Hazard Mitigation Technical Assistance Program
Contract No. EMW-2000-CO-0247
Task Orders 444 & 449
Hurricane Rita Rapid Response
Texas Coastal & Riverine High Water Mark Collection
FEMA-1606-DR-TX

Final Report

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Submitted to:

Federal Emergency Management Agency
Region IV
Atlanta, GA

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Authority and Purpose

This study documents a high water mark (HWM) survey conducted along the Texas coast and streams following Hurricane Rita that began affecting states on September 23, 2005. The study was performed to assist Federal Emergency Management Agency (FEMA) Mitigation Program efforts to assess storm conditions and aid people victimized by the storm. Time-sensitive surveys were performed to investigate evidence of high water conditions and to collect coastal high water marks (CHWMs) and riverine high water marks (RHWMs).

President George W. Bush issued a major disaster declaration on September 24, 2005, under the authority of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), for damage in certain areas in Texas resulting from Hurricane Rita (FEMA-1606-DR-Texas), ordering the Federal Government to provide all necessary resources and assets for Texas to aid people devastated by Hurricane Rita which made landfall early on September 24, 2005 just 4 weeks after Hurricane Katrina made landfall. URS Group, Inc. (URS) was contracted by FEMA under Task Orders 444 and 449 of the Hazard Mitigation Technical Assistance Program (HMTAP) contract to assist in the disaster recovery by conducting HWM study in Texas. The URS team for these Task Orders includes URS and its subconsultants Michael Baker Jr., Inc., PBSJ, and Dewberry.

The purpose of this project is to conduct field surveys to find evidence of coastal and riverine high water levels; to document, photograph, and survey coastal and riverine HWMs; and to provide a report explaining the work and results. This report includes a summary of Hurricane Rita storm conditions, descriptions of the disaster declaration and Federal assistance, descriptions of the HWM study methodologies, and results. The information contained in this report is an important step in assisting communities in establishing high water marks to be used in flood hazard mitigation and for further studies for wind and water damage line assessment, flood inundation mapping, and flood frequency analyses. This report supersedes all submissions of preliminary HWM data for the Texas coast.

BACKGROUND

Hurricane Rita was the seventeenth name tropical storm, ninth hurricane, fifth major hurricane, and second Category 5 hurricane of the 2005 Atlantic hurricane season. Hurricane Rita was one of the strongest storms to impact the coast of the United States during the last 100 years. While over open water, it was rated as being the strongest to enter the Gulf of Mexico. The National Oceanic and Atmospheric Administration (NOAA) reported Rita's record-setting Category 5 strength as a result of achieving a minimum central pressure of 897 millibars (mb) (26.49 inches of mercury) on the afternoon of September 21, 2005. This record strength steadily diminished prior to landfall after Rita moved over cooler waters in the northern Gulf of Mexico.

Hurricane Rita made landfall at 2:38 am local time on September 24, 2005, between Sabine Pass, Texas and Johnson's Bayou, Louisiana. At landfall, the storm was Category 3 with sustained winds of 120 mph and barometric pressure of 937 mb. The Hurricane Rita storm track is shown in Figure 1. (http://cimss.ssec.wisc.edu/tropic/archive/2005/storms/rita/RITA.track.gif)

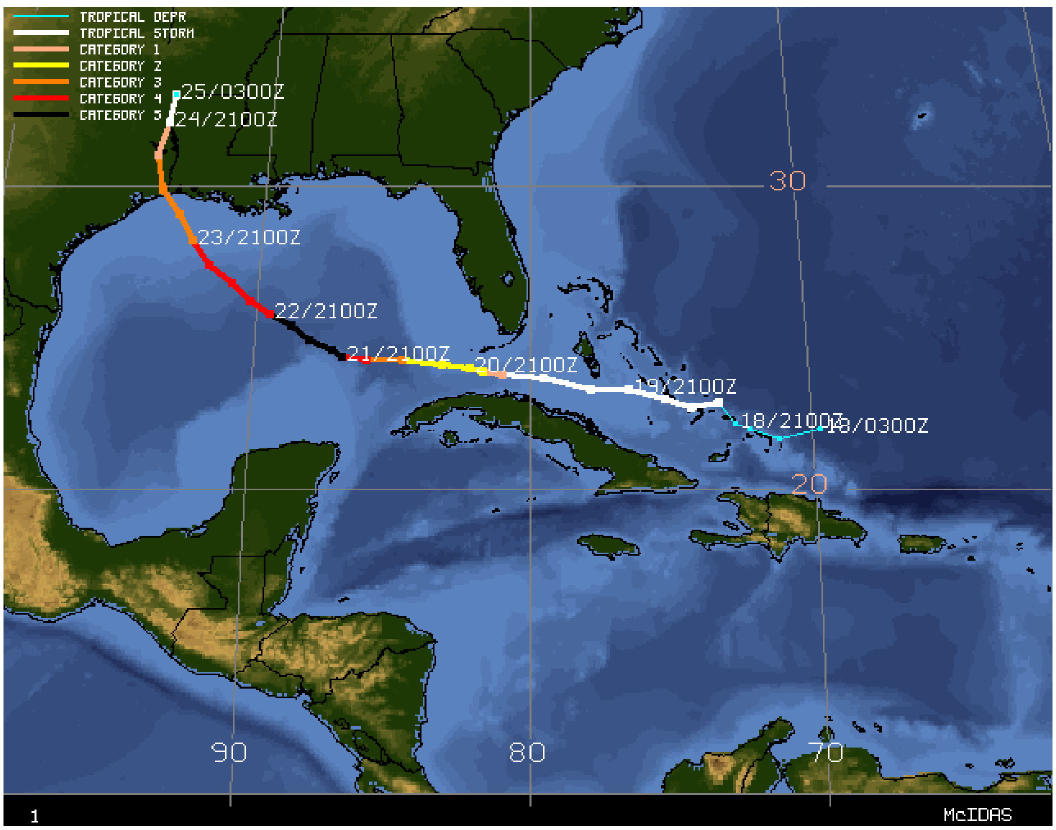


Figure 1. Hurricane Rita Storm-Track

Figure 2 shows a composite image of Hurricane Rita. This is an Advanced Very High Resolution Radiometer/Multi-channel Visible and Infrared Radiometer composite image provided by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) obtained from NOAA and the Joint Typhoon Warning Center. (http://cimss.ssec.wisc.edu/tropic/archive/2005/storms/rita/avhrr/N18L.html).

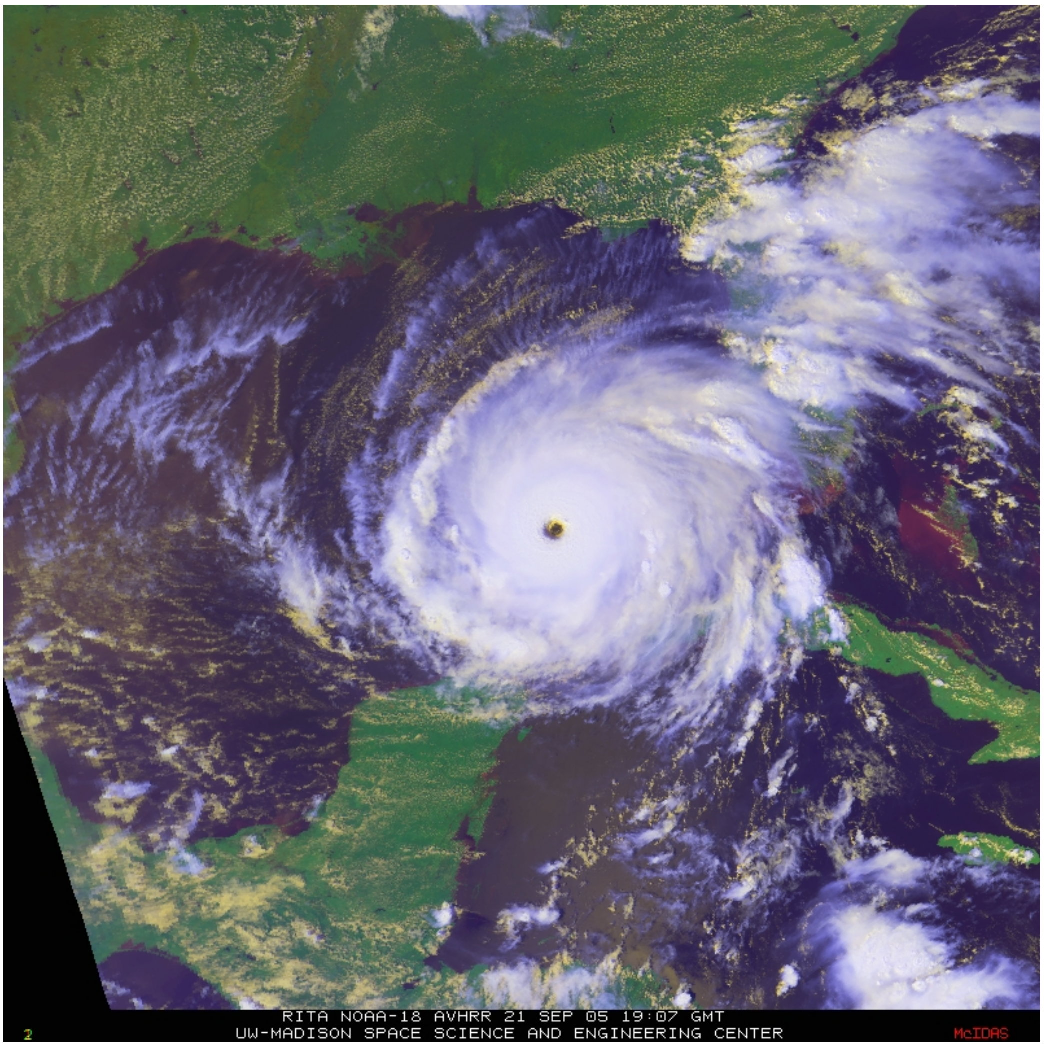


Figure 2. Hurricane Rita Approaches

Hurricane Rita caused widespread devastation due to loss of life and property along the central Gulf Coast states including Texas. For the most part, Houston seems to have escaped major damage, apart from extensive loss of power. North of Houston, the 2.5 mile Lake Livingston dam sustained substantial damage from powerful waves driven by 117 mph winds and had to conduct an emergency release in order to lessen pressure on the dam. As reported by news outlets, on Sunday, September 25, 2005, this discharge had impacts downstream. (http://en.wikipedia.org/wiki/Hurricane_rita)

All communities in the Golden Triangle formed by Beaumont, Port Arthur, and Orange sustained heavy damage from Rita's winds. Texas Governor Rick Perry declared a nine county disaster area. A large number of houses and businesses suffered extensive damage due to falling trees and directly from Rita's winds. The "Golden Triangle" area was spared a more devastating ocean surge by the redirection of Rita's path hours before landfall. This placed most of the coastal community to the left of the eye and in the least damaging hurricane quadrant. Rita's ocean surge was handled by Port Arthur's extensive levee system. Bolivar Peninsula between Galveston and Sabine Pass had only a small ocean surge, in contrast to the eastern side of Rita's center which sent a significant ocean surge through Louisiana's unprotected towns. (http://en.wikipedia.org/wiki/Hurricane_rita)

Federal Assistance

In a letter dated September 24, 2005, that the President declared a major disaster under authority of the Stafford Act for damage in certain areas in Texas resulting from Hurricane Rita (FEMA-1606-DR-Texas; http://www.fema.gov/news/dfrn.fema?id=4745). The declaration provides the necessary Federal assistance to meet immediate needs and to help recover as quickly as possible. The Texas counties that were designated for Disaster Declaration FEMA-1606-DR-TX, as of October 20, 2005, are shown in Figure 3.

Federal assistance, including Individual Assistance, Public Assistance, and the Hazard Mitigation Grant Program, is made available to counties as they are listed in the original declaration and as amendments are made. The declared counties and levels of assistance as of the last update shown on the FEMA Web site on October 24, 2005 (http://www.fema.gov/news/eventcounties.fema?id=5026) are described in Table 1.

FEMA-1606-DR, Texas
Disaster Declaration as of 10/20/2005

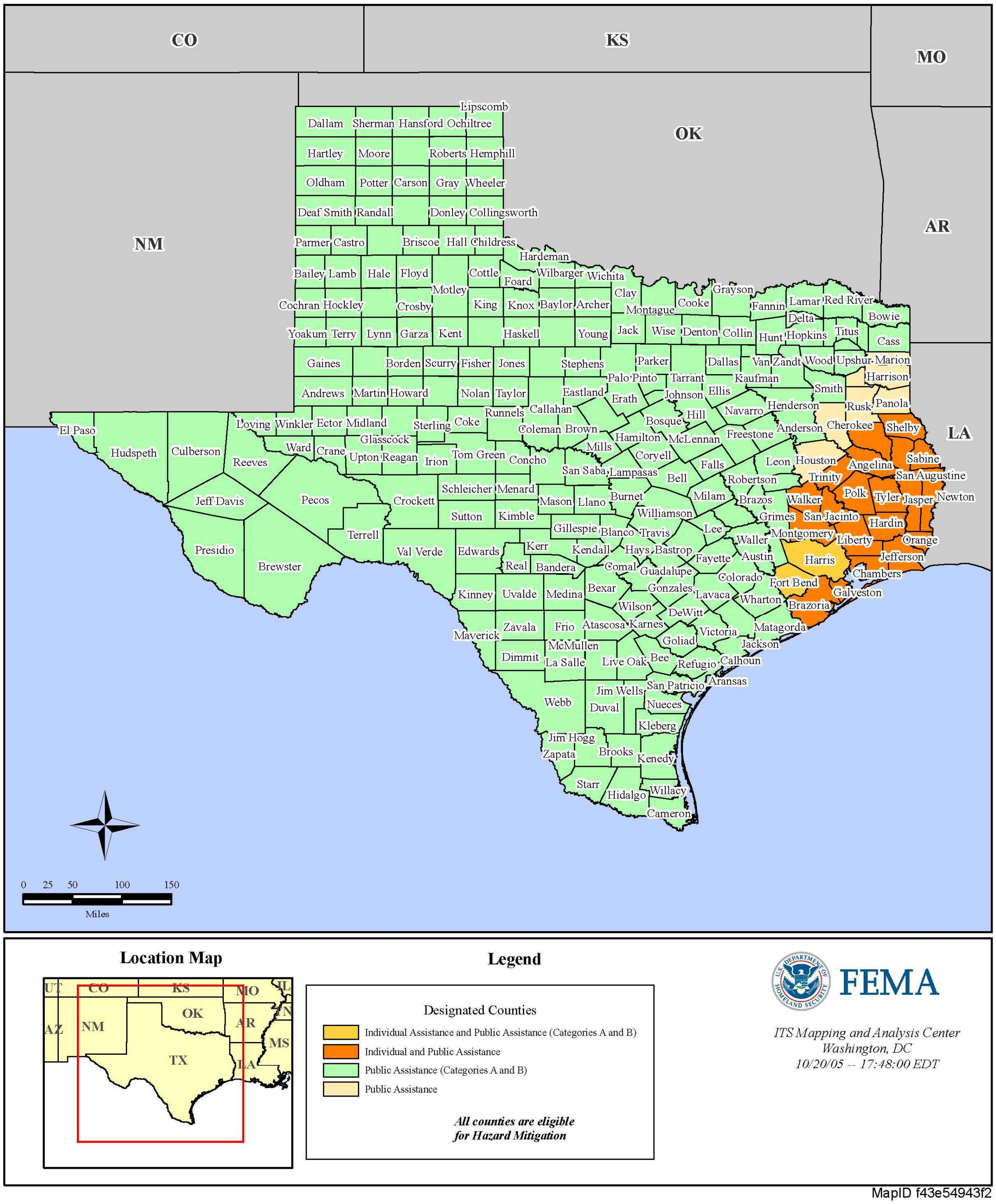


Figure 3. Disaster Declaration Map

Table 1. Federal Assistance to November 28, 2005 – Hurricane Rita

Federal Assistance	Assistance Provided
Individual Assistance Assistance to individuals and households:	Angelina, Brazoria, Chambers, Fort Bend, Galveston, Hardin, Harris, Jasper, Jefferson, Liberty, Montgomery, Nacogdoches, Newton, Orange, Polk, Sabine, San Augustine, San Jacinto, Shelby, Trinity, Tyler, and Walker Counties.
Public Assistance Assistance to State and local governments and certain private nonprofit organizations for the repair or replacement of disaster-damaged facilities:	All 254 Counties for debris removal and emergency protective measures, including direct Federal assistance (categories A and B). Angelina, Brazoria, Chambers, Cherokee, Galveston, Gregg, Hardin, Harrison, Houston, Jasper, Jefferson, Liberty, Marion, Montgomery, Nacogdoches, Newton, Orange, Panola, Polk, Rusk, Sabine, San Augustine, San Jacinto, Shelby, Trinity, Tyler, and Walker Counties for Public Assistance (Categories C-G).
Hazard Mitigation Grant Program (HMGP) Assistance to State and local governments and certain private nonprofit organizations for actions taken to prevent or reduce long-term risk to life and property from natural hazards:	All counties in the State of Texas are eligible to apply for assistance under the HMGP.
Other:	Additional designations may be made at a later date after further evaluation.

Area of Study

The area FEMA identified to be covered by the Rita Texas HWM Study Team extended throughout eastern Texas and included 16 counties. Study area selections were based on preliminary water level reports, directions from FEMA, and input from other Federal, State, and local agencies. The spacing of the observation points is irregular due to a number of factors, including the objective to adequately show the surge and flooding levels and how they vary across the area. Points are distributed along coastal areas along the Gulf of Mexico and along rivers. The presence of low marshy ground often makes determinations of the limit of the coastal storm surge along the coast and up river courses difficult to establish. Where possible, points have been established in these areas, but it was not practical in all of the coastal rivers. The HWMs flagged and surveyed by the URS team are listed in Table 2 and shown graphically in Figure 4.

Table 2. HWMs Surveyed by County

County	Number of HWMs Surveyed
Angelina	7
Chambers	3
Cherokee	1
Galveston	27
Hardin	6
Harris	2
Hunt	3
Jasper	20
Jefferson	20
Liberty	2
Nacogdoches	14
Newton	1
Orange	21
Polk	9
Sabine	6
San Augustine	11
Shelby	2
Smith	1
Tyler	1
Total	157

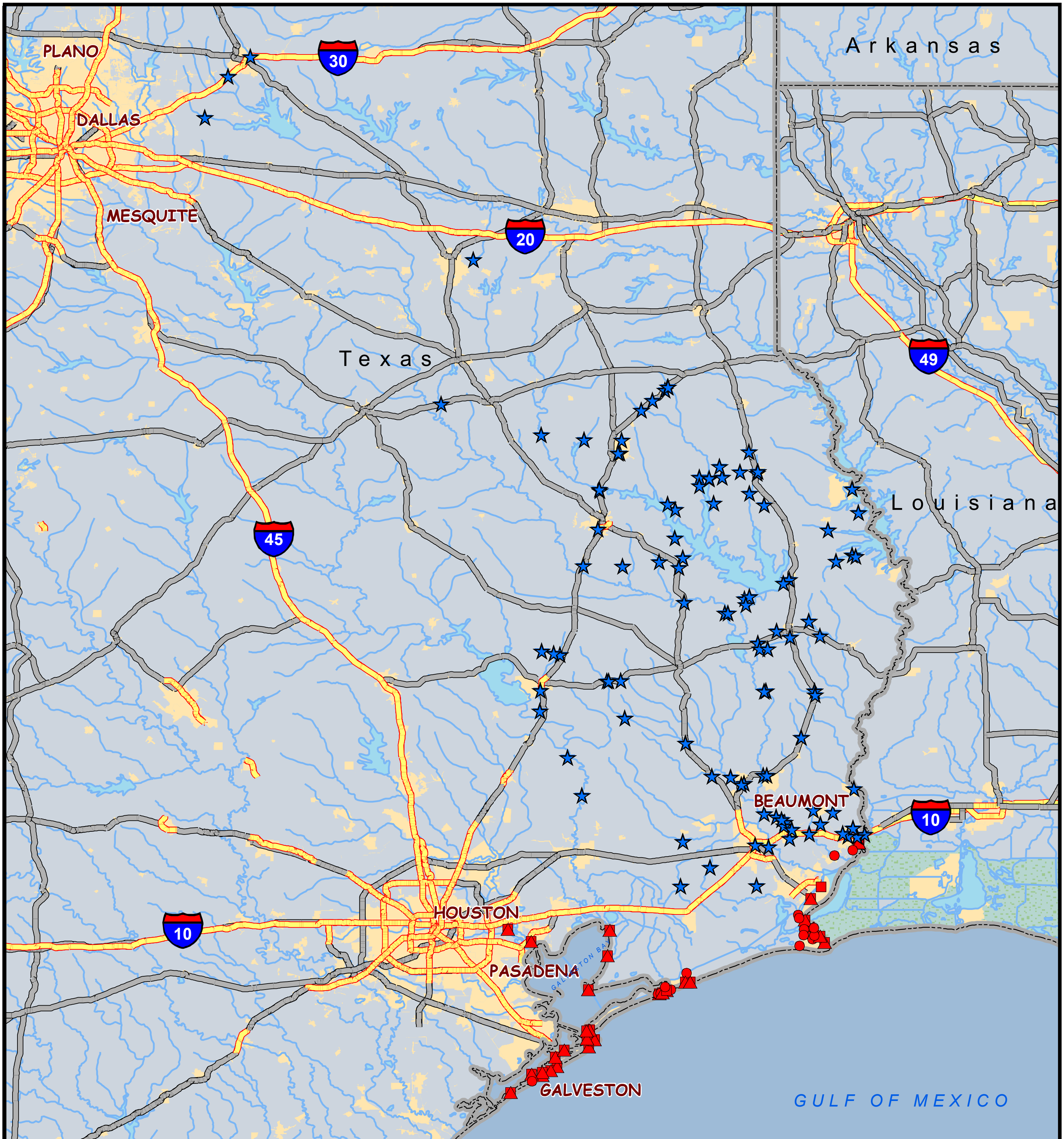
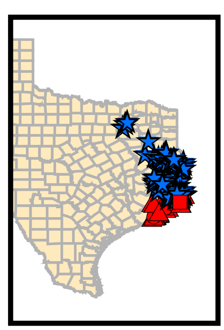


Figure 4: Hurricane Rita, Texas
Surveyed High Water Mark (HWM) Elevations



RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

- Coastal- Surge Only
- Coastal- Wave Height
- Coastal- Wave Runup
- Riverine- Hurricane

- Water Body
- Swamp or Marsh
- Municipalities
- State Boundaries

- Hydrology

Road Classification
- Limited Access
- Highway
- Major Road

FEMA

N

0 12.5 25 50
Miles

0 20 40 80
Kilometers

Site investigations for high water conditions were also conducted at some FEMA Repetitive Loss (Rep Loss) and Mitigation properties. “Repetitive loss structure” is a term that is usually associated with the National Flood Insurance Program (NFIP). For Flood Mitigation Assistance program purposes, this is a structure, covered by a contract of flood insurance under the NFIP, that has suffered flood damage on two or more occasions over a 10-year period and the cost to repair the flood damage, on average, equals or exceeds 25 percent of the market value of the structure at the time of each flood loss event. For the Community Rating System of the NFIP, a repetitive loss property is any property that the NFIP has paid two or more flood claims of $1,000 or more in any 10-year period since 1978.

Mitigation properties are those where Federal funding has been requested and granted through the HMGP. Authorized under Section 404 of the Stafford Act, the HMGP is administered by FEMA and provides grants to state and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the program is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. A list of mitigation properties was provided by FEMA for use on this project.

A sampling of Rep Loss and Mitigation sites were visited during the HWM flagging operations. Where HWMs were available, they were flagged and surveyed as shown in Tables 3a. Many Rep Loss and Mitigated property sites were visited, but no HWM was available to be surveyed. These sites are presented in Tables 3b and 4.

Table 3a. FEMA Repetitive Loss Properties with High Water Marks

Address[1]	Latitude	Longitude	City	County	HWM
	30.08562	-94.12549	Beaumont	Jefferson	RTXC-01-01
	29.92995	-94.12076	Beaumont	Jefferson	RTXC-01-02
	30.17528	-94.01100	Vidor	Orange	RTXC-01-04
	30.12006	-93.73219	Orange	Orange	RTXC-02-02
	29.81450	-93.96020	Port Arthur	Jefferson	RTXC-05-07
	29.51873	-94.48346	Gilchrist	Galveston	RTXC-05-09
	29.50946	-94.49569	Gilchrist	Galveston	RTXC-05-11
	31.60100	-94.64807	Nacogdoches	Nacogdoches	RTXR-02-06 (nearby)
	31.60100	-94.64807	Nacogdoches	Nacogdoches	RTXR-02-06 (nearby)
	30.20757	-94.09090	Vidor	Orange	RTXR-05-44

[1]Addresses were removed to protect privacy of residents.

Table 3b. FEMA Repetitive Loss Properties Visited, But No Available High Water Marks

Address[1]	Latitude	Longitude	City	County	Comments
	29.80604	-94.38558	Winnie	Jefferson	No Visible Flooding
	30.09045	-84.1458	Beaumont	Jefferson	No Visible Flooding
	29.93198	-94.11751	Beaumont	Jefferson	No Visible Flooding
	29.93058	-94.119	Beaumont	Jefferson	Flooded
	29.57089	-94.39907	High Island	Chambers	No Visible Flooding
	30.09011	-93.99841	Vidor	Orange	No Visible Flooding
	30.11229	-93.99126	Vidor	Orange	No Visible Flooding
	30.11141	-93.98650	Vidor	Orange	No Visible Flooding
	30.12623	-93.99092	Vidor	Orange	No Visible Flooding
	30.128696	-93.95917	Vidor	Orange	No Visible Flooding
	30.15008	-93.98339	Vidor	Orange	No Visible Flooding
	30.15020	-93.98329	Vidor	Orange	No Visible Flooding
	30.16657	-94.01265	Vidor	Orange	No Visible Flooding
	30.19017	-94.02477	Vidor	Orange	No Visible Flooding
	30.12735	-93.83368	Orange	Orange	No Visible Flooding
	30.12397	-93.82427	Orange	Orange	No Visible Flooding
	30.12892	-93.82767	Orange	Orange	No Visible Flooding
	30.16161	-93.75334	Orange	Orange	No Visible Flooding
	30.03800	-93.82903	Bridge City	Orange	No Visible Flooding
	30.03944	-93.85906	Bridge City	Orange	Flooded
	30.02297	-93.83670	Bridge City	Orange	No Visible Flooding
	30.02466	-93.83670	Bridge City	Orange	No Visible Flooding
	30.18705	-94.74412	Liberty	Liberty	No Visible Flooding
	30.03739	-94.66884	Raywood	Liberty	No Visible Flooding
	31.67192	-94.95200	Nacogdoches	Nacogdoches	No Visible Flooding

[1]Addresses were removed to protect privacy of residents.

Table 4. FEMA Mitigation Properties Visited, But No Available High Water Mark

Address	Property Action	Latitude	Longitude	City	County	Comments
	Other - SWM Basin	30.09869	-94.14759	Beaumont	Jefferson	No Visible Flooding
	Other - Minor Flood Control	30.12220	-94.10873	Beaumont	Jefferson	No Visible Flooding
	Acquisition	30.07136	-94.79021	Liberty	Liberty	No Visible Flooding
	Acquisition	30.06968	-94.79003	Liberty	Liberty	No Visible Flooding
	Acquisition	30.07131	-94.78713	Liberty	Liberty	No Visible Flooding
	Acquisition	30.06746	-94.79183	Liberty	Liberty	No Visible Flooding
	Acquisition	30.06117	-94.78677	Liberty	Liberty	No Visible Flooding
	Acquisition	30.06886	-94.79006	Liberty	Liberty	No Visible Flooding
	Acquisition	30.06848	-94.79035	Liberty	Liberty	No Visible Flooding
	Acquisition	30.08224	-94.80162	Liberty	Liberty	No Visible Flooding
	Acquisition	30.06030	-94.79699	Liberty	Liberty	No Visible Flooding
	Acquisition	30.08543	-94.76275	Liberty	Liberty	No Visible Flooding
	Acquisition	30.08596	-94.75973	Liberty	Liberty	No Visible Flooding
	Acquisition	30.13890	-94.82010	Dayton	Liberty	No Visible Flooding, Vacant Lot
	Acquisition	30.03739	-94.66884	Raywood	Liberty	No Visible Flooding, Vacant Lot
	Acquisition	30.21250	-94.79595	Hardin	Liberty	No Visible Flooding

[1]Addresses were removed to protect privacy of residents.

High Water Mark Types

High water mark types associated with hurricanes vary based on the intensity of the hurricane, the extent which it covers and the land conditions. Typically, high water conditions are identified by CHWMs and by RHWMs. With Hurricane Rita in Texas, high water conditions were also identified by HWMs impacted by levee systems. The following descriptions provided an understanding of the conditions that generate these 3 main types of HWMs.

Coastal HWMs

CHWMs are more varied in their origin than those associated with riverine floods. In the Texas Rita HWM study, CHWMs are classified as either surge only, wave height, or wave runup, whereas RHWMs are classified as riverine. Conditions associated with CHWMs can be defined with an understanding of the various types of CHWMs. CHWM types are described in this section and presented graphically in Figures 6 through 12 shown below. The series of CHWM schematics were provided to aid in the understanding of how CHWMs are formed. These schematics illustrate ideal situations that lead to the formation of coastal high water conditions, and do not all necessarily occur in any one particular storm event.

The Texas Rita CHWM survey was conducted under HMTAP Rapid Response Task Orders that involved the timely collection of perishable high water mark data at field-observed, point locations. Determination of conditions of areas around CHWMs, such as topography, bathymetry, locations of dunes, sloped water surface, overwash or breaching, which might aid in determining the corresponding CHWM scenario or how surges differ, was not included within the scope of work for these Task Orders. Therefore, all classifications are estimates based on the best data available at the time.

Figure 5 shows the simplest form of a CHWM. As the water level during the storm rises to a maximum level, it can leave marks on both the interior and exterior walls of a structure that are of equal elevation. Both of these water marks indicate a surge level that is not complicated by other factors. However, these situations occur only where the structure is at a location sheltered from waves. In all cases, even very simple ones, it is important for the teams finding the CHWMs to distinguish between flooding caused by the direct effects of rainfall and that caused by rising ocean water. High water marks from rainfall flooding are not considered valid CHWMs.

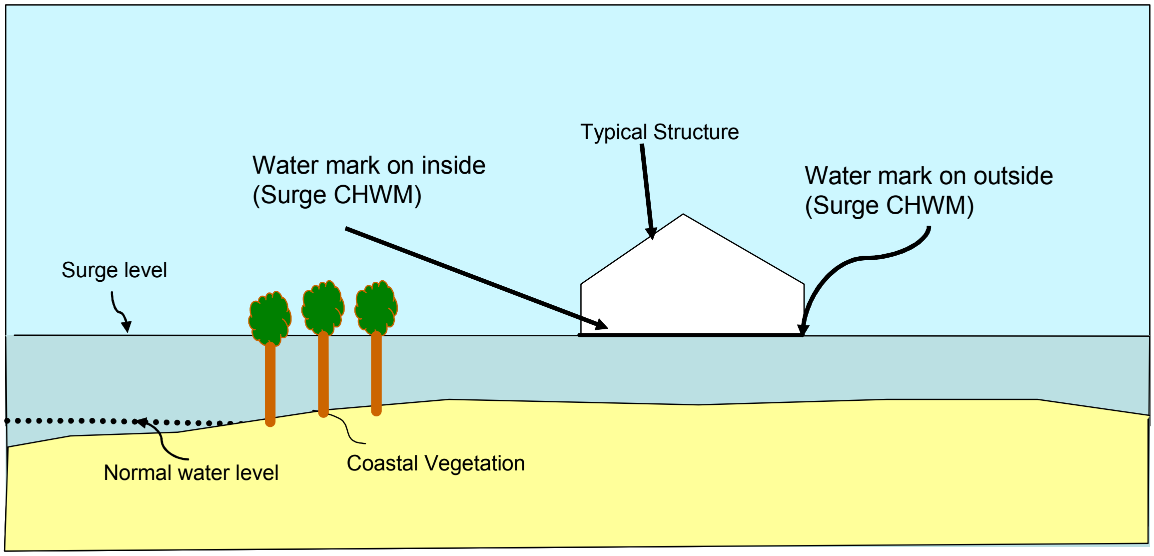


Figure 5. A Simple Surge-Only CHWM

In most common situations, coastal surge is either level or has a slight slope that is not easily detected visually. This is shown schematically in Figure 6. However, this is not always the case in the coastal zone. High water caused by a hurricane storm surge is brought about by the combination of rapidly changing factors such as wind speed, wind direction, and low atmospheric pressure. In some cases the surge develops in open water areas and spreads inland over large distances because the coastal lands have minimal to no increase in elevation. The overland flow can be retarded by inland marsh areas and other obstructions so that the water surface slopes and the maximum inland CHWM is lower than those nearer the coast. Case A shown in Figure 7 illustrates this condition. Under other circumstances, a strong onshore wind can force the overland flow inland, forming an upward slope as shown in Case B in Figure 7.

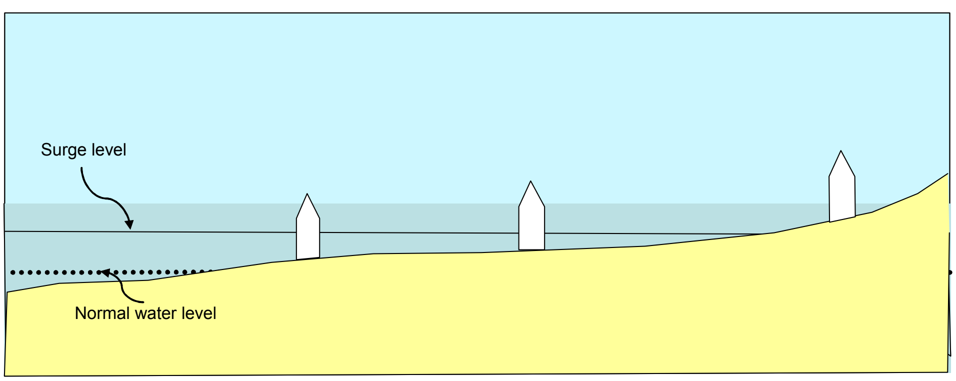


Figure 6. A Coastal Storm Surge With a Level Water Surface

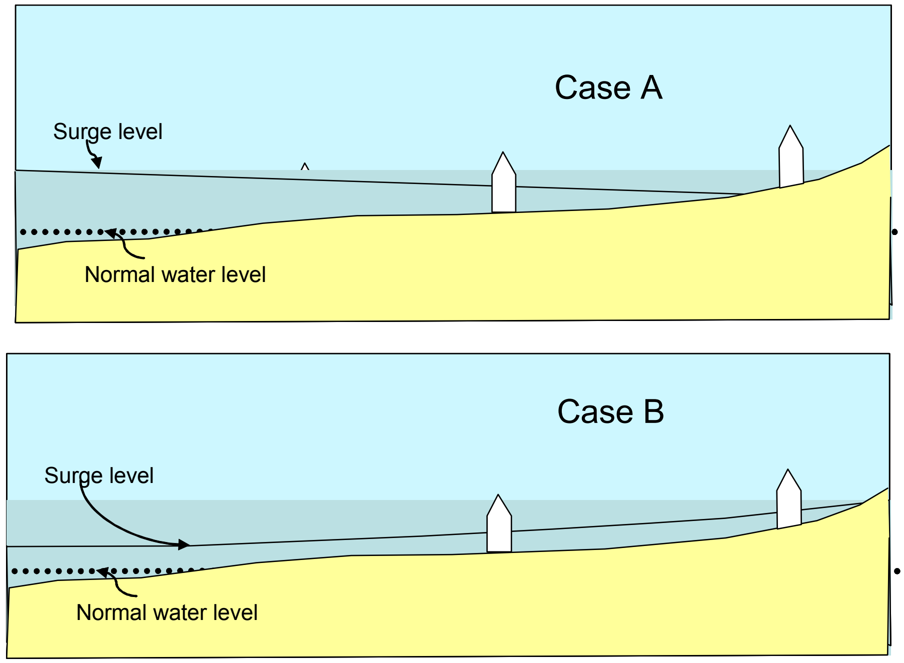


Figure 7. Two Cases of Storm Surges With Sloped Water Surfaces

Waves complicate these conditions even further. Figure 8 shows how HWMs found inside and outside of a structure can differ considerably. These two types of water marks are distinguished in this report. CHWMs corresponding to the conditions shown on the exterior wall in Figure 8 are designated as ***wave height*** points because the crests of the waves that are riding on the surge leave the highest mark. CHWMs corresponding to the situation shown on the interior wall in Figure 8 are designated as ***surge only*** points because the whole structure acts as a stilling-well, and the HWM corresponds to water level unaffected by the waves.

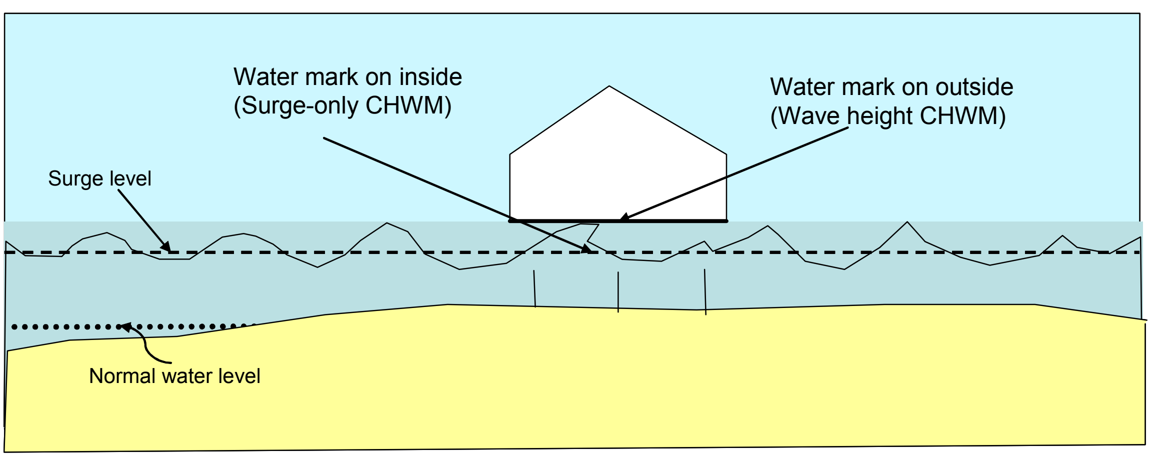


Figure 8. The Formation of Surge and Wave Height CHWM Types

The third basic type of CHWM is illustrated in Figure 9. Here the situation is complicated by the presence of a surf zone, which is the broad zone of spilling and breaking waves between the open Gulf (or other water body) and the beach. The processes associated with the way that the waves diminish in height as they move across the surf zone cause the average water level to rise against the shore. At the very top of the surf zone, the last remains of the waves wash up and then down the beach slope. As shown in Figure 10, this is referred to as wave runup. Wave runup often pushes debris to its maximum limit where it is left as a wrack line. CHWMs of this type are designated as ***wave runup*** points.

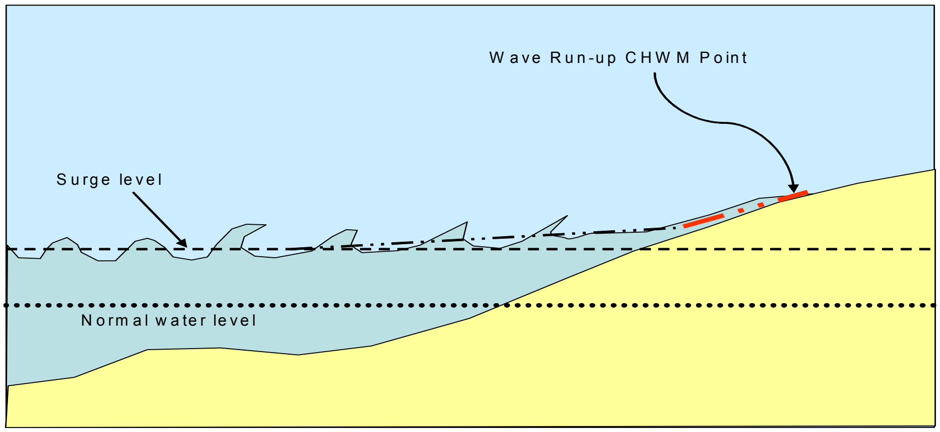


Figure 9. The Formation of a Wave Runup CHWM

Each of the three basic types of CHWMs, ***surge only, wave height, and wave runup,*** could be, and often are, found close to each other. These CHWM types can differ in elevation, and each provides information that describes the nature and behavior of the coastal flooding.

Figure 10 shows more variable conditions in the way that CHWMs are formed. It is not uncommon for the wave runup in a storm to be so large that it completely crosses the beach and surges through gaps in the coastal dunes. These are called "washover channels," and they convey the water over the area of the dunes and downhill to low areas behind the dunes. Figure 11 shows three structures at three different locations along the dune, each impacted by a different high water level at the height of the storm. When the corresponding CHWMs are found, marked, and surveyed, the elevations can be different by as much as several feet over a relatively short distance (e.g., about 1,000 feet).

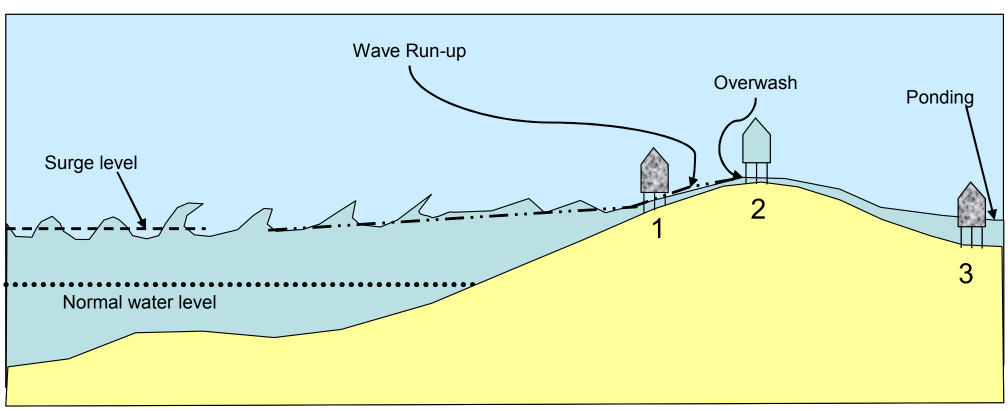


Figure 10. Variations in Coastal Flooding Levels Due to Washover of Coastal Dunes

During some hurricanes, changes in the shape of the beach and dunes can substantially affect the CHWMs. Typically, beaches erode in a storm. The combined effects of this erosion and the rise of the storm surge that brings the breaking waves into the dunes can cause so much erosion that the whole level of the coastal protection is substantially reduced, resulting in inland inundation and flooding that would not have occurred if the coastal dunes had held. Figure 11 illustrates this situation. Coastal inundation elevation in these areas can depend on how long the dune line held the ocean back compared to the rate that the storm moved inland. If the dunes held back the ocean long enough, the backshore flooding may have occurred after the maximum surge height occurred.

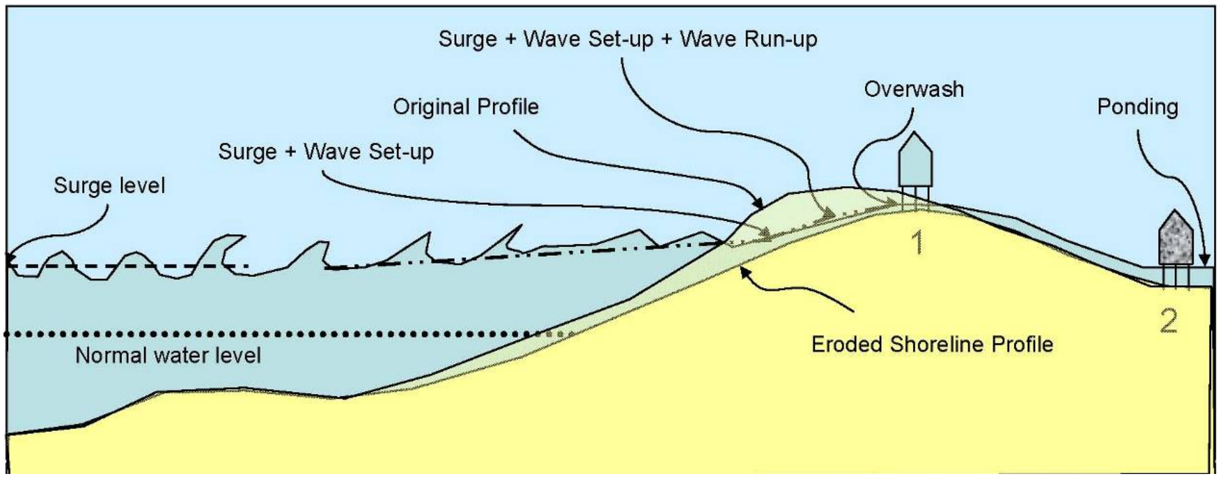


Figure 11. Interaction of Profile Erosion and Coastal Flooding

There are other factors to consider related to local conditions. On barrier islands the CHWMs on the seaward side may differ in elevation from those on the bay side because the maximum surge levels formed at different times during the storm. Within bays, the surge may be amplified by the effect of wind acting on broad, shallow areas. In other cases, the tidal inlet may retard the flow of water into the bay so that its level cannot rise up to the level of the ocean. Conversely, it is common to find that where the shorelines of the bay converge towards the head of the bay, there is a funneling action that amplifies the surge level.

Riverine HWMs

RHWMs, the second main type of HWMs, are points that document high water conditions in riverine areas inland of coastal areas. High water in these areas is mainly driven by rainfall associated with the intensity, speed and progression of the hurricane as it moves inland. Often the peak water elevations from riverine flooding along major rivers occurs on one or more days after the hurricane has made landfall, as the rainfall from the hurricane impacts the watershed and makes its way through downstream rivers. Riverine high water conditions are also affected by the extent of downstream coastal flooding or surge. As riverine high water conditions are less varied in origin than those associated with coastal conditions, these points are identified as one type, RHWMs.

Levee-Related HWMs

A third main type of HWM is those collected to document high water conditions in areas with levee systems. These HWMs are taken in areas inside the levee systems to document high water conditions in the general areas. These HWMs focus on water conditions associated with levee overtopping, levee breaks and levee interior drainage.

Marking and Survey Methodology

The Texas Rita HWMs were investigated and flagged by URS HWM flagger teams. The HWM flagging teams started work with an organization and training meeting held in Houston, Texas on September 30, 2005. Flagger teams were deployed on October 1, 2005.

Flaggers investigated high water conditions in coastal and riverine study areas. For each HWM, the flaggers completed a standardized form including detailed information about the data point, as shown in Figure A-1 in Appendix A. To the extent possible, flaggers noted RHWM conditions and CHWM conditions and types including surge, wave height, and wave runup. HWMs were located with latitude and longitude coordinates using hand-held Global Positioning System (GPS) units. A total of over 160 HWMs were flagged by URS teams for Hurricane Rita in Texas. HWMs are based on the flagger team's best judgment of height of flood waters at the location. Since some structures were severely damaged during Rita, which often made locating HWMs difficult, and since the height of floodwaters can be impacted by outside forces such as wind and shielding by other structures, all HWMs should be used to identify trends and not to extrapolate exact height of water throughout the area.

URS team survey crews followed the flagging teams to survey the HWMs flagged by the flagger teams. The survey crews used static GPS methods and conventional leveling to determine an accurate horizontal coordinate (latitude and longitude) and elevation for each HWM. Data were recorded in a standardized format as shown by the example Surveyor High Water Mark Data Collection Report Form, Figure A-2 in Appendix A. HWMs were surveyed horizontally on the North American Datum of 1983 (NAD 83), Louisiana State Plane Coordinates (South Zone), and vertically in the North American Vertical Datum of 1988 (NAVD 88), both in U.S. survey feet. The HWM elevations were also converted to the National Geodetic Vertical Datum of 1929 (NGVD 29) to aid review of data and maps available only in the NGVD 29 datum. The datum conversion was performed using Corpscon ver. 5.11.08, as described in the following report section. The HWM locations were surveyed to within accuracies of 0.25 foot vertically and 10 feet horizontally with a 95-percent confidence level. Any inclement weather that would have an adverse effect on the GPS surveys was avoided to ensure this level of accuracy. Wherever possible, a building floor elevation of structures was collected. These floor elevations were taken adjacent to the HWM where available and may or may not represent the first floor of the structure. This information was obtained as it may be used at a later date for possible damage assessments or HMGP applications.

Data collected for the HWMs are stored in a digital database and presented on one-page forms that are organized by parish in the appendices of this report. The HWMs are identified with a unique point number identifier, the High Water Mark Identifier (HWM ID) as shown on the one-page HWM form. The one-page HWM reports include data for the storm event, flood type, location, point description, and surveyed point coordinates (LAT/LON and state plane) and elevations.

The data collected for Hurricane Rita Texas HWMs are shown graphically on maps in Figures B-1 through B-5 included in Appendix B. These figures present HWM locations and limited data in the study reach. The location of each HWM is shown with the HWM ID and the field-surveyed HWM elevation shown in feet in the NAVD 88 vertical datum. The symbol representing the HWM point on the map is graphically coded, designating whether the HWM is riverine or coastal (i.e., surge, wave height, or wave runup).

Elevation Conversion from NAVD 88 to NGVD 29 Using Corpscon

The HWM elevations surveyed in NAVD 88 datum were converted to the NGVD 1929 datum using the Corpscon program version 5.11.08, http://www.cae.wisc.edu/site/software/?title=app199. The Corpscon program utilizes the VERTCON software internally. The VERTCON software was developed by the National Geodetic Survey (NGS) office to convert data between different vertical data scales. VERTCON is available as an element of the NGS Geodetic Toolkit and can be downloaded from the NGS website: http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html.

The VERTCON software allows the user to compute the modeled difference, or datum shift, in orthometric height for a given location specified by its latitude and longitude. Applying the computed datum difference value to a specific elevation converts from one datum to another.

For converting elevations in NAVD 88 to NGVD 29, the datum shift has to be subtracted from the NAVD 88 elevation. This can be demonstrated by two examples, one with a positive shift (Case 1) and one with a negative shift (Case 2):

	Case 1	Case 2
NAVD 88 Elevation	5.33	5.33
Datum shift	(+0.50 feet)	(-1.17 feet)
NGVD 29 Elevation	5.33 – (0.50 feet)	5.33 – (-1.17)
	= 4.83	= 6.50

Other Data and Studies

Gage data and coastal surge modeling, prepared by other sources, were investigated to help define the conditions experienced with Hurricane Rita. The reference data collected are presented in this section. It should be noted that many established benchmarks, gages and other reference points may have elevations surveyed to either NAVD 88 or NGVD 29. Datum references are noted for data sources mentioned in this section.

Tide Gage Data

Tidal data were collected from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) (http://co-ops.nos.noaa.gov/). The CO-OPS stations recorded elevated water levels, primarily from Galveston, Texas to Port Fourchon, Louisiana (Figure 12). Maximum water levels for Hurricane Rita in Texas are provided in Table 5. All water level observations are measured in the amount above the standard tidal charting datum, Mean Lower Low Water (MLLW), based on the National Tidal Datum Epoch 1983-2001. Report water levels include highest observed water levels, referred to as the storm tide, which is the sum of the storm surge and the astronomic tide. Also included is the difference between observed water levels and predicted astronomic tides. These measurements are for storm surge only and do not include wave effects.

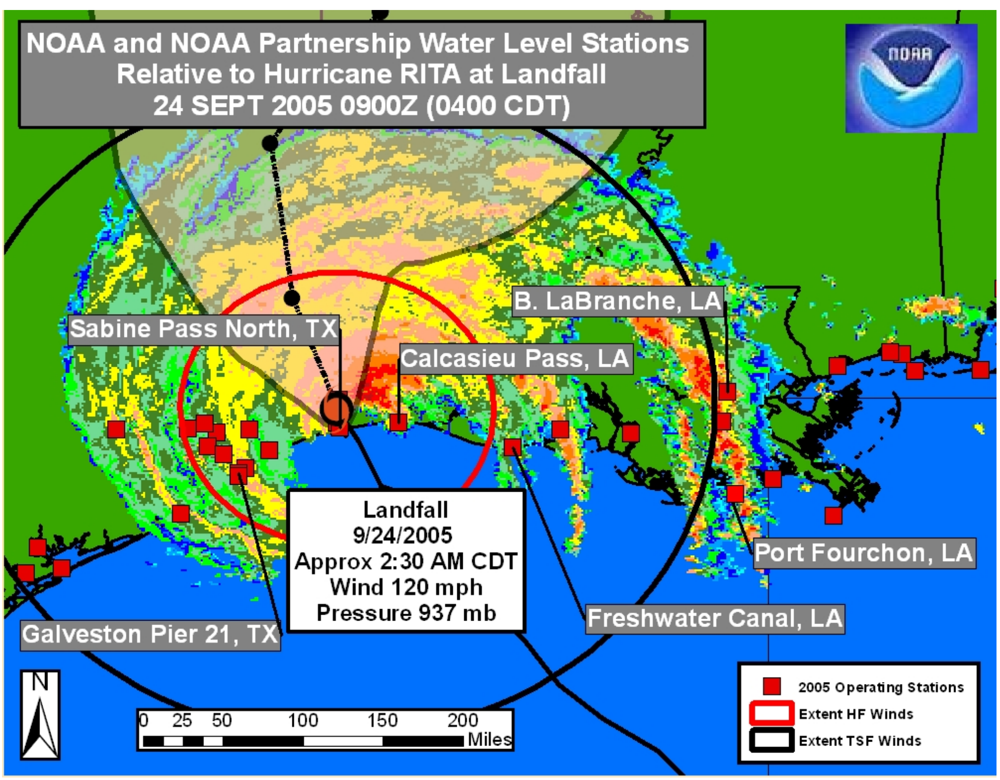


Figure 12. NOAA Hurricane Rita Water Level Station Locations*

The Bayou Port Arthur, TX, station recorded the highest storm tide, followed by gradually lower levels at Galveston Bay Entrance, TX, and Galveston Pier, TX.

Table 5. NOAA CO-OPS Maximum Water Levels for Hurricane Rita, September 2005. All preliminary data are subject to NOS verification.

Station Name	**Station ID**	**Date & Time** GMT	**Max Water Level** (ft above MLLW)	**Predicted Normal Tide Water Levels** (ft)	**Difference** (ft)
Port Arthur, TX	8770475	9/24/2005 22:18	3.14	0.78	2.36
Galveston Pier 21, TX	8771450	9/24/2005 22:18	2.09	1.48	0.61
Galveston Bay Entrance, TX	8771341	9/24/2005 20:54	2.21	1.53	0.68

Surge Models

The NOAA National Hurricane Center (NHC) prepared a preliminary Sea, Lake and Overland Surges from Hurricanes (SLOSH) model of the Hurricane Rita coastal surge. The NHC provided output from the model, which was run just before Hurricane Rita made landfall. The SLOSH model output, shown in Figures 13 and 14, includes graphical, color-designated maximum surge-only levels in feet relative to the NGVD 29 vertical datum that occurred at any time during the modeled storm. The SLOSH model calculations are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads and other physical features. The SLOSH model is generally accurate within plus or minus 20 percent. For example, if the model calculates a peak 10 foot storm surge for the event, you can expect the observed peak to range from 8 to 12 feet. The model accounts for astronomical tides (which can add significantly to the water height) by specifying an initial tide level, but does not include rainfall amounts, river flow, or wind-driven waves.

For Hurricane Rita in Louisiana, NHC SLOSH model output shows maximum values which reached the figure color chart limit of about 8 feet NGVD 29 in Jefferson and Orange Counties. Model output values, shown in Figures 13 and 14, need to be adjusted before being used for comparison to HWM values in this report. First, NHC SLOSH model values need to be adjusted from the initial NOAA tide level to actual tidal conditions. Secondly, values need to be converted from the NGVD 29 datum to the study datum of NAVD88.

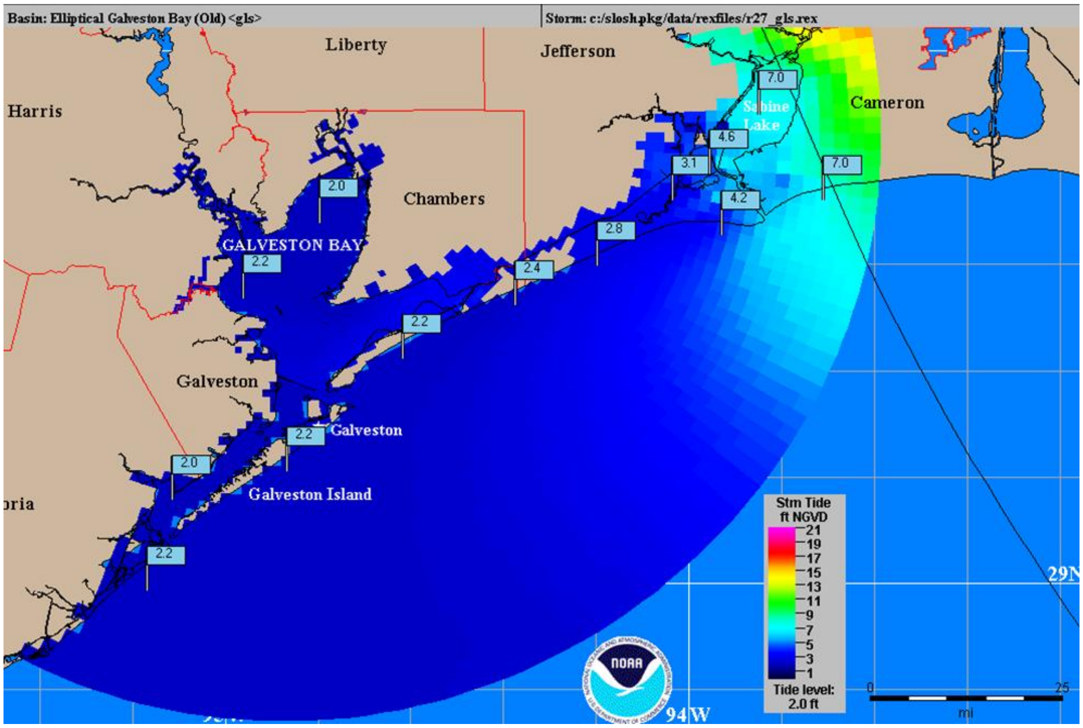


Figure 13. NOAA Rita Coastal SLOSH Data – Galveston Bay Area

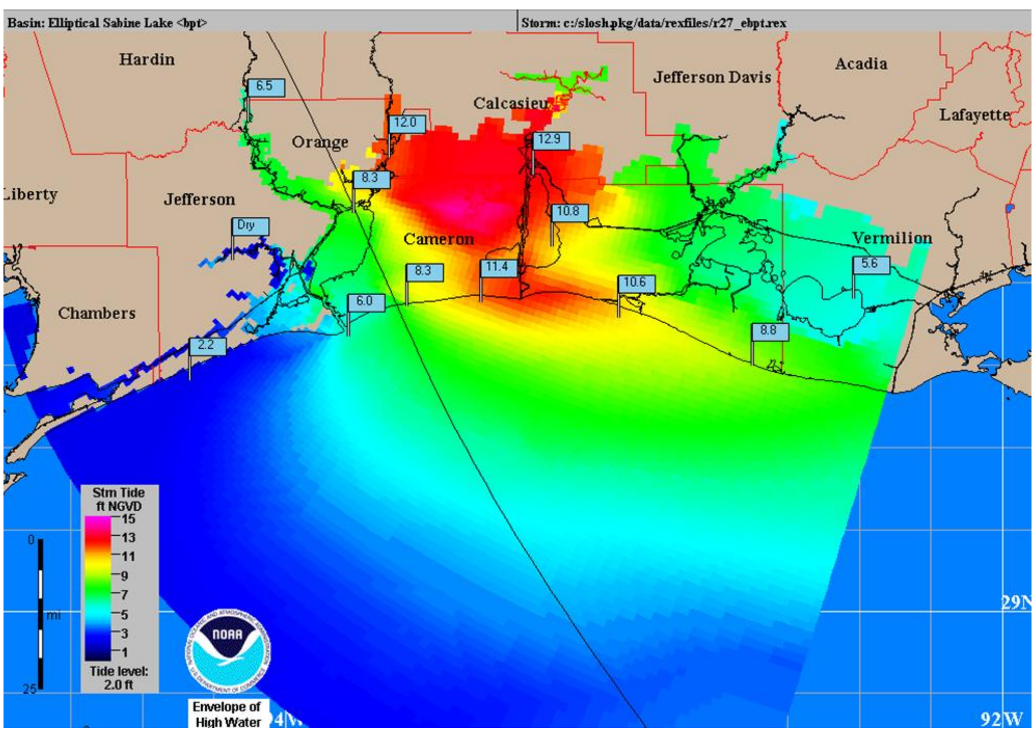


Figure 14. NOAA Rita Coastal SLOSH Data – Southern Louisiana Area

Coastal Flood Frequency Analysis

Michael Baker Jr., Inc. is preparing a flood frequency analysis of tide gage data to quickly provide information to assist in the planning and rebuilding efforts. Table 6 shows the initial draft results of their study using NOAA gage data, which show in the Galveston area that Rita had less than a 10-year frequency.

Table 6. Summary of Coastal Flood Elevations for Texas Coast Between Galveston and Sabine Pass, Texas.

Station	Rita Elevation (ft above Mean Sea Level)	FEMA FIRM 100-year stillwater	FEMA FIRM 10-year stillwater
Sabine Pass	5.41*	11.7	---
Galveston Pleasure Pier	3.58	13.5	6.8
Galveston Pier 21	2.98	11.5	6.2

* Gage malfunctioned before maximum surge level occurred

River Stage Gage Data

Many of the USGS stream gages in Texas have NWS-determined flood stage thresholds. As of September 30, 2005, several USGS gages recorded stages in excess of the NWS flood stage. A summary of these gages and their stages in relation to flood stage is shown in Table 7.

Table 7. USGS Texas Flood Stage Gages from September 21 – September 30, 2005

Station Name	County	NWS Flooding Stage (feet)	Measured Stage (feet)	Flooding Date and Time
S Fk Sabine Rv nr Quinlan, TX	Hunt	15	15	9/21/2005
Attoyac Bayou nr Chireno, TX	Nacogdoches	14	22	9/25/2005
Ayish Bayou nr San Augustine, TX	San Augustine	12	13	9/25/2005
Neches Rv nr Town Bluff, TX	Jasper	64	69	9/25/2005
Hillebrandt Bayou nr Lovell Lake, TX	Jefferson	8	9	9/25/2005
Trinity Rv nr Goodrich, TX	Polk	36	37	9/25/2005
Trinity Rv at Liberty, TX	Liberty	26	27	9/26/2005

River Flow Gage Data

In addition to the river stage data discussed above, river flows or discharge data are available at some locations throughout the impacted area. Michael Baker Jr., Inc. conducted a preliminary analysis for riverine flooding associated with Hurricane Rita for most severely affected counties.

All real time flow data were from USGS web site http://waterdata.usgs.gov/nwis/rt and all peak data were from http://nwis.waterdata.usgs.gov/usa/nwis/peak. The real-time data are provisional and subject to revision by USGS. While the frequency analysis for this select area does not compare elevations of HWMs collected in this study, it does estimate the approximate frequency of flooding that resulted in the HWMs.

Real time peak data for selected locations in the period of September 23 through September 27 were used to compare with the frequency curves developed for gaging stations where long term peak flow data were available. Stations with the flow affected by reservoir regulations were in general excluded from the frequency analysis. For stations where only stage data were available, stage-frequency curves were estimated by using graphic plotting positions, and the peak stages of Rita event were used to comparing with the stage frequency curves. Changes in gage data due to sediment or erosion over time were not considered.

Real time data from total 13 stations in four counties, Jasper, Jefferson, Newton, and Orange, were investigated (Table 8).

Table 8. Gaging Stations Investigated for Frequency Estimate

Station Number	Station Name	Peak Flow (cfs*)	Peak Elevation (NGVD)	Notes
Jasper County				
08039300	Sam Rayburn Res. near Jasper	N/A	N/A	Reservoir regulated stage
08040600	Neches River nr. Bluff	24,100	N/A	Peaked at 09/25/05; affected by regulation
08041000	Neches River at Evadale	17,600	N/A	Peaked at 09/27/05; affected by regulation
Jefferson County				
08041700	Pine Island Bayou nr Sour Lake	880	21.99	N/A
08042000	Taylor Bayou near LaBelle	N/A	>9.	Gage broken at 09/24
08042500	Hillebrandt Bayou nr Lovell Lake	N/A	9.17	Peaked at 09/25/05
Newton County				
08025350	Toledo Bend Reservoir near Burkeville	N/A	N/A	Reservoir regulated stage
08025360	Sabine River at Toledo Bend Reservoir nr Burkeville	12,000	N/A	Regulated flow at this rate for several days
08028500	Sabine River nr Bon Wier	7,090	N/A	Regulated flow
08029500	Big Cow Creek near Newton	2,650	N/A	N/A
08030500	Sabine River near Ruliff	N/A	N/A	Regulated flow
Orange County				
08031000	Cow Bayou near Mauriceville	1,270	17.84	N/A
0801780	Neches River Saltwater Berries at Beaumont	15,700	4.8	N/A

*cfs = cubic feet per second

Among these real time stations, three stations, 08031000, 08029500, and 08041700, also have non-regulated peak flow record sufficient for conducting frequency analyses. Station 08042500 has long-term stage data. Frequency curves were developed for these stations and the Rita peak was compared with the frequency curves, as shown in Table 9.

Table 9. Frequency Estimate of Non-Regulated Stations

Station	Flow Rate (cfs)					
	2-yr	5-yr	10-yr	50-yr	100-yr	Rita
08031000	1,420	2,390	3,170	5,260	6,320	1,270, ≈ 2 yr
08029500	2,960	5,940	8,670	17,080	21,840	2650 ≈ 2 yr
08041700	4,790	9,760	14,520	30,440	40,070	880 < 2 yr
	Elevation above NGVD					
08042500	13.6	16.9	17.8	18.2		9.17 < 2 yr

Frequency analyses were conducted for two stations with long record of regulated flows (since 1951) as shown in Table 10. This information is for reference only.

Table 10. Frequency Estimate for Regulated Stations

Station	Flow Rate (cfs)					
	2-yr	5-yr	10-yr	50-yr	100-yr	Rita
08041000	21,010	32,130	39,820	57,320	64,950	17,600 < 2-yr
08040600	19,860	30,620	38,610	58,550	68,010	24,100 2-5 yr

Based on the above preliminary analyses, the best estimate for Rita riverine flooding in these Texas counties is about 2-year; at some locations it may be higher than 2-year but no more than 5-year.

Findings and Observations

The HWM data collected for this study demonstrate that the Hurricane Rita coastal storm surge and wave-related high water conditions affected coastal and riverine areas in Texas. The following observations pertain to the data and figures in this report and are referenced in NAVD 88.

A total of 165 HWMs were surveyed in the 16 counties investigated, all 165 as identified and flagged by URS teams. Site visits were also made at 35 FEMA Rep Loss properties, 10 of which resulted in collection of HWMs, and at 16 FEMA Mitigated properties, where no HWMs were available. The Hurricane Rita HWM data are summarized in Table 11, sorted by county and appendix sheet number. For convenience, a second table containing the same data, but sorted by HWM ID number, Table B-2, is presented in Appendix B.

The landfall of Hurricane Rita was just east of the Texas-Louisiana border. It landed between Johnson's Bayou and Sabine Pass. This places the upper Texas coast in the left front hurricane quadrant. In this section of the counterclockwise circulation of the storm winds, the forward speed of the storm does not add to the magnitude of the maximum wind speeds. This explains the lower coastal storm surge in Texas compared to Louisiana.

Maximum measured storm surge along the open Gulf was above 10 feet from Johnson's Bayou to Marsh Island, a distance of about 100 miles. The easternmost Gulf shoreline in Texas is characterized by low narrow beaches backed by extensive wetlands. The 10 miles of shoreline west of Sabine Pass are not accessible by road. The CHWMs found in this area are several miles inland within the coastal lowlands. Here the maximum surge heights were in the order of 8 feet. The surge along the Gulf shoreline going westward as far as Galveston Island remained in the 5- to 7-foot range with variations indicating that local conditions tend to amplify or reduce the general surge level. Much of the shoreline between Sabine Pass and the Bolivar Peninsula is thinly settled due to the low-lying shore and lack of roads.

Sabine Lake and Galveston Bay are the two significant coastal estuaries on the Texas coast that were affected by the Hurricane Rita storm surge. The navigation channel into the Sabine estuary is narrow and about 7 miles long. The next 7 miles of this channel lead to the City of Port Arthur. This upper portion of the navigation channel is isolated from the broader extent of the shallow estuary by a dredge spoil island that follows the whole length of the eastern shore of the channel. This arrangement provided some attenuation of the storm surge from Sabine Lake as it approached the Texas shore. It also caused significant variations in maximum surge levels. The hurricane surge was held back by an extensive levee system protecting Port Arthur. Further towards the maximum elevation, the surge levels varied in the range of 4 to 7 feet on the Texas mainland shore and up to almost 9 feet on the eastern shore of Pleasure Island.

Galveston Bay is about 80 miles west of the point that Hurricane Rita made landfall. For the most part, it escaped coastal flooding because the maximum surge levels were in the range of 4 to 5 feet. At Smith Point, Chambers County a Coastal wave runup HWM was measured with an elevation of 6.5 feet. Houston escaped major damage, apart from extensive loss of power. North of Houston, the 2.5-mile Lake Livingston Dam sustained substantial damage from powerful waves driven by 117-mph winds and had to conduct an emergency release to lessen pressure on the dam. As reported by news outlets on Sunday, September 25, 2005, this discharge had impacts downstream. (http://en.wikipedia.org/wiki/Hurricane_rita)

The HWMs from riverine flooding were found in many eastern counties in Texas. However, most of these HWMs were found within the stream channels beneath bridges. It appears that riverine flooding had limited impact on buildings, except in some areas in or near Orange County. Lake Livingston Dam, in Polk County, reportedly had to be opened to send excess amounts of water down the Trinity River. As a result of this release, the Trinity River channel in Polk County was flooded, but no homes or structures were flooded or damaged in Polk County.

Table 11. Hurricane Rita Texas HWM Data Summary[1]

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-02-21	Angelina	Riverine - Hurricane	165.9	31.165997	-94.791391	Ange-1
RTXR-02-22	Angelina	Riverine - Hurricane	245.3	31.307467	-94.733732	Ange-2
RTXR-02-23	Angelina	Riverine - Hurricane	164.8	31.164870	-94.638609	Ange-3
RTXR-02-24	Angelina	Riverine - Hurricane	169.2	31.196571	-94.40469	Ange-4
RTXR-04-27	Angelina	Riverine - Hurricane	168.1	31.273684	-94.436535	Ange-5
RTXR-04-28	Angelina	Riverine - Hurricane	192.7	31.181468	-94.496486	Ange-6
RTXR-06-27	Angelina	Riverine - Hurricane	242.0	31.158365	-94.420281	Ange-7
RTXC-03-03	Chambers	Coastal - Wave Run-up	4.5	29.755744	-94.68885	Cham-1
RTXC-03-04	Chambers	Coastal - Wave Run-up	4.8	29.657630	-94.697554	Cham-2
RTXC-03-05	Chambers	Coastal - Wave Run-up	6.5	29.526794	-94.771424	Cham-3
RTXR-02-12	Cherokee	Riverine - Hurricane	284.5	31.791068	-95.339656	Cher-1
RTXC-03-09	Galveston	Coastal - Wave Run-up	5.9	29.305183	-94.770101	Galv-1
RTXC-03-10	Galveston	Coastal - Wave Run-up	7.3	29.195736	-94.949062	Galv-2
RTXC-03-11	Galveston	Coastal - Wave Run-up	7.0	29.229238	-94.89239	Galv-3
RTXC-03-12	Galveston	Coastal - Wave Run-up	3.3	29.129880	-95.07236	Galv-4
RTXC-03-13	Galveston	Coastal - Wave Run-up	3.8	29.265050	-94.898958	Galv-5
RTXC-03-14	Galveston	Coastal - Wave Run-up	2.8	29.333797	-94.747078	Galv-6
RTXC-03-15	Galveston	Coastal - Wave Run-up	5.9	29.337266	-94.777393	Galv-7
RTXC-03-16	Galveston	Coastal - Wave Run-up	3.8	29.293360	-94.86525	Galv-8
RTXC-04-01	Galveston	Coastal - Wave Run-up	8.9	29.214180	-94.917232	Galv-9
RTXC-04-02	Galveston	Coastal - Wave Run-up	4.6	29.206754	-94.950205	Galv-10
RTXC-04-03	Galveston	Coastal - Wave Run-up	3.9	29.199537	-94.9912	Galv-11
RTXC-04-04	Galveston	Coastal - Surge Only	6.4	29.171900	-94.988866	Galv-12
RTXC-05-08	Galveston	Coastal - Wave Run-up	5.6	29.555592	-94.391413	Galv-13
RTXC-05-09	Galveston	Coastal - Surge Only	6.3	29.518685	-94.483386	Galv-14
RTXC-05-10	Galveston	Coastal - Wave Height	7.0	29.511548	-94.496657	Galv-15
RTXC-05-11	Galveston	Coastal - Surge Only	5.4	29.509491	-94.495617	Galv-16

[1] Note - For HWM data summary listed sorted by HWM-ID, refer to Table B-2

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXC-05-12	Galveston	Coastal - Surge Only	4.5	29.509277	-94.502299	Galv-17
RTXC-05-18	Galveston	Coastal - Surge Only	4.5	29.590121	-94.391274	Galv-18
RTXC-05-19	Galveston	Coastal - Wave Run-up	5.6	29.556602	-94.395971	Galv-19
RTXC-05-20	Galveston	Coastal - Wave Run-up	4.5	29.556345	-94.378214	Galv-20
RTXC-05-21	Galveston	Coastal - Surge Only	5.9	29.526036	-94.451525	Galv-21
RTXC-05-22	Galveston	Coastal - Surge Only	6.8	29.512182	-94.492287	Galv-22
RTXC-05-23	Galveston	Coastal - Wave Run-up	6.5	29.514093	-94.484011	Galv-23
RTXC-05-24	Galveston	Coastal - Wave Height	7.1	29.523001	-94.469563	Galv-24
RTXC-05-25	Galveston	Coastal - Surge Only	6.8	29.536855	-94.475231	Galv-25
RTXC-05-53	Galveston	Coastal - Wave Run-up	3.0	29.370968	-94.766848	Galv-26
RTXC-05-54	Galveston	Coastal - Wave Run-up	2.5	29.367641	-94.777946	Galv-27
RTXR-06-06	Hardin	Riverine - Hurricane	74.6	30.480751	-94.394918	Hard-1
RTXR-06-07	Hardin	Riverine - Hurricane	48.8	30.351552	-94.293296	Hard-2
RTXR-06-08	Hardin	Riverine - Hurricane	29.9	30.349763	-94.220465	Hard-3
RTXR-06-09	Hardin	Riverine - Hurricane	25.5	30.356402	-94.094156	Hard-4
RTXR-06-32	Hardin	Riverine - Hurricane	37.0	30.324327	-94.169259	Hard-5
RTXR-06-33	Hardin	Riverine - Hurricane	43.4	30.319324	-94.179749	Hard-6
RTXC-03-01	Harris	Coastal - Wave Run-up	2.8	29.760479	-95.082014	Harr-1
RTXC-03-02	Harris	Coastal - Wave Run-up	3.6	29.713220	-94.99314	Harr-2
RTXR-06-01	Hunt	Riverine - Hurricane	470.4	32.897870	-96.253173	Hunt-1
RTXR-06-02	Hunt	Riverine - Hurricane	498.7	33.056682	-96.164139	Hunt-2
RTXR-06-03	Hunt	Riverine - Hurricane	501.2	33.133071	-96.077392	Hunt-3
RTXR-06-11	Jasper	Riverine - Hurricane	77.3	30.501854	-93.948304	Jasp-1
RTXR-06-12	Jasper	Riverine - Hurricane	118.6	31.038276	-94.167122	Jasp-2
RTXR-06-13	Jasper	Riverine - Hurricane	203.6	31.111779	-93.993433	Jasp-3
RTXR-06-14	Jasper	Riverine - Hurricane	174.9	31.097805	-94.016182	Jasp-4
RTXR-06-15	Jasper	Riverine - Hurricane	113.7	31.047415	-94.148864	Jasp-5
RTXR-06-16	Jasper	Riverine - Hurricane	104.3	30.983060	-94.243049	Jasp-6
RTXR-06-17	Jasper	Riverine - Hurricane	102.2	30.982311	-94.231058	Jasp-7
RTXR-06-18	Jasper	Riverine - Hurricane	96.1	31.015493	-94.161473	Jasp-8
RTXR-06-19	Jasper	Riverine - Hurricane	178.6	30.913108	-94.042619	Jasp-9

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-06-20	Jasper	Riverine - Hurricane	260.6	30.951089	-93.917723	Jasp-10
RTXR-06-21	Jasper	Riverine - Hurricane	118.0	30.867139	-94.115022	Jasp-11
RTXR-06-22	Jasper	Riverine - Hurricane	107.6	30.845122	-94.108668	Jasp-12
RTXR-06-23	Jasper	Riverine - Hurricane	126.1	30.843879	-94.077497	Jasp-13
RTXR-06-24	Jasper	Riverine - Hurricane	55.1	30.681823	-94.083626	Jasp-14
RTXR-06-25	Jasper	Riverine - Hurricane	62.3	30.680772	-94.090761	Jasp-15
RTXR-06-28	Jasper	Riverine - Hurricane	219.6	30.895472	-93.875055	Jasp-16
RTXR-06-29	Jasper	Riverine - Hurricane	182.7	30.889815	-93.990831	Jasp-17
RTXR-06-30	Jasper	Riverine - Hurricane	105.6	30.682927	-93.896002	Jasp-18
RTXR-06-31	Jasper	Riverine - Hurricane	90.0	30.666450	-93.893886	Jasp-19
RTXR-06-34	Jasper	Riverine - Hurricane	25.6	30.356105	-94.080263	Jasp-20
RTXC-05-01	Jefferson	Coastal - Wave Height	10.4	29.765856	-93.902209	Jeff-1
RTXC-05-02	Jefferson	Coastal - Wave Run-up	8.8	29.795801	-93.934669	Jeff-2
RTXC-05-03	Jefferson	Coastal - Surge Only	7.3	29.760627	-93.937494	Jeff-3
RTXC-05-05	Jefferson	Coastal - Surge Only	8.3	29.721809	-93.905246	Jeff-4
RTXC-05-06	Jefferson	Coastal - Surge Only	7.7	29.696547	-93.954485	Jeff-5
RTXC-05-07	Jefferson	Coastal - Surge Only	5.1	29.814491	-93.960203	Jeff-6
RTXC-05-16	Jefferson	Coastal - Surge Only	2.8	29.737831	-93.938404	Jeff-7
RTXC-05-17	Jefferson	Coastal - Surge Only	3.9	29.802801	-93.955727	Jeff-8
RTXC-05-26	Jefferson	Coastal - Wave Runup	5.8	29.923588	-93.871296	Jeff-9
RTXC-05-27	Jefferson	Coastal - Wave Run-up	5.9	29.879044	-93.911091	Jeff-10
RTXC-05-28	Jefferson	Coastal - Wave Run-up	9.8	29.709895	-93.858535	Jeff-11
RTXC-05-30	Jefferson	Coastal - Wave Run-up	5.6	29.733242	-93.874272	Jeff-12
RTXC-05-31	Jefferson	Coastal - Surge Only	5.6	29.734858	-93.896909	Jeff-13
RTXC-09-22	Jefferson	Coastal - Wave Height	10.5	29.764515	-93.899625	Jeff-14
RTXC-01-01	Jefferson	Riverine - Hurricane	18.0	30.085586	-94.12547	Jeff-15
RTXC-01-02	Jefferson	Riverine - Hurricane	4.3	29.930002	-94.120889	Jeff-16
RTXC-02-01	Jefferson	Riverine - Hurricane	9.3	30.078601	-94.073987	Jeff-17
RTXR-03-18	Jefferson	Riverine - Hurricane	38.3	29.928164	-94.414512	Jeff-18
RTXR-03-19	Jefferson	Riverine - Hurricane	28.5	30.099948	-94.405795	Jeff-19
RTXR-03-20	Jefferson	Riverine - Hurricane	18.7	30.000144	-94.299465	Jeff-20

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-02-20	Liberty	Riverine - Hurricane	57.8	30.425047	-94.850246	Libe-1
RTXR-03-17	Liberty	Riverine - Hurricane	34.3	30.277310	-94.795598	Libe-2
RTXR-02-03	Nacogdoches	Riverine - Hurricane	224.3	31.671770	-94.952367	Naco-1
RTXR-02-05	Nacogdoches	Riverine - Hurricane	262.6	31.600920	-94.648103	Naco-2
RTXR-02-06	Nacogdoches	Riverine - Hurricane	264.5	31.601125	-94.656176	Naco-3
RTXR-02-07	Nacogdoches	Riverine - Hurricane	202.4	31.507679	-94.341383	Naco-4
RTXR-02-08	Nacogdoches	Riverine - Hurricane	175.8	31.383260	-94.434327	Naco-5
RTXR-02-09	Nacogdoches	Riverine - Hurricane	285.9	31.653590	-94.786458	Naco-6
RTXR-02-10	Nacogdoches	Riverine - Hurricane	178.1	31.457027	-94.726456	Naco-7
RTXR-02-11	Nacogdoches	Riverine - Hurricane	192.0	31.461645	-94.728281	Naco-8
RTXR-04-11	Nacogdoches	Riverine - Hurricane	311.0	31.766547	-94.566767	Naco-9
RTXR-04-16	Nacogdoches	Riverine - Hurricane	190.4	31.475800	-94.341718	Naco-10
RTXR-04-17	Nacogdoches	Riverine - Hurricane	169.5	31.403812	-94.464223	Naco-11
RTXR-04-18	Nacogdoches	Riverine - Hurricane	306.6	31.652054	-94.642403	Naco-12
RTXR-04-19	Nacogdoches	Riverine - Hurricane	327.7	31.804844	-94.523208	Naco-13
RTXR-04-20	Nacogdoches	Riverine - Hurricane	301.1	31.844880	-94.475348	Naco-14
RTXR-09-36	Newton	Riverine - Hurricane	17.2	30.303599	-93.744066326	Newt-1
RTXC-03-06	Orange	Coastal - Wave Run-up	5.6	30.093966	-93.725332	Oran-1
RTXC-03-07	Orange	Coastal - Wave Run-up	5.5	30.095754	-93.726338	Oran-2
RTXC-05-13	Orange	Coastal - Surge Only	4.5	30.044948	-93.820616	Oran-3
RTXR-05-14	Orange	Coastal - Surge Only	4.8	30.064795	-93.749126	Oran-4
RTXC-01-03	Orange	Riverine - Hurricane	17.4	30.112524	-93.992122	Oran-5
RTXC-01-04	Orange	Riverine - Hurricane	22.2	30.175267	-94.010928	Oran-6
RTXC-02-02	Orange	Riverine - Hurricane	5.7	30.119633	-93.732247	Oran-7
RTXC-03-08	Orange	Riverine - Hurricane	5.2	30.126995	-93.703121	Oran-8
RTXR-05-15	Orange	Riverine - Hurricane	6.7	30.121387	-93.767185	Oran-9
RTXR-05-42	Orange	Riverine - Hurricane	13.7	30.184924	-94.023677	Oran-10
RTXR-05-43	Orange	Riverine - Hurricane	11.7	30.195471	-94.043822	Oran-11
RTXR-05-44	Orange	Riverine - Hurricane	8.6	30.207612	-94.090816	Oran-12
RTXR-05-45	Orange	Riverine - Hurricane	13.1	30.160946	-94.014787	Oran-13
RTXR-05-46	Orange	Riverine - Hurricane	18.8	30.146228	-93.984146	Oran-14

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-05-47	Orange	Riverine - Hurricane	22.2	30.220589	-93.901487	Oran-15
RTXR-05-48	Orange	Riverine - Hurricane	18.7	30.167349	-93.872893	Oran-16
RTXR-05-49	Orange	Riverine - Hurricane	9.2	30.130380	-93.91597	Oran-17
RTXR-05-50	Orange	Riverine - Hurricane	21.2	30.213154	-93.824153	Oran-18
RTXR-05-51	Orange	Riverine - Hurricane	7.2	30.152023	-93.746417	Oran-19
RTXR-05-52	Orange	Riverine - Hurricane	5.9	30.132023	-93.786601	Oran-20
RTXR-06-10	Orange	Riverine - Hurricane	13.4	30.184483	-94.024154	Oran-21
RTXR-05-32	Polk	Riverine - Hurricane	76.8	30.603910	-94.958894	Polk-1
RTXR-05-33	Polk	Riverine - Hurricane	93.8	30.683508	-94.956434	Polk-2
RTXR-05-34	Polk	Riverine - Hurricane	142.6	30.576513	-94.630642	Polk-3
RTXR-05-35	Polk	Riverine - Hurricane	216.0	30.719594	-94.699277	Polk-4
RTXR-05-36	Polk	Riverine - Hurricane	216.8	30.719954	-94.692902	Polk-5
RTXR-05-37	Polk	Riverine - Hurricane	272.2	30.722243	-94.645115	Polk-6
RTXR-05-39	Polk	Riverine - Hurricane	179.0	30.822651	-94.880068	Polk-7
RTXR-05-40	Polk	Riverine - Hurricane	176.6	30.826605	-94.903763	Polk-8
RTXR-05-41	Polk	Riverine - Hurricane	184.5	30.836182	-94.952005	Polk-9
RTXR-02-14	Sabine	Riverine - Hurricane	175.3	31.463430	-93.750692	Sabi-1
RTXR-02-15	Sabine	Riverine - Hurricane	172.8	31.372359	-93.726832	Sabi-2
RTXR-02-16	Sabine	Riverine - Hurricane	191.4	31.303720	-93.844623	Sabi-3
RTXR-02-17	Sabine	Riverine - Hurricane	218.0	31.183614	-93.812745	Sabi-4
RTXR-02-18	Sabine	Riverine - Hurricane	176.3	31.207798	-93.751392	Sabi-5
RTXR-02-19	Sabine	Riverine - Hurricane	176.4	31.201414	-93.73674	Sabi-6
RTXR-02-13	San Augustine	Riverine - Hurricane	186.5	31.504410	-94.303611	San -1
RTXR-04-05	San Augustine	Riverine - Hurricane	291.9	31.522930	-94.11874	San -2
RTXR-04-06	San Augustine	Riverine - Hurricane	290.7	31.522880	-94.11863	San -3
RTXR-04-07	San Augustine	Riverine - Hurricane	230.6	31.446375	-94.147265	San -4
RTXR-04-10	San Augustine	Riverine - Hurricane	241.4	31.400623	-94.091004	San -5
RTXR-04-13	San Augustine	Riverine - Hurricane	184.6	31.407820	-94.287069	San -6
RTXR-04-14	San Augustine	Riverine - Hurricane	241.2	31.508336	-94.252991	San -7
RTXR-04-15	San Augustine	Riverine - Hurricane	221.4	31.550145	-94.263548	San -8
RTXR-04-23	San Augustine	Riverine - Hurricane	302.0	31.528875	-94.183686	San -9

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-04-24	San Augustine	Riverine - Hurricane	299.6	31.530104	-94.115788	San -10
RTXR-04-25	San Augustine	Riverine - Hurricane	300.3	31.606276	-94.149261	San -11
RTXR-04-21	Shelby	Riverine - Hurricane	287.0	31.856480	-94.463843	Shel-1
RTXR-04-22	Shelby	Riverine - Hurricane	290.8	31.857574	-94.462362	Shel-2
RTXR-06-04	Smith	Riverine - Hurricane	407.5	32.350088	-95.214808	Smit-1
RTXR-06-05	Tyler	Riverine - Hurricane	123.0	31.024214	-94.399366	Tyle-1

Appendix A. Field Data Collection Forms

FLAGGER HIGH WATER MARK – COASTAL and RIVERINE
DATA COLLECTION REPORT FORM
(For Use By Flaggers) **HMTAP TO No.____________________**

HWM ID (e.g. DFLC-07-01) (Repeat in case forms are separated)		
HWM Street Address		
Rep Loss Number		
Multiple HWM	**(Circle One)**: Yes No	
HWM Area Identifier		
Subdivision / Industrial Park		
Date of Flagging/Interview		
Date of Flood Event		
Type/Name of Storm Event	**(Circle One)**: Hurricane, Tropical Storm, Tropical Depression, Other:	Name of storm event (e.g., Dennis)
Disaster Number (e.g.: DR-1539-FL)		
Date of Peak		
Source for Date of Peak		
Stream Name/Flood Source (Closest/responsible water body)		
Municipality, City or Town (Circle One: Known, closest)		
County		
State		
Type of HWM – **(Circle One)** **If Personal Account or Other, you MUST provide comment**	Mud Line Wrack Line Debris Line Water Line Personal Account Other Comment	
Wind Water Debris Line	**(Circle One)**: Yes No	
HWM Object, Surface (What object, surface is the HWM on? An interior/exterior wall, tree, fence, etc…)		

FLAGGER HIGH WATER MARK – COASTAL and RIVERINE
DATA COLLECTION REPORT FORM
(For Use By Flaggers) **HMTAP TO No.____________________**

HWM ID (e.g. DFLC-07-01) (Repeat in case forms are separated)		
Location/Directions to HWM Object		
Was a Vertical Offset Measurement used for HWM **(Circle Yes, No. If Yes, enter data)**	Yes No	If Yes: Measurement: Description of offset point:
Vertical Distance HWM to existing ground (feet) (Required		
HWM Quality – **(Circle One)**	GOOD FAIR POOR	
Description of Marker Used To Flag HWM **(e.g. red paint, tape. NOTE: HWM IS LINE AT BOTTOM OF TAPE OR PAINT. UNLESS the Flagger indicates that there is a vertical offset from the marked point)**		
Survey of HWM Needed	YES NO	
Flagger HWM Latitude (Decimal Degrees ex: 29.12345 (5 places))	N DECIMAL DEGREES	
Flagger HWM Longitude (Decimal Degrees ex: 84.12345 (5 places))	W DECIMAL DEGREES	
Flooding Type – **(Circle One)**	**Riverine Choices are**: - Riverine - Heavy Rain - Riverine - Hurricane **Coastal Choices are:** - Coastal - surge only - Coastal - wave height - Coastal - wave runup **Breached Levee**	
Estimated HWM Surge Level and what is this based on (Coastal HWM Only)	Elevation (Feet) Based On:	
Timestamp of Surge Estimate (Coastal HWM Only)	____ : ____ AM / PM CENTRAL / EASTERN	
Photo ID (HWM ID)-(Photo file name from camera)	Photo 1 (HWM mark from 20 feet away)	Photo 2 (Structure / Area from 50 feet away)
Photos Location/Orientation		
Photos Description/Subject		
Unit Number (2-digit number)		

FLAGGER HIGH WATER MARK – COASTAL and RIVERINE DATA COLLECTION REPORT FORM

(For Use By Flaggers) **HMTAP TO No.____________________**

HWM ID (e.g. DFLC-07-01) (Repeat in case forms are separated)		
Name of Flagger 1/Flagger 2	1	2
Flagger 1 Company/Flagger 2 Company	1	2
Flagger's Comments		
Resident/Eyewitness Information		
Name		
Address		
Obtained Permission to Survey	Yes	No
Phone		
Length of residence or familiarity with area		
Relevant witness Information (Document only if witness is willing to have personal information included in record)		
Wind Damage Data		
Structure Damage **(Circle as applicable)**	1) No Damage; 2) Structure type (use): residential, commercial, agricultural, mobile home; 3) Cause: wind, fallen objects, blown debris; 4) Severity (subjective): light, moderate, severe	
Tree Damage **(Circle as applicable)**	1) No Damage; 2) Tree Species: oak, pine, palm, other; 3) Damage: uprooted, snapped, twisted; 4) Severity (subjective): light (single tree), moderate, severe	
Overhead Utility Damage **(Circle as applicable)**	1) No Damage; 2) Materials: wood, metal, concrete; 3) Utility Type: power, telephone, cable; 4) Cause: wind, fallen objects, blown debris; 5) Severity (subjective): light, moderate, sever	

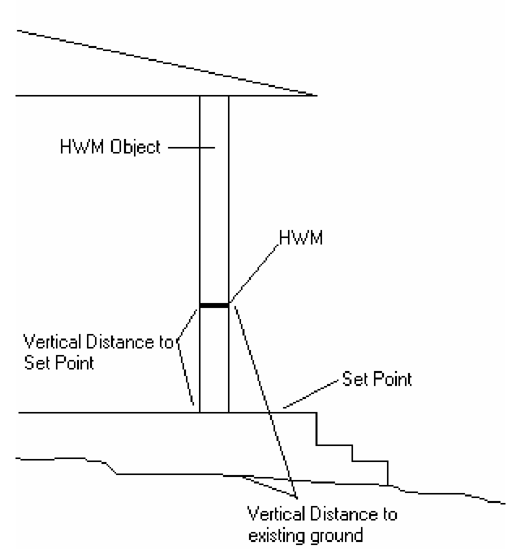
FLAGGER HIGH WATER MARK – COASTAL and RIVERINE
DATA COLLECTION REPORT FORM
(For Use By Flaggers) **HMTAP TO No.____________________**

HWM ID (e.g. DFLC-07-01) (Repeat in case forms are separated)	
Other Damage/Comments	

Required Plan/ Elevation View Sketches (use back if needed)

Required: 1) Sketch/Plan of nearest cross roads, directions to get to the HWM
2) Plan and Elevation views of the HWM

Example Measurements



SURVEYOR'S
HIGH WATER MARK (HWM) – COASTAL AND RIVERINE
DATA COLLECTION REPORT FORM HMTAP TO No.________________

HWM ID (Repeat in case forms are separated)		
HWM Street Address		
Municipality, City or Town (Known, closest)		
County		
State		
Exact Mark To Survey		
HWM Flood Elevation (NAVD 88 Datum) (1)		
HWM Flood Elevation (NGVD 29) (1)		
Was Flagger's Vertical Offset Measurement used to survey HWM Elevation (1)		No Yes
If Yes, then:	Flagger Vertical Offset Distance	
	Surveyed Elevation of Reference Point (NAVD 88)	
Survey Latitude **Must Use Decimal Degrees (6 Decimal places)**		N
Survey Longitude **Must Use Decimal Degrees (6 Decimal places)**		W
Northing (feet)		
Easting (feet)		
Approx. First Floor Elevation (NAVD 88)		
Map Projection Used During Survey		
Vertical Datum		NAVD 88 NGVD 29 OTHER:
Horizontal Datum		NAD 83 OTHER:
Survey Crew		
Responsible Licensed Professional Land Surveyor Name and Number		PLS Name:
Survey Company / Office Location		

SURVEYOR'S
HIGH WATER MARK (HWM) – COASTAL AND RIVERINE
DATA COLLECTION REPORT FORM HMTAP TO No.________________

HWM ID (Repeat in case forms are separated)	
Survey Date (e.g. 07/15/2005)	
Surveyor's Comments	

(1) note that the HWM is the line at the bottom of the tape or paint **UNLESS the Flagger indicates that there is a vertical offset from the marked point**

Surveyor Plan/ Elevation View Sketches (if needed)

APPENDICES

Appendix B. Maps

Table B-1. Appendix B Figures

County	Figure
ANGELINA	B-4
CHAMBERS	B-1
CHEROKEE	B-4
GALVESTON	B-1
HARDIN	B-2
HARRIS	B-1
HUNT	B-5
JASPER	B-3
JEFFERSON	B-2
LIBERTY	B-3
NACOGDOCHES	B-4
NEWTON	B-2
ORANGE	B-2
POLK	B-3
SABINE	B-4
SAN AUGUSTINE	B-4
SHELBY	B-4
SMITH	B-5
TYLER	B-3

Table B-2. Hurricane Rita Texas HWM Data Summary (same as Table 11, sorted by HWM-ID)[1]

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXC-01-01	Jefferson	Riverine - Hurricane	18.0	30.085586	-94.12547	Jeff-15
RTXC-01-02	Jefferson	Riverine - Hurricane	4.3	29.930002	-94.120889	Jeff-16
RTXC-01-03	Orange	Riverine - Hurricane	17.4	30.112524	-93.992122	Oran-5
RTXC-01-04	Orange	Riverine - Hurricane	22.2	30.175267	-94.010928	Oran-6
RTXC-02-01	Jefferson	Riverine - Hurricane	9.3	30.078601	-94.073987	Jeff-17
RTXC-02-02	Orange	Riverine - Hurricane	5.7	30.119633	-93.732247	Oran-7
RTXC-03-01	Harris	Coastal - Wave Run-up	2.8	29.760479	-95.082014	Harr-1
RTXC-03-02	Harris	Coastal - Wave Run-up	3.6	29.713220	-94.99314	Harr-2
RTXC-03-03	Chambers	Coastal - Wave Run-up	4.5	29.755744	-94.68885	Cham-1
RTXC-03-04	Chambers	Coastal - Wave Run-up	4.8	29.657630	-94.697554	Cham-2
RTXC-03-05	Chambers	Coastal - Wave Run-up	6.5	29.526794	-94.771424	Cham-3
RTXC-03-06	Orange	Coastal - Wave Run-up	5.6	30.093966	-93.725332	Oran-1
RTXC-03-07	Orange	Coastal - Wave Run-up	5.5	30.095754	-93.726338	Oran-2
RTXC-03-08	Orange	Riverine - Hurricane	5.2	30.126995	-93.703121	Oran-8
RTXC-03-09	Galveston	Coastal - Wave Run-up	5.9	29.305183	-94.770101	Galv-1
RTXC-03-10	Galveston	Coastal - Wave Run-up	7.3	29.195736	-94.949062	Galv-2
RTXC-03-11	Galveston	Coastal - Wave Run-up	7.0	29.229238	-94.89239	Galv-3
RTXC-03-12	Galveston	Coastal - Wave Run-up	3.3	29.129880	-95.07236	Galv-4
RTXC-03-13	Galveston	Coastal - Wave Run-up	3.8	29.265050	-94.898958	Galv-5
RTXC-03-14	Galveston	Coastal - Wave Run-up	2.8	29.333797	-94.747078	Galv-6
RTXC-03-15	Galveston	Coastal - Wave Run-up	5.9	29.337266	-94.777393	Galv-7
RTXC-03-16	Galveston	Coastal - Wave Run-up	3.8	29.293360	-94.86525	Galv-8
RTXC-04-01	Galveston	Coastal - Wave Run-up	8.9	29.214180	-94.917232	Galv-9
RTXC-04-02	Galveston	Coastal - Wave Run-up	4.6	29.206754	-94.950205	Galv-10
RTXC-04-03	Galveston	Coastal - Wave Run-up	3.9	29.199537	-94.9912	Galv-11
RTXC-04-04	Galveston	Coastal - Surge Only	6.4	29.171900	-94.988866	Galv-12

[1] Note - For HWM data summary listed sorted by County and HWM sheet number, refer to Table 11

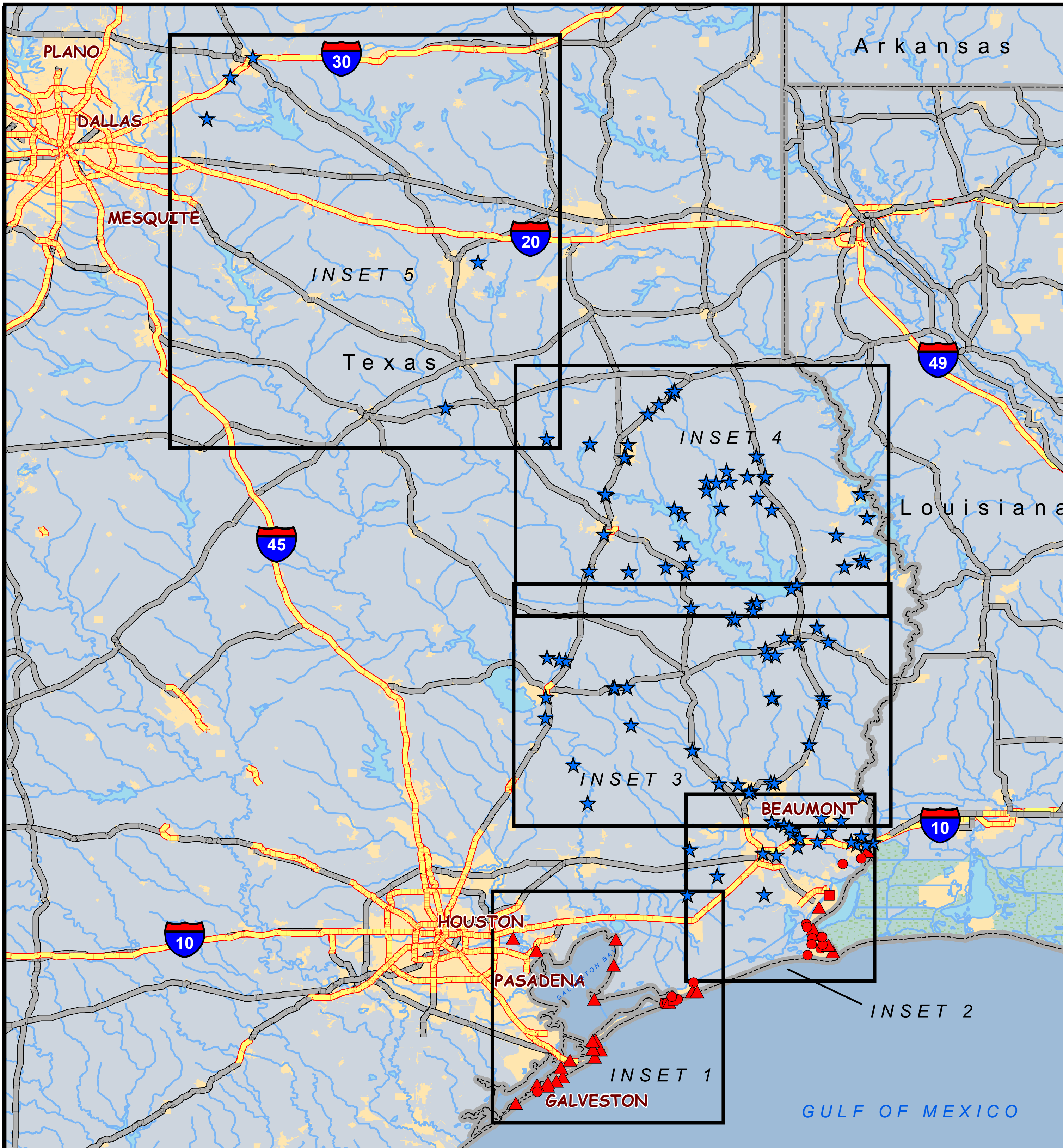
HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXC-05-01	Jefferson	Coastal - Wave Height	10.4	29.765856	-93.902209	Jeff-1
RTXC-05-02	Jefferson	Coastal - Wave Run-up	8.8	29.795801	-93.934669	Jeff-2
RTXC-05-03	Jefferson	Coastal - Surge Only	7.3	29.760627	-93.937494	Jeff-3
RTXC-05-05	Jefferson	Coastal - Surge Only	8.3	29.721809	-93.905246	Jeff-4
RTXC-05-06	Jefferson	Coastal - Surge Only	7.7	29.696547	-93.954485	Jeff-5
RTXC-05-07	Jefferson	Coastal - Surge Only	5.1	29.814491	-93.960203	Jeff-6
RTXC-05-08	Galveston	Coastal - Wave Run-up	5.6	29.555592	-94.391413	Galv-13
RTXC-05-09	Galveston	Coastal - Surge Only	6.3	29.518685	-94.483386	Galv-14
RTXC-05-10	Galveston	Coastal - Wave Height	7.0	29.511548	-94.496657	Galv-15
RTXC-05-11	Galveston	Coastal - Surge Only	5.4	29.509491	-94.495617	Galv-16
RTXC-05-12	Galveston	Coastal - Surge Only	4.5	29.509277	-94.502299	Galv-17
RTXC-05-13	Orange	Coastal - Surge Only	4.5	30.044948	-93.820616	Oran-3
RTXC-05-16	Jefferson	Coastal - Surge Only	2.8	29.737831	-93.938404	Jeff-7
RTXC-05-17	Jefferson	Coastal - Surge Only	3.9	29.802801	-93.955727	Jeff-8
RTXC-05-18	Galveston	Coastal - Surge Only	4.5	29.590121	-94.391274	Galv-18
RTXC-05-19	Galveston	Coastal - Wave Run-up	5.6	29.556602	-94.395971	Galv-19
RTXC-05-20	Galveston	Coastal - Wave Run-up	4.5	29.556345	-94.378214	Galv-20
RTXC-05-21	Galveston	Coastal - Surge Only	5.9	29.526036	-94.451525	Galv-21
RTXC-05-22	Galveston	Coastal - Surge Only	6.8	29.512182	-94.492287	Galv-22
RTXC-05-23	Galveston	Coastal - Wave Run-up	6.5	29.514093	-94.484011	Galv-23
RTXC-05-24	Galveston	Coastal - Wave Height	7.1	29.523001	-94.469563	Galv-24
RTXC-05-25	Galveston	Coastal - Surge Only	6.8	29.536855	-94.475231	Galv-25
RTXC-05-26	Jefferson	Coastal - Wave Runup	5.8	29.923588	-93.871296	Jeff-9
RTXC-05-27	Jefferson	Coastal - Wave Run-up	5.9	29.879044	-93.911091	Jeff-10
RTXC-05-28	Jefferson	Coastal - Wave Run-up	9.8	29.709895	-93.858535	Jeff-11
RTXC-05-30	Jefferson	Coastal - Wave Run-up	5.6	29.733242	-93.874272	Jeff-12
RTXC-05-31	Jefferson	Coastal - Surge Only	5.6	29.734858	-93.896909	Jeff-13
RTXC-05-53	Galveston	Coastal - Wave Run-up	3.0	29.370968	-94.766848	Galv-26
RTXC-05-54	Galveston	Coastal - Wave Run-up	2.5	29.367641	-94.777946	Galv-27
RTXC-09-22	Jefferson	Coastal - Wave Height	10.5	29.764515	-93.899625	Jeff-14

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-02-03	Nacogdoches	Riverine - Hurricane	224.3	31.671770	-94.952367	Naco-1
RTXR-02-05	Nacogdoches	Riverine - Hurricane	262.6	31.600920	-94.648103	Naco-2
RTXR-02-06	Nacogdoches	Riverine - Hurricane	264.5	31.601125	-94.656176	Naco-3
RTXR-02-07	Nacogdoches	Riverine - Hurricane	202.4	31.507679	-94.341383	Naco-4
RTXR-02-08	Nacogdoches	Riverine - Hurricane	175.8	31.383260	-94.434327	Naco-5
RTXR-02-09	Nacogdoches	Riverine - Hurricane	285.9	31.653590	-94.786458	Naco-6
RTXR-02-10	Nacogdoches	Riverine - Hurricane	178.1	31.457027	-94.726456	Naco-7
RTXR-02-11	Nacogdoches	Riverine - Hurricane	192.0	31.461645	-94.728281	Naco-8
RTXR-02-12	Cherokee	Riverine - Hurricane	284.5	31.791068	-95.339656	Cher-1
RTXR-02-13	San Augustine	Riverine - Hurricane	186.5	31.504410	-94.303611	San -1
RTXR-02-14	Sabine	Riverine - Hurricane	175.3	31.463430	-93.750692	Sabi-1
RTXR-02-15	Sabine	Riverine - Hurricane	172.8	31.372359	-93.726832	Sabi-2
RTXR-02-16	Sabine	Riverine - Hurricane	191.4	31.303720	-93.844623	Sabi-3
RTXR-02-17	Sabine	Riverine - Hurricane	218.0	31.183614	-93.812745	Sabi-4
RTXR-02-18	Sabine	Riverine - Hurricane	176.3	31.207798	-93.751392	Sabi-5
RTXR-02-19	Sabine	Riverine - Hurricane	176.4	31.201414	-93.73674	Sabi-6
RTXR-02-20	Liberty	Riverine - Hurricane	57.8	30.425047	-94.850246	Libe-1
RTXR-02-21	Angelina	Riverine - Hurricane	165.9	31.165997	-94.791391	Ange-1
RTXR-02-22	Angelina	Riverine - Hurricane	245.3	31.307467	-94.733732	Ange-2
RTXR-02-23	Angelina	Riverine - Hurricane	164.8	31.164870	-94.638609	Ange-3
RTXR-02-24	Angelina	Riverine - Hurricane	169.2	31.196571	-94.40469	Ange-4
RTXR-03-17	Liberty	Riverine - Hurricane	34.3	30.277310	-94.795598	Libe-2
RTXR-03-18	Jefferson	Riverine - Hurricane	38.3	29.928164	-94.414512	Jeff-18
RTXR-03-19	Jefferson	Riverine - Hurricane	28.5	30.099948	-94.405795	Jeff-19
RTXR-03-20	Jefferson	Riverine - Hurricane	18.7	30.000144	-94.299465	Jeff-20
RTXR-04-05	San Augustine	Riverine - Hurricane	291.9	31.522930	-94.11874	San -2
RTXR-04-06	San Augustine	Riverine - Hurricane	290.7	31.522880	-94.11863	San -3
RTXR-04-07	San Augustine	Riverine - Hurricane	230.6	31.446375	-94.147265	San -4
RTXR-04-10	San Augustine	Riverine - Hurricane	241.4	31.400623	-94.091004	San -5
RTXR-04-11	Nacogdoches	Riverine - Hurricane	311.0	31.766547	-94.566767	Naco-9

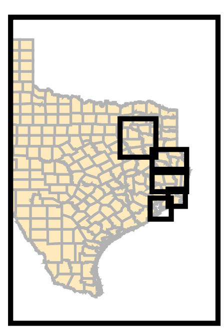
HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-04-13	San Augustine	Riverine - Hurricane	184.6	31.407820	-94.287069	San -6
RTXR-04-14	San Augustine	Riverine - Hurricane	241.2	31.508336	-94.252991	San -7
RTXR-04-15	San Augustine	Riverine - Hurricane	221.4	31.550145	-94.263548	San -8
RTXR-04-16	Nacogdoches	Riverine - Hurricane	190.4	31.475800	-94.341718	Naco-10
RTXR-04-17	Nacogdoches	Riverine - Hurricane	169.5	31.403812	-94.464223	Naco-11
RTXR-04-18	Nacogdoches	Riverine - Hurricane	306.6	31.652054	-94.642403	Naco-12
RTXR-04-19	Nacogdoches	Riverine - Hurricane	327.7	31.804844	-94.523208	Naco-13
RTXR-04-20	Nacogdoches	Riverine - Hurricane	301.1	31.844880	-94.475348	Naco-14
RTXR-04-21	Shelby	Riverine - Hurricane	287.0	31.856480	-94.463843	Shel-1
RTXR-04-22	Shelby	Riverine - Hurricane	290.8	31.857574	-94.462362	Shel-2
RTXR-04-23	San Augustine	Riverine - Hurricane	302.0	31.528875	-94.183686	San -9
RTXR-04-24	San Augustine	Riverine - Hurricane	299.6	31.530104	-94.115788	San -10
RTXR-04-25	San Augustine	Riverine - Hurricane	300.3	31.606276	-94.149261	San -11
RTXR-04-27	Angelina	Riverine - Hurricane	168.1	31.273684	-94.436535	Ange-5
RTXR-04-28	Angelina	Riverine - Hurricane	192.7	31.181468	-94.496486	Ange-6
RTXR-05-14	Orange	Coastal - Surge Only	4.8	30.064795	-93.749126	Oran-4
RTXR-05-15	Orange	Riverine - Hurricane	6.7	30.121387	-93.767185	Oran-9
RTXR-05-32	Polk	Riverine - Hurricane	76.8	30.603910	-94.958894	Polk-1
RTXR-05-33	Polk	Riverine - Hurricane	93.8	30.683508	-94.956434	Polk-2
RTXR-05-34	Polk	Riverine - Hurricane	142.6	30.576513	-94.630642	Polk-3
RTXR-05-35	Polk	Riverine - Hurricane	216.0	30.719594	-94.699277	Polk-4
RTXR-05-36	Polk	Riverine - Hurricane	216.8	30.719954	-94.692902	Polk-5
RTXR-05-37	Polk	Riverine - Hurricane	272.2	30.722243	-94.645115	Polk-6
RTXR-05-39	Polk	Riverine - Hurricane	179.0	30.822651	-94.880068	Polk-7
RTXR-05-40	Polk	Riverine - Hurricane	176.6	30.826605	-94.903763	Polk-8
RTXR-05-41	Polk	Riverine - Hurricane	184.5	30.836182	-94.952005	Polk-9
RTXR-05-42	Orange	Riverine - Hurricane	13.7	30.184924	-94.023677	Oran-10
RTXR-05-43	Orange	Riverine - Hurricane	11.7	30.195471	-94.043822	Oran-11
RTXR-05-44	Orange	Riverine - Hurricane	8.6	30.207612	-94.090816	Oran-12
RTXR-05-45	Orange	Riverine - Hurricane	13.1	30.160946	-94.014787	Oran-13

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-05-46	Orange	Riverine - Hurricane	18.8	30.146228	-93.984146	Oran-14
RTXR-05-47	Orange	Riverine - Hurricane	22.2	30.220589	-93.901487	Oran-15
RTXR-05-48	Orange	Riverine - Hurricane	18.7	30.167349	-93.872893	Oran-16
RTXR-05-49	Orange	Riverine - Hurricane	9.2	30.130380	-93.91597	Oran-17
RTXR-05-50	Orange	Riverine - Hurricane	21.2	30.213154	-93.824153	Oran-18
RTXR-05-51	Orange	Riverine - Hurricane	7.2	30.152023	-93.746417	Oran-19
RTXR-05-52	Orange	Riverine - Hurricane	5.9	30.132023	-93.786601	Oran-20
RTXR-06-01	Hunt	Riverine - Hurricane	470.4	32.897870	-96.253173	Hunt-1
RTXR-06-02	Hunt	Riverine - Hurricane	498.7	33.056682	-96.164139	Hunt-2
RTXR-06-03	Hunt	Riverine - Hurricane	501.2	33.133071	-96.077392	Hunt-3
RTXR-06-04	Smith	Riverine - Hurricane	407.5	32.350088	-95.214808	Smit-1
RTXR-06-05	Tyler	Riverine - Hurricane	123.0	31.024214	-94.399366	Tyle-1
RTXR-06-06	Hardin	Riverine - Hurricane	74.6	30.480751	-94.394918	Hard-1
RTXR-06-07	Hardin	Riverine - Hurricane	48.8	30.351552	-94.293296	Hard-2
RTXR-06-08	Hardin	Riverine - Hurricane	29.9	30.349763	-94.220465	Hard-3
RTXR-06-09	Hardin	Riverine - Hurricane	25.5	30.356402	-94.094156	Hard-4
RTXR-06-10	Orange	Riverine - Hurricane	13.4	30.184483	-94.024154	Oran-21
RTXR-06-11	Jasper	Riverine - Hurricane	77.3	30.501854	-93.948304	Jasp-1
RTXR-06-12	Jasper	Riverine - Hurricane	118.6	31.038276	-94.167122	Jasp-2
RTXR-06-13	Jasper	Riverine - Hurricane	203.6	31.111779	-93.993433	Jasp-3
RTXR-06-14	Jasper	Riverine - Hurricane	174.9	31.097805	-94.016182	Jasp-4
RTXR-06-15	Jasper	Riverine - Hurricane	113.7	31.047415	-94.148864	Jasp-5
RTXR-06-16	Jasper	Riverine - Hurricane	104.3	30.983060	-94.243049	Jasp-6
RTXR-06-17	Jasper	Riverine - Hurricane	102.2	30.982311	-94.231058	Jasp-7
RTXR-06-18	Jasper	Riverine - Hurricane	96.1	31.015493	-94.161473	Jasp-8
RTXR-06-19	Jasper	Riverine - Hurricane	178.6	30.913108	-94.042619	Jasp-9
RTXR-06-20	Jasper	Riverine - Hurricane	260.6	30.951089	-93.917723	Jasp-10
RTXR-06-21	Jasper	Riverine - Hurricane	118.0	30.867139	-94.115022	Jasp-11
RTXR-06-22	Jasper	Riverine - Hurricane	107.6	30.845122	-94.108668	Jasp-12
RTXR-06-23	Jasper	Riverine - Hurricane	126.1	30.843879	-94.077497	Jasp-13

HWM ID	County	Flooding Type	HWM Flood Elevation - NAVD 88	Survey Latitude	Survey Longitude	HWM Report Sheet No.
RTXR-06-24	Jasper	Riverine - Hurricane	55.1	30.681823	-94.083626	Jasp-14
RTXR-06-25	Jasper	Riverine - Hurricane	62.3	30.680772	-94.090761	Jasp-15
RTXR-06-27	Angelina	Riverine - Hurricane	242.0	31.158365	-94.420281	Ange-7
RTXR-06-28	Jasper	Riverine - Hurricane	219.6	30.895472	-93.875055	Jasp-16
RTXR-06-29	Jasper	Riverine - Hurricane	182.7	30.889815	-93.990831	Jasp-17
RTXR-06-30	Jasper	Riverine - Hurricane	105.6	30.682927	-93.896002	Jasp-18
RTXR-06-31	Jasper	Riverine - Hurricane	90.0	30.666450	-93.893886	Jasp-19
RTXR-06-32	Hardin	Riverine - Hurricane	37.0	30.324327	-94.169259	Hard-5
RTXR-06-33	Hardin	Riverine - Hurricane	43.4	30.319324	-94.179749	Hard-6
RTXR-06-34	Jasper	Riverine - Hurricane	25.6	30.356105	-94.080263	Jasp-20
RTXR-09-36	Newton	Riverine - Hurricane	17.2	30.303599	-93.744066326	Newt-1



Overview Map: Inset Index
Hurricane Rita, Texas
Surveyed High Water Mark (HWM) Elevations



FEMA

N

0	12.5	25		50

Miles

0	20	40		80

Kilometers

RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

- Coastal- Surge Only
- Coastal- Wave Height
- Coastal- Wave Runup
- Riverine- Hurricane

- Swamp or Marsh
- Inset
- Municipalities
- State Boundaries

- Water Body
- Hydrology

Road Classification

- Limited Access
- Highway
- Major Road

Figure B-1: Inset Map 1 Hurricane Rita, Texas
Galveston Bay Area, Texas
Surveyed High Water Mark (HWM) Locations

FEMA

RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

- Coastal- Surge Only
- Coastal- Wave Height
- Coastal- Wave Runup
- Riverine- Hurricane

- Swamp or Marsh
- Inset
- Municipalities
- County Boundaries

- Water Body
- Hydrology

Road Classification
- Limited Access
- Highway
- Major Road

0 3 6 12
Kilometers

0 2 4 8
Miles

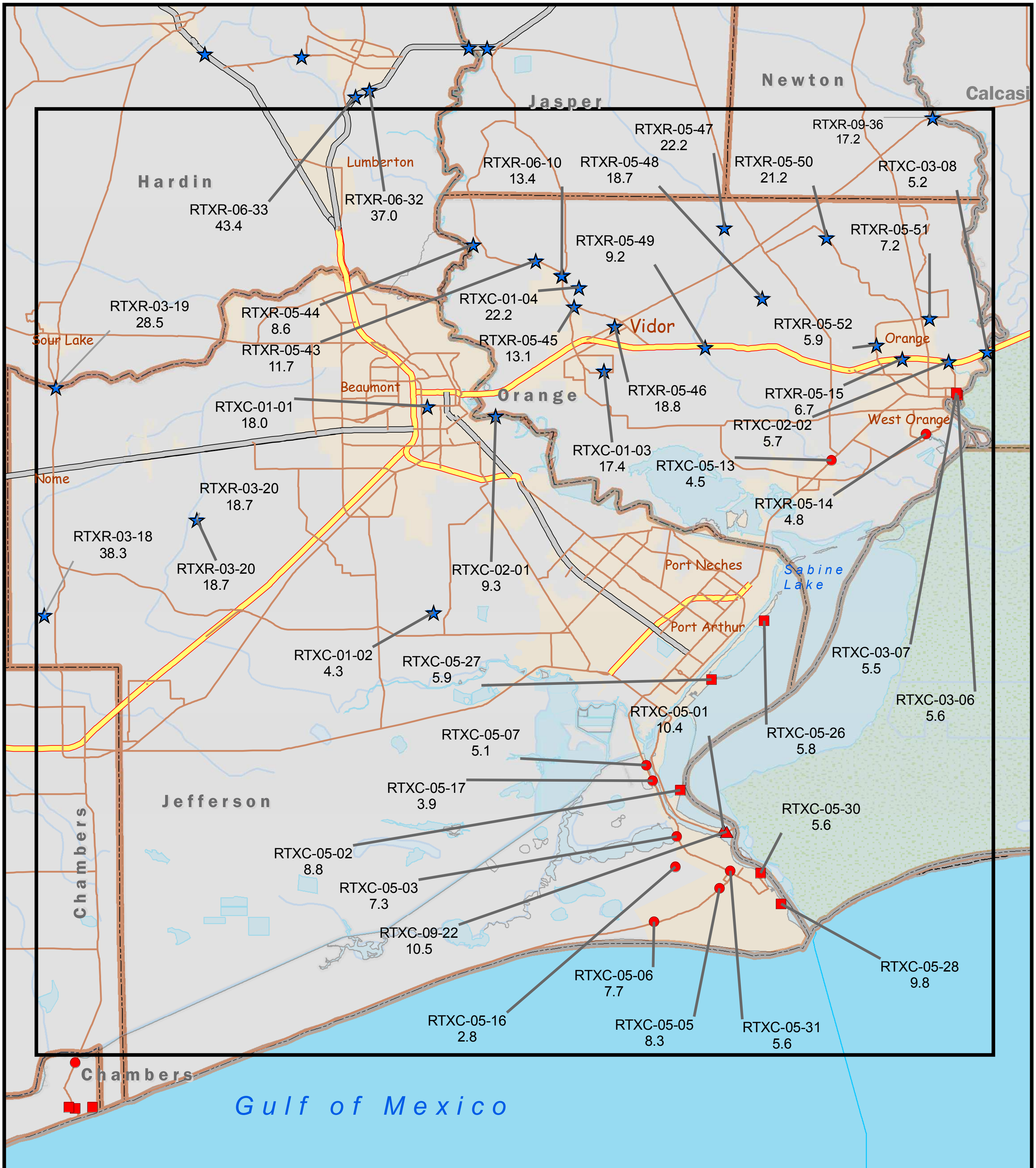


Figure B-2: Inset Map 2 Hurricane Rita, Texas Orange County Area Surveyed High Water Mark (HWM) Locations

RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

- ● Coastal- Surge Only
- ▲ Coastal- Wave Height
- ■ Coastal- Wave Runup
- ★ Riverine- Hurricane

- Swamp or Marsh
- Inset
- Municipalities
- County Boundaries

- Water Body
- Hydrology

Road Classification

- Limited Access
- Highway
- Major Road

FEMA

0 3 6 12
Kilometers
0 2 4 8
Miles

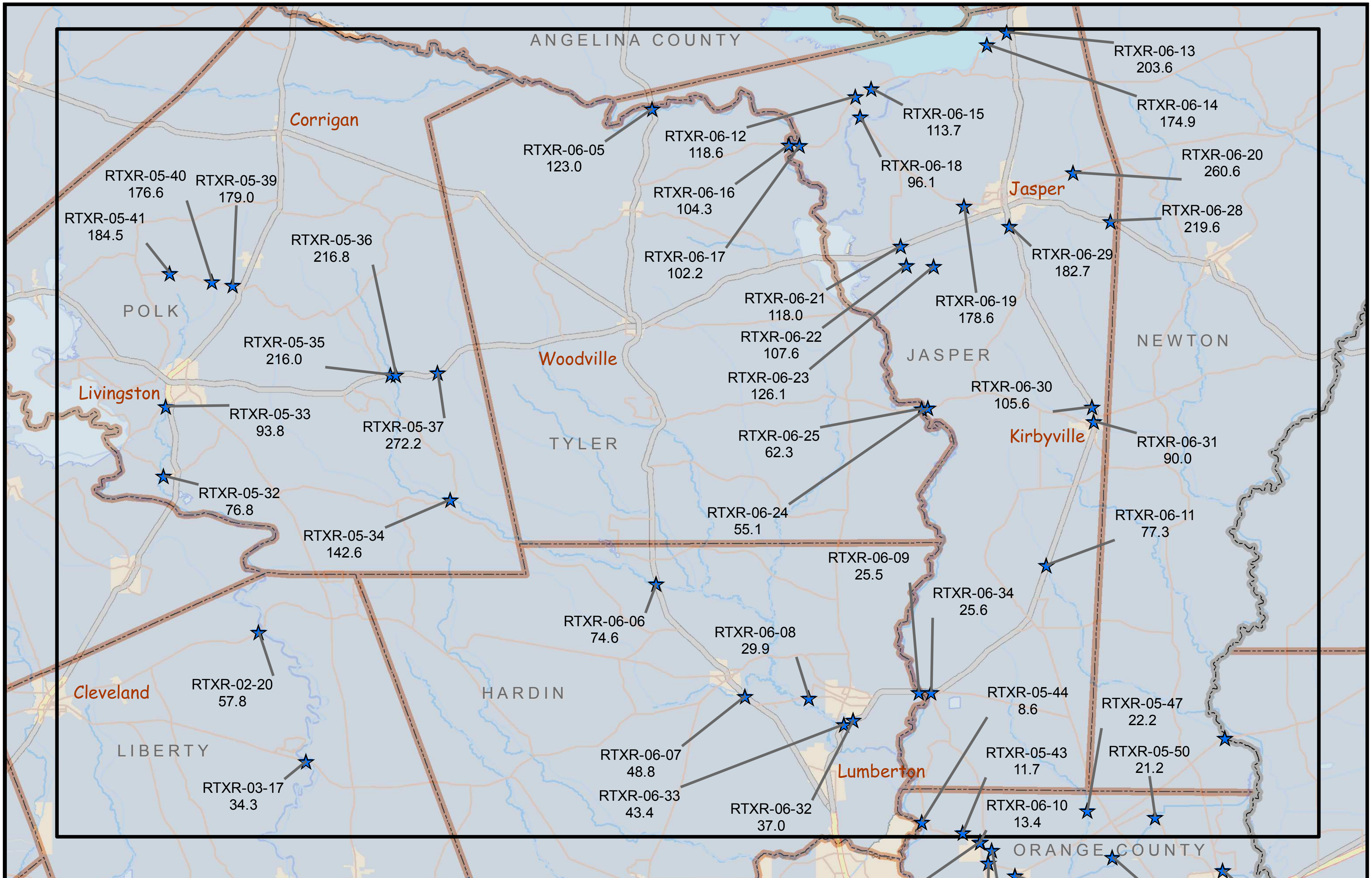
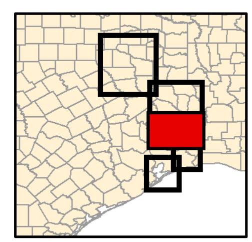


Figure B-3: Inset Map 3 Hurricane Rita, Texas
Tyler, Polk, Liberty & Hardin Counties
Surveyed High Water Mark (HWM) Locations

GULF OF MEXICO



FEMA

N

0 4 8 16
Kilometers
0 2.5 5 10
Miles

- Coastal- Surge Only
- Coastal- Wave Height
- Coastal- Wave Runup
- Riverine- Hurricane

RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

Inset

Municipalities
State Boundaries
County Boundaries

Water Body
Hydrology
Swamp or Marsh

Road Classification
Limited Access
Highway
Major Road

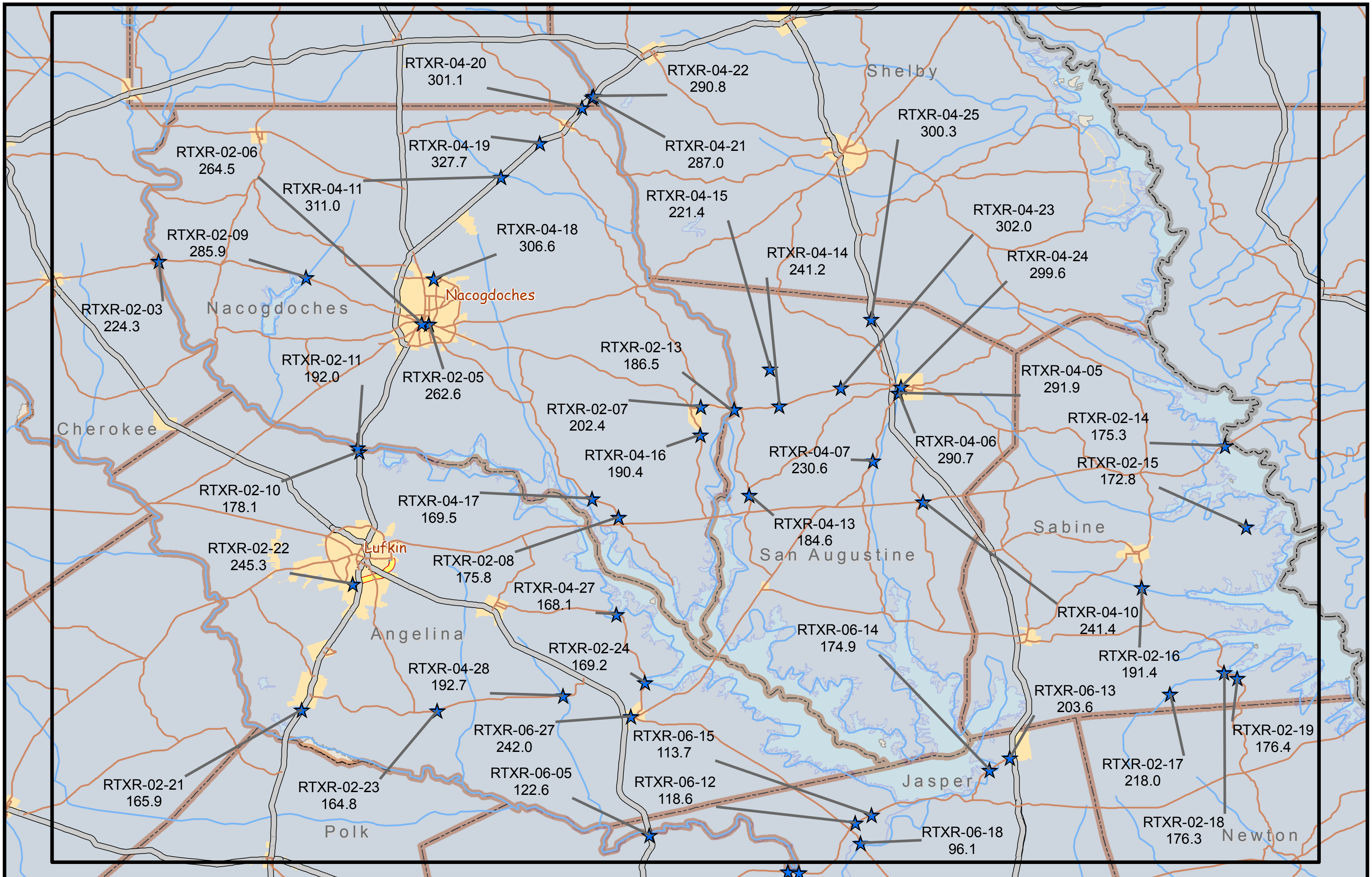
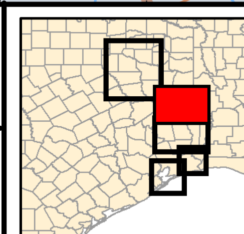


Figure B-4: Inset Map 4 Hurricane Rita, Texas
Shelby, Nacogdoches, Sabine, Angelina, & St. Augustine Counties
Surveyed High Water Mark (HWM) Locations



FEMA

N

0 4 8 16
Kilometers
0 2.5 5 10
Miles

● Coastal- Surge Only
▲ Coastal- Wave Height
■ Coastal- Wave Runup
★ Riverine- Hurricane

RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

Inset
Municipalities
County Boundaries

Water Body
Hydrology
Swamp or Marsh

Road Classification
Limited Access
Highway
Major Road

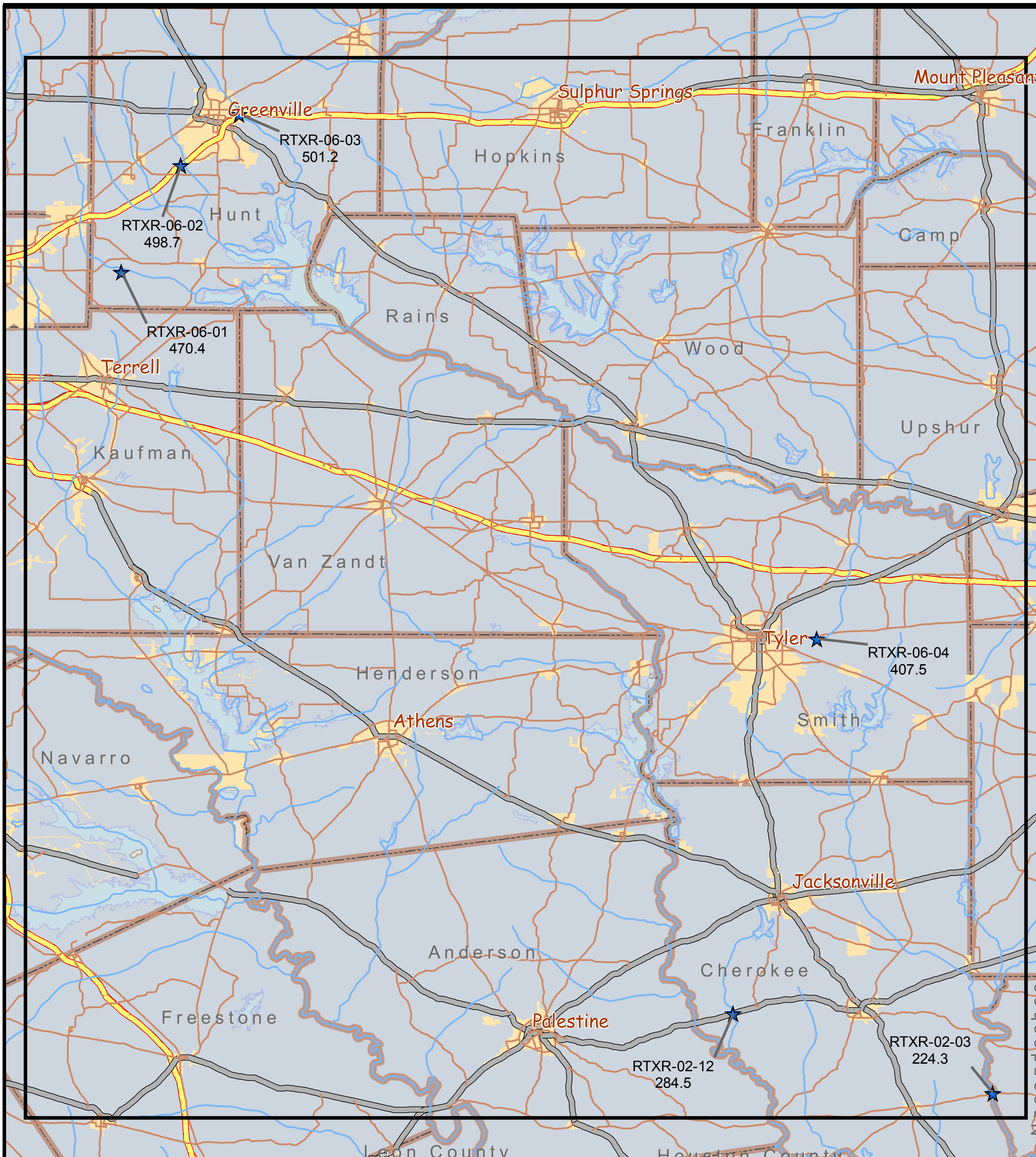


Figure B-5: Inset Map 5 Hurricane Rita, Texas
East Dallas Area
Surveyed High Water Mark (HWM) Locations

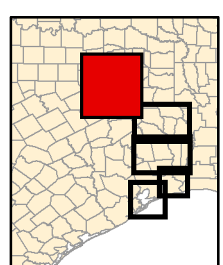
RLAC-11-21 - HWM ID
10.4 - Surveyed Elevation, NGVD88, feet

- Coastal- Surge Only
- Coastal- Wave Height
- Coastal- Wave Runup
- Riverine- Hurricane

Swamp or Marsh
Inset
Municipalities
County Boundaries

Water Body
Hydrology

Road Classification
Limited Access
Highway
Major Road



FEMA

N

0 5 10 20
Kilometers

0 4 8 16
Miles

**Appendices C-U are not included in this report due to privacy issues.