1. Introduction

Hurricane Ivan made landfall as a Category 3 hurricane on September 16, 2004, near Gulf Shores, Alabama, with hurricane force winds extending up to 105 miles outward from the center of the storm. Many of the barrier islands exposed to Hurricane Ivan's strongest winds are low lying and could not contain the storm surge associated with the storm. Coastal storm surge flooding crossed the barrier islands, undermining buildings and roads, and opening new island breaches. In addition to the storm surge, breaking waves eroded dunes and battered structures.

The purpose of this project is to provide immediate coastal flood hazard information to local, regional, State and Federal agencies via high resolution maps that illustrate coastal flood impacts from Hurricane Ivan, which can be used during recovery, mitigation, and redevelopment.

2. Methodology

The storm surge inundation maps were developed for the four coastal counties most severely affected by the storm: Baldwin County, Alabama, and Escambia, Santa Rosa, and Okaloosa Counties, Florida. In addition to showing effective Flood Insurance Rate Map (FIRM) data, the maps provide the following information:

- ✓ Surveyed coastal high water mark (HWM) flood elevations;
- ✓ Coastal flood inundation limits;
- ✓ Inland limits of waterborne debris;
- ✓ Coastal storm surge elevation contours; and
- ✓ Approximate recurrence interval(s) associated with the observed flood elevations.

The methods for generating each of these elements are discussed in greater detail below.

2.1 High Water Mark Collection

Under separate task orders, field and survey crews from URS and URS Team subconsultants, Dewberry and PBS&J, were deployed to interview residents, find evidence of coastal high water levels, take digital photographs, and survey coastal HWMs from Hurricane Ivan. Coastal HWMs included mud lines, water stains, debris, and eyewitness testimony. For each HWM, the field crews completed a form that contained detailed information about the mark, including estimated storm surge heights. These estimates were referenced to the normal range of tides as best estimated by the observers. The purpose of these observations was to provide an initial of estimate water levels before the surveyors' work was completed. The coastal HWM flagging crews were deployed on Tuesday, September 28, 2004, and were shortly followed by the survey crews.

The survey crews followed the field crews 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. Wherever possible, the finished floor elevations of structures adjacent to the coastal HWMs were collected. This information may be used at a later date for possible damage assessments or Hazard Mitigation Grant Program applications. Coastal HWM locations were surveyed horizontally in North American Datum of 1983 (NAD 83), State Plane feet, and vertically in North American Vertical Datum of 1988 (NAVD88) 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.

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
- 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.

Based upon the location and type, each HWM was classified as either "indoor" (I), "outdoor" (O), or "debris" (D). "Indoor" HWMs are located inside a structure and are unlikely to include wave effects. "Outdoor" and "Debris" HWMs may or may not include wave effects, depending on location and local flooding characteristics. A more detailed discussion of the coastal HWM collection and results will be presented in a separate report currently under development by FEMA.

2.2 Inundation Mapping

Flood inundation limits for Hurricane Ivan were created for the coastline of Baldwin, Escambia, Santa Rosa, and Okaloosa Counties by mapping the coastal HWM elevations onto digital, pre-storm topographic contour data. These inundation limits represent the inland extent of flooding caused by the Hurricane Ivan storm surge. In areas where the coastal HWMs were close together but elevations differed significantly (more than 2-3 feet), engineering judgment was used to interpolate the inundation limit between coastal HWMs.

According to the data reported by the coastal HWM field crews, a majority of the coastal HWMs were recorded as reflecting storm surge only and did not include wave heights. Where the coastal HWM descriptions indicated that the point contained the effects of wave heights, the coastal HWM was not used directly. Instead, water level without wave effects was estimated (i.e., storm surge elevation) based on surrounding coastal HWMs. Coastal HWMs that were identified as including wave runup were used directly to map the inundation limit. It is important to note that FEMA's effective FIRMs include local wave effects and therefore may not be directly comparable to this surge inundation mapping.

In areas where the mapped waterborne debris line was landward of the initial mapped inundation limit, it was assumed that the debris line represented the minimum extent of flooding. Therefore, the inundation limit was adjusted to match the debris line. This generally occurred in areas between widely spaced coastal HWMs, where the inundation limit was interpolated.

Based on reports, aerial photographs, visual observations made by coastal HWM field crews, and input provided by community officials, it was determined that many of the barrier islands in the hardest hit areas were overtopped and the sand dunes either no longer remain or were inundated. Therefore, these barrier islands were generally shown as completely inundated on the maps.

The topographic data sources outlined below were utilized for the inundation mapping. At the time this project was conducted, post-hurricane topography was not available for the study area.

Baldwin County, Alabama

Woolpert, LLC, 1-ft and 5-ft contour interval mapping, dated 2001, prepared for Baldwin County, Alabama, Scales 1:12000 and 1:24000, NAVD88.

Escambia County, Florida

Analytical Surveys, Inc., 1-ft and 2-ft contour interval mapping, dated 2003, prepared for Escambia County, Florida, NAVD88.

Okaloosa County, Florida

Okaloosa County GIS Department, 2-ft contour interval mapping compiled from aerial photographs dated, February 1999 (Fort Walton Beach and Niceville areas), Scale 1"=100', NAVD88.

Okaloosa County GIS Department, 1-ft contour interval mapping compiled from aerial photographs dated, September 2001 (Destin area), NAVD88.

Florida Department of Environmental Protection, 5-ft and 10-ft contour interval mapping digitized from U.S. Geological Survey 7.5-Minute Series Topographic Maps dated 1970 - 1987, Scale 1:24000, National Geodetic Vertical Datum of 1929 (NGVD29).

Santa Rosa County, Florida

Florida Department of Environmental Protection, 5-ft and 10-ft contour interval mapping digitized from U.S. Geological Survey 7.5-Minute Series Topographic Maps dated 1969 and 1973, Scale 1:24000, NGVD29.

2.3 Debris Mapping

Under a separate task order, the inland limits of waterborne debris were mapped for FEMA. The area evaluated was from Fort Morgan (Baldwin County), Alabama to Navarre Beach (Santa Rosa County), Florida. The debris lines were delineated based on an interpretation of digital aerial color photography that was flown by the U.S. Army Corps of Engineers a few days after the storm. Photo-interpreters inspected the aerial imagery to identify high concentrations of waterborne debris, with some interpolation necessary in areas of dense vegetation or standing water. At the time of this project, the aerial photography had been georeferenced but not orthorectified. As a result, the debris limits have an estimated accuracy of ±75 feet in any direction. In addition, the debris line shown on the inundation maps are preliminary; final results were not available at the time of inundation mapping.

Because identification of the debris line from the aerial photographs was often subjective, an attribute of "1" was assigned in the mapping database to sections of the debris line for which there is high confidence in the inland limit, while an attribute of "2" was assigned to those sections for which the inland limit of the debris line had been estimated.

2.4 Surge Contour Mapping

Surge contours were mapped at one-foot intervals in the impacted areas of Baldwin, Escambia, Santa Rosa, and Okaloosa Counties. The contours are based upon the surveyed coastal HWM elevations. The coastal HWM elevations were used to find patterns in the coastal storm surge as it pushed against the open coast and into the inland bays. The known path and landfall location of Hurricane Ivan, 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. Assumptions are made in some locations to allow the contours to "step" up or down at one-foot intervals. Because of the inherent uncertainty 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 assessed from the coastal HWMs.

Wave effects were not considered in the development of the storm surge contours. Wave crest elevations can be estimated at the shoreline, or other areas not sheltered from the coastal flooding source by structures (e.g., seawalls, bulkheads) or dense vegetation, by applying a standard FEMA method. In this method, the depth of the water must be determined at a point of interest by subtracting the ground elevation from the surge height (derived from a HWM or surge contour elevation). This water depth is then multiplied by 1.55 to obtain the height of the wave crest above the ground at that point.

2.5 Recurrence Intervals

A limited assessment was made to determine the magnitude of the Hurricane Ivan storm surge elevation compared to a reasonable assessment of corresponding coastal high water levels that have a 1% chance of being equaled or exceeded in any given year (i.e., the “100-year event”).

The recurrence interval of an event is a statistical descriptor, and can be applied to various storm characteristics, such as the storm surge levels and meteorological conditions. This assessment focused on the full effects of the storm surge levels, and relied on the methods and results of the 1997 Hurricane Opal storm surge study prepared by Dewberry & Davis (1997). This Hurricane Opal storm surge study examined several lines of evidence and resulted in an assessment of the open coast storm surge height versus recurrence interval for several specific locations. One of these locations was National Oceanic and Atmospheric Administration (NOAA) gage number 8729840, located on the Pensacola Municipal Pier, within Pensacola Bay. At the time of the Hurricane Opal study, storm surge levels that had occurred over a 73-year observation period were adjusted, plotted, and fitted with a trend line. The trend line was then used to extrapolate a 1%-annual-chance storm surge elevation of 9.2 feet NGVD29 at this gage.

Although this specific gage failed during Hurricane Ivan, a HWM located in the gage housing indicated a maximum storm surge elevation of 10.2 feet NGVD29. This storm surge elevation was applied to a trend line incorporating recent storm activity. The results indicate a recurrence interval of 157 years at this location for Hurricane Ivan. An estimate of the area that experienced surge elevations greater than the 1%-annual-chance event was then made based upon the results at Pensacola Pier and a review of the coastal HWMs from building interiors (to avoid local wave effects). This zone is shown highlighted in green on the surge inundation map overview diagram on each map panel.

It is important to note that the storm surge elevation, and the associated recurrence interval, applies only to the area surrounding the Pensacola Municipal Pier. Local effects significantly alter the storm surge levels in different parts of the overall estuary and adjoining waters. A review of the tide gage data for other locations, as presented in the 1997 report, showed that none of the gages within the area affected by Hurricane Ivan had a length of record sufficient to perform a meaningful recurrence interval assessment.

A more detailed discussion of the recurrence interval calculations is provided as Attachment A.

3. Presentation of Results

The methodologies and information outlined above are presented in a set of maps. Three different map products were created:

- Hurricane Ivan Storm Surge Inundation Maps (239 panels) – These maps are created at 1”=500’, and show the coastal HWMs, inundation limit, debris line, storm surge contours, and effective FIRM data on aerial photographs provided by each of the counties.
- Overview Map (1 panel) – Shows the entire four-county study area, including the HWM locations, inundation limits, surge contours, and numbered panel grid (see Figure 1). A second version of this map, showing all of the above information along with the FIRM panel grid, was also produced.
- Paneling Grid Index (4 panels) – A map was created for each county showing both the effective FIRM panel outlines and numbers, as well as the inundation map panel grid and numbers.

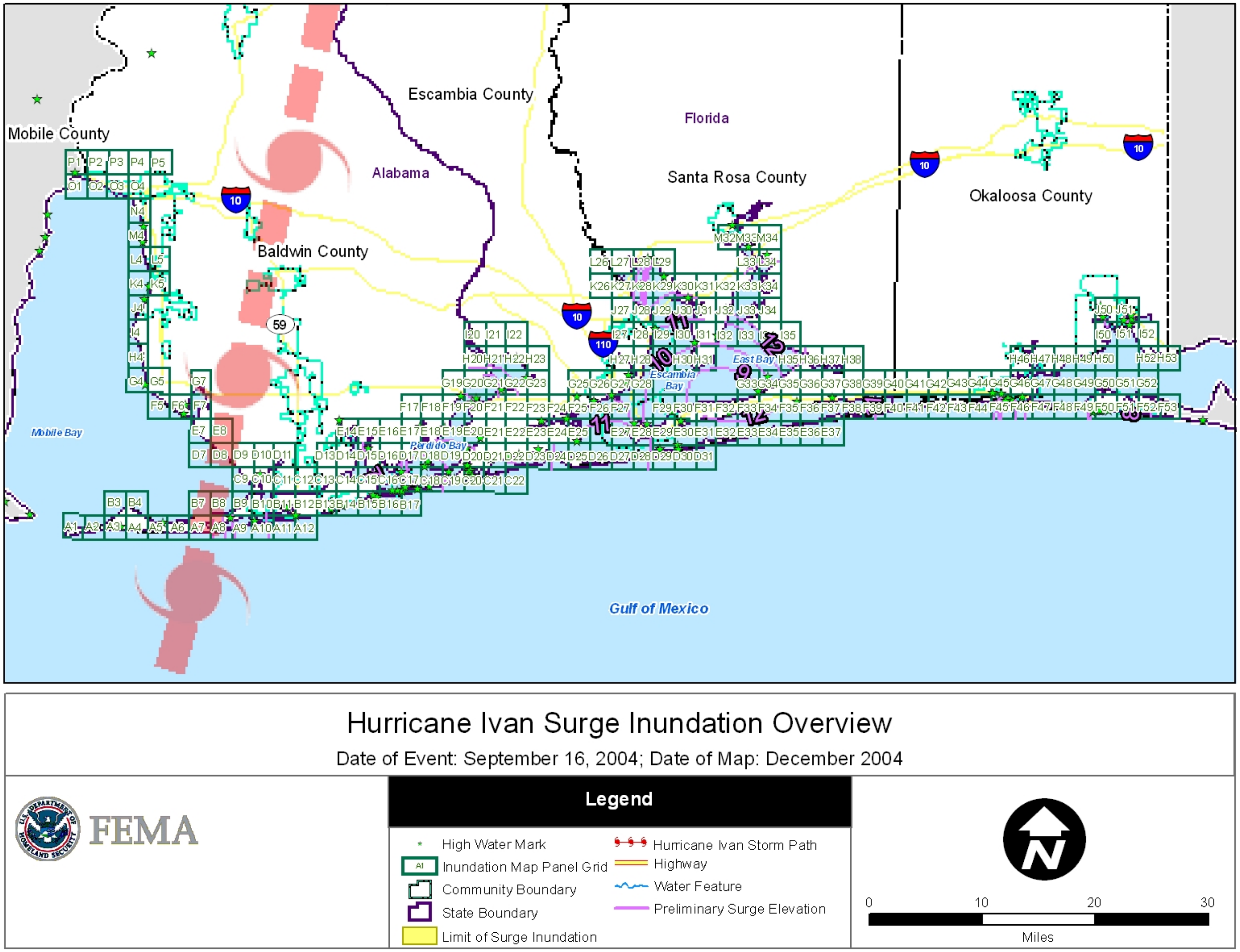

Figure 1: Overview map showing Hurricane Ivan surge inundation levels and inundation map paneling scheme.

Please note, to facilitate comparison to FEMA's effective FIRMs, all elevation data presented in Baldwin County, Alabama are referenced to the vertical datum of NAVD88, and elevation data presented in Escambia, Santa Rosa, and Okaloosa Counties, Florida are referenced to NGVD29. However, it is important to note that the elevations of most coastal HWMs and all storm surge contours do not include wave heights; as a result, these elevations are not directly comparable to the BFEs shown on the effective FIRMs.

Individual reports summarizing the coastal HWM (URS Corporation, 2004) and debris mapping efforts are being prepared by FEMA under separate task orders.

Acknowledgements

FEMA gratefully acknowledges the assistance provided by the many Federal, state, and local agencies and organizations that have provided data, technical support, and other critical information for this project. Specifically, the NOAA National Weather Service provided data on the storm path and parameters; the U.S. Army Corps of Engineers provided post-hurricane aerial photographs and tide gage data; and numerous state, county, and community officials in the four impacted counties provided aerial photographs, topographic data, and valuable input on flood damage and inundation.

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Attachment A

Preliminary Evaluation of the Storm Surge Parameters for Hurricane Ivan
in the Gulf Shores, Alabama to Destin, Florida Vicinity

1. Purpose

One goal of the overall recovery-mapping task is to make a preliminary assessment of the flood zone boundaries shown on the effective Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) in light of the storm surge caused by Hurricane Ivan. An important step in this assessment is to determine the magnitude of the actual Hurricane Ivan storm surge heights compared to a reasonable assessment of corresponding coastal high water levels that have a 1% chance of being equaled or exceeded in any given year (100-year event).

2. Limitations

It must be emphasized that this work was carried out as an emergency assignment, with the purpose of making a quick assessment to support subsequent coastal flood recovery analyses and mapping. It is understood that this ranking of the Hurricane Ivan storm surge is a preliminary effort, and that a follow-up task is planned. This follow-up work will establish the 1%-annual-exceedence storm surge elevations according to FEMA's guidelines for developing a Flood Insurance Study. There may be adjustments of the approximate results given in this report once this more rigorous, follow-up study is completed.

3. Approach

The recurrence interval of a flood is often used as a descriptor of its magnitude. For coastal storm surges, it corresponds to a level that can be statistically related to a very large population of events occurring over many years. The most common descriptor is the "100-year event," which is defined as the event that has a 0.01 (1%) statistical probability of being equaled or exceeded in any given year.

Not only is the recurrence interval of an event a statistical descriptor, it can be applied to the surge level at a given location (surge recurrence) or to the intensity of the storm event (meteorological recurrence). These may not be the same because local geography interacts with the storm intensity to produce the storm surge levels. Depending on an individual storm track, one location may be shielded and another location may be exposed to the full effects of the wind, thus causing different storm surge levels at different locations during a single storm. This assessment focuses on the recurrence of storm surge elevations.

4. Estimation of the Hurricane Ivan Recurrence Interval

In light of the available data, the most expedient method to evaluate the recurrence interval of the Hurricane Ivan storm surge would be to adopt the method and results of the 1997 FEMA-funded study conducted by Dewberry & Davis under subcontract to Woodward-Clyde Federal Services (Dewberry & Davis, 1997). This study, which was completed over a period of several months, examined the storm surge produced by Hurricane Opal along the Florida Panhandle coast. The study examined several lines of evidence and resulted in an assessment of the open coast storm surge height verses recurrence interval for several specific locations, including Pensacola Bay. The results of the 1997 Hurricane Opal study were used as the basis for the preliminary assessment of the Hurricane Ivan storm surge parameters developed here.

The only tide gage with a sufficient record to estimate a recurrence interval in the post-Hurricane Opal study was National Oceanic and Atmospheric Administration (NOAA) gage number 8729840, which is located on the Pensacola Municipal Pier, inside of Pensacola Bay. At the time of the Hurricane Opal study, the data recorded by this gage included measured storm surge levels of 15 hurricanes and tropical storms that occurred over a 73-year observation period. The water levels included the tide at the time of the storm surge and were adjusted for an annual sea level rise rate of 0.008 feet per year. These adjusted storm surge heights were plotted (Dewberry & Davis, 1997; Figure 18) and fitted with a trend line. The trend line was used to extrapolate to the 100-year recurrence interval, yielding a value of 9.2 feet at this gage. The trend line and the supporting hurricane and tropical storm surge height measurements have been replotted and are shown in Figure A-1.

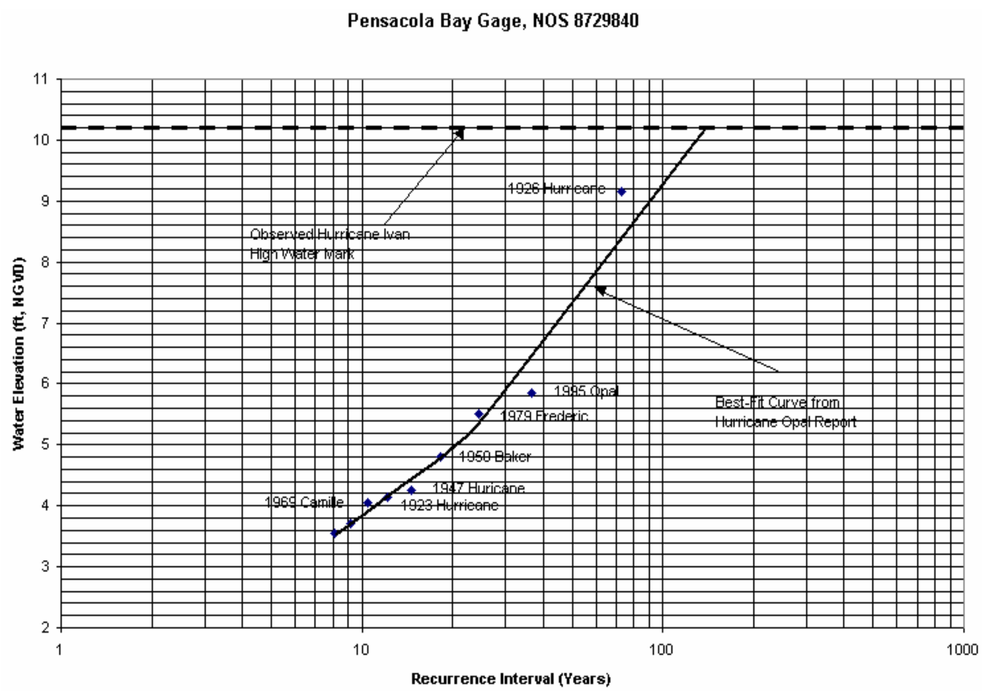

Figure A-1: Replotted hurricane surge recurrence interval data from Dewberry & Davis (1997), Figure 18.

Three storms have made landfall near Pensacola since 1995: Hurricane Danny in 1997, Hurricane Georges in 1998, and Hurricane Lili in 2002. Examination of the water levels at the Pensacola gage for these events has shown that these new data would not significantly change the trend line shown on Figure 18 of the Hurricane Opal report. This justifies continuing the use of the results of this report in the present analysis of the recurrence interval of the Hurricane Ivan storm surge.

NOAA gage 8729840 failed during the Hurricane Ivan storm surge, but interior watermarks in the gage housing indicated a 10.2-foot maximum storm surge elevation (USACE, 2004). The gage is located on a pier so as to avoid recording the effects of wave set-up. Local wind set-up within Pensacola Bay may have caused this shore to have a higher level than the opposite lee-shore; however, no adjustment to the water level was made in the present analysis to allow the methods employed here to remain consistent with those used in the post-Hurricane Opal study.

The 10.2-foot Hurricane Ivan storm surge is the highest in the 82-year record of the Pensacola tide gage. If this storm surge is regarded as an outlier to the trend shown on Figure A-1, then it would fit at a recurrence interval of 157 years. Because these results are based on the water level observed at the Pensacola tide gage, this storm surge elevation and its estimated recurrence interval only apply to the area of the Pensacola City waterfront; local effects significantly alter the storm surge levels in different parts of the overall estuary and adjoining waters.

5. Open Coast Surge

The NOAA tide gage record at Pensacola does not contain the effects of wave set-up. To apply the gage data to open beaches along the Gulf of Mexico, adjustments to the water levels would have to be applied. In the Hurricane Opal report, there is considerable discussion of the proper algorithm and proper data to be applied in the Florida Panhandle area. The authors concluded that a uniform value of 2.5 feet for wave set-up is proper for the 100-year recurrence interval. The report also explained that the open coast base flood elevation should be, "a (lower-bound) set of water elevations clearly justified by all available measurements of hurricane flooding events." The report suggested combining the results from several locations across the Florida Panhandle coast to establish the area-wide open coast base flood elevation. This resulted in a recommended elevation of 10.5 feet as the 100-year recurrence interval storm surge level, taken to include the 'steady' component of wave set-up. This value has been adopted for the current assessment along the open Gulf shore and beaches.

6. Hurricane Ivan Surge Magnitude and Extent

A FEMA coastal High Water Mark (HWM) survey provided observed values of the maximum flood elevations throughout the area impacted by Hurricane Ivan (URS, 2004). The measured coastal HWMs along the open beaches of the Gulf of Mexico are above the 100-year elevations from just west of Gulf Shores, Alabama to just east of Destin, Florida. The measured coastal HWMs include the effects of wave set-up. Only data taken from building interiors were used to evaluate the extent of the zone thought to be above the 100-year values. This zone is shown on Figure A-2 and has been applied to the map set that accompanies this report.

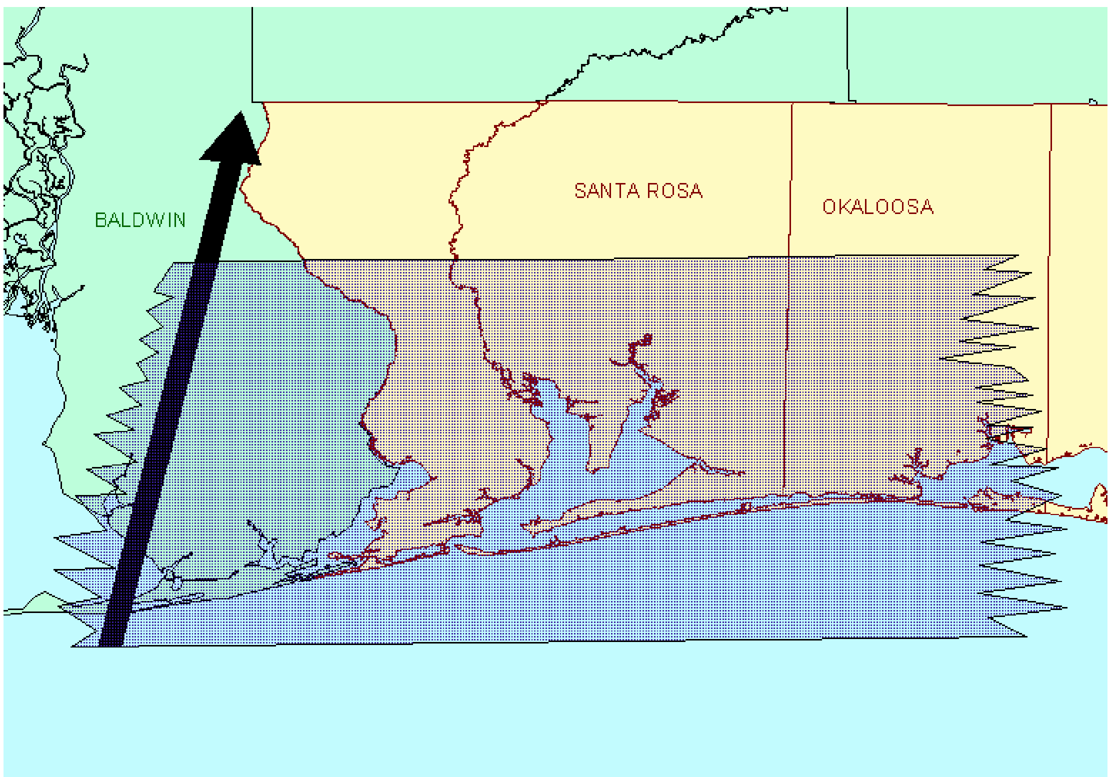

Figure A-2: Area impacted by conditions in excess of the 100-year expected return period for surge conditions.

The Hurricane Ivan coastal HWM data clearly show that the storm surge levels varied within the bays. This observation indicates that the 157-year recurrence interval determined from the Pensacola Bay tide gage applies to a limited area within the bay. Comparable tide gage data are not available to assess the Hurricane Ivan surge recurrence interval of Wolf Bay, Perdido Bay, and the various arms of Pensacola Bay. Extreme storm surge conditions extended along a 90-mile length of the open coast, reaching 5 miles west and 85 miles east of the storm track. As an initial assessment, it is reasonable to assume that conditions capable of producing hurricane storm surge elevations exceeding the 100-year recurrence magnitudes extended inland over this whole length of the coast.

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