Hurricane Katrina Rapid Response Wind Water Line Report – Alabama

Task Order 417

June 9, 2006 (Final Report)

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Hurricane Katrina Rapid Response
Wind Water Line (WWL) Data Collection – Alabama
FEMA-1605-DR-AL

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
DRG	Digital Raster Graphics
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
kts	Knots
LiDAR	Light Detection and Ranging or Laser Image Detection and Ranging
mb	Millibar
mph	Miles Per Hour
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center
NFIP	National Flood Insurance Program
NGS	National Geodetic Survey
NGVD 1929	National Geodetic Vertical Datum of 1929
PA	Public Assistance
PNP	Private Non-Profit
RGB	Red-Green-Blue
RHWM	Riverine High Water Mark
RMS	Root Mean Square
USGS	United States 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 Geographic Information System (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	All the information required to create lines of equal elevation on a map. These are referred to as contour lines on topographic maps and are used to describe land forms based on elevation above a defined vertical datum.
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 (HWM) flood elevations, flood inundation limits, the inland limit of waterborne debris (trash lines), and storm-surge elevation contours based on the HWMs. 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

Word	Definition
	of feature classes sharing the same spatial reference.
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.
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.
Infrastructure	The basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water, and power lines.
Inundated	Flooded or covered with water.
Inundation polygon	Aerial extent of flooding as shown by polygon feature in ArcGIS.
Knot	A unit of speed, one nautical mile per hour, approximately 1.85 kilometers (1.15 statute miles) per hour.
LiDAR	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 one thousandth 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.
National Flood Insurance Program	The Federal program created by an Act of Congress in 1968 that makes flood insurance available in communities that 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	Used as the standard map coordinate system default by the majority of Global Positioning System (GPS) devices.
North American Vertical Datum of 1988	The most widely used vertical control datum in the U.S. today, it was established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations.
Orthorectification	Process by which the effects of relief displacement and imaging geometry are removed from aerial photographs. These adjustments are made to correct for the natural distortions caused by the perspective of the aircraft or spacecraft that took the photographs, and recreate the ground geometry in the imagery as it would appear from directly above each point in the photograph. From this process, orthophotos are created that generally have the same geometric characteristics as topographic maps.

Word	Definition
Polygon	In ArcGIS, a shape defined by one or more rings, where a ring is a path that starts and ends at the same point. If a 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 split with the applicants.
RGB color model	An additive model in which red, green, and blue lights are combined in various ways to reproduce other colors.
Riverine flooding	Occurs when rivers and streams overflow their banks.
Seed file	Used within software applications and serve as templates in which standard file parameters are set to predetermined standards.
Shapefile	Stores 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 United States 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 (WWL) 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 debris such as grass and weeds is carried by floodwaters and then dropped as the floodwaters recede.

Background

Hurricane Katrina began as a tropical depression in the southeastern Bahamas on August 23, 2005. By the next day, the depression had developed into Tropical Storm Katrina. Moving slowly northwesterly then westerly through the Bahamas, Katrina strengthened over time. Just before landfall in South Florida on August 25, 2005, Tropical Storm Katrina developed into a Category 1 hurricane, with wind speeds of 74 miles per hour (mph) (64 knots[kts]) or greater.[1] Landfall occurred around 6:30 p.m. eastern daylight time (EDT) between Hallandale Beach and North Miami Beach, with wind speeds of approximately 80 mph (70 kts). Gusts of 90 mph (78 kts) were measured as Katrina came ashore. The storm moved southwesterly across the tip of the Florida peninsula with its winds decreasing slightly (see Figure 1). However, having spent only 7 hours on land, Katrina was not significantly diminished and regained intensity shortly after moving over the warm waters of the Gulf of Mexico.

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

Over the Gulf of Mexico, Hurricane Katrina moved almost due west. A mid-level ridge from Texas weakened and moved westward, causing Katrina to gradually move northwest and then north over the next few days. Katrina attained "major hurricane" status on the afternoon of August 26, 2005, due to the atmospheric and sea level conditions that rapidly intensified the storm.

[1] Wind speed and central pressure data are from National Climatic Data Center (NCDC).

Over the next 48 hours, Hurricane Katrina continued to intensify, moving in a northerly direction. The storm reached maximum sustained wind speeds of 175 mph (152 kts) with gusts of 215 mph (187 kts) on the morning of August 28, 2005, making it a Category 5 hurricane. Its minimum central pressure dropped that afternoon to 902 millibars (mb), giving it the fourth lowest recorded central pressure for an Atlantic storm at the time and the sixth lowest by the end of the 2005 Hurricane Season.[2] Tropical cyclones rarely stay at Category 5 strength for long; Katrina weakened slightly to a Category 4, and then became a Category 3 at its second landfall near Buras, Louisiana, on August 29, 2005, at approximately 6:10 a.m. central daylight time (CDT) (see Figure 1). Maximum sustained winds at landfall near Buras were approximately 127 mph (110 kts), making Hurricane Katrina a Category 3 storm.

After crossing over Lake Borgne (located east of New Orleans) and the Mississippi Sound, Katrina made its third landfall along the Louisiana/Mississippi border with wind speeds of approximately 121 mph (105 kts). Gusts of over 90 mph (78 kts) were recorded in Biloxi, Mississippi, while gusts reached approximately 80 mph (70 kts) in Mobile, Alabama.

[2] Later in the 2005 Hurricane Season, Hurricanes Rita and Wilma developed with minimum pressures of 897 mb and 882 mb, respectively. As a result, Katrina became the sixth most intense Atlantic Basin hurricane on record (Rita is now the fourth and Wilma ranks as the first).

Overview of Impacts in Alabama

On August 29, 2005, the President authorized a disaster declaration for several counties in southwest Alabama (FEMA-1605-DR-AL). The declaration provided the necessary assistance to meet immediate needs and to help Alabama 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, PA 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 (reimbursement for hotel or motel expenses, 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 may be used to fund 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 authorized 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 Alabama counties were eligible for HMGP funds. Table 1 summarizes assistance designations for IA and PA by county. Figure 2 presents the IA and PA designation information graphically. In all, 11 counties were designated for IA, and 22 were designated for PA, All Categories.

Table 1: County Designations for IA and PA

County	IA	PA - All Categories
Baldwin	X	X
Bibb		X
Choctaw	X	X
Clarke	X	X
Colbert		X
Cullman		X
Greene	X	X
Hale	X	X
Jefferson		X
Lamar		X
Lauderdale		X
Marengo	X	X
Marion		X
Mobile	X	X
Monroe		X
Perry		X
Pickens	X	X
Sumter	X	X
Tuscaloosa	X	X
Washington	X	X
Wilcox		X
Winston		X

Due to Hurricane Katrina, more than 250,000 people lost power in Alabama. The western part of the state sustained high winds and flooding, and damages in many coastal areas of Alabama were devastating. Bayfront portions of the City of Mobile were inundated, leading to the imposition of a dusk-to-dawn curfew for the City. In Mobile County, local officials estimated 80 percent of the homes in Bayou Le Batre were uninhabitable as the result of flooding. On Dauphin Island, local officials estimated that a third of the homes on the western side of the island were destroyed and another third were significantly damaged (see Figure 3). The worst damages in Baldwin County were along Mobile Bay south of Fairhope and along the Ft. Morgan Peninsula.

FEMA-1605-DR, Alabama
Disaster Declaration as of 10/05/2005

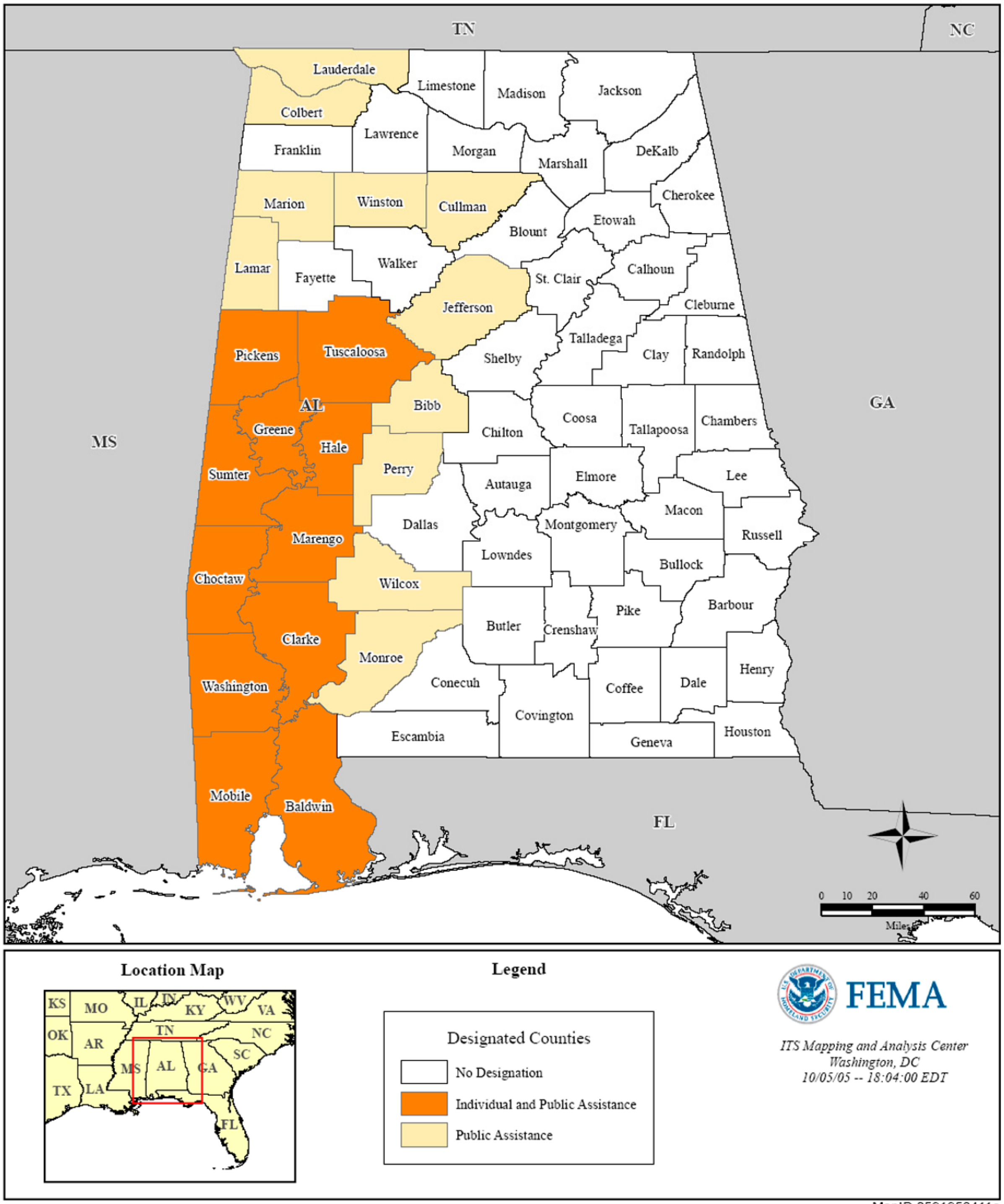

Figure 2. FEMA-1605-DR-AL Disaster Declaration

Figure 3: Destruction of Houses on Dauphin Island
Source: http://www.weather.com/newscenter/slideshow/katrinaALA.html

As of January 2006, the Alabama Emergency Management Agency estimated that more than 37,000 individuals sought service from Disaster Recovery Centers, and nearly 7,000 individuals were still living in interim housing facilities.

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. 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 purpose of this particular data collection effort was to document the extent of flooding caused by storm surge that occurred as a result of Hurricane Katrina in coastal Alabama. There are several potential uses for these data, including:

- Estimating storm frequency and severity
- Assessing accuracy of Flood Insurance Rate Maps (FIRMs)
- Providing information for use with other studies, including FEMA Building Performance Assessments
- Assisting with the prioritization of mitigation projects and providing data for use in benefit/cost analyses
- Sharing information for calibrating models that simulate the storm (for example, HAZUS and other coastal storm-surge models)
- When coupled with sufficient data density and observational information, the data can be used to help create flood recovery maps; building officials can use the maps to update guidance for both reconstruction and future construction by local citizens, developers, and contractors

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

- IA Program – advises individuals on how to use Federal grants to increase their homes' flood resistance
- PA Program – identifies appropriate flood mitigation measures to pursue when providing Federal grants to repair infrastructure;
- HMGP – ensures that accurate benefit/cost analysis is performed
- NFIP – provides insurance claim information, floodplain management, repetitive loss classification, and flood hazard identification

The purpose of WWL data collection is to determine the inland extent of damages caused by storm surge-induced flooding, and differentiate this area from those areas farther inland where damages were primarily the result of wind forces. By delineating the WWL, an approximate boundary is created to distinguish 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 storm 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.

Overview of Related Projects

URS Group, Inc. (URS), with support from Government Services Integrated Process Team, LLC, was tasked by FEMA under their existing Hazard Mitigation Technical Assistance Program (HMTAP) contract to assist in disaster recovery efforts for Hurricane Katrina. Assistance provided by this Task Order included data collection and visual survey of the debris line and the extent of flooding to identify the WWL in Alabama.

After Hurricane Katrina, FEMA issued several task orders under the HMTAP contract called Rapid Response Task Orders. Generally, the purpose of these task orders was to allow FEMA contractors to move quickly into disaster-stricken areas to collect perishable data for use in defining the parameters of the event that can be used for future studies and flood mitigation activities. In addition to the WWL Task Order, which is summarized in this report, there were several other Rapid Response Task Orders, including Aerial Imagery Data Collection, Coastal High Water Mark (CHWM) Surveys, and Riverine High Water Mark (RHWM) Surveys. HWM Survey findings are used to define the extent of flooding and therefore can be used in conjunction with field findings from WWL Task Orders to determine the extent of the WWL. Aerial imagery is also used to estimate the WWL; post-event imagery can be used to identify areas affected by flood damages, as well as the approximate inland extent of storm surge flooding.

In response to Katrina, HMTAP Task Order 417, Rapid Response, Hurricane Katrina Wind Water Line Data Collection – Alabama, was issued and is the focus of this report. In addition, HMTAP Task Order 411, Rapid Response, Aerial Radar – Louisiana, Mississippi, and Alabama, HMTAP Task Order 414, Rapid Response, Hurricane Katrina Coastal High Water Mark Survey – Alabama, and HMTAP Task Order 421, Rapid Response, Hurricane Katrina Riverine High Water Mark Survey – Alabama, were also issued. An overview of these task orders is provided below.

- Under Task Order 411, Rapid Response, Aerial Radar – Louisiana, Mississippi, and Alabama, cartographic analysts were tasked with using post-event aerial imagery to delineate areas affected by flooding along the Alabama Coast. (Uses of post-event aerial imagery for Louisiana and Mississippi are discussed in WWL Data Collection Reports prepared under separate HMTAP task orders for those states.)

- Under Task Order 414, Rapid Response, Hurricane Katrina Coastal High Water Mark Survey – Alabama, field crews collected perishable HWM data at field-observed 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 in coastal Alabama were recorded at several locations as part of this Task Order. These data can be used to help determine the extent of flooding

- Under Task Order 421, Rapid Response, Hurricane Katrina Riverine High Water Mark Survey – Alabama, field crews also collected HWM data at field-observed point locations. Field crews for RHWMs were focused on areas of overbank flooding where heavy and/or prolonged precipitation resulted in an exceedance 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.

This report focuses on the results of data collected in Alabama to determine the WWL. Figure 4 shows the WWL Study Area within Alabama. The study area consists of Baldwin and Mobile Counties in southern coastal Alabama, which are highlighted in yellow in Figure 4.

Figure 4: WWL Study Area within Alabama

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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 Katrina, 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 collected data for Hurricane Katrina in Alabama. Teams were mobilized within 8 days of the disaster declaration. The crews met in Tallahassee, Florida, in early September 2005 to be briefed on the project and to form field crews. During the week of September 5, 2005, field crews were given their assignments and began data collection efforts.

The project team contacted county emergency managers prior to the start of field work and site investigations to acquire any 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 significant flooding were given priority.

Data collection for Task Order 417, Rapid Response, Hurricane Katrina Wind Water Line Data Collection – Alabama, was performed in conjunction with data collection for Task Order 414, Rapid Response, Hurricane Katrina Coastal High Water Mark Survey – Alabama, and Task Order 421, Rapid Response, Hurricane Katrina Riverine High Water Mark Survey – Alabama. Under Task Orders 414 and 421, field crews collected perishable HWM data at field-observed point locations. Under Task Order 414, they looked for evidence of the peak elevation of flooding caused by storm surge, then inventoried and surveyed the elevations.

CHWM points are taken where surge directly affects flood levels, including the shoreline of open coasts, bays, and tidally influenced rivers. CHWMs 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. CHWM field crews are responsible for identifying these marks and recording basic information about the data point. Survey crews then use these initial records to later relocate the points and survey them to determine the peak elevation of flooding.

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 inland extent of 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 damages, which includes direct rain damage where the envelope of the structure may be compromised by high winds. Seaward of the line, damage is the result of surge-induced flooding with wind forces contributing as well (see Figure 5).

Each field crew was tasked with identifying the WWL and collecting data points along the coastline. To define points along the WWL, field crews visited areas of known flood damage. Traveling away from the coast to the edge of damaged areas, they attempted to locate debris lines (see Figure 6) or water marks (see Figure 7) close to the ground, and trace them along topographic features to determine the extent of flooding and flood damages. Generally, when these features were observed within 1.5 feet of the ground and the field crews could validate through field observations or interviews with local citizens that these features were near the edge of inundation, these points were marked as WWL data points.

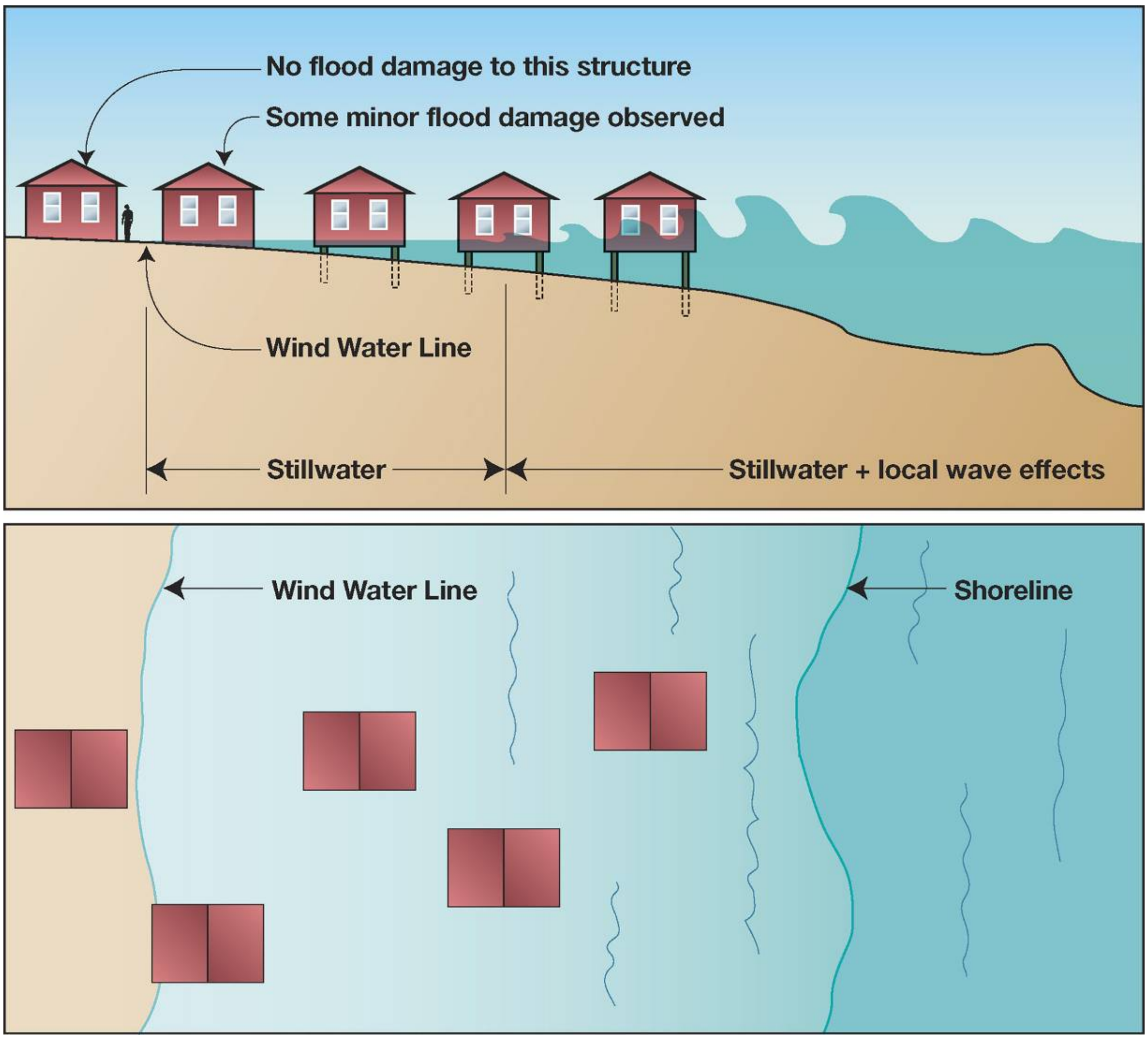

Figure 5: WWL Illustration (Profile View/Plan View)

Data collection had to be completed quickly given the perishable nature of the data; as community cleanup efforts progressed, valuable debris line and HWM data were being destroyed. The field crews collected raw data for both WWLs and HWMs from September 5 through September 12, 2005. The data for each data point were stored in a database (see Appendix A). In fact, as previously mentioned, the WWL points doubled as HWM points since a flood elevation could be determined at each of the WWL data points.

Therefore, the WWL data points were actually a subset of the HWM data points. WWL data points were assigned an HWM identification number, which was also used as their WWL identifier, using a three-part alphanumeric label. For example, a point might be labeled KALC-05-16. The leading 'K' indicates that the HWM/WWL data point is a Hurricane Katrina data point, the middle 'AL' stands for Alabama, and the last letter can be either a 'C' or an 'R' standing for coastal or riverine flooding. The middle two-digit number identifies the field crew that gathered the data, and the final two-digit number identifies the sequential data points collected by the field crew.

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

Figure 6: Example of a Debris Line

Figure 7: Example of a HWM

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 data point was taken
- Type of data point, including: debris line, water mark, and wrack line (indicates the high tide mark)
- Type and severity of observed wind damage
- Flood source
- Approximate flood depth (this is provided if it is a water mark data point and is noted as "Vertical Distance HWM to Existing Ground" in Appendix A)
- Digital photographs

The field crews worked their location assignments in Alabama from September 5 through September 12, 2005. Data had to be collected quickly; as community cleanup 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). After the WWL data points were compiled and checked for accuracy, they were surveyed for elevation. Surveyors worked from September 9 through November 4, 2005. Geographic Information System (GIS) analysts worked with the data to make geodatabases and create associated shapefiles. A URS engineer and GIS specialist then worked together to map the WWL.

Mapping Methodology

The methodology for determining the WWL in Mobile and Baldwin Counties differed. In Mobile County, the data points were used to perform a quality control check of the debris line and inundation extent that had already been delineated by cartographic analysts using post-storm aerial imagery under HMTAP Task Order 411, Rapid Response, Aerial Radar – Louisiana, Mississippi, and Alabama (see Appendix C). These analysts used natural color orthorectified imagery acquired between September 4 and September 17, 2005, by the firm 3001, Inc. The imagery covered the coastal areas impacted by Hurricane Katrina, including Mobile County. The analysts studied the imagery to locate the extent to which high-velocity floodwaters, including coastal storm surge, pushed debris inland, and to delineate areas beyond these debris lines where floodwaters had continued to push inland, causing additional flood inundation without major debris accumulation. Contour data were created using U.S. Geological Survey (USGS) Digital Elevation Models (DEMs) to perform checks as needed of the analysts' interpretations against elevation data. GIS coverage showing the approximate extent of flooding was created as part of Task Order 411, Rapid Response, Aerial Radar - Louisiana, Mississippi, and Alabama.

In Mobile County, the URS Team compared the locations of the field-collected data points with debris line and inundation extent mapping provided by the cartographic analysts. Where locations varied in excess of 200 feet from the photointerpreted flood area delineation, WWL (and nearby HWM) field data were verified. If the flood elevation data, supporting documentation, and topographic information (2-foot contour data obtained from the Mobile County Engineer's Office) confirmed that the field-acquired WWL point was correct, the inundation coverage was modified to agree with those data. Notes from these comparisons are included in tabular format in Appendix D.[3]

In at least one developed area of Mobile County, Dauphin Island, post-event imagery data were available only along a small portion of the island. Therefore, the 2-foot contour data were used here along with elevations from the CHWMs to delineate a WWL. Table 2 presents the CHWM points used to delineate the WWL on the island. The elevation value for the points averaged about 8 feet North American Vertical Datum 1988 (NAVD 88). While the whole western portion of the island was inundated, part of the eastern island is on high ground that was above inundation levels.

[3] The digital 2-foot contour data were generated from LiDAR data and have an accuracy of 0.892 feet at the 95 percent confidence level.

Table 2. CHWM Points Used to Determine WWL along Dauphin Island

Point	Surge Elevation (feet NAVD 88)	Elevation Used (feet NAVD 88)
KALC 05-03	9.8	8-9
KALC 05-05	7.3	
KALC 05-06	8.6	
KALC 06-16	8.8	
KALC 09-16	8.9	

In Baldwin County, there was no debris line or inundation extent mapping based on post-event aerial imagery. Here, each WWL data point was plotted on a base map using latitude and longitude readings obtained in the field. Digital imagery and 5-foot contour data that were obtained from Baldwin County and developed in 2001 using LiDAR data, were also added to the base map.[4] Along the northern extent of the Mobile River, these 5-foot contour data were not available for Baldwin County, so Digital Raster Graphics (DRG) files from the USGS were used for topographic data in this area.[5] The WWL was delineated based on the data points and field observations obtained, as well as on topographic features. Notes on this process are included in Appendix D.

The extent of flooding was defined not only by the WWL points, but also from data collected as part of the CHWM Survey (Task Order 414). In some areas, it is difficult to locate WWL points due to access issues, or because there is no clear physical evidence to define a WWL point. This happened particularly in marshy areas where it was not clear how far inland the surge had moved through the marshes. In these cases, the elevation data from the HWM surveys are used to complement the data. The HWM is a measure of the peak flood elevation and, when used along with reliable topography data, can help to determine an approximate WWL boundary. In these cases, HWM points that appear to be near the edge of inundation (based on interpolation from other WWL points or boundary estimates) should be used, as surge-induced-flood elevations are generally lower farther inland.

The WWL was added as a separate layer to the maps that show the inland extent of surge-induced flooding. Generally around the coast of Mobile Bay, the WWL follows the debris line as mapped from the post-event imagery. However, in areas where inundation extends

[4] The county 5-foot contour data are actually a subset of 1-foot contour data. The LiDAR elevation points were found to have a root mean square (RMS) error within ±15 centimeters (±0.5 feet). Additionally, the RMS error of the resulting solid-line 1-foot contours for well-defined points was within ±0.5 feet. This level of accuracy for the solid-line 1-foot contours was achieved using photogrammetrically compiled break lines and photogrammetric quality control of the LiDAR points.

[5] USGS, 19960912, Digital Raster Graphics, Reston, VA. www.gsa.state.al.us/gsa/gis/GISHOME.html. The Digital Raster Graphics (DRG) is a faithfully reproduced digital image of the original source map (USGS topographic quadrangles). Some differences may be detected between the source graphic used and the DRG due to the Red-Green-Blue (RGB) values assigned that particular color. For information on collection and inclusion criteria, see USGS, 1994, Standards for 1:24,000-Scale Digital Line Graphs and Quadrangle Maps: National Mapping Program Technical Instructions and USGS, 1994, Standards for Digital Line Graphs: National Mapping Program Technical Instructions. The National Map Accuracy Standards states that 90 percent of well-defined points on the map must be within .02 inch at scale.

farther inland past the debris line, but is still affected by surge flooding, the WWL follows the inundation polygon.

Along major streams that empty into coastal waters, HWMs were used to determine the extent of surge flooding. HWMs are grouped into two types, coastal and riverine, and serve as tools to help distinguish between the two types of flooding. Therefore, the first general indication of the extent of surge was the boundary between CHWMs and RHWMs along a given watercourse. After finding this boundary 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.

In Alabama, this procedure needed to be performed along the watercourses north of Mobile Bay that empty into the Bay. Two CHWM points were identified in this area for use in determining the inland extent of surge flooding (KALC 03-12 and KALC 03-13). Therefore, the average of the surge elevations at the points KALC 03-12 and KALC 03-13 was used as the limit of surge along the watercourses. The topography at this elevation was traced to show the extent of surge-induced flooding. Table 3 presents the data used to make this determination.

Table 3. CHWM Points Used to Determine Inland Extent of Surge Flooding along the Watercourses North of Mobile Bay

Point	Distance Inland from Mobile Bay (linear miles)	Surge Elevation (feet NAVD 88)	Elevation Used (feet NAVD 88)
KALC 03-12	15.5	8.3	8
KALC 03-13	15.6	8.1	

GIS maps of the WWL were produced at a scale of 1:24,000 (see Appendix E). The WWL is shown on 23 map sheets, which also show the location of each WWL data point. The GIS maps are based on USGS 7.5-minute topographic quadrangle maps.

Recommendations

The use of post-event imagery analyzed through photointerpretation, combined with field data and observations, allowed for a balanced interpretation of the WWL in Mobile County, as shown on the maps in Appendix E. The post-event imagery provided an overview of the extent of flooding within the area and a basis for determining the general flood boundaries. The field data, including field crews' damage observations, pictures, notes about flood depths, etc., provided true ground observations to compare to the WWL developed through the use of the debris line and flood extent created via photointerpretation of the post-event imagery. In Baldwin County, field data points and field crews' observations were important since post-event imagery was not available for most of the county.

One potential area for improvement in the field data collection methodology would be the use of teams with a more specific focus on WWL data collection. While HWM data and field crew observations were helpful in interpreting the WWL locations, field crews with a more narrow focus aimed solely at determining the WWL may have allowed for more specific and/or descriptive data about WWL indicators and damages at sites, as well as better visual documentation (photographs) illustrating evidence of the WWL.

Also, a better log or record of field crews' attempts to access areas where no data points were identified would help to create a clearer picture of the efforts made and the ground covered when there are no WWL data points to illustrate the crews' findings. One possible solution to this issue would be to make better use of mapping/navigational software that can be used to record crews' movements each day. Crews could note directly on a map what hindrances or problems kept them from collecting data in specific areas.

Findings and Observations

In Alabama, the WWL was generally delineated by the debris line. However, inundation extended farther inland in some areas as the result of surge flooding. This type of flooding occurred most notably along the system of rivers and bayous north of Mobile Bay, including the Mobile River, which flows just east of the City of Mobile, but also up the Dog River just south of Mobile, and south of Alabama Port at Heron Bay. Table 4 presents a summary of inland distances of the WWL (with a focus on developed areas), their corresponding flood sources, and the map sheet names and numbers contained in Appendix E. Again, the WWL is generally defined by the inland distance of the debris line since flooding did not extend farther inland in most areas along the coastline.

Table 4: WWL Findings and Map Sheets by Community

County	Location (City or Area)	Distance Inland of Debris Line (feet)	Distance Inland of Inundation (feet)[a]	Major Flood Source(s)	Map Sheet Name(s) and Number(s)
Baldwin	Most of southeast Baldwin County, including Orange Beach	100	N/A	Gulf of Mexico	Orange Beach – 19
Baldwin	Southeast Baldwin County along Gulf Bay Road	1,000 to 1,500	N/A	Wolf Bay	Orange Beach – 19
Baldwin	Romar Beach	100 or less	N/A	Gulf of Mexico	Gulf Shores – 18 Gulf Shores OE S – 24
Baldwin	Gulf Shores	500 to 1,000	N/A	Gulf of Mexico	Gulf Shores – 18 Pine Beach – 23 Gulf Shores OE S – 24
Baldwin	Cedar Grove, Gasque, and Palmetto Beach	1,000 to 2,000	N/A	Bon Secour Bay and Gulf of Mexico	Bon Secour Bay – 17 Pine Beach – 23
Baldwin	Northward along Bon Secour Bay at Beach Road	500	N/A	Bon Secour Bay	Bon Secour Bay – 17
Baldwin	Along Weeks Bay	200 or less	N/A	Weeks Bay	Magnolia Springs – 14
Baldwin	Between Weeks Bay and Point Clear	100 to 200	N/A	Bon Secour Bay and Mobile Bay	Point Clear – 13
Baldwin	Darling Landing and Point Clear	1,000 to 1,500	N/A	Mobile Bay and Point Clear Creek	Point Clear – 13
Baldwin	Fairhope and Daphne	< 200 (limited by steep, bluff terrain)	N/A	Mobile Bay	Bridgehead – 7 Daphne – 9
Mobile	Chickasaw	N/A	12,000 to 16,000	Mobile River	Chickasaw – 4
Mobile	Saraland	N/A	12,000	Mobile River	Chickasaw – 4
Mobile	Eastern City of Mobile	< 200	6,000 to 20.000	Mobile Bay and Mobile River	Mobile – 6
Mobile	South of Mobile to north of Alabama Port, including Bellefontaine	50 to 500	N/A	Mobile Bay	Hollinger's Island – 8 Bellefontaine – 12
Mobile	Alabama Port	< 100 to 500	N/A	Mobile Bay	Little Dauphin Island – 16

County	Location (City or Area)	Distance Inland of Debris Line (feet)	Distance Inland of Inundation (feet)[a]	Major Flood Source(s)	Map Sheet Name(s) and Number(s)
Mobile	East Dauphin Island	Small 'island' in center was not inundated		Mississippi Sound and Gulf of Mexico	Little Dauphin Island – 16 Fort Morgan – 21
Mobile	West Dauphin Island (spit)	Complete overwash		Mississippi Sound and Gulf of Mexico	Heron Bay – 15 Fort Morgan NW – 20
Mobile	Coden, Sans Souci Beach, and Bayou Le Batre	1,000 to 4,000	N/A	Mississippi Sound	Grand Bay – 10 Coden – 11 Heron Bay – 15
Mobile	Coastline west of Sans Souci Beach	1,500 to 5,000+	N/A	Grand Bay and Mississippi Sound	Grand Bay – 10

[a] Distance the inundation polygon extends inland beyond the debris line (in areas where a debris line has been delineated).

In areas directly exposed to the Mississippi Sound and Gulf of Mexico, the inland limit of surge effects is notably further than areas along the bay or farther inland. This is illustrated on map sheets 10, 11, 12, and 15, which show the southern coastline of Mobile County including Bayou Le Batre and Sans Souci Beach where inland limits of surge flooding extended several thousand feet in some areas. Another example is Dauphin Island where much of the island was washed over by surge, particularly the west side. The east side of the island is shown on map sheets 16 and 21 where there is some high ground that was not inundated. Similarly Gulf Shores and nearby communities in Baldwin County along Ft. Morgan Peninsula were more directly affected by surge flooding and experienced flooding extending up to 1,000 feet inland in some areas. Ft. Morgan peninsula is shown on map sheets 17, 21, 22, and 23.

Along the east coast of Mobile Bay in Baldwin County, many communities were protected due to the bluff formations along the coast. The WWL in these areas is located at the bluff. This phenomenon is illustrated on map sheets 7, 9, and 13, which show the Point Clear and Daphne areas.

Along the western coast of Mobile Bay (map sheets 6, 8, 12, and 16), the WWL is relatively close to the coast. The only exception was along Fowl River (map sheets 11 and 12) and Dog River (map sheet 8) where surge moved up these watercourses causing flooding.

In the City of Mobile, surge pushed up the Bay and into the Mobile River (and adjacent watercourses including several bayous and streams), causing flood damage in the eastern part of the City. Flooding affected City areas as far as 2 miles inland from the river as shown on map sheet 6, and surge effects were responsible for flooding an estimated 25 miles upstream from the Bay. Upstream from Mobile in Chickasaw, flooding reached Highway 43 just south of State Highway 158 as shown on map sheet 4. There is some development in this area, including an airport. Farther north in Saraland, which is also shown on map sheet 4, floodwaters generally stayed 1 to 3 miles east of Highway 43.

Conclusion

Storm surge clearly had a major impact along Alabama's coastline in Baldwin and Mobile Counties as shown by the WWL. The maps in Appendix E illustrate that flooding affected several developed areas, including Dauphin Island, Bayou Le Batre, Gulf Shores, Orange Beach, and Mobile.

In Alabama, 71 WWL points were identified; of those, 46 points were in Baldwin County and 25 were in Mobile County. Using the field crews' observations, photographs, post-event imagery, local topography, and base mapping, engineers compared the field-collected data to the photointerpreted debris line and inundation area to determine the approximate boundary of the WWL in Mobile County. The field data presented a complement to the information developed solely from analyzing the post-event imagery. In Baldwin County, the field data alone served as the main record of the inland limit of surge flooding and of the WWL, and was used with topography to delineate the WWL.

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Appendix A: WWL Data Points

Appendix A contains a table with field-collected data for each WWL data point. These data are first referenced in the Data Collection Methodology section of this report and were collected between September 5 and September 12, 2005. As described in the Mapping Methodology section, the data points were used together with the information about the debris line and the extent of flooding determined through photointerpretation of post-event imagery to delineate the WWL for Mobile County as presented on the maps in Appendix E. For Baldwin County, neither a photointerpreted flood inundation coverage nor a debris line were developed; topography, WWL data points, and HWMs were used to delineate the WWL. A description of how the data points were used to edit the debris line and limits of inundation defined through photointerpretation (Mobile County) or develop the WWL (Baldwin County) can be found in Appendix D.

APPENDIX A IS NOT INCLUDED IN THE REPORT VERSION FOR PUBLIC RELEASE DUE TO PRIVACY ISSUES.

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Appendix B: WWL Photographs

Appendix B contains an index and thumbnails of the photographs that correspond to each WWL data point presented in Appendix A. The naming convention for the photographs uses the data point ID Number (KALC-XX-XX) and then a sequential number for the photograph(s) associated with that ID Number (KALC-XX-XX-1, KALC-XX-XX-2). In most instances, two photographs were taken for each data point.

APPENDIX B IS NOT INCLUDED IN THE REPORT VERSION FOR PUBLIC RELEASE DUE TO PRIVACY ISSUES.

Appendix C: Debris Line and Inundation Mapping Report, HMTAP T.O. 411 Rapid Response, Aerial Radar - Louisiana, Mississippi, and Alabama

Appendix C contains a summary report of debris line and inundation mapping performed under HMTAP Task Order 411: Rapid Response, Aerial Radar – Louisiana, Mississippi, and Alabama. Photoanalysts used the post-event aerial imagery to estimate the location of the debris line and the extent of inundation from Hurricane Katrina in Mobile County. As described in the Mapping Methodology section of the report, this information developed by the photoanalysts was used as the initial estimate of the WWL delineation for the county, which was further edited based on the field-collected data presented in Appendices A and B.

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

Background

As part of the Hurricane Katrina 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 Katrina. The areas mapped include the storm-struck areas along the Gulf Coast of Alabama, Mississippi, and Louisiana.

The primary purpose of this mapping effort was to provide a comprehensive, region-wide inventory of areas damaged by Hurricane Katrina 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 ensure that Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) provide reasonable risk information.

Area of Interest

Mapping coverage extended along the entire Gulf Coast region of Louisiana, Mississippi, and Alabama. The area mapped was approximately 12,000 square miles and included portions of or all of the following counties:

1. **Alabama Counties:** Baldwin and Mobile
2. **Mississippi Counties:** Forrest, George, Greene, Hancock, Harrison, Jackson, Lamar, Marion, Pearl River, Perry, and Stone
3. **Louisiana Parishes:** Jefferson, Livingston, Orleans, Plaquemines, Saint Bernard, Saint Charles, Saint John the Baptist, Saint Tammany, Tangipahoa, and Washington

Imagery Source

EarthData used natural color digital aerial orthophotographs acquired between September 4 and September 17, 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 (Kevin Carlock, USACE, Rock Island District, 309-794-5249). The 3001, Inc. imagery provided to EarthData by URS covered approximately 3,600 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 Katrina 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 Katrina. 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 16, 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 WWL Data Points

Appendix D contains notes about the comparison of WWL data points to the debris line and inundation data that were created from photointerpretation of post-Katrina aerial imagery for Mobile County. The notes include actions taken to resolve discrepancies between the two data sets. The Mapping Methodology section of the report provides a description of how the field-collected data presented in Appendices A and B were used to edit the photointerpreted debris line and inundation limit, which were developed as explained in Appendix C. Appendix D provides detailed descriptions of how each WWL data point was used to either confirm the proper delineation of the WWL based on the photointerpreted data, or to edit this initial delineation of the WWL where the two data sets did not agree.

For Baldwin County, there are notes on how the field-collected data presented in Appendices A and B were used with contour data to delineate the WWL. This process is also described in the Mapping Methodology section of the main report.

Hurricane Katrina, Alabama
Mobile County
Notes on Comparison of WWL Data Points to Photointerpreted Data

Data Point ID	Distance to debris line (ft)	Distance to flood boundary (ft)	Action	Explanation
KALC 01_01	-------	2200	Reviewed imagery and used WWL points as guide to expand inundation polygon.	Reviewed imagery - the original inundation polygons were not capturing all of the surge that came through this inlet. Surge from the gulf had much bigger impact on inlet than is currently being shown.
KALC 01_02	-------	570	Left as it was from photointerpretation of aerial imagery.	Difference in elev. is only 2 feet and current inundation mapping is more conservative
KALC 01_03	-------	250	Extended flood polygon to include this point.	Flaggers note there is a wrack line at this point. Imagery seems to indicate flooding went further inland as well.
KALC 01_10	210	-------	Adjusted boundary through here to keep it at 10 ft and between this point and 08_13, transition from 11 to 10	The debris line is all over the place in terms of elevation through here and is crossing contour lines of all elevations - need some smoothing
KALC 01_11	-------	90	Smoothed out floodplain boundary using 8 feet as guide. Checked CHWMs to make sure they agreed.	The inundation boundary is all over the place in terms of elevation through here. Near this point, its at elev 0, but further 'upstream' goes to elev 12.
KALC 02_01	700	-------	Left as it was from photointerpretation of aerial imagery.	Swampy, flat area and existing line is slightly more conservative (further inland)
KALC 02_02*	1050	-------	Left as it was from photointerpretation of aerial imagery.	Swampy, flat area and existing line is slightly more conservative (further inland)
KALC 02_04	1300	-------	Left as it was from photointerpretation of aerial imagery.	Very flat through here and current inundation mapping is more conservative (further inland). Double checked imagery and delineation from imagery and decided to leave as is.
KALC 02_05**	60	inside polygon	Left as it was from photointerpretation of aerial imagery.	Very close to debris line delineated from post-event imagery and inside inundation polygon.
KALC 02_06	70	-------	Left as it was from photointerpretation of aerial imagery.	Very close to debris line delineated from post-event imagery.
KALC 02_07	-------	110	Use 4 ft NAVD 88 as elevation guide through here.	Inundation boundary is at elevation zero - doesn't make sense.
KALC 02_13	-------	2300	Review imagery - and use WWL points as guide here to expand inundation polygon.	Review of imagery and WWL points show inundation was further spread than current mapping shows.
KALC 02_14	2500	-------	Need to make debris line here closer to 12-14 feet in elevation. Should be going further inland.	On both west and east sides of this area, the line is mapped at an elevation of 12-14 ft. Flaggers noted there was a debris line at this point.
KALC 02_16	n/a	n/a	Extended flooding upstream to include this point.	WWL point was reliable and other CHWMs indicated there had been flooding here too.
KALC 02_17**	n/a	n/a	Extended flooding upstream to include this point.	WWL point was reliable and other CHWMs indicated there had been flooding here too.
KALC 03_04	-------	2000	Left as it was from photointerpretation of aerial imagery.	Inundation boundary extends further inland and is more conservative. Checked imagery and delineation appeared to be correct.
KALC 03_06	-------	442	Included this point and used 10-ft topo as upper limit of extent of flooding for rounding out inundation in this area.	With this point being more than 400 feet away from mapped inundation polygon, there must be some discrepancy in photointerpretation here. Inundation polygon seems to run perpendicular to coast and follow pattern of 0 ft contour from DEMs, but this pattern changes as you go inland and isn't strictly parallel lines against the shore. Flaggers noted on form that 'debris line was very well defined, perfect mark for wind/water debris line.'
KALC 03_07	-------	4000	Left as it was from photointerpretation of aerial imagery.	Inundation boundary extends further inland and is more conservative. Checked imagery and delineation appeared to be correct.
KALC 03_20	-------	50	Left as it was from photointerpretation of aerial imagery.	Only a few feet beyond 50 ft buffer for flooding.
KALC 05_06	1800	-------	Did not use for delineation on Dauphin Island.	Elevation (~4 ft) seemed low and point was very near coast.
KALC 08_09	80	-------	Left as it was from photointerpretation of aerial imagery.	Very close to debris line delineated from post-event imagery.
KALC 08_11	30	-------	Left as it was from photointerpretation of aerial imagery.	Very close to debris line delineated from post-event imagery.
KALC 08_14	190	-------	Left as it was from photointerpretation of aerial imagery.	Very close to debris line delineated from post-event imagery.
KALC 09_18	-------	340	Adjusted debris line to elev. ~10 in this area.	Debris line is crossing elevation lines - doesn't make sense. Smooth out using 2 ft contours as guide.
KALC 09_20*	110	-------	Left as it was from photointerpretation of aerial imagery.	Very close to debris line delineated from post-event imagery.

* Point not used as HWM because elevation deemed not reliable. Location of point is still appropriate for WWL use; elevation not used.

**Point deleted from HWM database because it is a duplicate of another point. Use is still appropriate for the WWL.

Appendix E: WWL Maps

Appendix E contains the WWL maps that illustrate the location of the WWL. Summaries of the WWL by community are found in Table 4 of the main report. Table 4 also highlights which of the following map sheets correspond to each community.