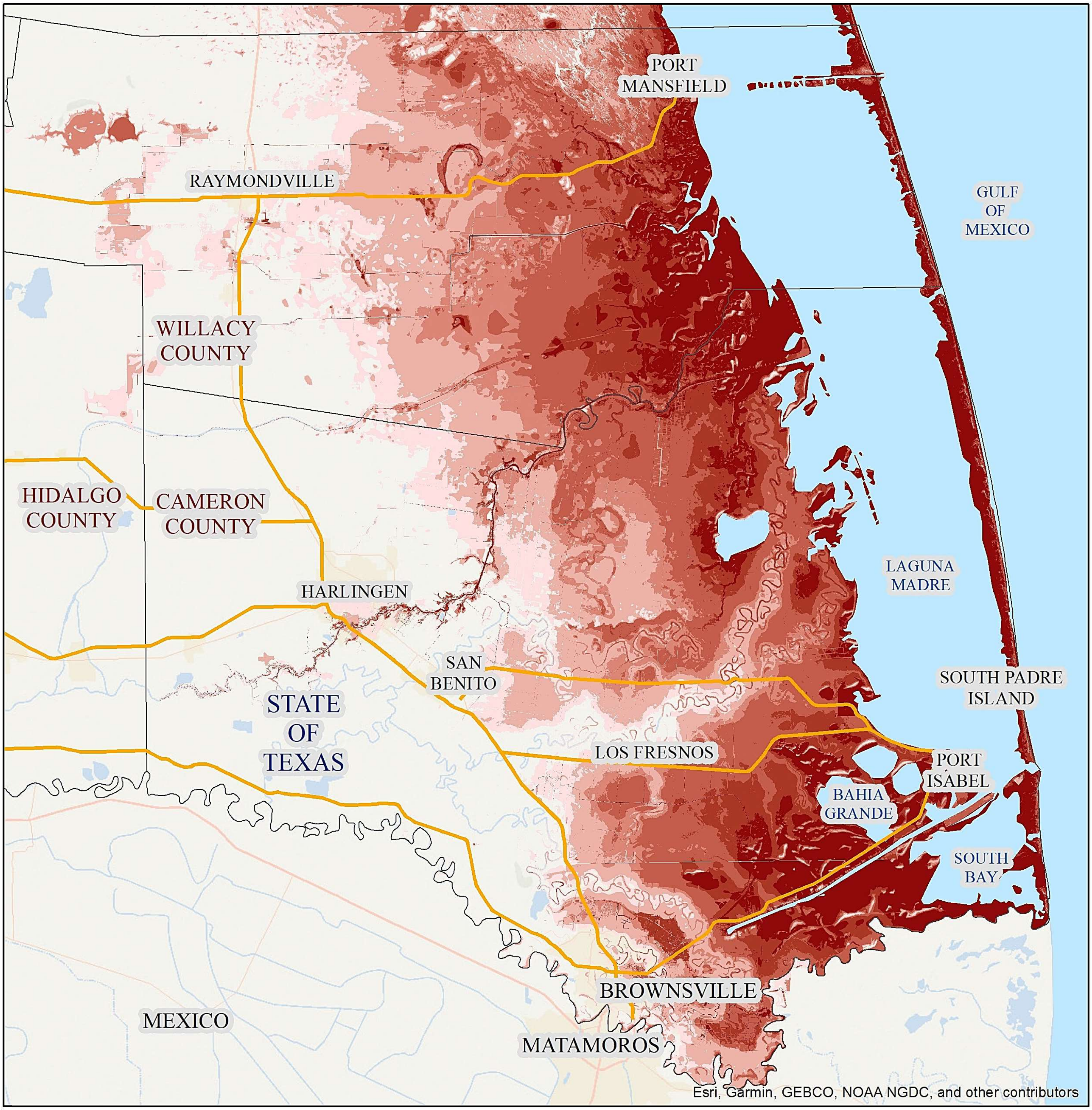

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 25-year
Storm Duration: 1 day

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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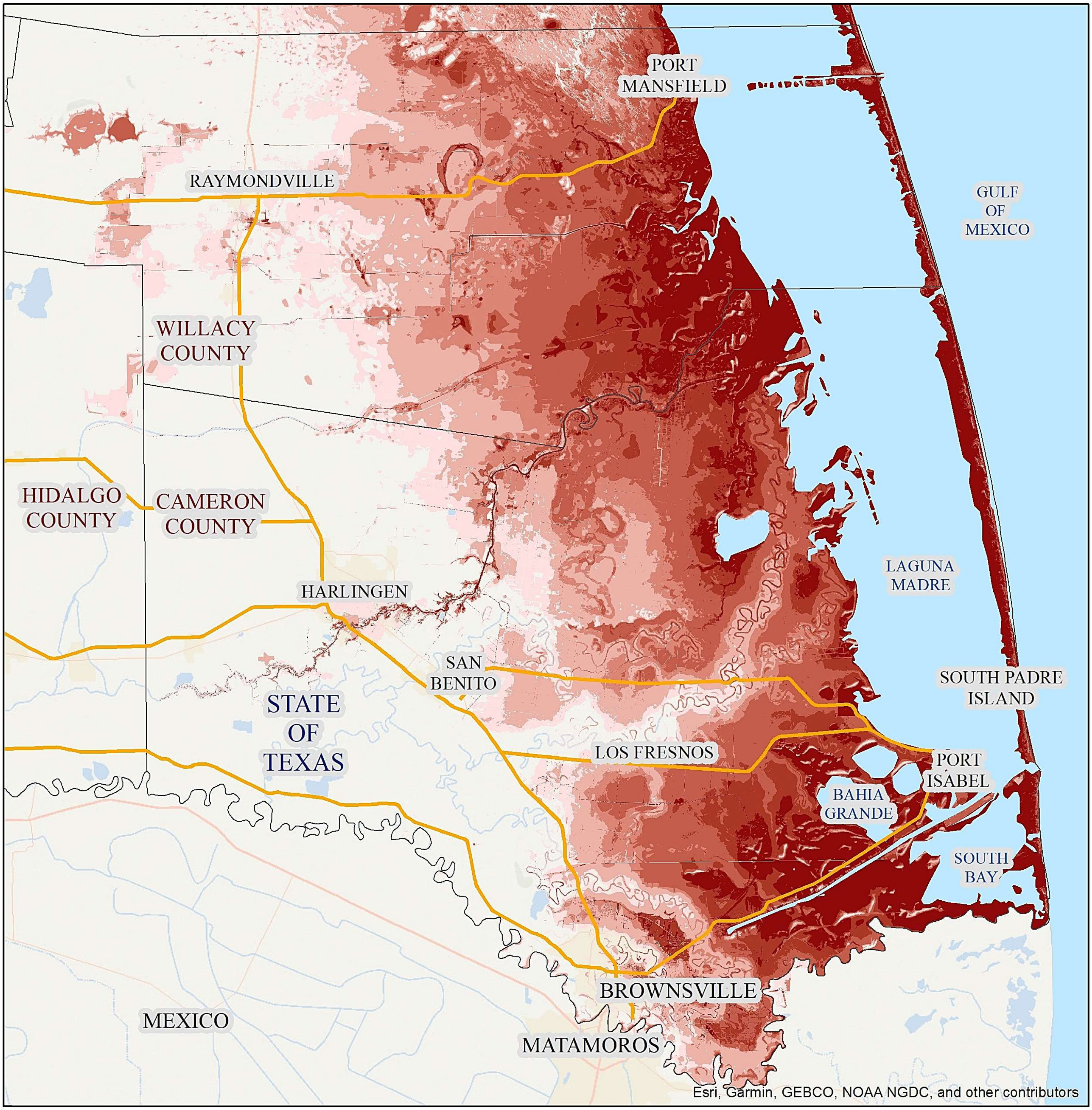

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 25-year
Storm Duration: 2 days

0 2 4 8 12 Miles

N
S

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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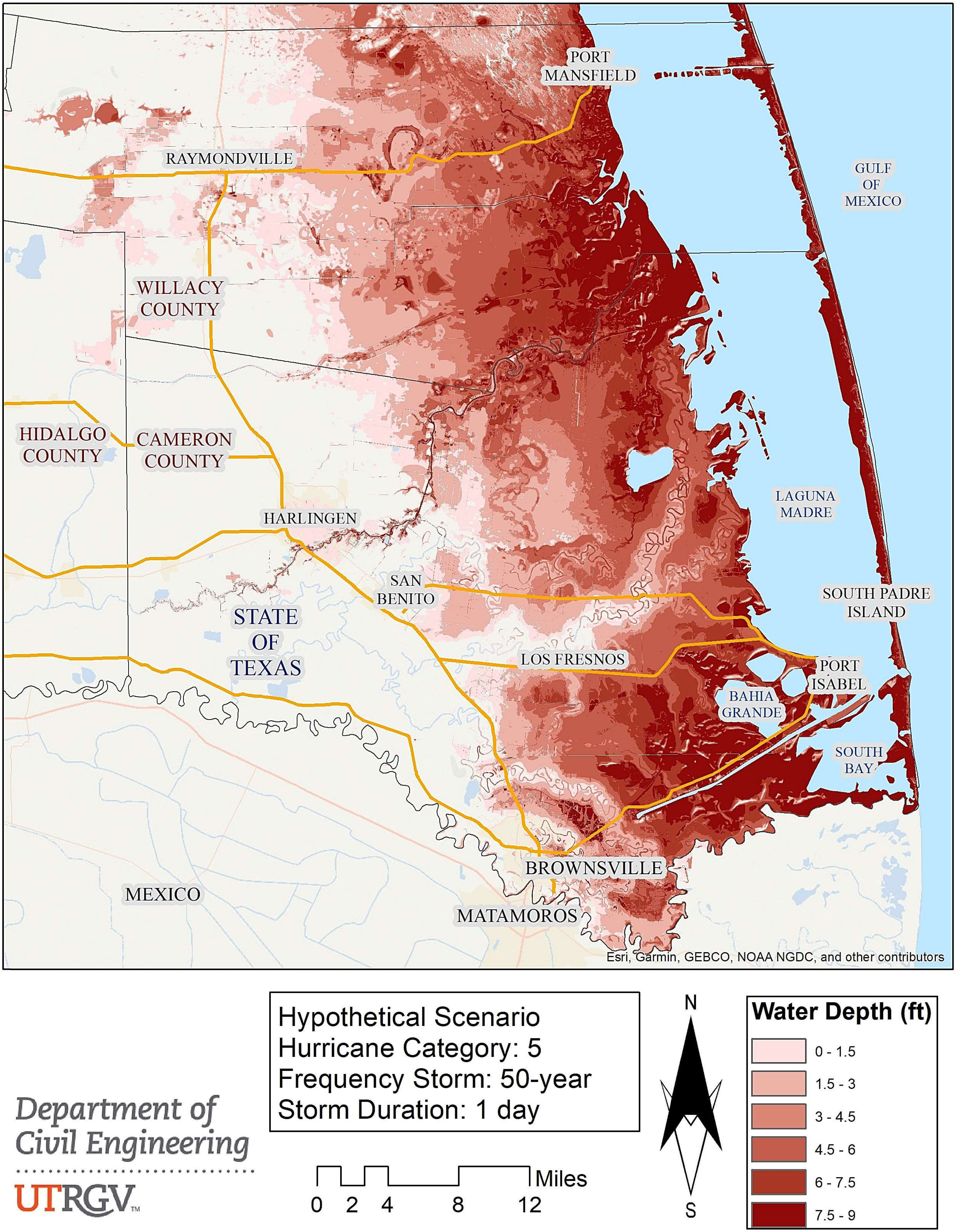

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 50-year
Storm Duration: 1 day

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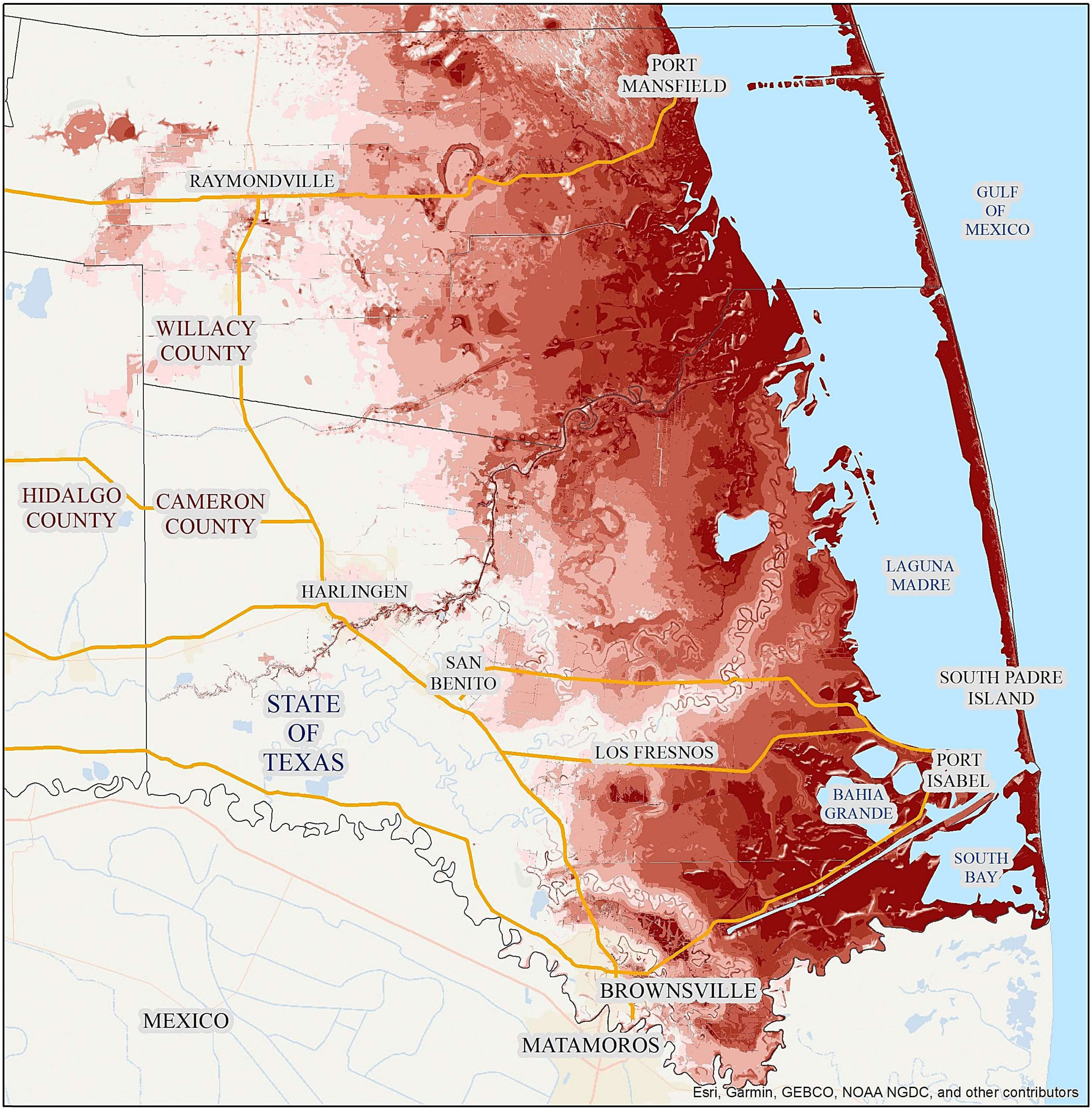
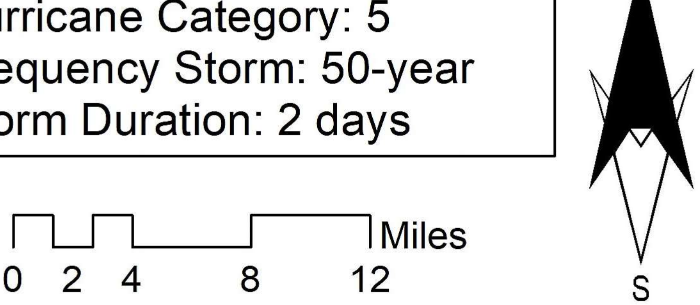


Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 50-year
Storm Duration: 2 days



Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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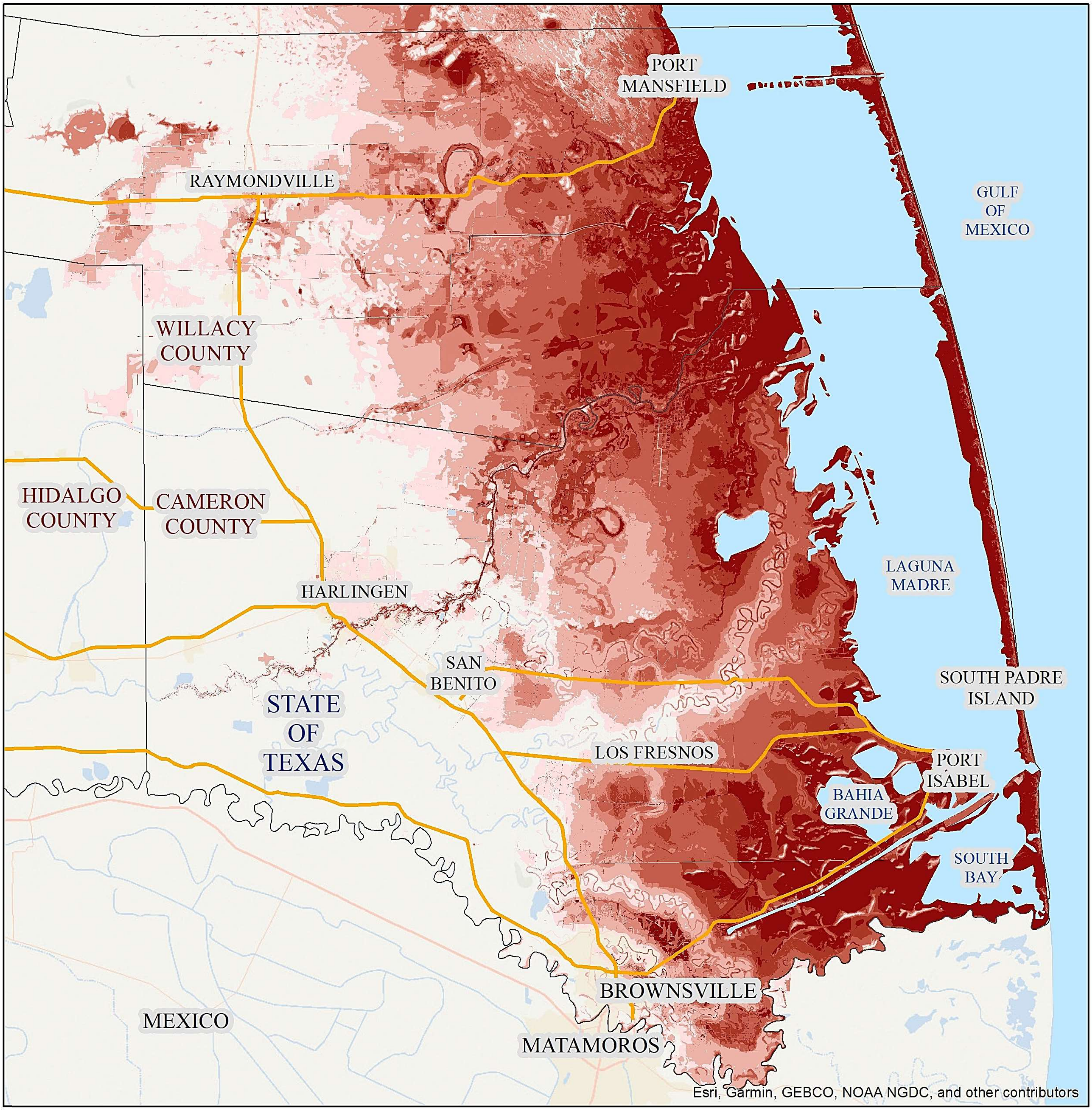

Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 100-year
Storm Duration: 1 day

0 2 4 8 12 Miles

N
S

Water Depth (ft)	
▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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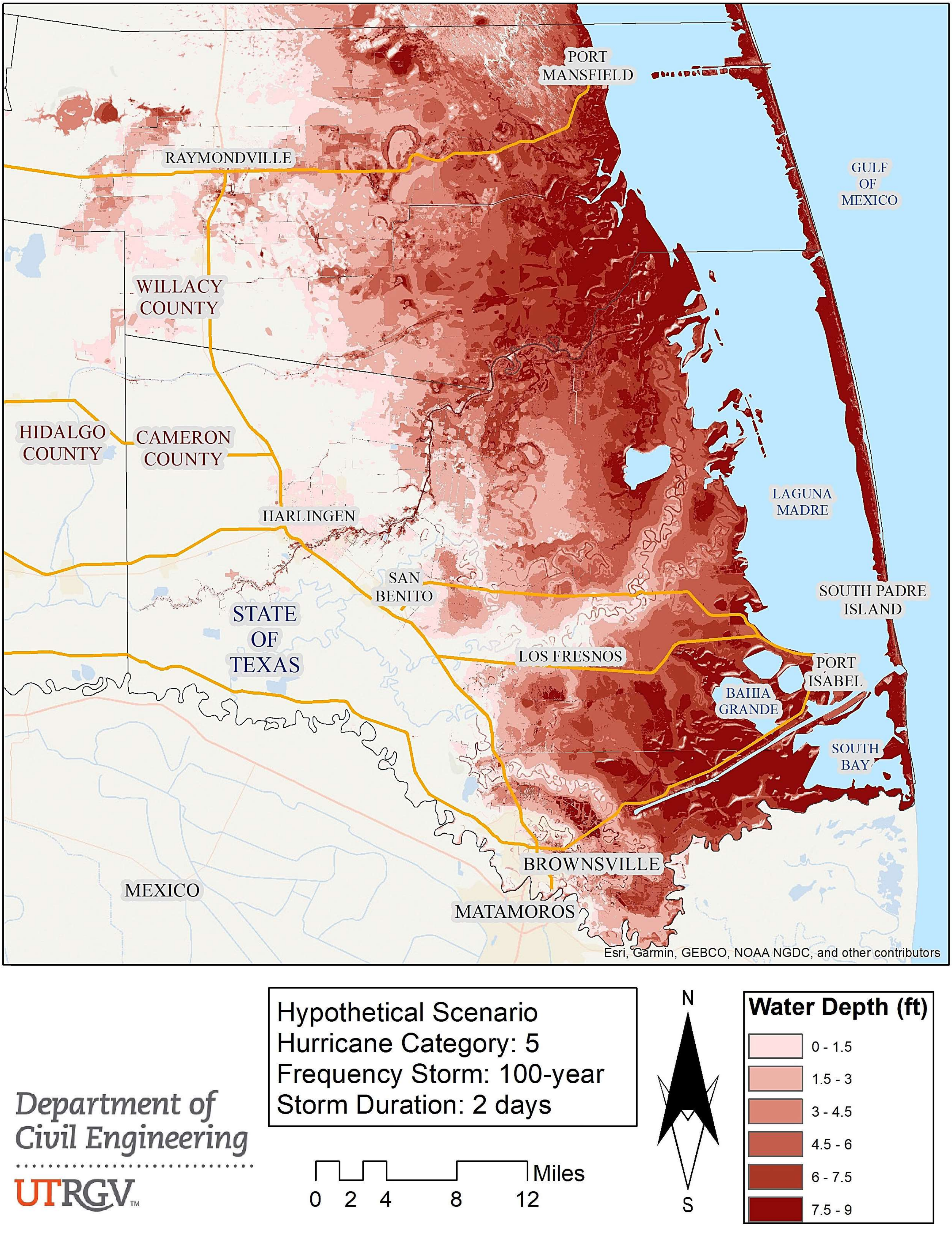

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 100-year
Storm Duration: 2 days

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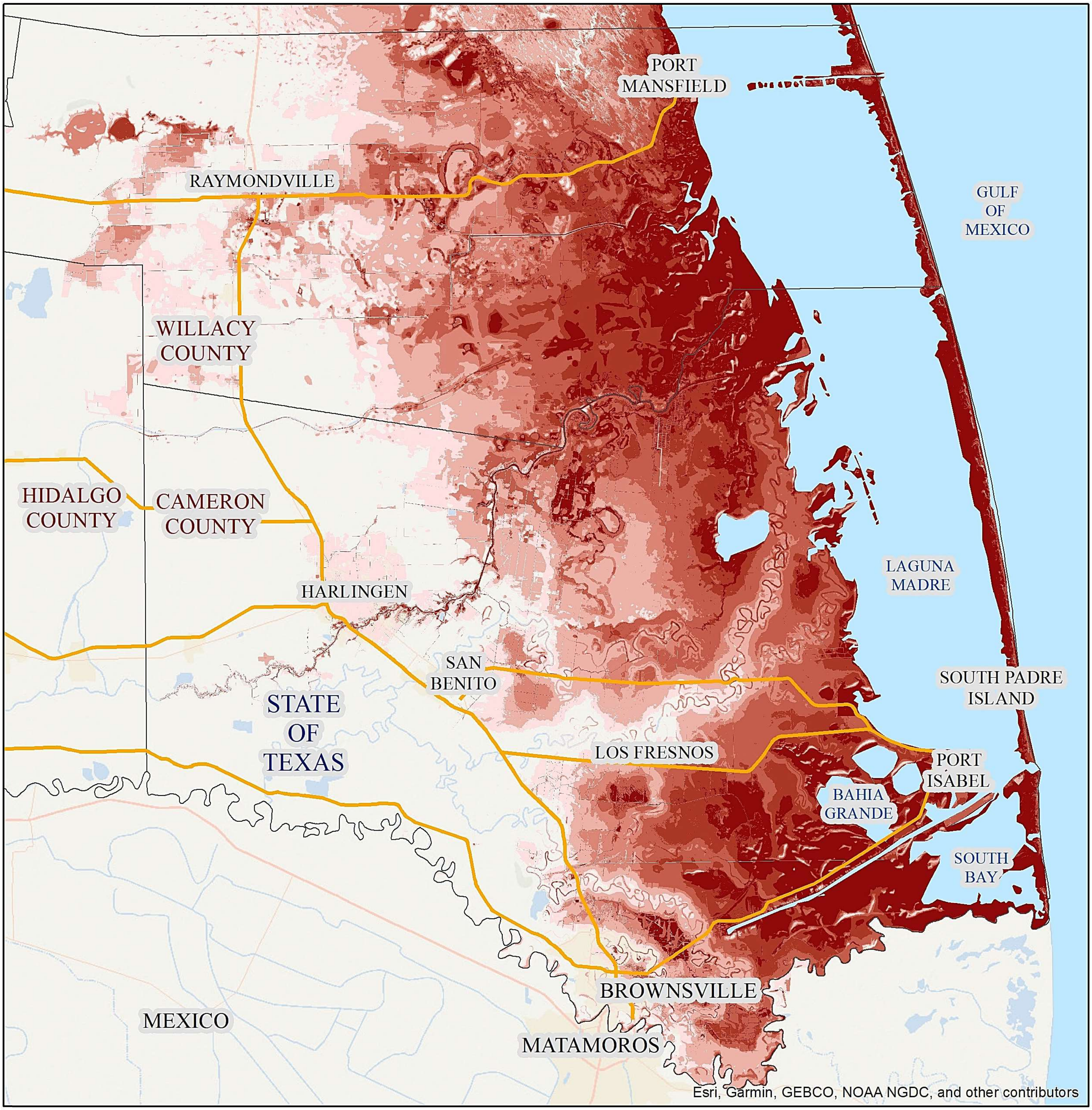

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 500-year
Storm Duration: 1 day

Water Depth (ft)	
🟥	0 - 1.5
🟥	1.5 - 3
🟥	3 - 4.5
🟥	4.5 - 6
🟥	6 - 7.5
🟥	7.5 - 9

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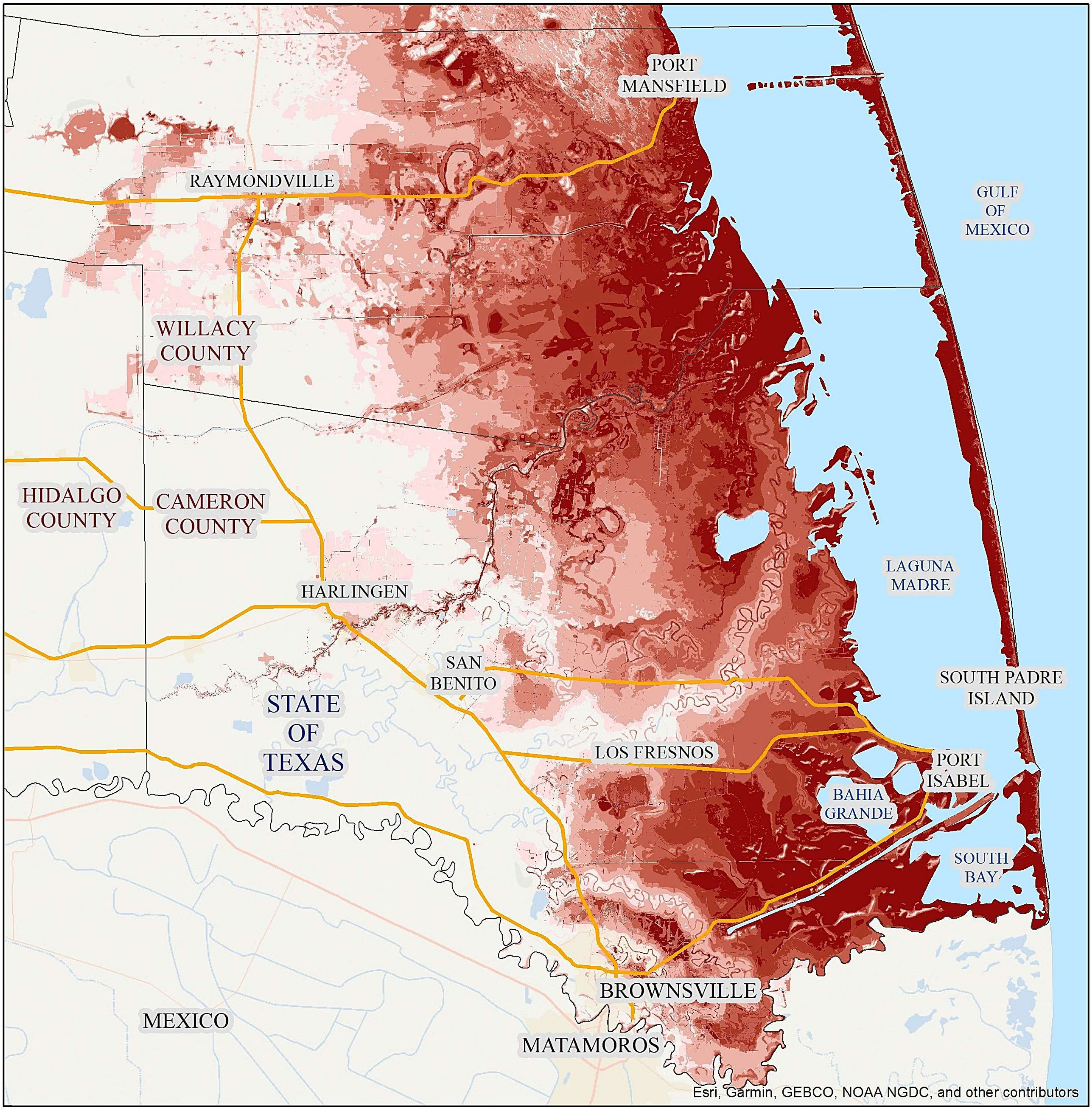

Hypothetical Scenario
Hurricane Category: 5
Frequency Storm: 500-year
Storm Duration: 2 days

Water Depth (ft)

▨	0 - 1.5
▨	1.5 - 3
▨	3 - 4.5
▨	4.5 - 6
▨	6 - 7.5
▨	7.5 - 9

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