Hurricane Rita Rapid Response Wind Water Line Report – Texas

Task Order 446

February 28, 2006 (Final)

FEMA

Hazard Mitigation Technical Assistance Program
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Hurricane Rita Rapid Response
Wind Water Line (WWL) Data Collection – Texas
FEMA-1606-DR-TX

Final Report

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ABBREVIATIONS AND ACRONYMS

Acronyms	Explanation
CDT	Central Daylight Time (daylight savings time zone)
CHWM	Coastal High Water Mark
DEM	Digital Elevation Model
EDT	Eastern Daylight Time (daylight savings time zone)
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
GIS	Geographic Information System
GPS	Global Positioning System
HMGP	Hazard Mitigation Grant Program
HMTAP	Hazard Mitigation Technical Assistance Program
HWM	High Water Mark
IA	Individual Assistance
km	Kilometers
kts	Knots
LiDAR	Light Detection and Ranging
mb	Millibar
mph	Miles Per Hour
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NFIP	National Flood Insurance Program
NGVD 29	National Geodetic Vertical Datum of 1929
NUAR	Not Used After Review
PA	Public Assistance
PNP	Private Non-Profit
RHWM	Riverine High Water Mark
SOC	State Operations Center
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WWL	Wind Water Line

GLOSSARY OF TERMS

Word	Definition
ArcCatalog®	Software application from ESRI that organizes and manages all GIS information such as maps, globes, data sets, models, metadata, and services.
ArcGIS®	The comprehensive name for the current suite of GIS products produced by ESRI that are used to create, import, edit, query, map, analyze, and publish geographic information.
ArcView®	A software application from ESRI that provides extensive mapping, data use, and analysis, along with simple editing and geoprocessing capabilities.
Base map	A map or chart showing certain fundamental information, used as a base upon which additional data of a specialized nature are compiled or overprinted.
Contour data	Ground elevation data displayed as continuous lines for given elevations.
Contour lines	Lines that connect a series of points of equal ground elevation and are used to illustrate topography, or relief, on a map.
Data point	A point associated with a discrete geographic location where data pertaining to the study were collected.
Debris line	Defines the extent of flooding where debris such as parts of houses, docks, cars, or other non-natural material is generally carried by floodwaters with some velocity and is then dropped as the floodwaters lose velocity and begin to recede.
Disaster declaration	The formal action by the President to make a state eligible for major disaster or emergency assistance under the Stafford Act.
Emergency protective measures	Actions taken by Applicants before, during, and after a disaster to save lives, protect public health and safety, and prevent damage to improved public and private property.
Flood recovery map	High-resolution maps that show flood impacts, including high water mark flood elevations, flood inundation limits, the inland limit of waterborne debris (trash lines), and storm surge elevation contours based on the high water marks. The maps also show existing FEMA Flood Insurance Rate Map (FIRM) flood elevations for comparison to hurricane data.
Geodatabase	The geodatabase provides the common data access and management framework for ArcGIS. Geodatabases organize geographic data into a hierarchy of data objects. These objects are stored in feature classes, object classes, and feature datasets. An object class is a table in the geodatabase that stores nonspatial data. A feature class is a collection of features with the same type of geometry and the same attributes. A feature dataset is a collection of feature classes sharing the same spatial reference.

Word	Definition
Hazard Mitigation Grant Program	Provides grants to States and local government 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
High Water Mark	Indicators of high water levels found on the ground or on structures. Examples are debris lines, wrack lines, and mud lines.
Individual Assistance	Federal assistance provided to families or individuals following a major disaster or emergency declaration. Under a major disaster declaration, assistance to individuals and families is available through grants, loans, and other services offered by various Federal, state, local, and voluntary agencies.
Inundated	Flooded or covered with water.
Inundation polygon	Aerial extent of flooding as shown by polygon feature in ArcGIS.
Knot	A unit of speed, 1 nautical mile per hour, approximately 1.85 kilometers (1.15 statute miles) per hour.
LiDAR	LiDAR (Light Detection and Ranging or Laser Imaging Detection and Ranging) is a technology that determines distance to an object or surface using laser pulses. Like the similar radar technology, which uses radio waves instead of light, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal.
Millibar	A unit of atmospheric pressure equal to 1/1,000 of a bar. Standard atmospheric pressure at sea level is about 1,013 millibars.
Mitigation	Any measure that will reduce or eliminate the long-term risk to life and property from a disaster event.
Mud line	Type of high water mark found on structures. Occurs when suspended solids carried by floodwaters are deposited along the walls, doors, etc. of structures leaving an indicator of the peak flood level.
National Flood Insurance Program	The Federal program created by an Act of Congress in 1968 that makes flood insurance available in communities which enact and enforce satisfactory floodplain management regulations.
National Geodetic Vertical Datum of 1929	Vertical control datum that was widely used in the U.S. prior to the establishment of NAVD 88.
North American Datum of 1983	Horizontal datum used as the standard map coordinate system default by the majority of GPS devices.
North American Vertical Datum of 1988	The most widely used vertical control datum in the U.S. today, it was officially established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations.
Orthorectified	Orthorectification removes the effects of relief displacement and imaging geometry from aerial photographs.
Polygon	A polygon, in ArcGIS, is a shape defined by one or more rings, where a ring is a path that starts and ends at the same point. If a

Word	Definition
	polygon has more than one ring, the rings may be separate from one another or they may nest inside one another, but they may not overlap.
Public Assistance	Federal assistance provided to state and local government, Native American Tribes, and certain non-profit organizations after a disaster declaration. The assistance is for the repair, replacement, or restoration of disaster-damaged, publicly owned facilities and the facilities of certain Private Non-Profit (PNP) organizations. The Federal share of assistance is not less than 75 percent of the eligible cost for emergency measures and permanent restoration. The State determines how the non-Federal share (up to 25 percent) is divided among the applicants.
Riverine flooding	Occurs when rivers and streams overflow their banks.
Seed file	Seed files are used within software applications and serve as templates in which standard file parameters are set to predetermined standards.
Shapefile	Shapefiles store geographic features and their attributes. Geographic features in a shapefile can be represented by points, lines, or polygons (areas).
Storm surge	Onshore rush of water piled higher than normal as a result of high winds on an open water body's surface. It occurs primarily along the open coast, and can destroy houses, wash away protective dunes, and erode soil.
Topographic quadrangle maps	A standard map size and scale used by the U.S. Geological Survey to show topography, roads, and landmarks.
Water mark	A mark, usually on structures, left by floodwaters.
Wind Water Line	An approximate boundary to delineate the inland extent of the area where structures were damaged as a result of flooding from storm surge from a particular event. Landward of the line, most of the damage is attributable to winds and/or wind-driven rain. Sometimes, the Wind Water Line is located along the debris line, but in some cases, inundation and flood damage extends beyond the area where major debris was deposited.
Wrack line	Defines the extent of flooding where organic type debris such as grass and weeds are carried by floodwaters and then dropped as the floodwaters recede.

Background

The eighteenth tropical depression of the 2005 Hurricane Season formed on September 17, 2005, to the east of the Turks and Caicos Islands. It then became the seventeenth tropical storm of the season on September 18, less than a day after forming, and was named Rita. On September 18, a mandatory evacuation was ordered for the entire Florida Keys.

As Rita moved westward over the next couple of days, it was slow to become a hurricane. National Hurricane Center discussions issued early on September 20 indicated that while some wind measurements suggested Rita might have surface level wind speeds of 74 miles per hour (mph), or 144 knots (kts), the lack of a complete eyewall did not support the hurricane designation. Therefore, the National Hurricane Center continued to designate Rita as a tropical storm with wind speeds of 70 mph (136 knots). However, Rita did gain strength and by 11:00 a.m. eastern daylight time (EDT) on September 20, it was designated as a Category 2 strength hurricane with 100 mph (194 knots) maximum sustained winds. Rita stayed a Category 2 for the rest of the day on September 20, but began increasing in intensity rapidly on September 21. By 5 p.m. EDT on September 21, Hurricane Rita was a Category 5 storm with maximum wind speeds of 165 mph (321 knots). Rita continued to strengthen and by the night of September 21, its maximum sustained winds had increased to 175 mph (340 knots), with an estimated minimum pressure of 897 millibars (mb).

After peaking with steady winds of 175 mph (340 knots), Rita made landfall on September 24, between Sabine Pass, Texas, and Johnson’s Bayou, Louisiana, as a Category 3 hurricane with wind speeds of 120 mph (233 knots) and a storm surge of 10 feet (3 meters [m]). Figure 1 shows Rita’s path beginning on September 18, 2005, and ending on September 25 a day after making landfall.

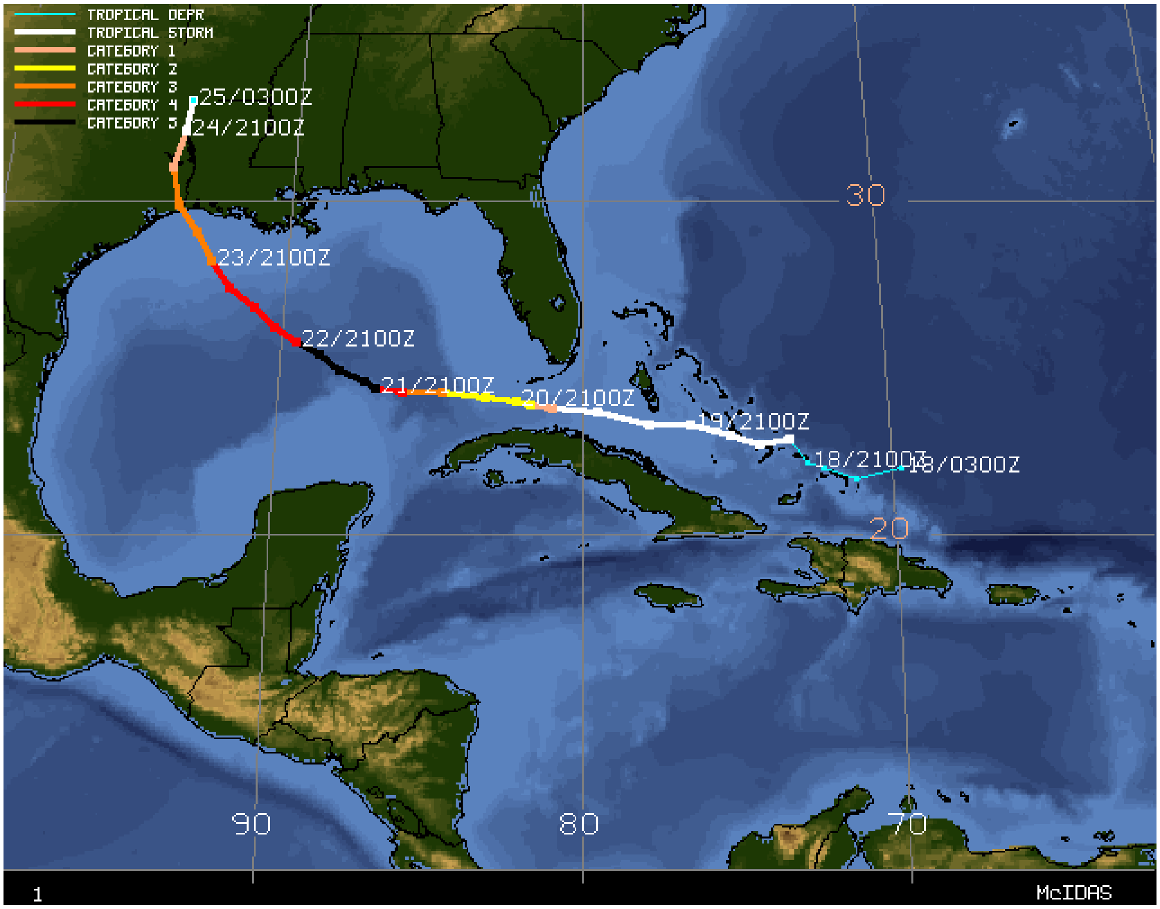

Figure 1: Hurricane Rita Storm Track
Source: http://cimss.ssec.wisc.edu/tropic/archive/2005/storms/rita/rita.html

Overview of Impacts in Texas

On September 24, 2005, the President authorized a disaster declaration for several Texas counties (FEMA-1606-DR-TX). Through subsequent amendments, all Texas counties were included in the declaration, which provided the necessary assistance to meet immediate needs and to help Texas recover as quickly as possible through the following means:

- Public Assistance (PA): includes supplemental Federal disaster grant assistance for the repair, replacement, or restoration of disaster-damaged publicly owned facilities, and the facilities of certain private non-profit (PNP) organizations. There are seven subcategories (A-G) within this designation under two work types: emergency work and permanent work. Unless otherwise noted, Public Assistance will include all categories under both work types. However, often only the emergency work categories are designated, which include Category A, debris removal, and Category B, emergency protective measures.

- Individual Assistance (IA): includes cash grants of up to $26,200 per individual or household for housing (hotel or motel expenses reimbursement, rental assistance, home repair and replacement cash grants, and permanent housing construction assistance in rare circumstances) and other needs (medical, dental, and funeral costs, transportation costs, and other disaster-related needs).

- Hazard Mitigation Grant Program (HMGP): funds projects that will reduce or eliminate the losses from future disasters by providing a long-term solution to a problem. Eligible applicants include State and local government, Indian tribes or other tribal organizations, and certain non-profit organizations. FEMA can fund up to 75 percent of the eligible costs of each project, and the State or grantee must provide a 25 percent match.

All of Texas' 254 counties are eligible for HMGP funds. The majority of Texas counties (225) were designated for Public Assistance, Categories A and B only, and not for Individual Assistance. Tables 1 through 3 provide listings of which designation(s) other counties received for IA and PA. If a county is not listed in these tables, then it is only eligible for Public Assistance, Categories A and B only. Figure 2 shows this information graphically.

Table 1: Counties Designated for Individual Assistance and Public Assistance, Categories A and B Only

Fort Bend	Harris

Table 2: Counties Designated for Individual Assistance and Public Assistance, All Categories

Angelina	Brazoria	Chambers	Galveston
Hardin	Jasper	Jefferson	Liberty
Montgomery	Nacogdoches	Newton	Orange
Polk	Sabine	San Augustine	San Jacinto
Shelby	Trinity	Tyler	Walker

Table 3: Counties Designated Only for Public Assistance, All Categories

Cherokee	Gregg	Harrison	Houston
Marion	Panola	Rusk	

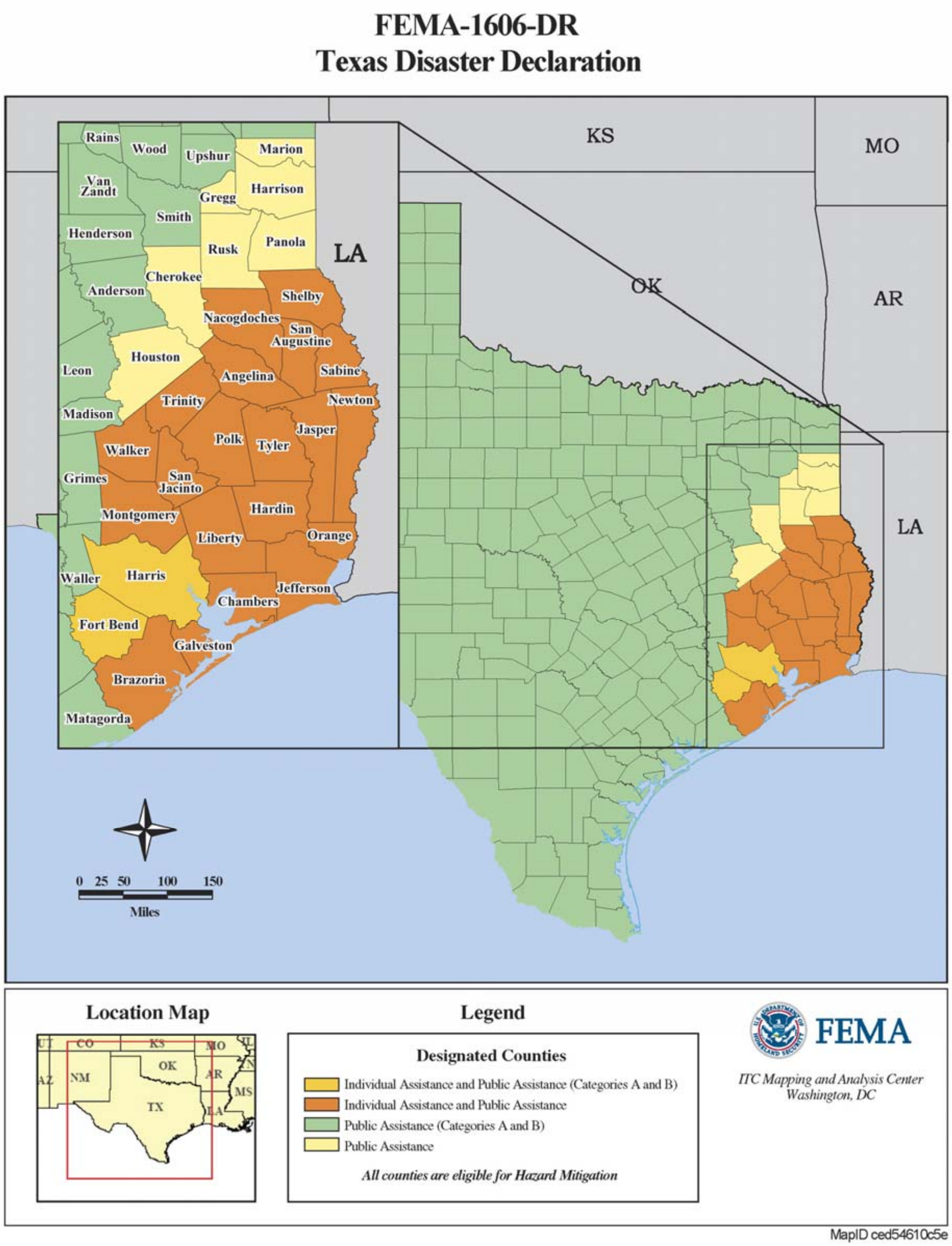

Figure 2: FEMA-1606-DR-TX Disaster Declaration

The effects of Rita were not as severe as expected. For the most part, Houston escaped major damage, apart from extensive loss of power. Some windows blew out of downtown skyscrapers, and some trees and traffic signals were downed.

North of Houston, the 2.5-acre Lake Livingston dam sustained substantial damage from powerful waves driven by wind speeds of 117 mph (102 kts) and operators had to conduct an emergency release to lessen pressure on the dam. This release put lives at risk downstream and also threatened a major bridge because it caused a sizable barge to become unmoored. Repairs to the dam are expected to take months. After water levels were lowered and an inspection was conducted by national and local experts, the dam was declared stable late on September 26.

All communities in the "Golden Triangle" formed by Beaumont, Port Arthur, and Orange Counties sustained enormous damage from Rita's winds. Texas Governor Rick Perry declared a nine-county disaster area. In Beaumont, an estimated 25% of trees in heavily wooded neighborhoods were uprooted. An enormous number of houses and businesses suffered extensive damage from Rita's winds and falling trees. The water treatment plant in Port Neches was heavily damaged. Some areas were without power for more than six weeks.

The Golden Triangle was spared a more devastating ocean surge by the redirection of Rita's path hours before the storm made landfall, which placed most of the coastal community to the left of the hurricane's eye in the least damaging quadrant. Rita's surge was easily handled by Port Arthur's extensive levee system. Bolivar Peninsula between Galveston and Sabine Pass experienced only a small surge, in contrast to Louisiana's unprotected communities east of Rita's center, which suffered under a 20-foot surge.

Still, there was widespread property damage and loss in Texas following Hurricane Rita. Table 4 provides a summary of damages to residential structures. These numbers are initial damage assessment results reported by impacted counties and cities to the State of Texas. The table is from Situation Report #41 issued by the State of Texas, State Operations Center (SOC) and dated December 20, 2005.

Table 4. Initial Damage Assessments for Residential Structures

COUNTY/CITY	SINGLE FAMILY DWELLINGS			MOBILE HOMES			APARTMENTS		
	Destroyed	Major Damage	Minor Damage	Destroyed	Major Damage	Minor Damage	Destroyed	Major Damage	Minor Damage
Angelina/Lufkin	0	30	85	0	3	12	0	0	48
Angelina	35	300	500	35	400	500	0	25	25
Chambers	7	134	167	15	66	70	0	4	4
Cherokee	0	0	15	0	0	10	0	0	0
Hardin	6,050	4,440	550	7,700	3,300	0	0	0	22
Harris	16	27	11,630	0	0	0	0	0	0
Harris/La Porte	0	0	70	1	2	5	0	0	0
Jasper	33	534	515	63	176	168	0	5	9
Jefferson	75	2,000	10,000	15	500	1,000	35	250	500
Jefferson/Port	750	3,000	9,000	900	25	40	200	3,000	500

COUNTY/CITY	SINGLE FAMILY DWELLINGS			MOBILE HOMES			APARTMENTS		
	Destroyed	Major Damage	Minor Damage	Destroyed	Major Damage	Minor Damage	Destroyed	Major Damage	Minor Damage
Arthur									
Jefferson/Groves	60	800	2,000	0	0	60	0	5	4
Jefferson/Nederland	116	1,456	3,961	77	193	116	47	332	475
Liberty	7	124	94	10	294	331	0	12	1
Liberty/Liberty City	0	3	6	1	3	5	0	0	0
Montgomery	4	25	67	30	40	60	0	0	0
Nacogdoches	0	1	10	1	1	75	0	0	0
Nacogdoches/ Nacogdoches City	1	33	125	3	1	1	0	0	0
Newton	55	200	800	60	100	310	0	0	0
Newton/Newton City	0	155	200	0	75	75	0	18	40
Orange	3,600	9,000	11,250	200	400	500	200	300	600
Polk	29	329	305	24	242	325	0	10	5
Sabine	20	94	408	40	250	482	1	5	0
San Augustine/San Augustine City	0	5	100	0	5	10	0	0	0
San Jacinto	250	500	1,500	250	1,000	500	0	0	0
Shelby	0	0	10	0	0	1	0	0	0
Shelby/Shelby City	0	3	10	0	3	5	0	0	0
Trinity	15	80	295	21	75	301	0	3	2
Tyler	150	375	459	131	450	650	0	0	0
Totals	11,273	23,648	54,132	9,577	7,604	5,612	483	3,969	2,235

Additionally, concerns have been raised over the state of the oil industry in the aftermath of Rita. The storm threatened a large portion of the industry's infrastructure that was left undamaged by Hurricane Katrina. The Texas Gulf Coast is home to 23% of U.S. oil refining capacity, and numerous offshore production platforms were potentially in Rita's path. While no potential storm path would threaten all of the capacity at once, a direct strike on Houston could disable up to 8% of the nation's refining capacity.

Purpose

After a hurricane impacts a coastal area with significant flooding, it is imperative that data be collected to document the event to assist in response, recovery, and mitigation efforts, and to improve disaster preparedness and prevention efforts for future disasters. Wind Water Line (WWL) data collection is an initial step in accurately documenting an event. These data help place the event in historical perspective and improve the ability to estimate current flood risk and future event prediction. Collection of site-specific flood inundation data along rivers, bays, and coasts has numerous applications.

The Federal Emergency Management Agency's (FEMA's) National Flood Insurance Program (NFIP) requires data to identify flood damages to provide a valid basis for establishing eligibility of flood insurance benefits. Information for insurance purposes is time-critical because the flood insurance and homeowner insurance claims cannot be concluded until the cause of damage is established. The WWL data provide a basis for delineating areas subject to flooding and help to identify approximate boundaries between areas where damages are due to flooding and wind versus areas of wind-only damages. FEMA will use these data to provide inundation boundaries and information on the flooding extent along the affected shoreline areas.

Other FEMA programs that directly benefit from post-disaster flood data collection include:

- Human Services: provides advice to individuals on how to use federal grants to increase their homes' flood resistance;
- Public Assistance (PA): identifies appropriate flood mitigation measures to pursue when providing federal grants to repair publicly owned infrastructure; and,
- Hazard Mitigation Grant Program (HMGP): ensures that accurate benefit/cost analysis is performed.

The purpose of the WWL Study is to determine the inland extent of damages caused by storm surge-induced flooding, and differentiate this area from those farther inland where damages were primarily the result of wind forces. By delineating the WWL, an approximate boundary is created between areas where both storm surge-induced flooding and wind forces caused damage to structures from those areas where wind forces were the primary cause of damages to structures and surge flooding did not have a significant impact. Sometimes, the WWL is located along the debris line, but in some cases, inundation and flood damages extend beyond the area where major debris was deposited.

The WWL study extended from the northern portion of the Gulf Coast of Texas eastward through southwestern Louisiana. This report focuses on the determinations based on data collected in Texas, where the northeast coastline was studied. Figure 3 shows the WWL Study Area within Texas.

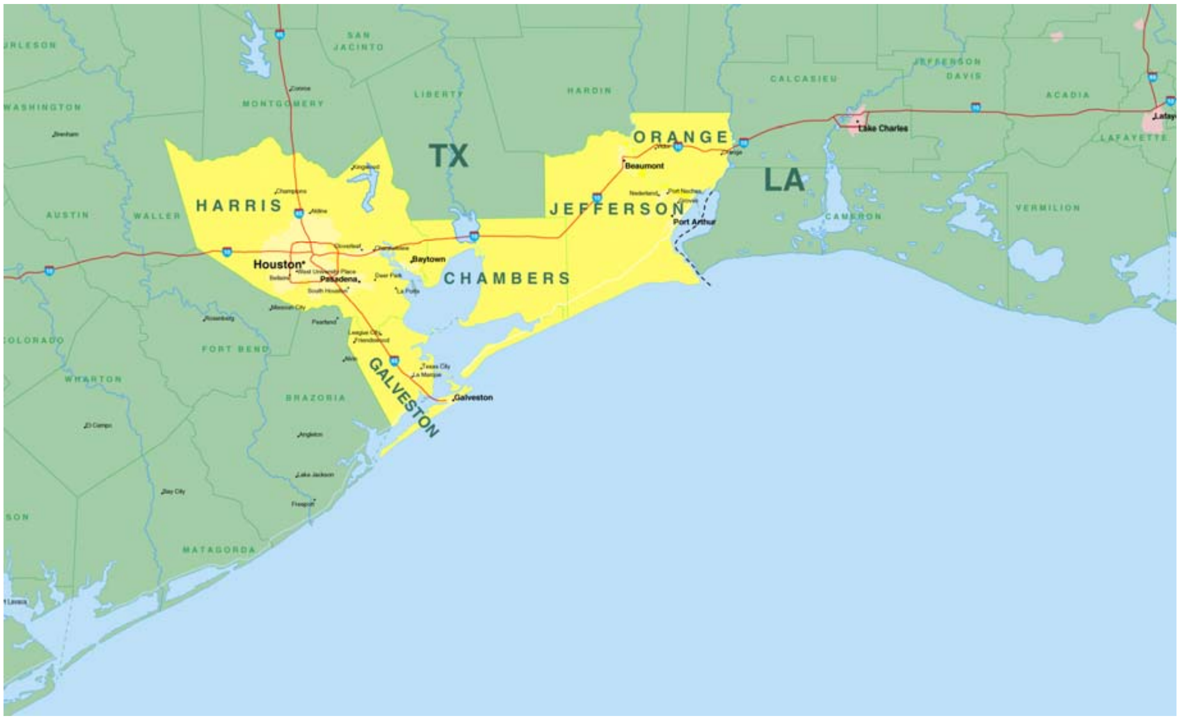

Figure 3: Study Area

Overview of Related Projects

In response to Rita, a Hazard Mitigation Technical Assistance Program (HMTAP) Task Order 446, *Rapid Response, Hurricane Rita Wind Water Line – Texas* was issued and is the focus of this report. In addition, HMTAP Task Order 443, *Rapid Response, Aerial Radar – Texas and Louisiana;* HMTAP Task Order 444, *Rapid Response, Hurricane Rita Coastal High Water Mark Survey – Texas;* and HMTAP Task Order 449, *Rapid Response, Hurricane Rita Riverine High Water Mark Survey – Texas* were also issued. An overview of these task orders is provided below:

- Under Task Order 443, *Rapid Response, Aerial Radar – Texas and Louisiana*, cartographic analysts were tasked with using post-event aerial imagery to delineate areas affected by flooding along the northeast portion of Texas' coastline and the western edge of Louisiana's Gulf Coast. In Texas, the imagery acquired covered portions of Galveston Island and the Bolivar Peninsula in Galveston County, the eastern coastline of Jefferson County, and Orange County.

- Through Task Order 444, *Rapid Response, Hurricane Rita Coastal High Water Mark Survey - Texas*, field crews collected perishable high water mark (HWM) data at field observation point locations. The crews looked for evidence of the peak elevation of flooding caused by storm surge, then inventoried and surveyed these elevations. Peak flood elevations along the northeast coastline of Texas were recorded at several locations as part of this task order. These data can be used to help determine the extent of flooding.

- For Task Order 449, *Rapid Response, Hurricane Rita Riverine High Water Mark Survey – Texas*, field crews also collected high water mark data at field observation point locations. Field crews for the riverine high water mark (RHWM) survey were focused on areas of overbank flooding where heavy and/or prolonged precipitation resulted in an exceedence of the capacity of rivers and streams to keep floodwaters within their banks. Peak flood elevations for riverine type flooding were surveyed and recorded as part of this task order. Riverine HWMs can be used to help delineate the extent of surge flooding by showing where riverine flooding predominates.

In addition, comparison of WWL data with the impacts projected by modeled storm events provides insight into how well numerical models simulate a specific event (e.g., coastal storm surge, riverine flooding). When coupled with sufficient data density and observational information, it is possible to create flood recovery maps, which are high-resolution maps that show flood impacts, including HWM flood elevations, flood inundation limits, the inland limit of waterborne debris (trash lines), and storm surge elevation contours based on the HWMs. These event-related data can be used in conjunction with or, in some cases, instead of effective Flood Insurance Rate Map (FIRM) data to establish recommended coastal flood elevations for redevelopment and rebuilding purposes.

Methodology

There were two basic elements to this project: field data collection and WWL mapping. While field crews worked to collect data in the weeks following Hurricane Rita, the WWL mapping process occurred after the data had been collected and involved interpretation and analysis of data from several sources.

Data Collection Methodology

URS field crews were mobilized within 7 days of the disaster declaration. Field teams tasked with locating HWMs, marking them, and performing general data collection were called ‘flaggers’ and began field work on October 1, 2005, and continued through October 15. Surveying teams followed the flaggers and surveyed the points the flaggers had identified, working from October 31 through November 16. Data collection for Task Order 446, *Rapid Response, Hurricane Rita Wind Water Line – Texas* was performed in tandem with data collection for Task Order 444, *Rapid Response, Hurricane Rita Coastal High Water Mark Survey - Texas* and Task Order 449, *Rapid Response, Hurricane Rita Riverine High Water Mark Survey – Texas*. The WWL points, which are also located by identifying water marks on structures or debris or wrack lines, doubled as HWMs.

WWL points are used to define the extent inland of where there is damage to structures caused by surge flooding. Thus the points generally form a line showing the approximate inland limit of surge flooding. The WWL is so called because landward of the line in coastal areas, damage to structures is usually limited to wind damage, which includes direct rain damage where the envelope of the structure may have been compromised by high wind damage. Seaward of the line, damage is the result of surge-induced flooding with wind forces contributing as well (see Figure 4).

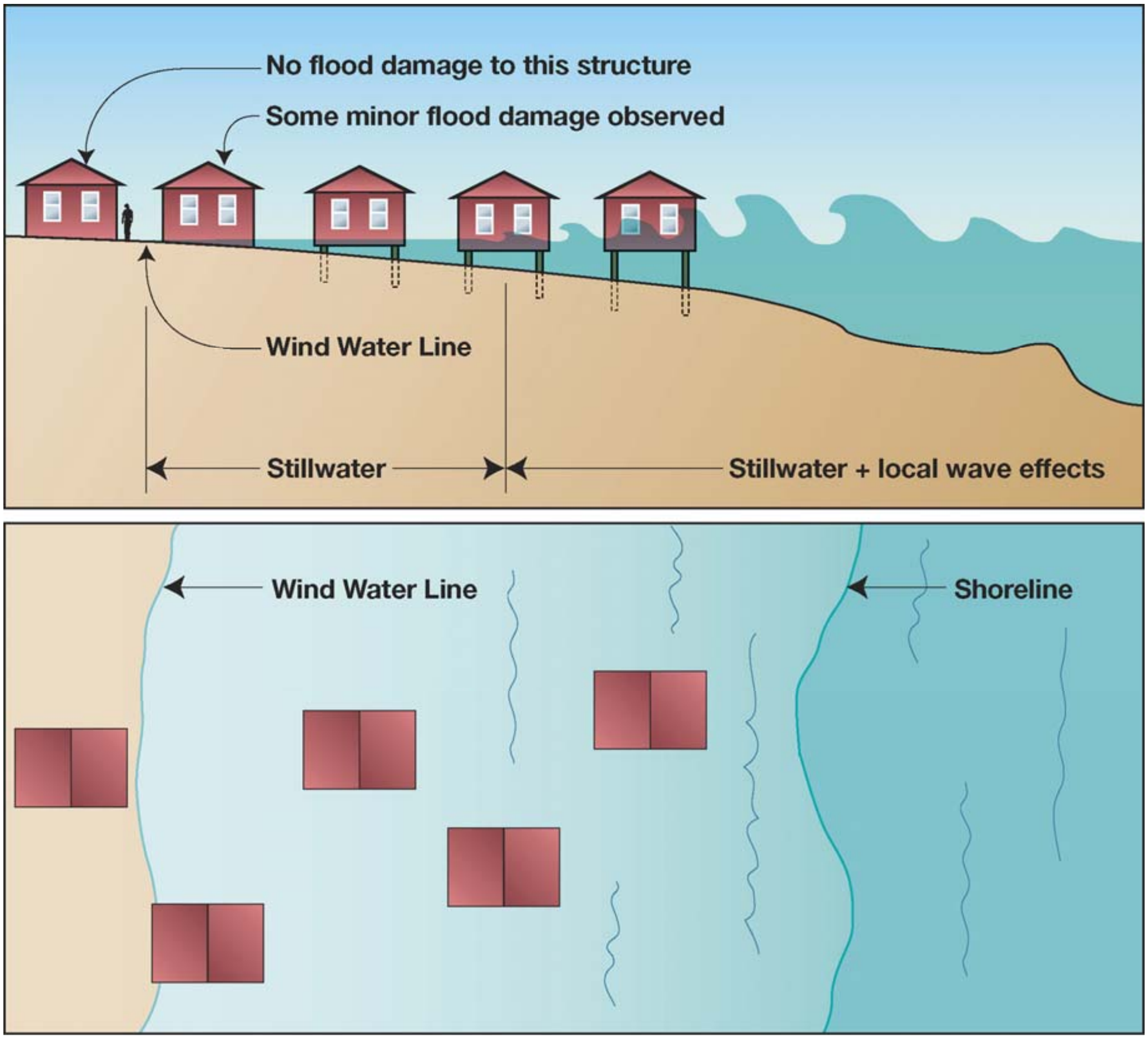

Figure 4: Wind Water Line Illustration (Profile View/Plan View)

Each field crew was tasked with identifying and documenting the WWL and collecting data points along the coastlines. The WWL data points were documented using a standardized flagger form to collect detailed information about the point. To define points along the WWL, field crews visited areas of known flood damage. Traveling away from the coast to the edge of damage, they attempted to locate debris fields (see Figure 5) or water marks close to the ground, and to trace them along topographic features to determine the extent of flooding (see Figure 6) and flood damages.

Field crews notified County Emergency Managers prior to the start of field work in order to obtain all available information about the location and extent of damage to structures in the county. Areas identified by County Emergency Managers as having been damaged and/or having higher flood levels were given higher priority.

Figure 5: Example Debris Field

Figure 6: Example Water Mark

Generally, WWL data were collected every 2 to 4 miles in developed areas inland. However, in areas with significant damage to structures from flooding along the coastlines, the density of data points was sometimes higher. Similarly, there were certain stretches of coastline where field crews could not take data points either because these areas could not be accessed (no roads, thick vegetation or swampy areas, etc.) or because there was no clear physical evidence to define a WWL point.

The following data were collected at each observed WWL point:

- Address (if the point was near an addressable structure);
- Latitude/longitude reading, taken in North American Datum 1983 (NAD 83), which is used as the standard map coordinate system default by the majority of Global Positioning System (GPS) devices;
- Location description (e.g., neighborhood or other descriptive name);
- Date the data point was taken;
- Type of data point, including debris line, water mark, wrack line (indicates the high tide mark), etc.;
- Type and severity of observed wind damage;
- Flood source;
- Approximate flood depth (if water mark data point); and,
- Digital photographs.

Data had to be collected quickly; as community clean-up efforts progressed, valuable debris line and water mark data were being destroyed. WWL data were entered into a database (see Appendix A). Each photograph was named according to the WWL point reference number (see Appendix B). In all, thirty-six WWL data points were collected.

After the WWL data points were compiled and checked for accuracy, they were surveyed for elevation. Geographic information system (GIS) analysts worked with the data to make geodatabases and create associated shapefiles.

Mapping Methodology

To create the Wind Water Line maps, the project team relied heavily on data supplied from HMTAP Task Order 443, *Rapid Response, Aerial Radar – Texas and Louisiana*, HMTAP Task Order 444, *Rapid Response, Hurricane Rita Coastal High Water Mark Survey – Texas*, and HMTAP Task Order 449, *Rapid Response, Hurricane Rita Riverine High Water Mark Survey – Texas.*

Under Task Order 443, *Rapid Response, Aerial Radar – Texas and Louisiana,* cartographic analysts used post-event aerial imagery to delineate areas affected by flooding along the Texas Coast. The analysts used natural color, orthorectified 3001, Inc. imagery acquired between September 30, 2005 and October 9, 2005. The imagery and secondary sources were interpreted by a team of professional cartographic analysts, which identified where inundation occurred from visual evidence of the HWM, and where relatively high velocity storm surge occurred, from visual evidence of deposited debris. The team of analysts produced a shapefile for the debris line and one for the inundation area extending inland of the debris line. All shapefiles were reprojected from latitude/longitude to Universal Transverse Mercator (UTM) Zone 16, NAD 83. Obscured polygons outline areas where imagery was void, corrupt, or covered by clouds. A summary report for this effort is provided as Appendix C. The post-event imagery used under Task Order 443, *Rapid Response, Aerial Radar – Texas and Louisiana* was captured for areas closest to where the hurricane made landfall that generally experienced the most damage; the imagery did not cover all of the affected areas. In Texas, this imagery (and thus the photointerpreted debris line and inundation areas) was available for Orange County, Jefferson County, and portions of Chambers and Galveston Counties.

Through Task Order 444, *Rapid Response, Hurricane Rita Coastal High Water Mark Survey – Texas*, field crews collected perishable HWM data at field-observed, point locations. They looked for evidence of the peak elevation of flooding caused by storm surge, then inventoried and surveyed these elevations. HWM points are taken where surge directly affects flood levels including the shoreline of open coasts, bays, and tidally influenced rivers. HWMs are formed when the water level during a storm rises to a maximum elevation and leaves marks on the interior and/or exterior walls of a structure, or debris or wrack lines along the ground. HWM field crews were responsible for identifying these marks and recording some basic information about the data point. Survey crews then used these initial records to later relocate the points and survey them, thus determining the peak elevation of flooding. Sometimes, the accuracy of the individual WWL points was verified by comparing them to surrounding HWM data points. In these cases, the elevation data from the HWM surveys were used to complement the WWL data.

Under this task order, field WWL data points were used together with the information about the extent of flooding determined as part of the aerial imagery task order to finalize the aerial measure of inundation based on both photointerpretation and field ground-truthed data. The inundation areas defined under Task Order 443, *Rapid Response, Aerial Radar – Texas and Louisiana*, served as the 'base data' for determining the WWL, and the field data collected under the effort described in this report (Task Order 446) were compared to this base data to determine if the two data sets were in agreement. This base data was only available in certain areas including Orange County, Jefferson County, and along the Gulf Coast of Chambers and Galveston Counties along Bolivar Peninsula. Where WWL field data points did not agree with the photointerpreted flood area delineation, analyses using information about the depth of flooding and flood elevation for the WWL (and potentially for nearby HWM points) were conducted. If the flood elevation data and supporting documentation, including comments and photographs from the field crews, confirmed that the WWL point was correct, the inundation coverage was modified to agree with the field collected data and topography was used to delineate the boundaries for these modifications.

Where the aerial imagery, and subsequently the photointerpreted debris line and inundation area, were not available, the WWL data from the flaggers were used in conjunction with local topography to delineate the WWL. This methodology was used in Harris County and portions of Chambers and Galveston Counties. The local topography was obtained from the Texas Natural Resources Information System and was available online at http://www.tnris.org/hurricanerita/.

To determine the inland limit of surge along major coastal rivers, HWMs were used. HWMs are grouped into two types, coastal and riverine[1], and serve as a good tool in helping to distinguish the two types of flooding. Therefore, the first general indication of the extent of surge was the boundary between coastal HWMs (CHWMs) and RHWMs along these rivers. After finding this area, surge elevations for the CHWMs closest to this boundary were identified, and the inland limit of surge was mapped by following the topography along these elevations. Where there was more than one CHWM, the CHWM elevations were averaged. This methodology was used in Jefferson and Orange Counties along the Neches River, Sabine Lake/Willie Slough Gully, the Sabine River, and two tributaries of the Sabine River.

Notes from these data analyses are included in tabular format in Appendix D and are summarized by county below. As described previously, post-event imagery and the photointerpreted debris line and areas of inundation were only available in limited portions of the study area including Orange County, Jefferson County, and portions of Chambers and Galveston Counties. No debris line or inundation mapping was done around Galveston Bay (Chambers, Harris and Galveston Counties) or on Galveston Island (Gavelston County).

Chambers County

Three WWL data points were identified in Chambers County: RTXC-03-03, RTXC-03-04, and RTXC-03-05. A review of the flagger forms and photographs and local topography indicated that wrack lines were located around the coastline of Galveston Bay. To reflect this evidence, the WWL, a debris line in this area, was extended along Galveston Bay by following the 5-foot (1.5-meter) contour.

Galveston County

In Galveston County, 19 WWL data points were identified (see Appendices A and D). Of the 19 points, 12 were located long the perimeter of Galveston Island. A review of the flagger forms and photographs provided evidence that coastal surge left wrack and debris lines along the island's coast. An evaluation of local topography and spotty aerial imagery indicated the debris line followed the 5-foot (1.5-meter) contour. To reflect this evidence, a debris line was added along the perimeter of Galveston Island.

The remaining seven points were located along the Bolivar Peninsula. Similar to the recommendation for Galveston Island, the WWL along the Bolivar Peninsula was extended along the northern border. Along the southern border where post-event imagery and a photointerpreted debris line were available, the WWL was adjusted slightly to generally follow the 5-foot contour. Although there are no WWL data points along the northern border of the Bolivar Peninsula due to lack of access, it was assumed that a WWL

[1] The flooding type is provided in a column of Appendix A for each point. While the naming convention for RHWMs and CHWMs generally includes a 'C' or an 'R' within the point name to indicate the type of flooding, for Task Orders 444 and 449 these labels were not always true. Therefore, the flooding type data from Appendix A should be used.

also formed along the perimeter of the bay side of the peninsula, which was the case with Galveston Island. Post-event aerial imagery, which was available for portions of Galveston Island and Bolivar Peninsula, was used in conjunction with local topography to delineate the WWL in this area.

Harris County

Two WWL data points were identified in Harris County. After a review of the flagger forms and photographs and topography, only point (RTXC-03-02) was deemed to accurately represent the WWL. To reflect this evidence, the WWL was extended along the bay by following the 5-foot (1.5-meter) contour to reach point RTXC-03-02. However, the comments on the flagger form and photographs for RTXC-03-01 do not provide conclusive evidence of a WWL. The flagger noted, "…[the] high water mark may be [due to the] normal high tide." Therefore, RTXC-03-01 was not included in the WWL analysis. No post-event aerial imagery for this county was available for review.

Jefferson County

Aerial imagery, topography, and flagger forms and photographs were reviewed to assess the inundation coverage for the four WWL points identified in Jefferson County. Field data for repetitive loss point RTXC-01-01 did not provide clear evidence of a WWL. The photograph shows a wrack line, but the flagger commented, "[there is] no flooding or damage to [the] building." A review of aerial imagery supported the flagger's comment, as no flooding in proximity to this point was evident. Points RTXC-05-06, RTXC-05-26, and RTXC-05-27 were within 200 feet (61 meters) of the photointerpreted debris line and deemed to be in agreement with the photointerpreted flood area and debris line.

Also in Jefferson, points RTXC-05-26 and RTXC-05-27 were used to delineate the extent of coastal flooding. Both of these points were coastal points and represented the furthest inland coastal flood data in the area. Elevations at these points were approximately 6 feet (1.8 meters) North American Vertical Datum of 1988 (NAVD 88), so the WWL was delineated at 6 feet (1.8 meters) NAVD 88 in this area.

Along Sabine Lake/Willie Slough Gully, points RTXC 05-07 and RTXC 05-17 were used to define the extent of surge flooding. Elevations at these points averaged 4.5 feet (1.4 meters) NAVD 88; this number was rounded to 5 feet (1.5 meters) NAVD 88 to delineate the WWL.

Orange County

Five WWL data points were identified in Orange County. After reviewing flagger forms and photographs, aerial imagery, and the photointerpreted inundation area, it was deemed that the inundation area should be extended to include the four points that accurately represented the WWL. The remaining point, RTXC-01-03, was not included as a WWL point because of its remote location from a body of water and the lack of conclusive evidence from aerial imagery to indicate that flooding occurred within proximity to the point.

Along the Sabine River, several points were used to determine the extent of surge flooding. In Texas, the points RTXR-05-14 (coastal), RTXC-03-06, and RTXC-03-07 show the inland extent of coastal data collected under the HWM task orders. In Louisiana, there was one point, RLAC-09-16, that was also used. The average of these points was approximately 6 feet (1.8 meters) NAVD 88 which was used to delineate the WWL.

Two tributaries of the Sabine River where also analyzed. The point RTXC 05-13 was used to delineate the WWL along one of these tributaries with an elevation of 5 feet (1.5 meters) NAVD 88. Along the second tributary, point RTXR 05-147 (coastal) was used; this point also had an elevation of 5 feet (1.5 meters) NAVD 88.

Polk County

Both points identified as WWLs in Polk County were discarded based on a review of local topography and flagger comments. Wrack lines were located along the channel bank, indicating that flooding occurred within the stream channel. This data corroborates reports of flooding along the Trinity River after excess amounts of water were released from Lake Livingston Dam. The Trinity River channel was flooded, but no homes or structures were flooded or damaged in Polk County. No post-event aerial imagery was available for this region of Polk County.

Sabine County

One WWL point was identified in Sabine County. By reviewing the local topography, it was determined that point RTXR-02-14 had an elevation of 175 feet (53 meters) and was approximately 118 miles (190 kilometers [km]) away from the Gulf Coast. An evaluation of the flagger's comments revealed that flooding generally occurred within the stream channel and was not due to coastal surge. The flagger commented, "It seems as if this corner [of the river] trapped some water, raising this [water surface elevation]. Otherwise the water in the area did not overflow the banks of the river." This point does not appear to be representative of the inundation trend and was therefore discarded for the purposes of modifying the inundation area. No post-event aerial imagery was available for this region.

Map Details

GIS maps of the WWL were produced at a scale of 1:24,000 (see Appendix E). The maps show the location and type of each WWL data point, the debris line, and the approximate coastal inundation extent of storm surge flooding. The GIS maps are based on U.S. Geological Survey (USGS) 7.5- minute topographic quadrangle maps.

It is important to note that the maps use both the debris line and extent of inundation to show the damage caused by flooding. While the debris line helps to show where higher velocity storm surge pushed debris inland, causing damage, the inundation caused by surge extends further inland and shows where less powerful and, in many cases, shallower flooding also caused damage. Together, these illustrate the extent of the WWL along the northeast Gulf Coast of Texas.

Findings and Observations

In Texas, the WWL was delineated primarily by the debris line. Surge flooding inland of the debris line generally seemed to occur only in eastern Jefferson County and Orange County. Along portions of Galveston Bay, a WWL was delineated, but it was not believed to be a Debris Line since the areas are largely undeveloped wetlands. Table 5 presents a summary of inland distances of the WWL with a focus on developed areas.

Damage caused by coastal storm surge effects was observed all along Texas' Gulf Coast. The land along Galveston Bay in Chambers County, Harris County, and Galveston County escaped major coastal flooding as maximum surge levels were in the range of 4 to 6 feet 1.2 to 1.8 meters) (see map panels 16, 17, 21-26, and 31).

Table 5: Wind Water Line Findings

COUNTY[1]	LOCATION (CITY OR AREA)	DISTANCE INLAND TO DEBRIS LINE (FT/M)	DISTANCE INLAND OF SURGE INUNDATION (FT/M)	MAJOR FLOOD SOURCES	MAP PANEL NAMES AND NUMBERS
Chambers	Anahuac National Wildlife Refuge	None	35,000/10,700	Gulf of Mexico (East Bay)	Frozen Point – 33 High Island – 34 Lake Stephenson – 32 Oyster Bayou – 25 Stanolind Reservoir – 26
Chambers	Trinty Bay Coast- Smith Point to the City of Anahuac	0-8,000/0-2,400	None beyond debris line	Trinity Bay	Anahuac – 17 Lake Stephenson – 32 Oak Island – 24 Smith Point – 31
Chambers	Trinity Bay Coast- the City of Anahuac to Beach City	None	0-25,000/0-7,600	Trinity Bay	Anahuac – 17 Cove – 16
Chambers	Galveston Bay Coast- Beach City to Harris County Border	0-2,000/0-600	None beyond debris line	Galveston Bay	Morgan Point – 22 Umbrella Point – 23
Galveston	Galveston Island	0-8,300/0-2,530	None beyond debris line	Gulf of Mexico (West Bay and Galveston Bay)	Galveston – 41 Lake Como – 44 San Luis Pass – 45 Sea Isle – 43 The Jetties – 42 Virginia Point – 40
Galveston	Gulf of Mexico Side of Bolivar Peninsula	0-4,500/0-1,400	None beyond debris line	Gulf of Mexico	Caplen – 39 Flake – 38 Frozen Point – 33 Galveston – 41 High Island – 34 The Jetties – 42
Galveston	East Bay Side of Bolivar Peninsula	1,000-12,000[2]/300-3,700	None beyond debris line	East Bay	Caplen – 39 Flake – 38 Frozen Point – 33 High Island – 34 Port Bolivar – 37

COUNTY[1]	LOCATION (CITY OR AREA)	DISTANCE INLAND TO DEBRIS LINE (FT/M)	DISTANCE INLAND OF SURGE INUNDATION (FT/M)	MAJOR FLOOD SOURCES	MAP PANEL NAMES AND NUMBERS
Harris	Coast- Border of Chambers County to Bayside Terrace	0-13,000/0-4,000	None beyond debris line	Gulf of Mexico (Crystal Bay, Galveston Bay)	La Porte – 21 Morgan Point – 22
Jefferson	Coast- Border with Chambers County to just west of Sabine	0-1,000/0-300	None beyond debris line	Gulf of Mexico	Clam Lake – 29 Mud Lake – 35 South of Star Lake – 36 Star Lake – 28
Jefferson	Sabine	600-3,000/180-900	1,000-20,000[3]/300-6,100	Gulf of Mexico	Sabine Pass – 30
Jefferson	Just north of Sabine to Port Arthur, Beaumont, and the border with Hardin County	None	0-6,000[4]/0-1,800	Sabine Lake, Neches River	Port Arthur North – 14 Port Arthur South – 20 Sabine Pass – 30 West of Greens Bayou – 15
Jefferson	South Beaumont, West Port Arthur	None	see maps for details	Willie Slough Gully	Alligator Hole Marsh – 18 Big Hill Bayou – 19 Fannett East – 12 Port Acres – 13
Jefferson/ Orange	From Port Arthur north to Hardin County along Neches River	None	0-25,000[4]/0-6,100	Neches River	Beaumont East – 8 Pine Forest – 5 Port Arthur North – 14 Terry – 9 Voth – 4
Orange	Border with Jefferson County and Louisiana	None	24,000/7,315 13,000/3,962	Neches River Sabine River	Echo – 7 Mauriceville – 6 Orange – 11 Orangefield – 10

1. Points in Polk and Sabine Counties were not deemed to accurately represent the WWL.
2. The bay side of Bolivar Peninsula consists of marshy areas and several water bodies and is not a solid land mass.
3. Distance inland from the debris line.
4. Distance inland from channel bank of flooding source.

In Chambers County, the WWL that falls within the Anahuac National Wildlife Refuge, located along the southern border of the county, extends up to approximately 7 miles (11 km) inland (see map panels 24-26 and 32-34). The WWL extending from Smith Point to Anahuac, as shown on map panels 17, 24, and 31, reaches from several blocks inland to 1.2 miles (1.9 km) inland. The remaining portion of Chambers County, which stretches from Anahuac to the border of Harris County and is shown on map panels 16, 17, 22, and 23, has a WWL that reaches up to 4 miles (6 km) inland in the marshy areas to the northeast of Dutton Lake and Cotton Lake.

The WWL in Harris County, which extends from the border of Chambers County to Bayside Terrace, reaches up to 2.5 miles (4 km) inland along the San Jacinto River and is shown on map panels 21 and 22.

In Galveston County, Galveston Island and the Bolivar Peninsula experienced a relatively mild ocean surge. The WWL follows the perimeter of both Galveston Island and the Bolivar Peninsula and extends from the coastline to approximately 1.6 miles (2.6 km) and 2.3 miles (3.7 km), respectively (see map panels 34, 37-39, and 40-45).

The most damage caused by coastal storm surge effects was observed in Jefferson County. Although the hurricane surge was held back by an extensive levee system protecting Port Arthur, Jefferson County sustained heavy damage from Rita's winds. The WWL is shown as both a debris line and inland inundation in this county on map panels 4, 5, 8, 9, 12-15, 18-20, 27-30, 35, and 36. The debris line extends from the border of Chambers County to Sabine and reaches up to 3,300 feet (84 meters) inland. The inundation area extends up the Neches River from Port Arthur past Beaumont to Jasper and Hardin Counties; surge effects reach to the northern edge of Jefferson County and thus the WWL extends to this area stretching approximately 25 miles (40 km) from the confluence with Sabine Lake. Within Jefferson County the inundation area extends up to approximately 2 miles (3 km) inland from the Neches River channel bank.

Orange County also sustained heavy damage from Rita's winds. The inundation extends up to 2.5 miles (4.0 km) inland from the Sabine River channel bank along the eastern border of Orange County, Texas and Calcasieu Parish, Louisiana. An inundation area also covers up to 5 miles (8 km) inland from the Neches River along the border of Orange County and Jefferson County. Orange County is shown on map panels 3, 5-7, 8-11, 14, and 15.

Conclusions

Storm surge and wind from Hurricane Rita clearly had a damaging effect along the Texas coastline. The coastal areas of Texas were vulnerable to Hurricane Rita's coastal storm surge due to the low-lying shore and extensive wetlands. However, as the upper Texas coast was in the left front hurricane quadrant where the forward speed of the storm did not add to the magnitude of the maximum wind speeds, Texas experienced a relatively low coastal storm surge compared to Louisiana. The coastal surge was significant enough to form debris lines along the coastline of Galveston Bay, around the perimeters of Galveston Island and the Bolivar Peninsula, and along the southern border of Jefferson County. Further east, in Jefferson and Orange Counties, surge induced flooding spread along the Neches and Sabine Rivers reaching as far as 5 miles (8 km) inland from the rivers' channel banks and upstream as much as approximately 25 miles (40 km)

Appendix A: Wind Water Line Data Points

Appendix A contains a data table for the WWL data points.

DUE TO PRIVACY ISSUES (ADDRESSES ARE INCLUDED TO IDENTIFY POINT LOCATIONS), THIS APPENDIX IS NOT AVAILABLE IN THE VERSION OF THE REPORT POSTED ON THE FEMA WEBSITE.

Appendix B: Photographs

Appendix B contains an index and thumbnails of the photographs. The naming convention for the photographs uses the data point ID Number (RTXC-XX-XX) and then a sequential number for the photograph(s) associated with that ID Number (RTXC-XX-XX-1, RTXC-XX-XX-2). In most instances, two photographs were taken for each data point; however, when additional information was needed, three photographs were taken.

DUE TO PRIVACY ISSUES, THIS APPENDIX IS NOT AVAILABLE IN THE VERSION OF THE REPORT POSTED ON THE FEMA WEBSITE.

Appendix C: Debris Line and Inundation Mapping Summary (HMTAP T.O. 443)

Appendix C contains a summary report from HMTAP Task Order 443: *Rapid Response, Aerial Radar – Texas and Louisiana*. The aerial imagery collected under this task order was used to delineate a debris line and flood boundaries that served as base data for HMTAP Task Order 446*, Rapid Response, Hurricane Rita Wind Water Line – Texas.* WWL data points were used in conjunction with these data to delineate the WWL.

Hurricane Rita Rapid Response:
Debris Line and Inundation Mapping
20 January 2006

Background

As part of the Hurricane Rita Rapid Response disaster relief efforts performed for the Federal Emergency Management Agency (FEMA), EarthData International, LLC (EarthData) supported URS Group, Inc. (URS) in its effort to identify areas of storm damage through mapping procedures. EarthData produced and delivered mapping in ESRI shapefile (SHP) format containing delineation of debris lines caused by ocean surge and polygons surrounding areas inundated by floodwaters from both surge and freshwater flooding from Hurricane Rita. The areas mapped include the storm-struck areas along the Gulf Coast of Louisiana and Texas.

The primary purpose of this mapping effort was to provide a comprehensive, region-wide inventory of areas damaged by Hurricane Rita with as quick a turnaround as possible. More specifically, the mapping products distinguished between areas damaged by high velocity floodwaters from surge along the coast (debris line), comparably slower moving floodwaters from surge and riverine flooding (inundation polygons), and high winds. FEMA's National Flood Insurance Program (NFIP) requires this type of data to help identify areas that experienced flood damage in order to provide a valid basis for establishing flood insurance benefits.

Area of Interest

Mapping coverage extended along the entire Gulf Coast region of Louisiana and Texas. The area mapped was approximately 8,000 square miles and included portions of or all of the following counties:

1. **Texas Counties:** Chambers, Galveston, Jefferson, Jasper, Hardin, Liberty, Newton, Orange, Tyler
2. **Louisiana Parishes:** Calcasieu, Cameron, Jefferson Davis

Imagery Source

EarthData used natural color digital aerial orthophotographs acquired between September 30 and October 9, 2005. The 3001, Inc. source imagery was acquired under an unrelated disaster response contract issued by the U.S. Army Corps of Engineers (USACE) to support their "blue tarp" task. The imagery was made available to URS for use in Hazard Mitigation Technical Assistance Program (HMTAP)-related work. Questions related to the imagery acquisition scope of work and technical specifications should be addressed to the USACE. The 3001, Inc. imagery provided to EarthData by URS covered approximately 2,800 tiles (4,077 x 4,092 pixels) and was projected in latitude/longitude coordinates.

Accuracy Standards

Digital orthophotography is normally created from aerial photographs combined in an aerotriangulation adjustment with ground and airborne positional control, which is rectified using a digital elevation model (DEM). In the Hurricane Rita response, USACE and their contractor, 3001, eliminated some of rigorous photogrammetric processing steps to expedite delivery of the imagery within 24 hours of acquisition. No ground control was acquired. Airborne Global Positioning System (GPS) and inertial measurement unit (IMU) data were used to provide an absolute orientation solution; however, a rigorous aerotriangulation block adjustment was not performed. Due to the flatness of the terrain, it was also decided that planar rectification (using a flat surface) would be performed, rather than rectification to an actual DEM. The resulting orthophotography, therefore, does not meet National Map Accuracy Standards or Federal Geographic Data Committee (FGDC) standards for the final map scale. No rigorous positional accuracy assessment was performed either by the USACE or URS due to 1) lack of extensive ground control check points and 2) turnaround time required for response and recovery products. Based on observations of positional displacements of distinguishable linear features between adjacent flight lines and comparisons of existing geographical information system (GIS) data layers overlaid on the orthophotographs, EarthData estimates the horizontal accuracy of the 3001, Inc. orthophotography to be on the order of ±10 meters. Again, this is not a rigorous accuracy assessment, but rather a subjective estimate of error based on the internal consistency of the image dataset. When using derived mapping products, such as the debris line and inundation mapping described in this report, the end user should be cognizant of the magnitude of the potential spatial errors.

Mapping Products

EarthData used a production staff of eight professional cartographic analysts to produce and deliver mapping products for the above-mentioned areas stricken by Hurricane Rita. EarthData's project manager and cartographic team leader/supervisor managed all of the day-to-day project functions throughout the life of the project. This mapping effort began on September 9, 2005 and was completed on October 7, 2005.

The final deliverable products consisted of polygon shapefiles in units of meters projected to Universal Transverse Mercator (UTM) Zone 16, North American Datum of 1983 (NAD83). A separate shapefile was produced for each of the mapping features—one for the debris line and one for inundation polygons.

Mapping analysts used 3001, Inc. imagery to interpret areas of storm surge damage along the coast marked by debris lines as well as inland areas that experienced surge and/or riverine flooding. As a secondary source, analysts used 10-foot contours produced from Light Detection and Ranging (LiDAR) and U.S. Geological Survey (USGS) DEM datasets covering the areas of interest. The contours were referenced with the imagery to locate low-lying areas where the potential for flooding was high and debris would likely collect. EarthData's staff used preliminary high water mark points provided by URS as another ancillary reference to locate areas field surveyors identified as flooded.

Using the imagery source provided along with the ancillary sources listed above, EarthData mapped the debris line where visual evidence of the high velocity ocean surge was present. For instance, significant debris from man-made structures, sand, mud, and other biomass would collect along lines where the surge carried it over land.

Additional indications of ocean surge extended along the coast, where trees and vegetation had turned brown due to salt water inundation. Flooding further inland was determined by visual evidence of standing water or deposited debris and mud along bays, rivers, lakes, and other water bodies farther inland; receding floodwaters left the debris behind. In areas where the imagery was either void, corrupt, or covered by clouds, a polygon was digitized around the area and labeled as "obscured."

Software Applications

EarthData used a combination of ESRI ArcCatalog and ArcView software to create the working file templates. These templates, or "seed files," set all of the parameters and applicable attribution that was later populated in the compilation stage, ensuring consistency in the file structure across the entire project.

Digitizing of the debris lines and flood polygons was performed using both ESRI ArcView and ArcMap software packages. All final data were merged to create a single file in ESRI shapefile format for each of the two separate featured themes: the debris line and inundation polygons. All shapefiles were reprojected from latitude/longitude to the UTM Zone 15, NAD83 using ArcCatalog.

Interpretation Obstacles

EarthData's analysts used professional interpretation and judgment in identifying areas damaged from ocean surge and inland flooding based on the sources of information provided. Due to the urgency associated with the hurricane response, some scattered areas of the aerial imagery contained cloud cover. Lighting conditions were often less than optimal for interpretation, and it was not physically possible to photograph the entire project area coincident with actual storm surge and peak inundation conditions. Mapping analysts were confronted with the need to make subjective decisions in interpretation.

Figure 1 shows a case of inland flooding along a river, where the high water had partially receded by the time the photograph was taken. In such cases, analysts designated any areas covered with mud, sand, or silt, as well as areas where the color of the ground or vegetation indicated a high level of moisture due to recent inundation, as “flooded.”

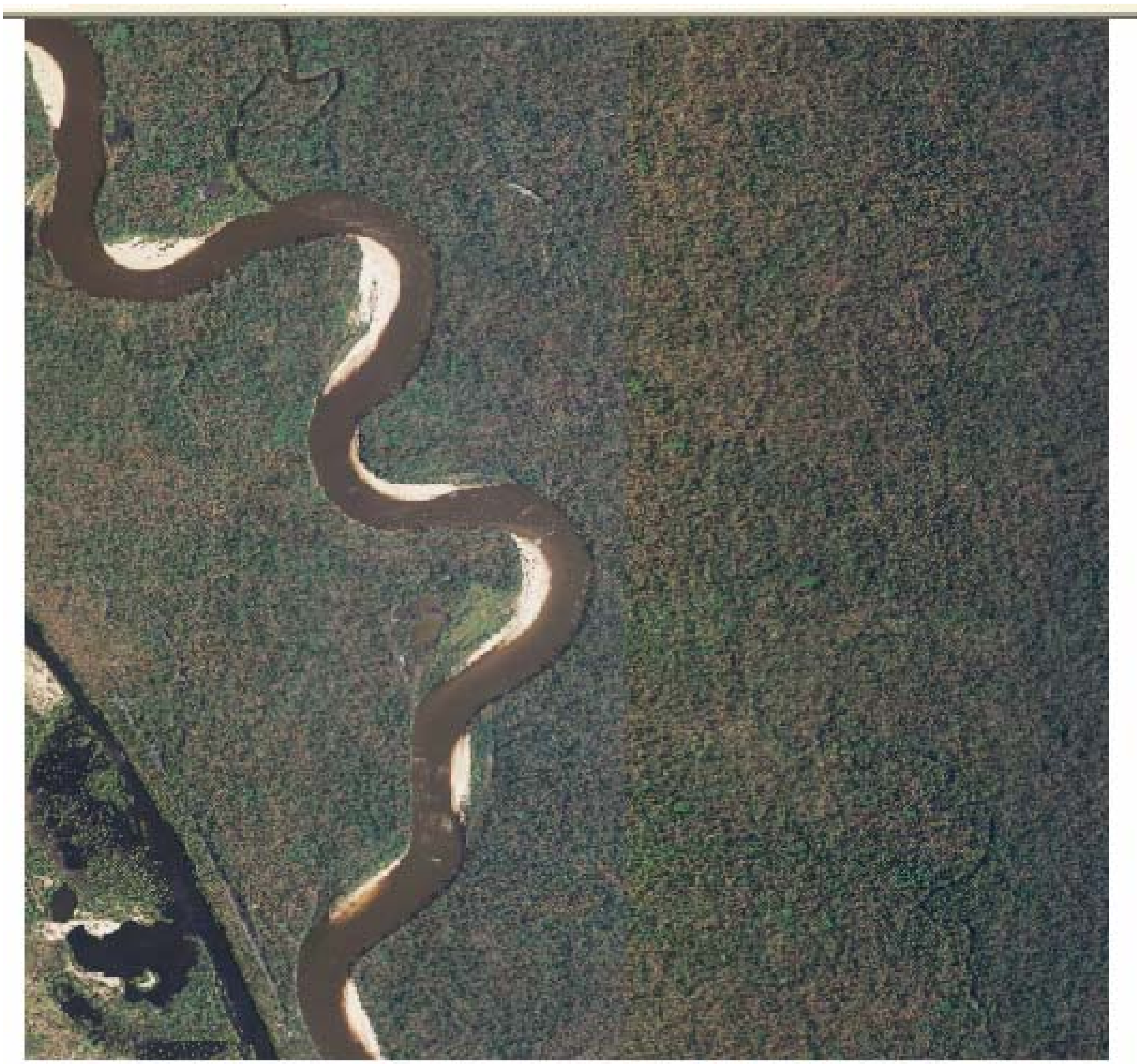

Figure 1

When flood waters recede quickly before the photographs are taken, analysts are confronted with a more complex interpretation assessment. In these cases, analysts look for signatures in the photographs, such as leaning trees, standing water, deposited debris (mud, silt, vegetation, etc.) and other features, that indicate the presence of inland flood waters. Figure 2 depicts an area which was interpreted to have been entirely inundated with water that receded before the photo was taken. This was determined by the presence of mud, fallen trees and saturated ground indicated by brown coloration throughout the image.

Figure 2

Figure 3 represents an area where the presence of marsh results in a unique situation whereby debris no longer collects as it would typically do on dry land. What is normally a visible debris line on dry land becomes less obvious for photo-interpretation when over marsh and other standing water bodies. In such cases, analysts may use contour lines, the presence of high water marks, deposited mud and silt, and/or any damage to vegetation that has been submerged by flood waters. The marsh in Figure 3 is evident in the lower left and lower right sectors of the image. URS engineers judged final placement of the wind/water line in such areas where photo interpretation alone was not conclusive.

Figure 3

Figure 4 depicts the presence of multiple debris lines. In such cases, the analyst must decide whether all debris was deposited by the ocean surge or some debris was later swept up by inland flooding caused by heavy rain. If tide waters are present along the coast, it can result in multiple debris lines being left behind. Typically, the analyst will place the debris line at the most evident and consistent debris line or along the furthest inland point (high water mark).

Figure 4

Coastal areas containing salt marshes and other low-lying areas such as that represented in Figure 5 can pose a challenge to photo-interpreters delineating flood waters. An analyst must determine whether or not to represent an area as flooded. There are many cases in which land appears to be flooded, but the area is really a marsh and always has saturated characteristics. In these cases analysts often review other sources such as secondary maps, historical data, and field surveyed conditions. Analysts also look for deposited mud and the condition of nearby vegetation to determine whether an area has been flooded or whether it is simply a marsh.

Figure 5

Appendix D: Notes on Analysis of Wind Water Line Data Points

Appendix D contains a record of the comparison of the photointerpreted data to the field data and the actions taken to resolve any differences between the two. Where photointerpreted data were not available, notes on how the WWL data points were used are included.

WWL DATA POINT ANALYSIS								
HWM ID	**County**	**Elevation (from 5' contours)**	**Original Debris Line Elev. (from 5' contours)**	**Original Flood Inundation Boundary Elev. (from 5' contours)**	**Distance to Original Debris Line (ft)**	**Distance to Original Flood Inundation Boundary (ft)**	**Action**	**Explanation**
RTXC-01-01	Jefferson	20	-----------	5	-----------	9,400	Designated as a WWL Data Point NUAR.	Photo shows wrack line, but flagger form indicates "no flooding or damage to building." It does not make sense to extend the inundation polygon to this point because aerials do not show evidence of flooding to the east of this point and the elevation is much higher than the flood elevation.
RTXC-01-03	Orange	15	-----------	5	-----------	10,600	Designated as a WWL Data Point NUAR.	Photo shows a water line 9" above ground, however flooding does not appear to be due to coastal surge. Point does not appear to be along a tributary.
RTXC-03-01	Harris	5	-----------	-----------	N/A		Designated as a WWL Data Point NUAR.	Flagger found a debris line, but noted "HWM may be normal high tide."
RTXC-03-02	Harris	5	-----------	-----------	N/A		Extended debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-03	Chambers	5	-----------	-----------	N/A		Extended debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-04	Chambers	5	-----------	-----------	N/A		Extended debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-05	Chambers	5	-----------	-----------	N/A		Extended debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-06	Orange	5	-----------	5	-----------	100	No action.	Point lies within 200 feet of the inundation polygon.
RTXC-03-07	Orange	5		5	-----------	400	Used imagery to extend inland flood polygon to flagger point.	Flagger observations indicate flooding occurred further west than shown.
RTXC-03-09	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-10	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-11	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-12	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-13	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-14	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-15	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-03-16	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.

WWL DATA POINT ANALYSIS								
HWM ID	County	Elevation (from 5' contours)	Original Debris Line Elev. (from 5' contours)	Original Flood Inundation Boundary Elev. (from 5' contours)	Distance to Original Debris Line (ft)	Distance to Original Flood Inundation Boundary (ft)	Action	Explanation
RTXC-04-01	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-04-02	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-04-03	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-04-04	Galveston	5	-----------	-----------	N/A		Added debris line to point using 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-05-06	Jefferson	5	-----------	5	-----------	220	Moved inland flood polygon north across the road to the point.	Debris line is along the other side of the inundation polygon and more conservative. Inland flooding extends beyond debris line.
RTXC-05-08	Galveston	5	5	-----------	2,500	-----------	Moved debris line inland to include point and follow 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-05-18	Galveston	5	-----------	-----------	N/A		Extended debris line to point along the 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-05-19	Galveston	5	5	-----------	3,300	-----------	Moved debris line inland to include point and follow 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-05-20	Galveston	5	5	-----------	900	-----------	Moved debris line inland to include point and follow 5-ft contour.	Flagger observations support that a debris line formed here.
RTXC-05-21	Galveston	5	5	-----------	120	-----------	No action.	Point is within 200 feet of the debris line.
RTXC-05-23	Galveston	5	5	-----------	260	-----------	No action.	Point is close to the debris line.
RTXC-05-26	Jefferson	<5	-----------	<5	-----------	0	No action.	Point is within 200 feet of the inundation polygon.
RTXC-05-27	Jefferson	<5	-----------	<5	-----------	100	No action.	Point is within 200 feet of the inundation polygon.
RTXC-05-53	Galveston	5	5	-----------	1,900	-----------	Moved debris line inland to include point and follow 5-ft contour.	Flagger observations support that a debris line formed here.
RTXR-02-14	Sabine	-----------	-----------	-----------	-----------	-----------	Designated as a WWL Data Point NUAR.	Point has elevation 175 feet and is 118 miles away from coast. The flooding only happened inside the stream channel and is irrelevant to coastal surge.
RTXR-05-35	Polk	-----------	-----------	-----------	-----------	220	Designated as a WWL Data Point NUAR.	Point has elevation above 200 feet and is 82 miles away from coast line. The flooding only happened inside the stream channel and is irrelevant to coastal surge.
RTXR-05-36	Polk	-----------	-----------	-----------	-----------	220	Designated as a WWL Data Point NUAR.	Point has elevation above 200 feet and is 82 miles away from coast line. The flooding only happened inside the stream channel and is irrelevant to coastal surge.
RTXR-05-51	Orange	5	-----------	5	-----------	2,000	Extended inland flood polygon northwest along 5-ft contour.	Flagger observations support that flooding occurred here.
RTXR-05-52	Orange	5	-----------	5	-----------	0	No action.	Point is within 200 feet of the inundation polygon.

Appendix E: Wind Water Line Maps

Appendix E contains the map panels illustrating the location of the Wind Water Line from Rita along the northeastern coastline of Texas.