HURRICANE KATRINA SURGE INUNDATION AND ADVISORY BASE FLOOD ELEVATION MAPS – SUMMARY OF METHODS

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1. Introduction

Hurricane Katrina was a long-lived hurricane that made landfall three times along the United States coast and reached Category 5 at its peak intensity. The storm initially developed as a tropical depression in the southeastern Bahamas on August 23, 2005. Two days later, it strengthened into a Category 1 hurricane a few hours before making its first landfall between Hallandale Beach and North Miami Beach, Florida. After crossing the tip of the Florida peninsula, Katrina followed a westward track across the Gulf of Mexico before turning to the northwest towards the Gulf Coast.

Hurricane Katrina made its second landfall as a strong Category 4 hurricane in Plaquemines Parish, Louisiana on August 29, 2005. Wind speeds of over 140 miles per hour (mph) were recorded in southeastern Louisiana and winds gusted to over 100 mph in New Orleans, just west of the eye. As Katrina made its third and final landfall four hours later along the Mississippi/Louisiana border, it was a Category 3 storm with wind speeds of approximately 125 mph. Hurricane-force winds extended up to 190 miles from the center of the storm and tropical storm-force winds extended for approximately 440 miles.

The strength and extent of Hurricane Katrina's wind field resulted in a storm surge greater than historical maximums. The combination of a storm surge of up to 30 feet, wave action, and high winds resulted in destruction of buildings and roads in the affected areas. Although recovery and reconstruction efforts will last several years, there is an urgent need for technical information to enable safer, sustainable redevelopment along the Gulf Coast.

The Federal Emergency Management Agency (FEMA) undertook this project to provide timely, up-to-date, and accurate coastal flood hazard information to local, regional, state and Federal officials to guide reconstruction in the portions of the Gulf Coast most severely affected by Hurricane Katrina. This information is being provided in the form of high-resolution maps that show coastal flood impacts from Hurricane Katrina. This report outlines the data sources and methods used to produce the Hurricane Katrina Surge Inundation and Advisory Base Flood Elevation maps (herein referred to as the "Katrina Recovery Maps"). As of the date of this report, Katrina Recovery Maps have been published for the following parishes: St. Charles (north of the Mississippi River); St. John the Baptist (north of the Mississippi River); St. Tammany; and Tangipahoa. Maps for the following parishes are still in development: Jefferson; Orleans; Plaquemines; and St. Bernard.

2. Methodology

Katrina Recovery Maps, including those already published for the aforementioned four parishes as well as those maps still in production, provide the following essential elements of information:

- ✓ Preliminary surveyed coastal high water mark (HWM) flood elevations from Hurricane Katrina's storm surge (i.e., excluding HWMs reflecting surge plus local wave effects);
- ✓ Hurricane Katrina coastal surge inundation limits; and
- ✓ Advisory Base Flood Elevations (ABFEs).

The methods for generating each of these essential elements of information are discussed in greater detail in the sections that follow. In addition to the detailed Katrina Recovery Map panels that show these elements, FEMA has also produced an overview map for the four parishes mapped to date. This overview map, which is explained in greater detail in Section 3, shows some of the same essential elements as well as regional surge elevation contours derived from the surge-only HWMs.

2.1 Hurricane Katrina Coastal High Water Mark Collection

Under separate task orders, field-based flagger and survey crews from URS and URS Team subconsultants, ESP and PBS&J, were deployed to interview residents, find evidence of coastal high water levels, take digital photographs, and survey coastal HWMs from Hurricane Katrina. Coastal HWMs included mud lines, water stains, debris, wrack lines, and eyewitness testimony.

The coastal HWM flagging crews received notice to proceed on August 30, 2005. Deployment of flagging crews was delayed due to ongoing recovery efforts, the concern for obtaining gasoline and other essential supplies, the lack of lodging, and the approach of Hurricane Rita. Once conditions improved, the flaggers were deployed along the affected areas of Louisiana and began flagging HWMs on September 9, 2005.

For each HWM, the flaggers completed a form that contained detailed information about the mark. To the extent possible, field crews noted the coastal flooding characteristics captured by the coastal HWM, including storm surge, wave runup, and wave height. These designations represent the field crew's best estimate of this characteristic based on a combination of physical flood evidence and interviews with witnesses at the time of collection. These characteristics are described as follows:

- Surge - represents the rise in the normal water level, also called stillwater flooding
- Wave runup - represents the height of water rise above the stillwater level due to water rush up from a breaking wave
- Wave height - represents the coastal HWM elevation due to more direct wave action

Typically, storm surge coastal HWMs are associated with a slow-rising flood that causes more water damage than structural damage. Wave height usually results in a higher elevation than just storm surge. All attempts were made to flag storm surge elevations, but in areas where storm surge characteristics were not obvious, wave runup or wave height may have been captured. For example, witnesses might claim the flooding was associated with a storm surge when in fact the flooding was from wave runup or riverine flooding.

The survey crews followed the flaggers and used static Global Positioning System (GPS) methods to determine an accurate elevation for each coastal HWM. Since static GPS requires an area with no tree cover to return an accurate result, in some cases it was necessary to perform a short level loop survey from the GPS point to the coastal HWM. Coastal HWM locations were surveyed horizontally in the North American Datum of 1983 (NAD 83), State Plane – Louisiana South (1702) feet, and vertically in the North American Vertical Datum of 1988 (NAVD 88) US survey feet. Coastal HWM locations have been surveyed to within accuracies of ±0.25 foot vertically and ±10 feet horizontally, with a 95% confidence level.

A more detailed discussion of the coastal HWM collection and final results will be presented in a separate report currently under development.

2.2 Hurricane Katrina Storm Surge Inundation Mapping

Flood inundation limits were created for the coastline for the Louisiana coastal parishes by mapping the coastal HWM elevations onto digital, pre-storm topographic data. These inundation limits represent the estimated inland extent of flooding caused by the Hurricane Katrina storm surge.

Note: Hurricane Rita inundated many of the same Louisiana parishes in September 2005; areas where HWMs show that Rita's coastal flood levels exceeded those of Katrina are being mapped under a separate FEMA project.

The HWMs surveyed by URS and its subconsultants were imported into a Geographic Information System (GIS) as points and pre-processed prior to analysis and mapping. The pre-processing of the HWMs included the Anselin Local Moran's I statistical analysis to identify those points that did not match the general trend of elevations in each point's immediate area. These HWMs were not used for the inundation mapping. In addition, HWMs identified as including wave effects or described to be of poor quality or have a low confidence were also excluded from the surge inundation mapping. Once the HWMs to be used were identified, a three-dimensional, raster surface was created using a standard interpolation function (Second Power Inverse Distance Weighting).

In a parallel effort, a digital elevation model (DEM) was developed for this project using pre-Katrina topographic data. The data were derived from Light Detection and Ranging (LIDAR) measurements collected in 2003 by 3001, Inc., a remote-sensing firm operating under subcontract to Watershed Concepts; this work was funded jointly by the State of Louisiana and FEMA. The LIDAR data were obtained for the recovery mapping effort from Atlas, the Louisiana statewide GIS (http://atlas.lsu.edu/). The LIDAR data have a posting interval of five meters, and are referenced to NAVD 88.

To create the Hurricane Katrina surge inundation limit, the interpolated HWM raster surface was intersected with the LIDAR DEM and then smoothed using PAEK smoothing algorithms. The inundation limit was then refined to remove small-scale, isolated areas of inundated and non-inundated terrain based on knowledge of overland surge propagation and engineering judgment.

2.3 Hurricane Katrina Surge Elevation Contour Mapping

Surge contours were mapped at one-foot intervals in the areas of St. Tammany, Tangipahoa, St. John the Baptist, and St. Charles parishes in Louisiana that were flooded by Hurricane Katrina. These contours, provided in one-foot increments, show the geographic variability of the storm's surge. To create the contours, the coastal HWMs were examined to find patterns in the coastal storm surge as it pushed against the open coast and into the inland bays and waterways. The known path and landfall location of Hurricane Katrina, together with the knowledge of how storm surge propagates inland, allowed surge contours to be drawn across the areas where the coastal HWMs indicate a change in storm surge elevation. Engineering judgment had to be applied in some locations to allow the contours to "step" up or down at one-foot intervals.

Because of the inherent uncertainty in and the random and irregular spacing of coastal HWMs, the surge contours represent a generalized maximum storm surge elevation, and required professional judgment in their creation. Within certain surge contours, coastal HWMs may be higher or lower than the contours if they did not fit the overall pattern discerned from the coastal HWMs. Local wave effects (wave heights and wave runup), which increase the total water surface above the surge elevation, were not considered in this contouring effort. Coastal HWMs that include wave effects may be several feet higher than the surge contours in a particular area.

Predictive numerical models of surge flooding, such as Hurricane Katrina forecasts from the National Oceanic and Atmospheric Administration's (NOAA's) Sea, Lake and Overland Surge from Hurricane (SLOSH) computer model, were used qualitatively to help refine the surge contours in areas of complex topographic and bathymetric changes. NOAA will be developing hindcasts of Hurricane Katrina's surge in the coming months. Consequently, the results presented here should be viewed as preliminary and subject to update as additional data become available.

2.4 Hurricane Katrina Advisory Base Flood Elevations

ABFEs are advisory flood hazard data that may be used by communities as best-available data when FEMA determines that the existing, effective Flood Insurance Rate Maps (FIRMs) understate the true flood risk. The general approach for mapping the ABFEs is described below, followed by explanations of any parish-specific mapping techniques or zones where coastal engineering judgment had to be applied.

As explained in the Flood Recovery Guidance published by FEMA for each Louisiana parish (http://www.fema.gov/hazards/floods/recoverydata/katrina_la_resources.shtm), ABFEs for this project were determined by adding freeboard to the Base Flood Elevations (BFEs) shown on each community's FIRM. To apply the freeboard specified in the Flood Recovery Guidance for each parish, the flood zone boundaries and elevations were first transferred electronically from the FIRM into a GIS format, where necessary. In the GIS, the specified freeboard value (usually one foot) was then added to the BFE, and the combined value was placed on the Recovery Map in the form of "ABFE" followed by the flood zone designation (e.g., "Zone VE") and advisory elevation in feet (e.g., " EL 11"). In addition, wherever possible, ABFEs were determined for approximate A Zone areas shown on the effective FIRMs. Further, some A and AE Zones were changed to V or VE Zones, respectively, where the increased flood levels would make damaging waves possible. The methods used to develop ABFEs in approximate areas and to change the flood zone type are described in further detail below.

A thick yellow line labeled, "Limit of ABFEs", marks the end of the area where the coastal ABFEs apply. ABFEs are generally limited to portions of the current FIRM's Special Flood Hazard Area (SFHA) (or 100-year floodplain) that were inundated by Hurricane Katrina. In addition, since these ABFEs pertain to the 1%-annual-chance (100-year) **coastal** flood elevations, a "Limit of ABFEs" line is also shown wherever detailed riverine flood elevations from the FIRM are higher than the coastal ABFEs. Lastly, areas shown on the effective FIRMs as shaded Zone X or that are inside of certified levees (per the effective FIRM) are labeled as "See Effective FIRMs" on the Katrina Recovery Maps.

Parish-Specific Approaches –St. Charles Parish:

As specified in the Flood Recovery Guidance, one foot of freeboard was applied to all flood zones. There were no approximate A Zones present in this portion of St. Charles Parish, so the new ABFEs are solely based on the application of freeboard to the effective FIRM data.

Parish-Specific Approaches – St. John the Baptist Parish:

As specified in the Flood Recovery Guidance, one foot of freeboard was applied to all flood zones. Advisory elevations have also been determined in areas shown as Approximate A Zones on the effective FIRMs. The large Zone A area in the center of the Parish was determined to have an ABFE of 12 feet, which is based on the effective coastal stillwater level of approximately 11 feet plus one foot of freeboard. On the north side of the Mississippi River (East Bank), the effective FIRM showed detailed riverine flood elevations which have now been converted to coastal approximate A Zones, with an ABFE of 12 feet. This is because the effective coastal stillwater elevation in this area is 11 feet, and once the freeboard is added, the ABFE of 12 feet is higher then any of the detailed riverine elevations in this area. This advisory A Zone is visible on many panels, starting with the GG series of maps.

Parish-Specific Approaches – St. Tammany Parish:

As specified in the Flood Recovery Guidance, one foot of freeboard was applied to flood zones located north and west of Interstate 10. Initially, ABFEs for areas south and east of Interstate 10 were to be calculated using advisory stillwater elevations plus a simplified wave-height calculation. This simplified method had been applied successfully by FEMA in the Mississippi Hurricane Katrina recovery mapping project. Once applied to southeastern St. Tammany Parish, however, a large (5-10 foot) discontinuity appeared at the point where the two methods met (Interstate 10). Rather than forcing the simplified method-derived (or southeastern) ABFEs to step down rapidly to meet the freeboard-derived (northern) ABFEs across the interstate, FEMA elected to employ a hybrid approach – namely, the advisory stillwater elevations were used to estimate an appropriate, higher freeboard value for the southeastern area.

Generally, FEMA's advisory stillwater elevations reflected an increase of approximately three feet over the effective stillwater levels in the same area. An increase in stillwater flood depth of three feet will also result in an increase in wave heights above the surge (stillwater) level; this wave height increase would be on the order of one to two feet at the shoreline. Without detailed wave height analyses like those done in official Flood Insurance Studies, FEMA could not determine exactly what additional wave height would occur inland from the shoreline. As a result, FEMA conservatively estimated that a freeboard of four feet would be adequate to account for the increased stillwater level and additional wave effects. This four-foot freeboard was applied uniformly across the area south and east of Interstate 10.

Once freeboard of one foot or four feet was applied throughout the parish, each ABFE zone was evaluated to determine whether the potential for high velocity flow due to wave action should be a concern. Specifically, AE Zones bordering VE Zones on the effective FIRM would be areas where the ABFE's increased flood depth could mean that waves in excess of three feet in height are now possible. For example, in the northwestern part of the parish (along the Lake Pontchartrain shoreline), the flood elevation threshold where VE Zones give way to AE Zones on the FIRM was 11 feet. Thus, any ABFE zone where the new flood elevation was 11 feet or higher could be susceptible to V Zone wave conditions. Thus, where physical conditions concerning obstructions (or lack thereof) warranted, the flood zone designation was changed from AE to VE on the advisory maps.

Parish-Specific Approaches – Tangipahoa Parish:

As specified in the Flood Recovery Guidance, one foot of freeboard was applied to all flood zones. Advisory elevations have also been determined in areas shown as Approximate A Zones on the effective FIRMs. This includes an elevation of 12 feet currently used by the Parish's local floodplain administrator based on information received by the U.S. Army Corps of Engineers, New Orleans District. The subject zone covers much of the northernmost Katrina Recovery Maps in Tangipahoa. In addition, this flood zone designation was changed from approximate Zone A to approximate Zone V due to the increased potential for damaging waves resulting from the increased flood depth.

3. Presentation of Results

The results of the technical analysis are presented in a series of Katrina Recovery Maps, on a regional overview map, and in the form of GIS files. Each of these products is summarized below:

- **Hurricane Katrina Surge Inundation and ABFE Maps** *(123 panels covering St. Charles, St. John the Baptist, St. Tammany, and Tangipahoa parishes)*: When plotted at their native size (ANSI D, 34 inches by 22 inches), the data on these maps are shown at a scale of 1 inch = 500 feet. Each map depicts the coastal HWMs used in the inundation mapping, the surge inundation limit, and ABFEs, all shown on a base map of aerial photographs collected by the U.S. Department of Agriculture (USDA) National Agriculture Imagery Program in 2004.

- **Parish Index Maps** *(four maps, one each for St. Charles, St. John the Baptist, St. Tammany, and Tangipahoa parishes)*: The maps' native size is ANSI E (44 inches by 34 inches), but can be scaled to print on smaller sheets. Each map depicts geographic boundaries of the parish, corporate limits, the Katrina Recovery Map paneling scheme (or index), the coastal HWM locations, the surge inundation limit, and the surge elevation contours.

- **Overview Map:** This, the first of several overview maps, covers the initial four-parish study area including Lake Pontchartrain. Like the parish index maps, its native size is ANSI E. The overview map shows geographic boundaries of the parishes, corporate limits, the Katrina Recovery Map paneling schemes, the coastal HWM locations, the surge inundation limit, and the surge elevation contours.

- **GIS Data:** GIS-compatible data for the following themes are provided for download on FEMA's Katrina Recovery Map site (www.fema.gov/hazards/floods/recoverydata/katrina_la_gis.shtm):

    - Surge inundation limits for each parish;
    - ABFEs for each parish;
    - Surge elevation contours for the four-parish region; and
    - HWMs for the full, eight-parish Hurricane Katrina region, including both the surge-only points used in the inundation mapping and points with wave effects or quality concerns (as of the date of this report