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HURRICANE KATRINA AND DISASTER RECOVERY GEOSPATIAL PROCESS FOR DAMAGE ASSESSMENT

Owen C. Griesemer, Robert Hanson, Jonathan H. Soulen*

ABSTRACT: On Monday, August 29, 2005, Hurricane Katrina made landfall near Buras, Louisiana, with 145 mph winds. This landfall caused a series of events that would lead to the flooding of Orleans Parish over the next 24-48 hours. For FEMA's Housing Recovery Support, the most significant issue was the inability to access much of Orleans Parish due to flooding. Therefore, field inspectors would be unable to access the area and would not be able to identify residences that had been flooded and would qualify for federal assistance. FEMA tasked Michael Baker Jr., Inc. (Baker) to perform a feasibility study to determine if remote sensing data and geographic information system (GIS) analysis could accelerate providing assistance to flood victims. Three different analysis efforts focused on Hurricane Katrina. The first was a feasibility study. Using LIDAR data to develop a surface model and flood gauge readings, Baker was able to generate estimated flood levels. Based on the success of this effort, an expanded analysis was performed for four parishes: Orleans, Jefferson, St. Bernard, and Plaquemines. The project was expanded again to include counties in Mississippi and Alabama. The success and validation of this approach resulted in additional analysis tasks for Hurricanes Rita and Wilma. This effort has helped change how FEMA's Housing Recovery Support group performs business. Due to increased speed and accuracy, this approach will now be used for future hurricanes, and is being evaluated as a method of response for other natural disasters, including large forest fires and earthquakes.

INTRODUCTION

On Monday, August 29, 2005, Hurricane Katrina made landfall near Buras, Louisiana, with 125 mph winds. This event triggered a series of events that would lead to the flooding of Orleans Parish and other areas in the vicinity of southeastern Louisiana over the next 24 - 48 hours. By Wednesday, August 31, 2005, the severity of this natural disaster was apparent, and it would create logistical challenges for all disaster responders, both Federal and local, whose mission involved assisting residents of the affected areas.

For FEMA's Housing Inspection Services Contract inspectors, a significant issue was the lack of access to much of Orleans Parish due to flooding. Without immediate access, they would be unable to identify the tens of thousands of residences that had been flooded, thus delaying Federal assistance to those affected residents qualified for assistance.

Given these factors, FEMA tasked Michael Baker Jr., Inc. (Baker) to perform a feasibility study using remote sensing, topography (Digital Elevation Model), photography, ZIP Code and parcel data and develop methods to perform a GIS analysis to quickly generate population statistics and estimated numbers of households by ZIP Code area that had experienced severe flooding.

The Geospatial Process for Catastrophic Damage Assessment Project provided reliable estimates of residential damage through geospatial analysis as an alternative to physical inspections in areas suffering extensive residential damage as a result of a natural disaster. The traditional process used by FEMA has been to send out teams of inspectors under the Housing Inspection Services contract to individually inspect each residential property in designated disaster areas. In cases of large-scale disasters, this inspection undertaking is time-consuming, logistically challenging and expensive to conduct. Using GIS technology, an objectively derived database of damaged structures was created that could be linked to FEMA's database of applicants for assistance. By removing the subjective elements of decisions made as a result of ground inspections, this new scientific approach produced consistent and defensible results.

Respectively, Program Coordinator, Vice President, Project Manager, Geospatial Information Technology Practice, Michael Baker Jr., Inc., 3601 Eisenhower Avenue, Suite 600, Alexandria, Virginia 22304, Phone (703) 960-8800, E-Mail: ogriesemer@mbakercorp.com, rhanson@mbakercorp.com, jsoulen@mbakercorp.com.

HURRICANE KATRINA

There were three separate analysis efforts that focused on Hurricane Katrina. Figure 1 identifies the areas for which an analysis task was performed and the figure's legend corresponds to the paragraph numbering used herewith. The first was a feasibility study centered on the area around New Orleans, the results of which were useful, but not sufficient for assistance efforts. Nevertheless, it was a successful proof of concept, so an expanded analysis was performed for four parishes: Orleans, Jefferson, St. Bernard, and Plaquemines. The third phase analysis included counties in Mississippi and Alabama. From beginning to end, with the analysis of each successive effort was modified based on differing conditions for an area and the lessons learned from the previous one.

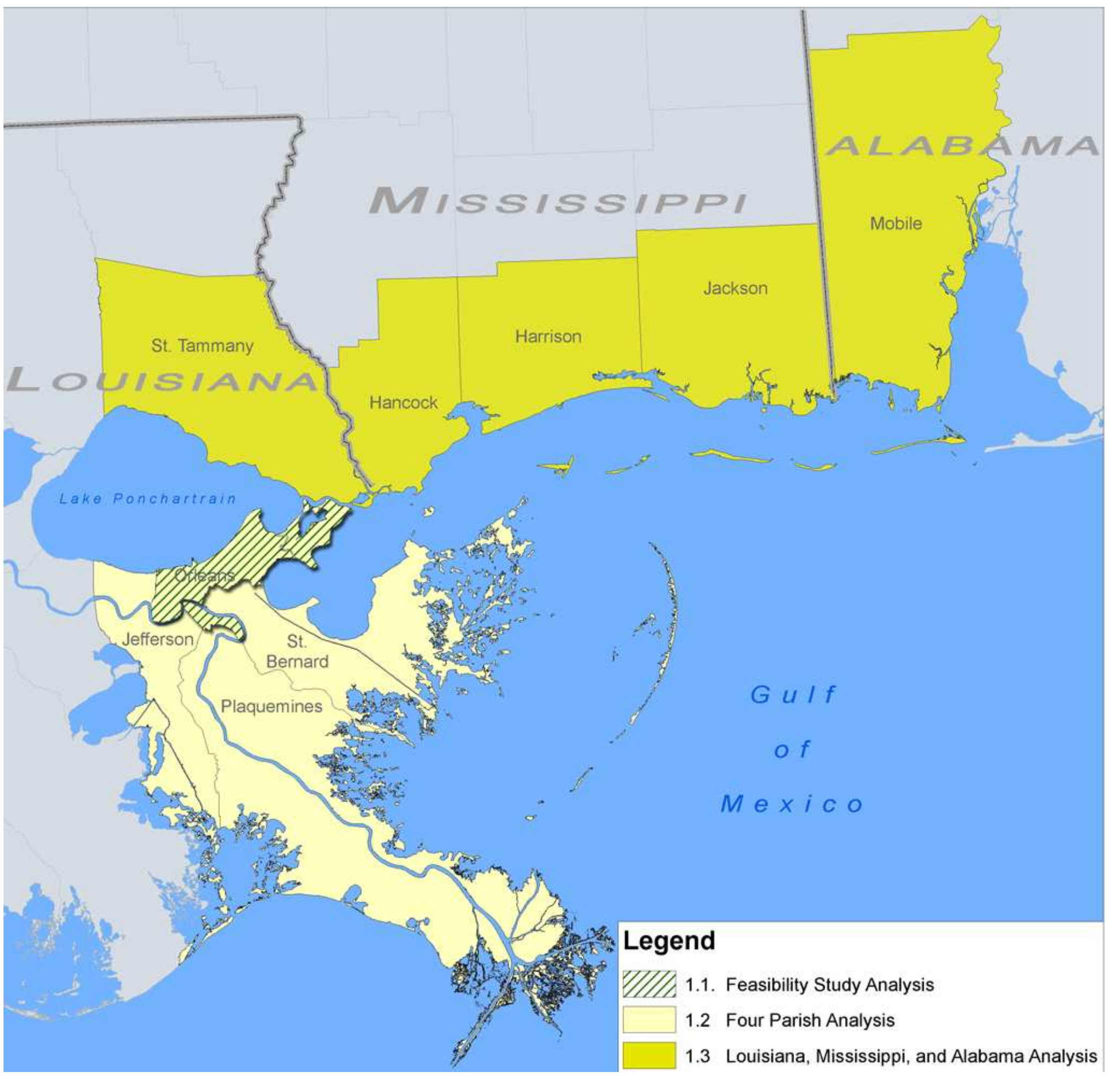

Figure 1 – Sequential Analysis of Hurricane Katrina Event

Feasibility Study Analysis

The deliverables for the Feasibility Project included a listing of the average depth of flooding for each of the five-digit ZIP Codes within the city limits of New Orleans. In addition, the analysis provided an estimated number of housing units and estimated population for each ZIP Code, as well as the quantification of severely damaged residential structures by ZIP Code. The success of this initial effort would determine if the approach should be expanded.

The technical approach for the Feasibility Study Project relied on four key steps:

- Utilize available LIDAR and gauge (flood stage levels) data for determination of base elevations (bare earth)
- Estimate the flood depth
- Determine the extent of the flooded (or ponded) areas
- Perform the analysis (subtracting the “bare earth” elevation from the estimated flood depth) and aggregate results by ZIP code

The approach estimated flooding depths for Orleans Parish by comparing water (flood stage) gauge readings and the “bare earth” digital elevation data derived from the LIDAR. Using GIS technology, the bare earth elevations were “subtracted” from the high water gauge readings for the event to arrive at the calculated flood depth. The result of this subtraction was the development of a five-meter square grid of flood depth values of Orleans Parish which corresponds to the five-meter grid resolution of the LIDAR data. The grid was attributed with the flood depth at the center of each grid square. With this information, the digital boundaries for five-digit ZIP Codes for Orleans Parish were used to also assign the corresponding ZIP Code value to each grid cell.

Based on a review of the gauge readings from Lake Pontchartrain, the Lake’s water level peaked on August 29, 2005, and, following the subsequent levee breaks, began a rapid descent. The levee breaches allowed the lake water to flow into portions of the city of New Orleans, with the water surface stabilizing over the area on September 1, 2005. The resulting water surface elevation was determined to be +2.37 ft NAVD88 (Figure 2), based on the gauge reading at the causeway at mid-lake on Lake Pontchartrain on September 2, 2005, at 15:19 hours.

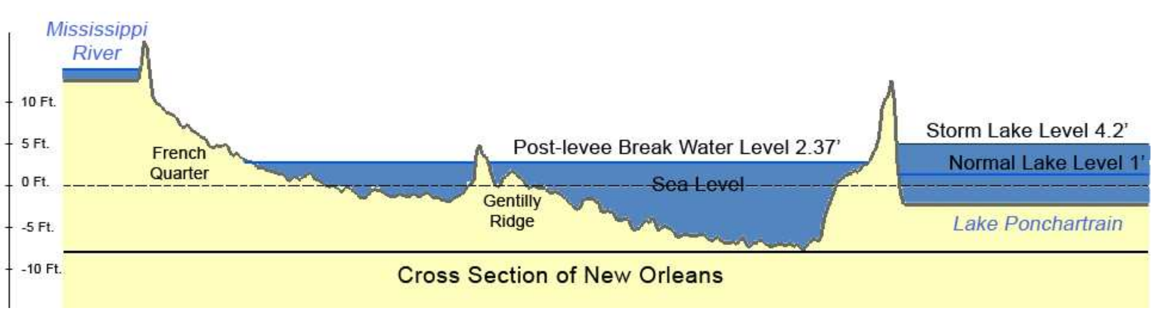

Figure 2 – Relative Water Levels in the New Orleans Area

For the Feasibility Study Project, the extent of the flooded areas that were analyzed was confined to Orleans Parish. This extent is shown in Figure 3. A water surface elevation of +2.37 feet NAVD88 was applied across the Parish area known to be potentially affected by flood waters from levee breaches. The method for determining individual areas affected by flooding from levee breaches was improved upon in the next analysis activity, discussed later in this project report.

After all of the data inputs were assembled, performing the analysis required a correlation of the flood depth grid with the ZIP Code polygons. The feasibility study showed that the geospatial process that was utilized is a viable alternative in major catastrophes compared to on-the-ground inspections, especially in cases where disaster areas are inaccessible. It was determined that, with refinements, the process could be used to support assistance determinations in the New Orleans area, and, on a broader level, in other Louisiana parishes that were affected by Hurricane Katrina.

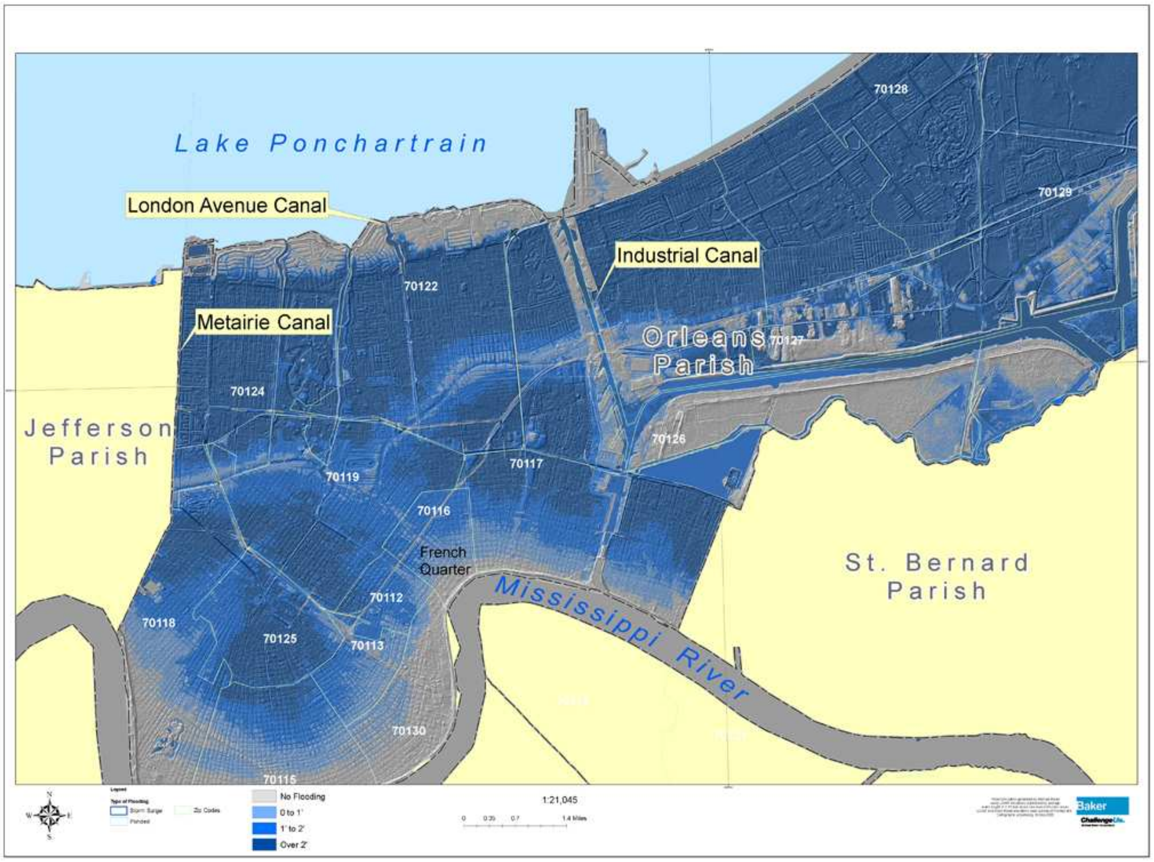

Figure 3 – Results from Feasibility Study Project

Four Parish Analysis

Immediately after the successful feasibility study project, a second analysis was conducted for the four parishes in the New Orleans vicinity that were deemed by FEMA to have encountered severe flooding: Orleans, Jefferson, St. Bernard, and Plaquemines parishes.

FEMA took the geospatial analysis results into consideration in making program determinations for individual assistance for affected applicants. In order to better link to FEMA's applicant database, (NEMIS), the reporting areas from the analysis were broken down to the ZIP 7 and ZIP 9 levels. This action also assisted in meeting the requirement of keeping, to a practical minimum, the number of homes reported by the analysis methods as having flooded that did not actually flood. A guiding principle was to be conservative in assigning a totally destroyed categorization to any residence or grouping of residences.

It was determined during the earlier Feasibility Study Project that most of the flooding in the New Orleans Parish could be calculated at +2.37 feet NAVD88. It was well known that the adjoining parishes flooded at different depths. Thus, a single surface water elevation for the flood at a macro level could not be applied across all four parishes included in this analysis.

Based on comparison with the National Geospatial-Intelligence Agency (NGA) damage area polygons, discussions with FEMA staff at the Joint Field Office, and review of NOAA aerial imagery, the extents of the flooded areas were developed for this analysis. Provided in Figure 4 is an overview map showing the final assumptions used to analyze flooded areas for this study across the four parishes.

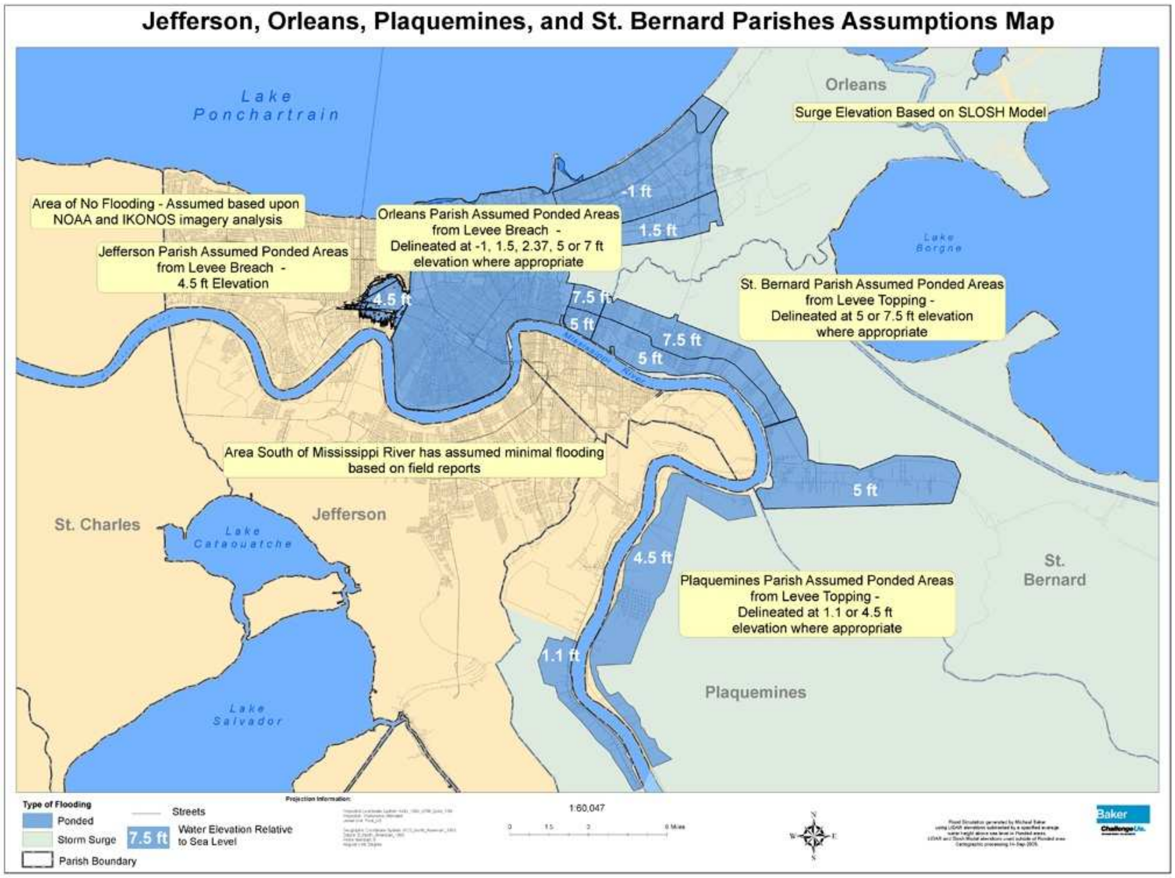

Figure 4 – Final Flood Level Assumptions for the Four Parishes

For the four parishes in the New Orleans vicinity (Orleans, Jefferson, St. Bernard, and Plaquemines), flood depth was determined during this study using two primary methods: empirical analysis and SLOSH model analysis. The empirical analysis used data from three sources: Lake Pontchartrain water level gauge readings; NOAA photography taken after the flood event; and LIDAR surface model data available from LSU.

DEFINITION: SLOSH

The SLOSH (Sea, Lake and Overland Surges from Hurricanes) is a computerized model run by the National Hurricane Center (NHC) to estimate storm surge heights resulting from historical, hypothetical or predicted hurricanes. The model uses several inputs, including pressure, size, forward speed, track, and winds. The SLOSH model is calculated several times as the hurricane approaches landfall.

Because the Katrina event produced several flooding influences and the system of levees and other barriers throughout the region constrained the flooding at various levels, different areas flooded to different depths. For example, the area of central New Orleans flooded due to levee breaks and inflowing water from Lake Pontchartrain. After stabilization with the Lake, the same levee system prohibited an outflow of water from the bowls formed by the levee system. However, areas east of the Industrial Canal flooded and in some cases the levees that were "topped" by surge waters impounded water due to the storm surge effect.

By analyzing imagery of the surge areas ponded, a series of flood area polygons were defined, and each assigned a different maximum flood depth value. For central New Orleans, the flood depth value was determined from the gauge in Lake Pontchartrain. Where gauge information was not available, it was necessary to use aerial imagery to delineate high water debris lines. Using several high water points, the maximum flood depth for an area was calculated by comparison of the intersection of the plain determined by the debris line with the corresponding locations in the LIDAR surface model.

In some cases it was necessary to employ the SLOSH model (see definition) to evaluate maximum potential flood effect. For purposes of this study, coordination was conducted with the NHC and a final SLOSH model developed for Hurricane Katrina, named K26. However, because the SLOSH model is predictive and not based on empirical data, it was only used as the primary source for estimating flood depths where more accurate methods were not feasible.

ZIP Code Analysis

Using an overlay analysis, flood depths were assigned to individual ZIP 9 points. Figure 5 shows points associated with a ZIP 9 location and the flood depth assigned to that point location. Because flooding does not follow ZIP Code boundaries, there are cases where the flood level in a ZIP Code area differs from the flood level assigned to a ZIP Code point. For the vast majority of points, however, the actual and estimated flood levels are very similar.

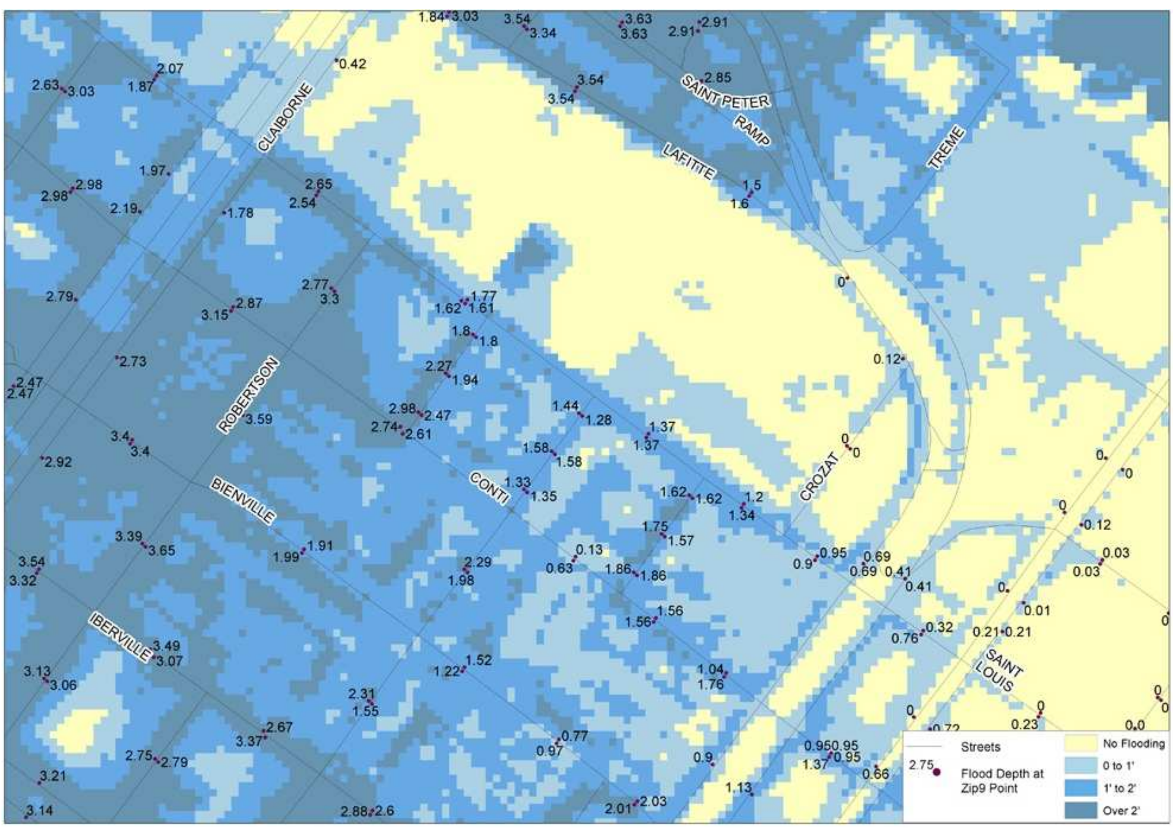

Figure 5 – ZIP Points and Flood Depths

Louisiana, Mississippi, and Alabama Analysis

Due to the favorable results of the Four Parish analysis, it was desirable to extend the process to the storm-damaged areas in Mississippi and Alabama as well as St. Tammany Parish, Louisiana. This extension of the analysis was done to facilitate determination of all Katrina aid recipients at the same time. The following parish/counties were included: St. Tammany, LA; Hancock, MS; Harrison, MS; Jackson, MS; and Mobile, AL.

The primary types of destruction found in St. Tammany, and counties in Mississippi and Alabama were related to storm surge and wind damage. In large measure, the storm surge did not leave any substantial standing flood waters days after the event. The damage (in the form of debris fields or structural damage) was visible from aerial photography; therefore, a revised technical approach for the analysis was developed for wind/storm surge areas.

As illustrated in Figure 6, by employing the GIS system's overlay functions, the geometric intersection of the ZIP 9 points and the damage polygons can be computed. This method allows the damage type classification of the damage polygons to be transferred to the ZIP 9 points which lie within them. Based on the definition used for this analysis, the area contained within the damage polygons is "completely destroyed". Further analysis, such as interpolation of the ZIP 9 points containing the damage type with flood depth or elevation data, can provide additional insight to the flooding or damage characteristics of a particular ZIP 9 point. Using this method, the data value at the x,y coordinate of the ZIP 9 point is extracted from the flood depth or elevation surface and added to the ZIP 9 data table. This powerful analysis capability allows for the reporting of multiple characteristics of geospatially related data.

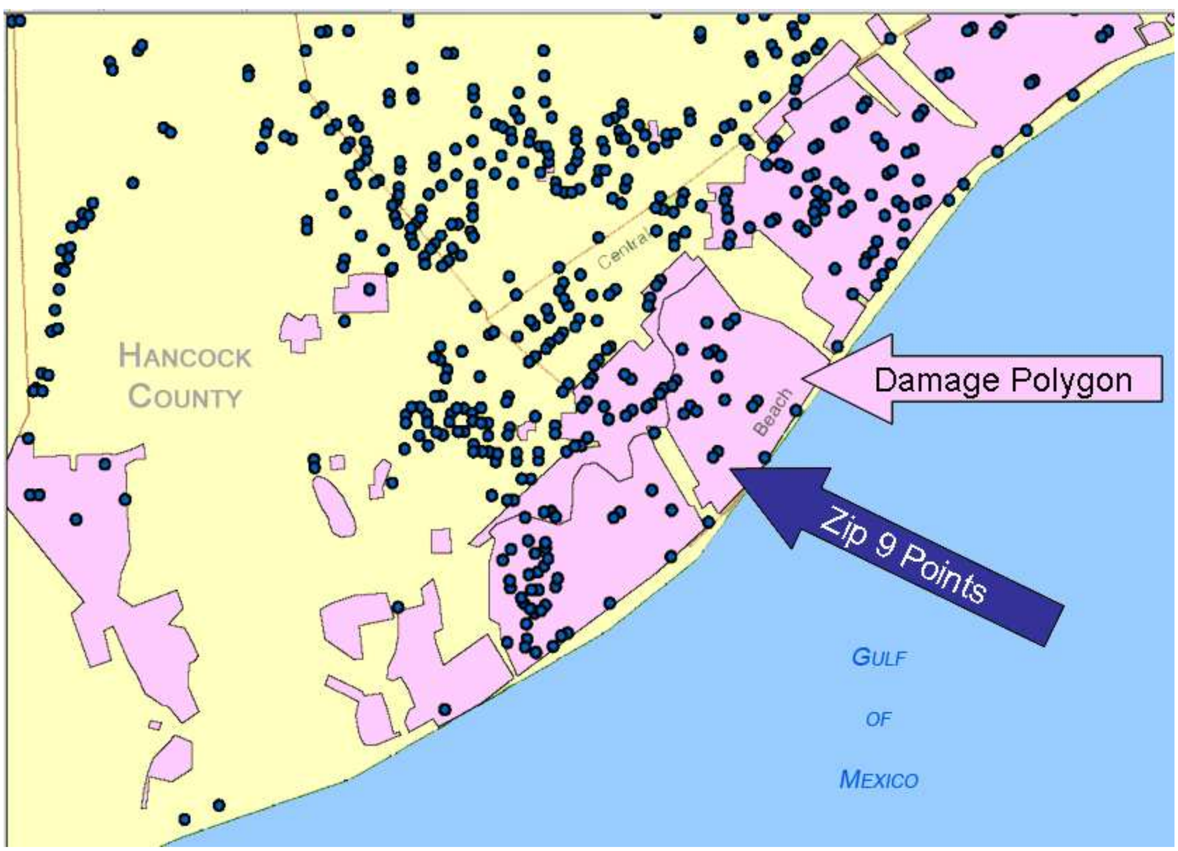

Figure 6 - Hancock County - Damage Polygons and ZIP 9 Points

The generation of damage polygons, through a photo interpretation process, was first performed using NOAA imagery along the coastal areas. Based on NOAA's internal requirements to examine areas for damage to coastal navigation structures or channels, initial photography is taken primarily of the coastline. This photography was very useful for purposes of this analysis. The orthophotographic imagery from the HMTAP program, which was available later in the process, was also utilized. The orthophotographic imagery was used to extend the initial analysis from coastal areas into the effected counties, and beyond the extent of photo coverage provided by the NOAA imagery. The analysis entailed a comprehensive review of all orthophotographic imagery to assess and delineate polygons that defined areas of catastrophic damage as established by the criteria provided herewith. Figure 7 shows the extent of the NOAA imagery as associated with a portion of the Mississippi and Louisiana coastal areas. For complete coverage of the imagery acquired by NOAA, refer to their website (www.noaa.gov).

Figure 7 - Extent of NOAA Imagery for Hancock County

Because tax parcel data was available in digital form (i.e. polygons) for certain counties, the analysis included the identification of specific properties that were associated with damage polygons. For the most part, non-coastal areas of the counties did not experience catastrophic damage in large "contiguous" areas. Damage extents in the non-coastal portions of the counties were more generally characterized by individual houses or small groups of houses that did not facilitate delineation of larger polygonal shapes coinciding with ZIP 9 points or even complete extent of a parcel.

Because of this, the non-coastal area damage polygons were not large enough to perform a ZIP 9 analysis. Therefore, the analysis "intersected" damage polygons with the tax parcel data where it was available in Mississippi (Figure 8). The results of this analysis were a list of those tax parcel IDs and addresses which had damage, with this information being forwarded to FEMA as supplemental information.

In order for a geospatial process for catastrophic damage assessment to be highly successful, it ideally must be completed within the first few days after a disaster event. Otherwise, the deployment of inspectors can achieve similar (but more costly) results during a comparably long time frame. Traditional inspection methods will likely still be more expensive. The timing of imagery acquisition is ideally accomplished in a very coordinated fashion to collect photographs of the most severely damaged areas within the first day following the event. Flood waters from storm surge may still be visible days after an event, or if waters have receded, the imagery may still reveal clear debris lines as evidence of "prior wetness" that can define a plain for a high water line.

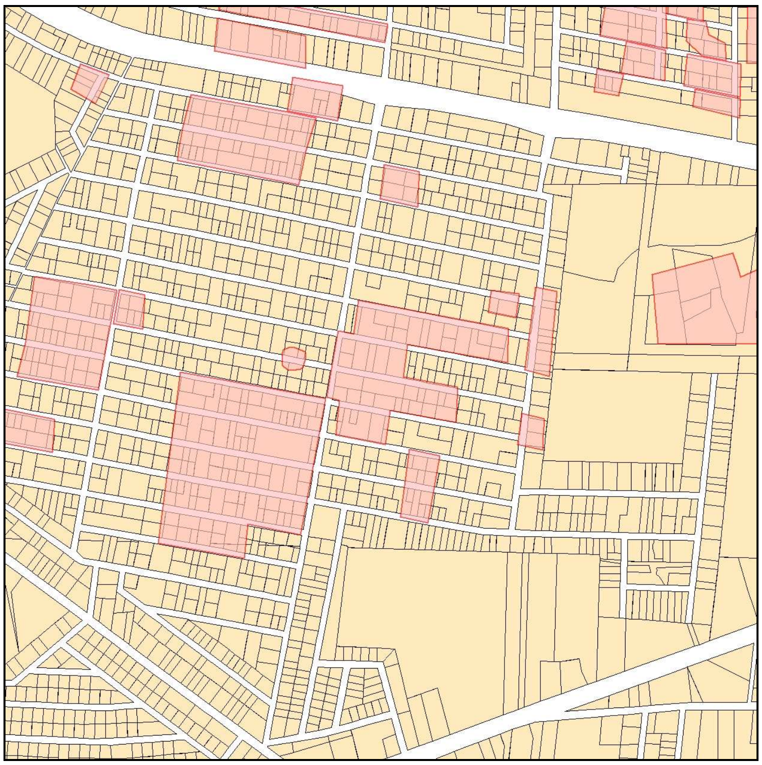

Figure 8 - Parcels and Damage Assessment Polygons

Since each hurricane event, and any associated residential damage, will be different, the type and quality of spatial GIS data that is available will likely vary from region to region. These varying characteristics require flexibility in any analytical approach, and adjustments to the strategy employed for each event.

A primary lesson learned in this effort is that pre-staging of data for a major event is highly desirable, and without pre-staging, it becomes necessary to tailor an analysis to the available data. For example, large contiguous areas of damage can be delimited by large polygons, and in such a case these data were well suited for a ZIP Code (9 digit) analysis. However, in rural portions of the counties, the damage polygons were generally small and isolated. ZIP Code-level analysis is not appropriate for these small, scattered polygons (in some cases, a single residential structure). In such cases, it would be better to use tax parcel polygons, which can be pre-staged and verified with tax roll information.

CONCLUSION

A part of a standard post-project quality control program, FEMA verified the accuracy of the geospatial process through statistical assurance sampling. A total of four thousand five hundred and seventy two (4,572) quality control field inspections were conducted by FEMA using in-house and contract inspectors for the areas effected by Katrina. This represented over 3% of the classified structures. This QC effort was also used to validate the average flood depths that the process arrived at in the areas subject to ponding. In many cases, the actual flood levels were determined by field inspectors to be greater than reported by the geospatial analysis, but the geospatial analysis was intended to be conservative.

Approximately 150,000 homes were analyzed/classified using the geospatial method for Katrina. There were only a few homes found during the quality control inspections that were incorrectly classified as totally destroyed, and this was due largely to issues associated with the use of ZIP code areas for reporting purposes. These few cases of misclassification that occurred were in the coastal surge areas of Mississippi. Overall, however, the analysis proved to be statistically valid, cost effective and timely, as compared to physical inspections, in large, catastrophically damaged areas.