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Introduction

On September 18, 2004, the Mitigation Division of the Department of Homeland Security's Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to the States of Alabama and Florida to assess damages caused by Hurricane Ivan. This report presents the MAT's observations, conclusions, and recommendations as a result of those field investigations.

Chapter 1 provides an introduction, a discussion of the event, historical information, and background on the MAT process. Chapter 2 discusses the floodplain management regulations and the codes and standards that affect construction in Alabama and Florida. Chapter 3 provides a general characterization of the observed flood and wind effects, and it documents observed hazard mitigation lessons learned and best practices. Chapter 4 details structural systems' performance in residential and commercial buildings as well as in critical and essential facilities. Chapter 5 presents an assessment of building envelope performance. Chapter 6 discusses damages and functional loss to critical and essential facilities. Finally, Chapters 7 and 8 present the conclusions and recommendations that are intended to help guide the reconstruction of hurricane-resistant communities in Alabama and Florida and construction in all hurricane-prone regions. Additional information related to the specific technical issues is provided in the appendices.

1.1 Hurricane Ivan – the Event

The National Hurricane Center (NHC) has issued its report on Hurricane Ivan.[1] The report traces the history of the hurricane and presents meteorological statistics, casualty and damage statistics, and a forecast and warning critique. In addition, the National Weather Service (NWS) office in Mobile, Alabama, has prepared its own report on the storm.[2] The NWS report includes hourly 0.5-degree radar reflectivity images taken from the NWS WSR-88D Doppler Weather Radar in Mobile, Alabama, prior to, during, and after landfall; observed peak wind gusts and times; observed storm surge data; and 48-hour rainfall totals.

[1] Stewart, Stacy R., "Tropical Cyclone Report Hurricane Ivan 2-26 September 2004," National Hurricane Center Report, 16 December 2004, Revised 6 January 2005.

[2] National Weather Service Mobile – Pensacola, "Powerful Hurricane Ivan Slams the US Central Gulf Coast as Upper Category-3 Storm," www.srh.noaa.gov/mob/ivan_page/Ivan-main.htm.

THE SIGNIFICANCE OF HURRICANE IVAN

Hurricane Ivan was the most severe hurricane to strike the eastern Alabama, western Florida coastline in many decades. The significance of Ivan and its effects are summarized below:

- Ivan approximated or slightly exceeded design flood conditions on many of the affected barrier islands, with the highest open coast flood levels near the area of landfall.
- On the bay and sound shorelines between Gulf Shores, Alabama, and Santa Rosa County, Florida, Ivan greatly exceeded a design flood event. Flood levels during the storm generally exceeded the Base (1-percent annual exceedance probability) Flood Elevations (BFEs) on many Flood Insurance Rate Maps (FIRMs) by several feet, calling into question the adequacy of the storm surge modeling used as the basis for the FIRMs and highlighting the importance of adding freeboard when constructing in coastal floodplains.
- Flood and erosion damages on barrier islands were generally consistent with expectations. Buildings closest to the shoreline sustained the most severe damage, and buildings in areas with the narrowest beaches and dunes before Ivan struck sustained more damage than buildings in areas with wide beaches and healthy dunes before the storm.
- On barrier islands, newer pile- and/or column-supported buildings elevated above the BFE generally performed well; however, they sustained non-structural damage to areas below the elevated floor. Some newer buildings elevated to the BFE sustained flood damage (structural and non-structural) above and below the BFE. Many older, post-FIRM buildings sustained significant structural damage due to piling failures (e.g., inadequate pile embedment, pile breakage, poor connections between the piles and the elevated building, etc.) or inadequate foundations, or because of insufficient elevation.
- On the barrier islands, several relatively new (less than 10-12 years old), three- to five-story multi-family buildings, constructed on shallow foundations in flood Zones B, C, or X, collapsed due to erosion and undermining. This is the first time that recent post-storm investigations have observed total failures of multi-family buildings due to flood effects.
- Flood damage along bay and sound shorelines was far beyond expectations. Even newer buildings constructed in compliance with minimum community foundation and elevation standards sustained severe damage due to waves, floodborne debris, and velocity flow. Flood (inundation) damage occurred in many areas outside the Special Flood Hazard Area (SFHA) shown on FIRMs. The only types of buildings that generally performed well in these areas were those built on piles or stemwall foundations with their lowest floor above Ivan's wave crest elevation.
- Ivan was less than a design wind event when expected loads are compared to the 2001 Florida Building Code (FBC) and the 2000/2003 International Building Code (IBC) and International Residential Code (IRC) load provisions. These codes use a design wind speed map developed for the 1998 edition of ASCE 7 where substantial increases in design wind speeds were introduced in this region.
- Ivan was a design wind event from the Gulf Shores area east through Orange Beach and Pensacola Beach and inland in some areas as far north as I-10 for structural frames of buildings built under Standard Building Code (SBC) 1979 through 1997 wind load provisions for structural systems. In addition, Ivan was a greater than design wind event for this same geographic area when estimated actual loads on roof corners and edges are compared to the SBC 1979 through 1997 wind load provisions for cladding elements.
- Wind damage to both commercial and residential buildings was widespread in the southern portions of Baldwin County, Alabama, and in the southern portions of Escambia and Santa Rosa Counties, Florida.
- In general, buildings functioning as critical and essential facilities did not perform significantly better than their commercial-use counterparts. As a result of poor building envelope performance, the operations and response at many critical and essential facilities were hampered or shut down and taken off-line after the hurricane. Most critical and essential facilities in the impacted area were housed in older buildings and most, if not all, apparently were not mitigated to resist known hurricane risks.
- Hurricane Ivan generated a greater number and value of flood claims than any other coastal flood event in the history of the National Flood Insurance Program (NFIP) – over 18,000 claims valued at over 1 billion dollars.
- Due to the severe destruction, the MAT was tasked to assess performance of buildings (residential, commercial, critical and essential facilities), floodplain management regulations and FIRMs, building codes, and construction practices.

When Hurricane Ivan made landfall on September 16, 2004, the NHC reported it as a major hurricane that produced sustained winds of 121 miles per hour (mph), torrential rains, coastal storm surge flooding of 10 to 16 feet above normal high tide, and large and battering waves along the Alabama and western Florida Panhandle coastline. The NWS reports that on September 15 through 16, Ivan spawned 23 tornadoes[3] in Florida and produced as much as 10 to 15 inches of rainfall in some areas. Widespread damage occurred, including the damage and/or destruction of buildings, infrastructure, and beach erosion.

After landfall, Hurricane Ivan gradually weakened over the next week, moving northeastward over the southeastern United States and eventually emerging off the Delmarva Peninsula as an extratropical low on September 19, 2004. The remnant circulation of Ivan then moved southwestward, passed over South Florida into the Gulf of Mexico, and became a tropical storm again on September 23. As a tropical storm, Ivan made its second landfall over southwestern Louisiana on September 24, and finally dissipated inland over East Texas later that day. Figure 1-1 shows Ivan's path associated with its initial landfall on September 16, 2004.

[3] The MAT did not investigate any sites impacted by tornadoes spawned by Hurricane Ivan.

Figure 1-1.
Path of Hurricane Ivan

Beyond the normal NWS Automated Surface Observing System (ASOS) (the nation's primary surface weather observing network stations in the area), data were collected at a number of military airports and at a number of sites where universities deployed portable meteorological instruments and towers in front of the advancing storm. The result is that there are a number of surface data observations available for Hurricane Ivan, particularly near the coast. These observations provide a good basis for assessing the performance of various wind field models in describing the geographical distribution of winds throughout the region impacted by Hurricane Ivan.

The flood and wind data and maps of probable maximum wind speeds included in this report reflect the best available estimates at the time of publication. With all hurricanes, there can be localized areas impacted by special features of the storm including convective cells that bring high winds down to the surface. Nevertheless, with the exception of one unofficial observation from a sailboat in Wolf Bay, the surface observations provide a portrait of a wind field that does not contain significant local variations and is generally consistent with the geographical distributions and magnitudes suggested by the leading wind field models. Furthermore, the leading models provide estimates of maximum peak overland surface wind speeds that are within a couple of mph of each other.

Hurricane Categories

Hurricanes are classified in different categories according to the Saffir-Simpson Hurricane Scale. Table 1-1 presents the categories of the Saffir-Simpson Hurricane Scale along with their respective wind speeds, presented as both 1-minute sustained wind speeds and as 3-second peak gust wind speeds. Hurricane Ivan is categorized as a Category 3 "major hurricane" by the NHC in its Tropical Cyclone Report. A "major hurricane" is defined as one that has estimated 1-minute sustained wind speeds (over open water) that exceed 111 mph. For Ivan, the NHC estimated sustained wind speeds at landfall of 121 mph. This is equivalent to the threshold velocity for a Category 3 storm on the Saffir-Simpson Hurricane Scale.

As the storm made landfall just west of Gulf Shores, Alabama, the eye diameter is estimated to have increased to between 46 and 58 miles with the strongest winds occurring in a narrow region near the southern Alabama-western Florida Panhandle border (NHC Tropical Cyclone Report). A number of surface observation sites provided data throughout the coastal region. The data indicate that most of the region impacted by the storm likely experienced Category 1 intensity winds with some areas near the Alabama-Florida border experiencing Category 2 intensity winds. None of the surface wind measurements for overland conditions correspond to Category 3 intensity winds. Category 3 intensity winds may have occurred in relatively small areas along the gulf/land and bay/land interfaces near the Alabama-Florida border. A more complete discussion of wind speed estimates based on surface wind measurements and computer modeling is provided in Section 1.1.2.

Table 1-1. Wind Speeds of the Saffir-Simpson Hurricane Scale

Strength	Sustained Wind Speed (mph)*	Gust Wind Speed (mph)**	Pressure (millibars)
Category 1	74-95	90-119	>980
Category 2	96-110	120-139	965-979
Category 3	111-130	140-164	945-964
Category 4	131-155	165-194	920-944
Category 5	>156	>195	<919

* 1-minute sustained over open water
** 3-second peak gust over open water

1.1.1 Storm Surge Analysis and Discussion

Many of the barrier islands exposed to Hurricane Ivan 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 storm's arrival was concurrent with high tide, which increased storm surge flooding that was estimated at 10 to 16 feet above normal tide levels. Large and dangerous battering waves occurred near and to the east of where the center of the storm made landfall.

National Oceanographic and Atmospheric Administration (NOAA) Gauge 8729840, located on the Pensacola Municipal Pier (Escambia Bay) in Florida, failed during Hurricane Ivan, but interior watermarks in the gauge housing indicated a 10.2-foot National Geodetic Vertical Datum of 1929 (NGVD) maximum water elevation (U.S. Army Corps of Engineers [USACE], 2004). The 10.2-foot water level is the highest ever recorded at the gauge site in its 82-year existence and is thought to reflect storm surge effects only, given that the gauge site is on a pier extending into the bay and that the contribution of Hurricane Ivan wave setup on the water level there was probably small.

An assessment to determine the recurrence interval of Hurricane Ivan was performed based on similar methodology used after Hurricane Opal in 1995. However, although the impacted area was very large with storm surge elevations exceeding the mapped 100-year flood elevations along the open coast and throughout the bays and sounds, only the Pensacola tide gauge was available to use for the recurrence interval analysis. Using this gauge, the analysis determined the recurrence interval was approximately 150 years. Given the limited data, this approximate recurrence interval applies only to the area surrounding the pier. Recurrence intervals in other parts of the affected area could have been higher or lower. Also, local effects (including the over washing of the barrier islands, which was not accounted for in the initial storm surge analysis performed over 20 years ago) significantly alter the storm surge levels in different parts of the area's bays and sounds.

To assist in the long-term recovery and mitigation effort, FEMA performed a Coastal High Water Mark (CHWM) study throughout the impacted area in Alabama and Florida. The study area extended from Dauphin Island, along Gulf Shores, Alabama, eastward to Destin, Florida, and northward into the Florida Panhandle to encompass Perdido, Escambia, and Blackwater Bays. The observations were taken at discrete points distributed along the open coast, the seaward and landward side of barrier islands, within the bays, and on the shores of several embayments.

FEMA's CHWM Survey provided observed values of the maximum flood elevations throughout the area impacted by Hurricane Ivan.[4] Table 1-2 presents a comparison of the High Water Marks (HWMs) and BFEs at the MAT investigation sites.

[4] FEMA 2004. Hurricane Ivan Flood Recovery Maps, http://www.fema.gov/ivanmaps/

Table 1-2. Comparison of HWMs and BFEs for MAT Investigation Sites

MAT Investigation Site	Flood Source	HWMs* (feet**)	FIS Stillwater Elevations (feet**)	BFEs (feet**)
Alabama				
Gulf Shores	Gulf of Mexico	10-14	10.0***	12-13
Orange Beach/ Perdido Key	Gulf of Mexico	12-15	9.9***	12-13
Florida				
Gulf Beach Heights	Perdido Bay	6-7	4.3	5
Seaglades	Big Lagoon	14	8.0	8-12
Pensacola Naval Air Station	Pensacola Bay	10-13	8.0	8-12
Pensacola	Escambia Bay	10-14	5.9/7.2	6-9
South Gulf Breeze	Santa Rosa Sound	10-14	8.0	9-12
West Gulf Breeze	Pensacola Bay	10-12	8.0	7-12
Northeast Gulf Breeze	Escambia Bay	7	4.9	5
Oriole Beach	Santa Rosa Sound	11	8.0	8-12
Floridatown	Escambia Bay	13-16	7.9	11-12
Avalon Beach	Escambia Bay	12	7.9	9
Pensacola Beach	Gulf of Mexico	6-12	10.5****	11-16

* HWMs are approximate stillwater elevations and do not include wave heights.

** In Alabama, elevations are referenced to the North American Vertical Datum of 1988. In Florida, elevations are referenced to the NGVD.

*** Includes wave setup of 2.2 feet.

**** Includes wave setup of 2.5 feet.

The measured CHWMs along the open beaches of the Gulf of Mexico are above the 100-year elevations from immediately west of Gulf Shores, Alabama, to just east of Destin, Florida. The measured CHWMs include the effects of wave setup. Data taken only from building interiors was used to evaluate the extent of the zone thought to be above the 100-year values. This eliminated the possibility of inadvertently including wave height.

Surge elevation contours were mapped in the impacted areas of Baldwin, Escambia, Santa Rosa, and Okaloosa Counties. The contours are based upon the surveyed CHWM elevations (referenced to the North American Vertical Datum of 1988). The CHWM 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 CHWMs indicate a change in storm surge elevation. Because of the inherent uncertainty and the random and irregular spacing of CHWMs, the surge contours represent a generalized maximum storm surge elevation, and required professional judgment in their creation. Within certain surge contours, CHWMs may be higher or lower than the contours if they did not fit the overall pattern assessed from the CHWMs.

Wave effects were not considered in developing the storm surge contours. To estimate the wave heights at the shoreline, standard FEMA methodology may be used, where the depth of water at the shoreline is multiplied by 1.55 to obtain the height of the wave crest above the ground at that point.

Surge elevation contours in Baldwin County are shown in Figure 1-2. HWM elevations along the open coast of Baldwin County were generally 2-3 feet higher than the effective BFEs shown on the FIRM. However, the HWM elevations along some of the inland bays (Bayou St. John, Perdido Bay, and Wolf Bay) were found to differ from the BFEs by only +/- 1 foot. It should be noted that several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

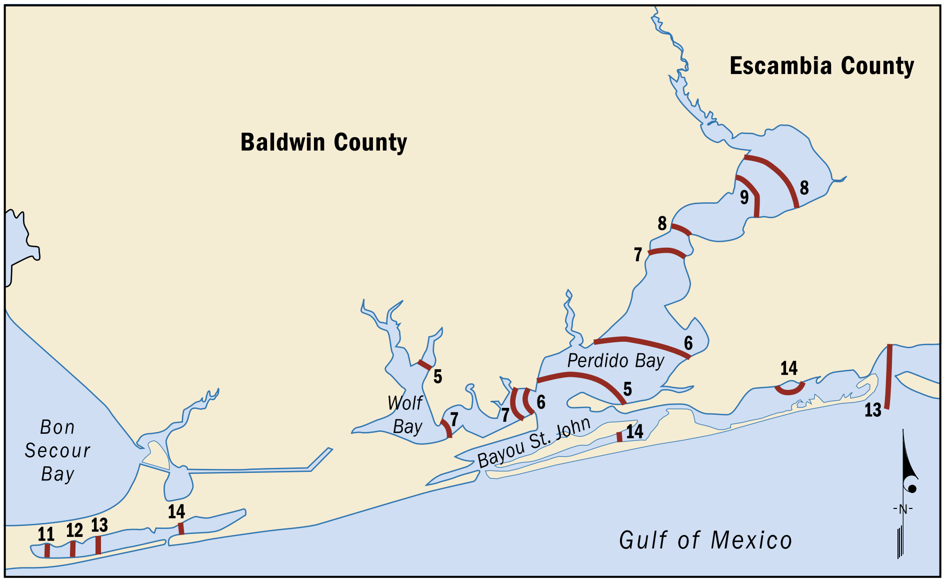


Figure 1-2.
Surge elevation contours in Baldwin County, Alabama

Figure 1-3 shows the surge elevation contours in Escambia County. Here, the HWM elevations in the inland bay areas varied greatly from the effective BFEs. Along Perdido Bay, the HWM elevations were found to be approximately 0-2 feet higher than the effective BFEs. Along Big Lagoon, HWMs were generally 6-8 feet higher than the BFEs. Along Pensacola Bay, they were about 4 feet higher, and along Escambia Bay, generally 5 feet higher. As with Baldwin County, it should be noted that several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

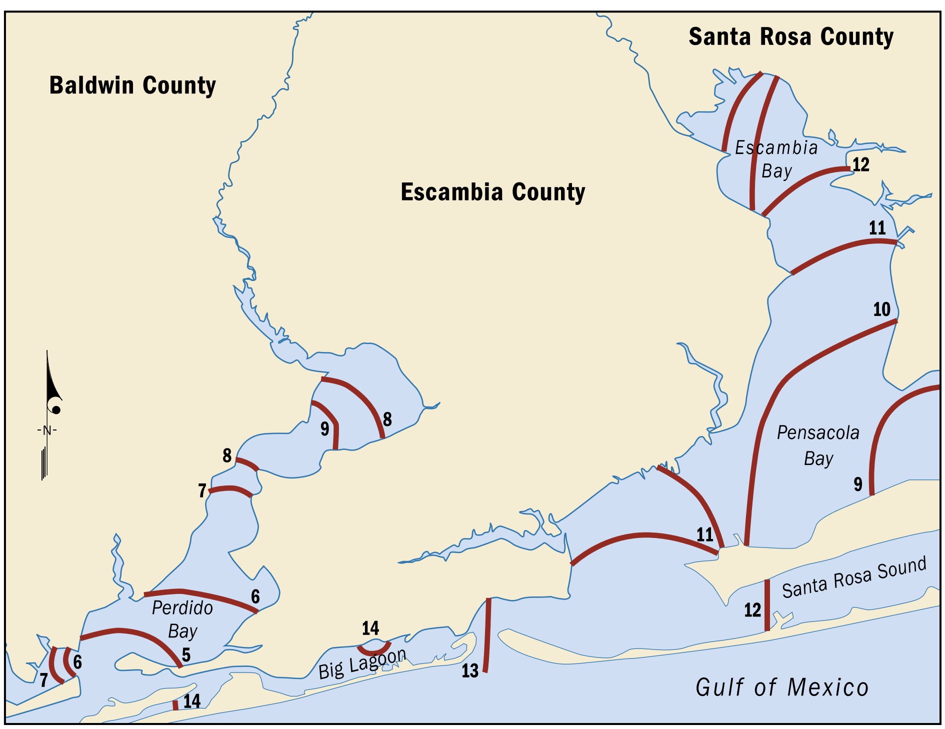


Figure 1-3.
Surge elevation contours in Escambia County, Florida

Figure 1-4 shows the surge elevation contours in Santa Rosa County. The HWM elevations in Santa Rosa County were generally found to be much higher than the effective BFEs in the inland bay areas. Along Pensacola Bay, the HWMs were generally 2-6 feet higher than the effective BFEs. However, there were also instances where the two elevations were equal, such as at Garcon Point along Pensacola Bay (both equal to 10 feet). Along Escambia Bay, the HWMs were found to be approximately 3-4 feet higher than the BFEs, and along East Bay, approximately 3-6 feet higher. Along the northern shoreline of Santa Rosa Sound, the HWM elevations differed from the BFEs by about +2 feet, while along Blackwater Bay, the HWMs were about 2-4 feet higher than the BFEs. As with the other impacted counties, several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

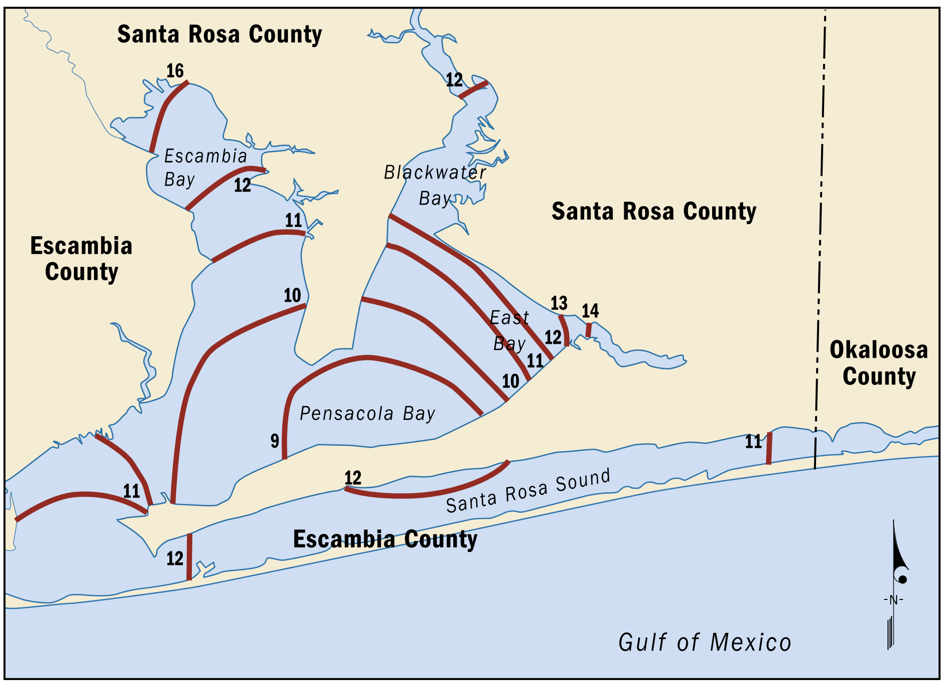


Figure 1-4. Surge elevation contours in Santa Rosa County, Florida

Surge elevation contours for Okaloosa County are shown in Figure 1-5. HWM elevations along the open coast of Okaloosa County were generally equal to or lower than the effective BFEs shown on the FIRM. The HWM elevations along some of the inland bays, such as Boggy Bayou, were found to be 2-3 feet lower than the effective BFEs. Again, it should be noted that several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

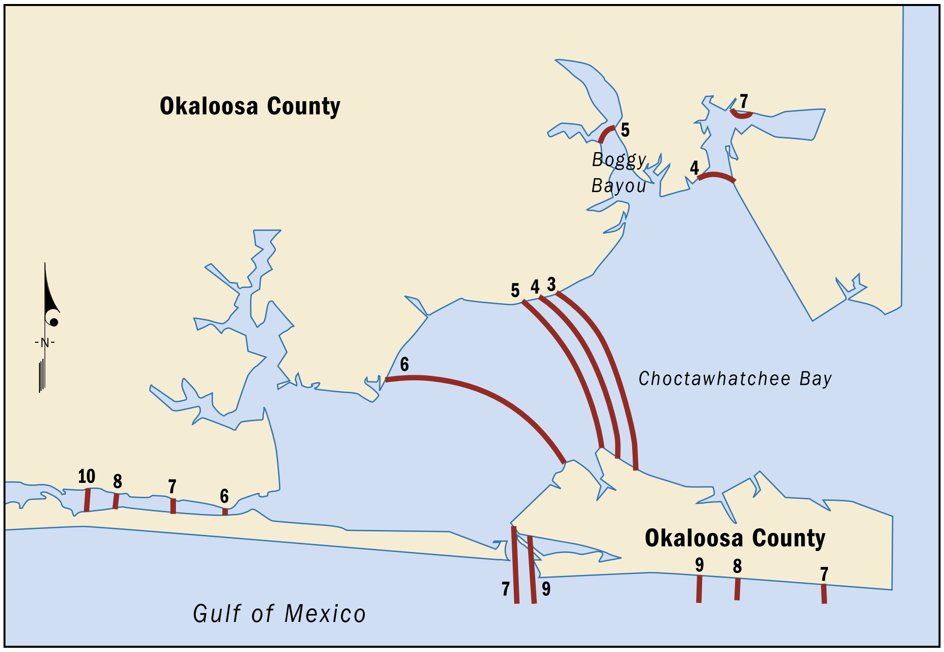


Figure 1-5. Surge elevation contours in Okaloosa County, Florida

The Hurricane Ivan CHWM data clearly show that the storm surge levels varied within the bays. This observation indicates that the 100-year level determined from the Pensacola Bay tide gauge applies to a limited area within the 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.

The NOAA *Sea, Lake and Overland Surges from Hurricanes* (SLOSH) model prediction run output shows that the maximum surge conditions moved across the area as the storm tracked across the coast. Figure 1-6 shows the results of the SLOSH model for Hurricane Ivan. The hurricane crossed the coast in the general area of Gulf Shores and Orange Beach. Because it tracked north-northeast from there, Mobile Bay and most of the Alabama coast was exposed to the weaker "left-front" storm quadrant. In Alabama, the major storm surge struck Orange Beach, Gulf Shores, and the peninsula between Bon Secour Bay (the southeastern corner of Mobile Bay) and the open gulf. In Florida, the first major surge was along the open coast, at Perdido Key.

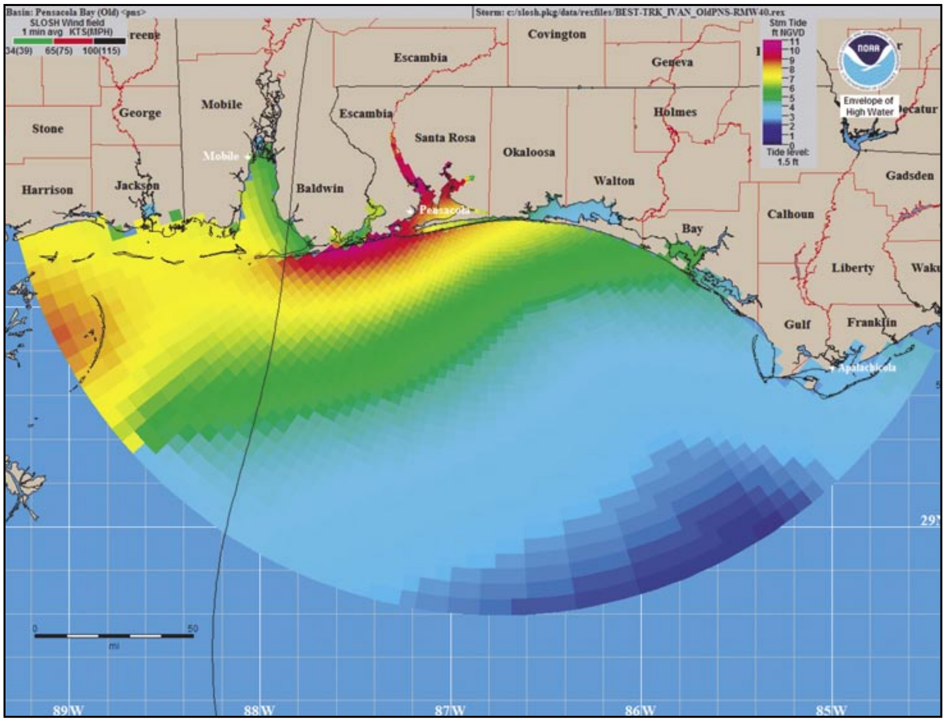


Figure 1-6.
The SLOSH model Envelope of High Water (EOHW) for Pensacola Bay, Florida

In general, the results of the SLOSH model correlated with the actual storm surge elevations from Ivan as compared by the MAT and NOAA. The results of FEMA's CHWM study are presented in Figures 1-7 through 1-10 for Alabama and Figures 1-11 through 1-17 for Florida. The points are shown to differentiate between surge, wave runup, and wave height data. Figure 1-7 shows the effect of the storm on Dauphin Island and the lower western part of Mobile County. Along the open coast, CHWM elevations reached 12 feet and ranged between 3 and 6.8 feet on the landward side of the island and the more protected areas.

Figure 1-7.
CHWM surveyed elevations for Dauphin Island area

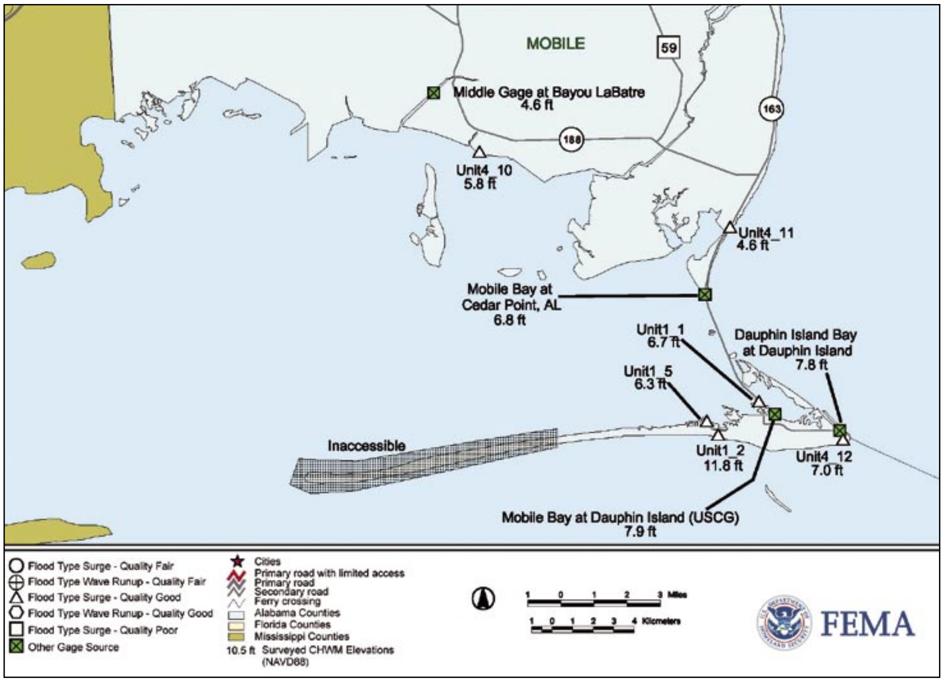
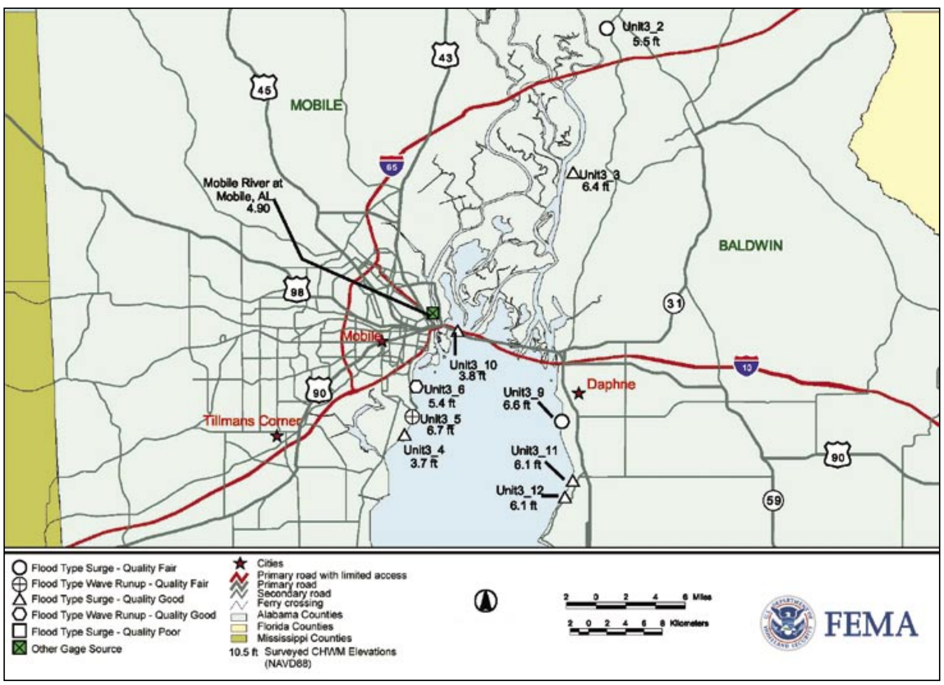


Figure 1-8.
CHWM surveyed elevations for Upper Mobile Bay area



Figures 1-9 and 1-10 show the CHWM elevations in Orange Beach, Ono Island, West Beach, and Fort Morgan. The surge height, determined from water marks in sheltered locations such as interior rooms, ranged between 12 and 14.5 feet along this portion of the open Alabama shore. Much of the beach system was overtopped or overwashed.

Little Lagoon filled with water, but the effects of wave setup may have been smaller than on the open coast, accounting for slightly lower CHWM elevations along its north shore.

The open gulf CHWM elevations decrease slightly near Perdido Pass, possibly because of the flow into Perdido Bay. Figure 1-10 shows that CHWM elevations in the lower Perdido Bay were 6 to 7 feet. Data from the Florida side of upper Perdido Bay (not shown) indicated that the water level increased towards the head of the bay with values in the range of 8.5 to 9 feet at its northern end. The surge was then amplified as it propagated up the lower Perdido River such that the U.S. Geological Survey (USGS) gauge at Barrineau Park indicated a level of 14 feet above the preceding river level. A similar effect appears to have affected the head of Wolf Bay as shown on Figure 1-10.

Figure 1-9 shows that the CHWM elevations were much lower along the eastern shore of Mobile Bay in Baldwin County compared to the open coast. Data on Figures 1-8 and 1-9 show that elevations on the order of 6.5 feet were characteristic of this eastern shore of Mobile Bay.

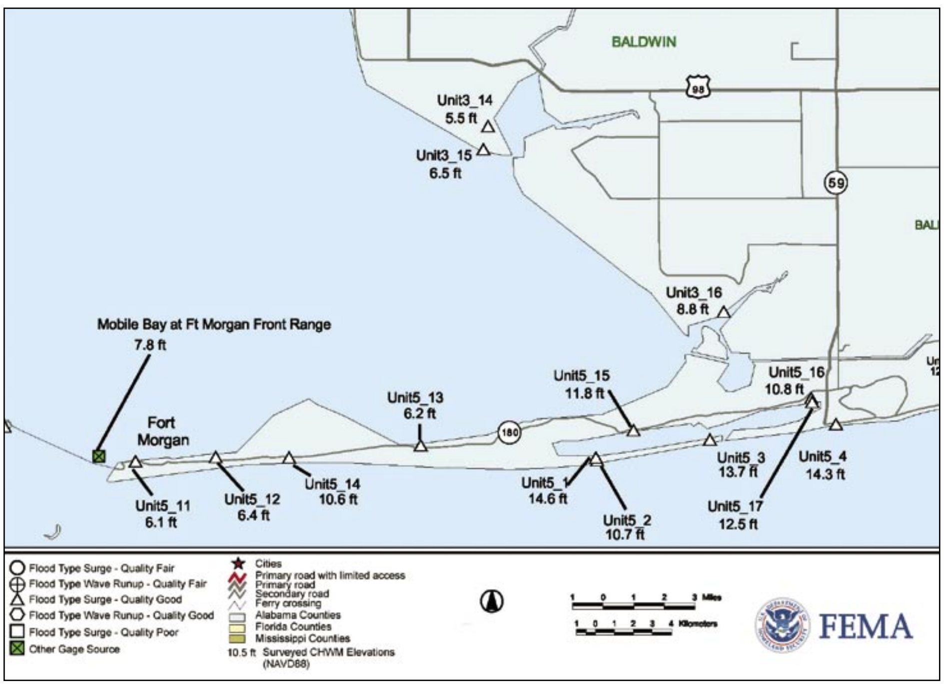
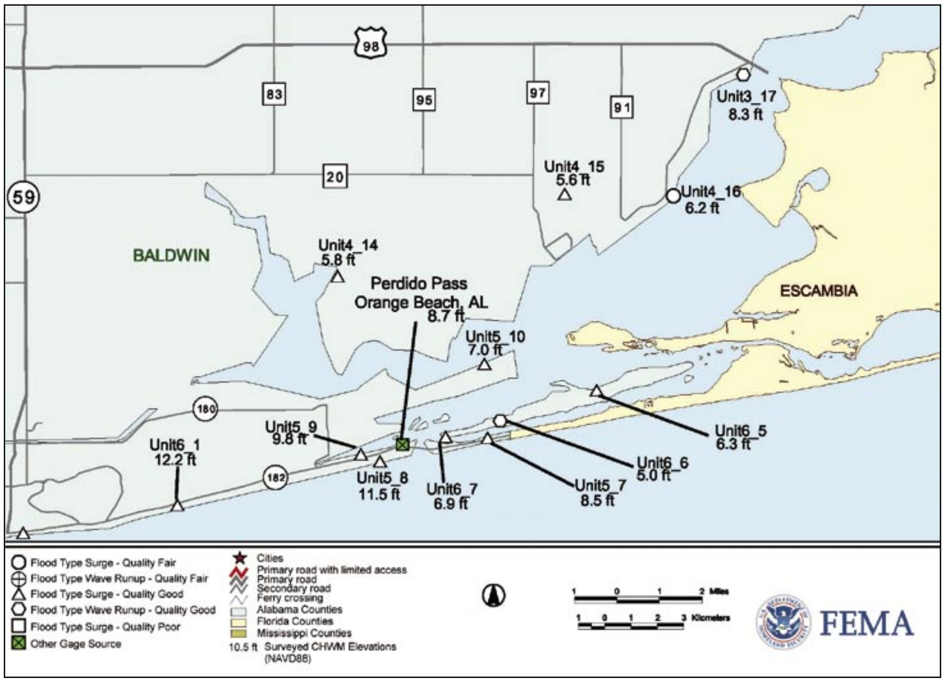


Figure 1-9. CHWM surveyed elevations for West Beach/Fort Morgan area

Figure 1-10.
CHWM surveyed elevations for Orange Beach/Ono Island



The great majority of the CHWM data points collected for Florida represent watermarks from protected locations such as interior walls of coastal buildings. In some areas, the storm damage was so extensive that coastal roads were washed out or entirely buried with sand. These areas are shown as being inaccessible on the figures. Many of the gulf beaches in this area are within parks or National Seashores. These natural areas contained scant record of the coastal storm surge compared to the built-up areas.

The highest CHWM elevations in Florida occur in the Perdido Key area (see Figure 1-11). Much of this barrier island was overtopped. Such overtopping of the barrier island would allow a huge volume of water to enter Big Lagoon, and this could explain the very high CHWM elevations along the mainland coast (Figure 1-11). Figure 1-11 also shows that there was a noticeable difference in the CHWM elevation over the length of Perdido Bay. Both Ono Island and Innerarity Point have high ground well above the flood elevation. It appears that bay water was displaced towards the upper bay faster than it could be refilled from the gulf. This results in a differential in the CHWM elevations of about 3 feet over the 12-mile length of the open bay.

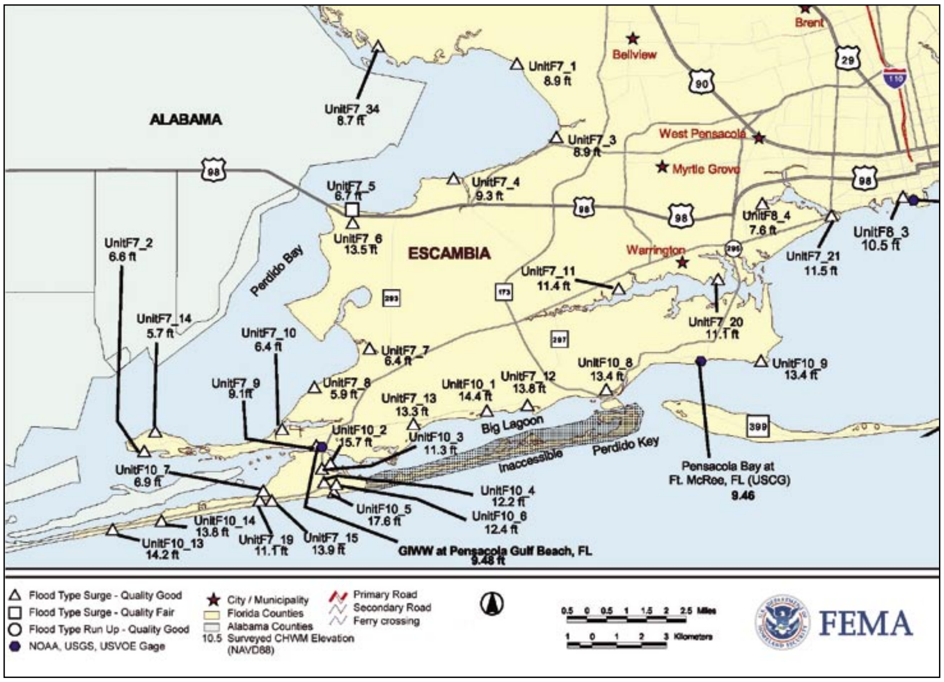


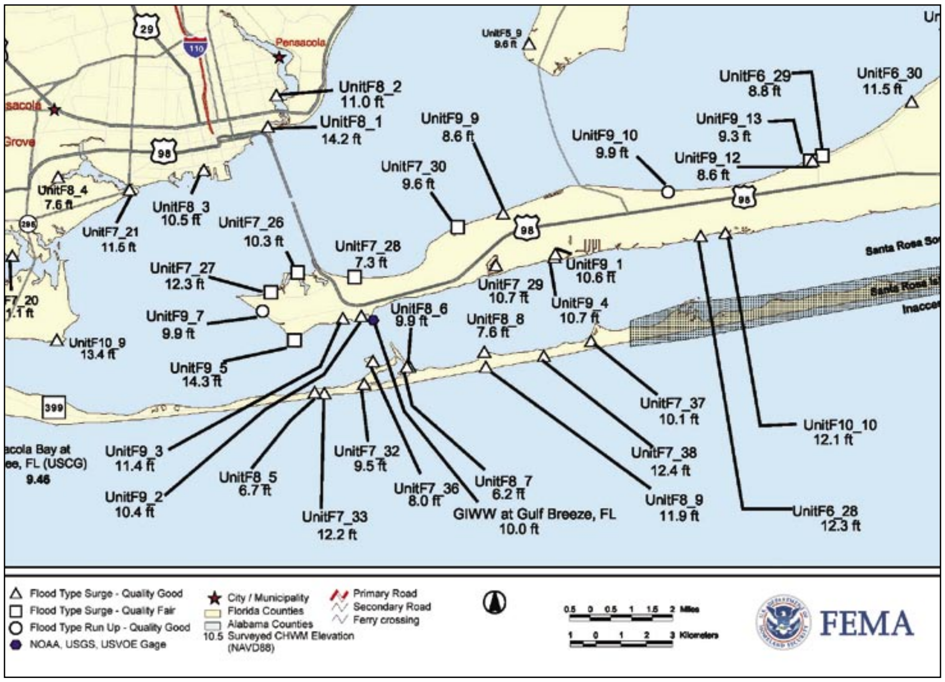
Figure 1-11. CHWM surveyed elevations for Innerarity Point and Perdido Key areas

Figure 1-12 shows the area between the entrance to Pensacola Bay and Garcon Point in the northwest corner. Much of the barrier island was subject to extensive damage by the surge. This includes overtopping and overwashing at many locations. The road was buried in many places, and access to the island was restricted for weeks. The surge along the Pensacola Beach Barrier Island may have been limited by the low height of the land. With nothing to back up against, the surge passed over the island into Santa Rosa Sound and lower Pensacola Bay. The differences in the CHWM elevations between the gulf and sound sides support this inferred surge behavior.

The Santa Rosa Peninsula, which lies behind the barrier island, has ground that is much higher than the maximum surge elevation. Figure 1-12 shows that the surge setup along the southern peninsula shoreline had elevations on the order of 11 and 12 feet. This is in contrast with values of 6 to 8 feet only 2 miles away across Santa Rosa Sound. These CHWM values also demonstrate that the volume of water within the Sound increased dramatically during the surge.

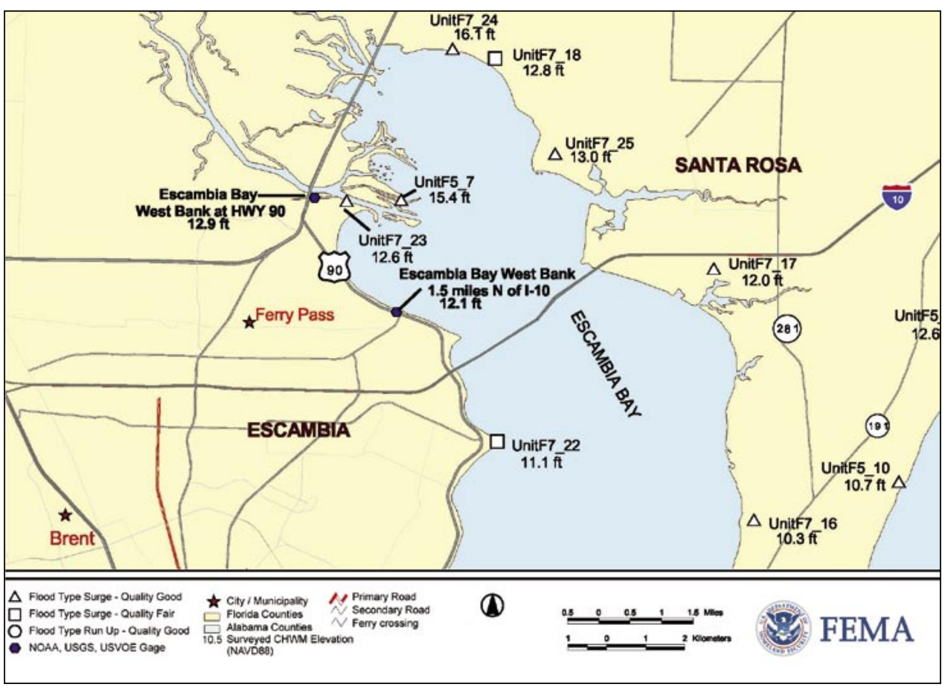
Figure 1-12 shows also that wind-driven water piled up along the south-facing shores of the Naval Air Station, the western suburb of Warrington, and the Port of Pensacola. This also brought high surge levels into Bayou Grande, Bayou Chico, and Bayou Texar. Maximum surge elevations throughout Pensacola Bay and the lower portions of Escambia and Blackwater Bays appear to have been on the order of 9.5 to 11 feet.

Figure 1-12.
CHWM surveyed elevations for Pensacola/ Gulf Breeze area



Figures 1-13 and 1-14 are centered on the Escambia and Blackwater arms of the estuary. In both cases there is a clear pattern of surge amplification towards the heads of these bays. The highest observed elevation in Escambia Bay was 16 feet in Floridatown at the north end of Escambia Bay. The Ward Basin is near the north end of Blackwater Bay just south of the I-10 highway. Here, the surge elevation reached close to 13 feet. In general, the CHWM elevations are a few feet higher along the shores of the arms of the estuary than in the main portion of Pensacola Bay.

Figure 1-13.
CHWM surveyed elevations for Upper Escambia Bay area



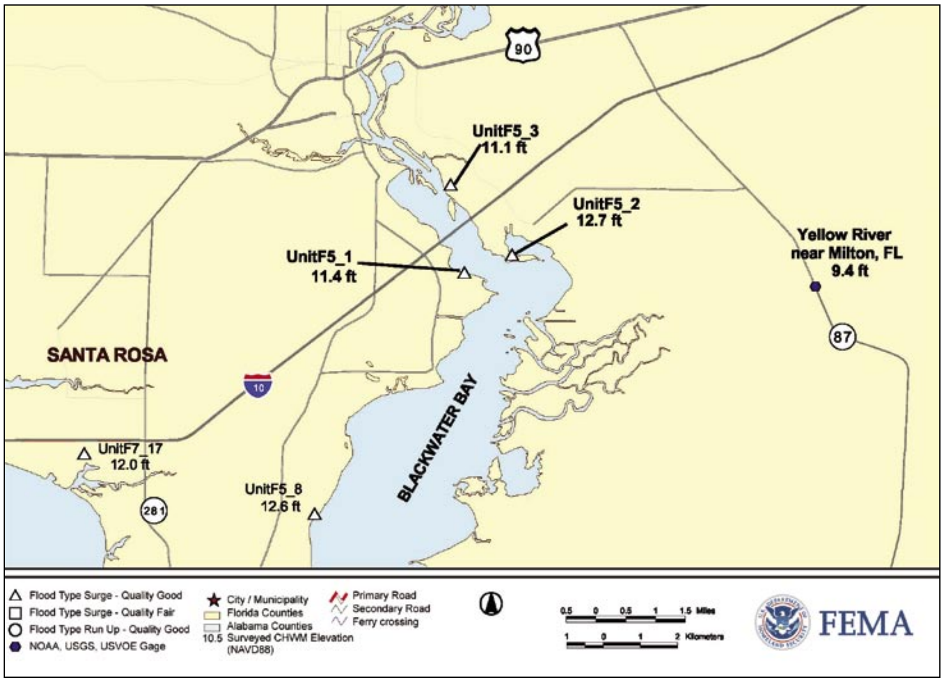


Figure 1-14. CHWM surveyed elevations for Blackwater Bay area

Figure 1-15 shows the eastern portion of Santa Rosa Sound near Navarre and the East Bay arm of the Pensacola Estuary. The CHWM elevations along the open gulf shore are consistent with the values further west. Considerable portions of this part of the island were overtopped or overwashed. Much of the barrier island was inaccessible due to road damage and burial.

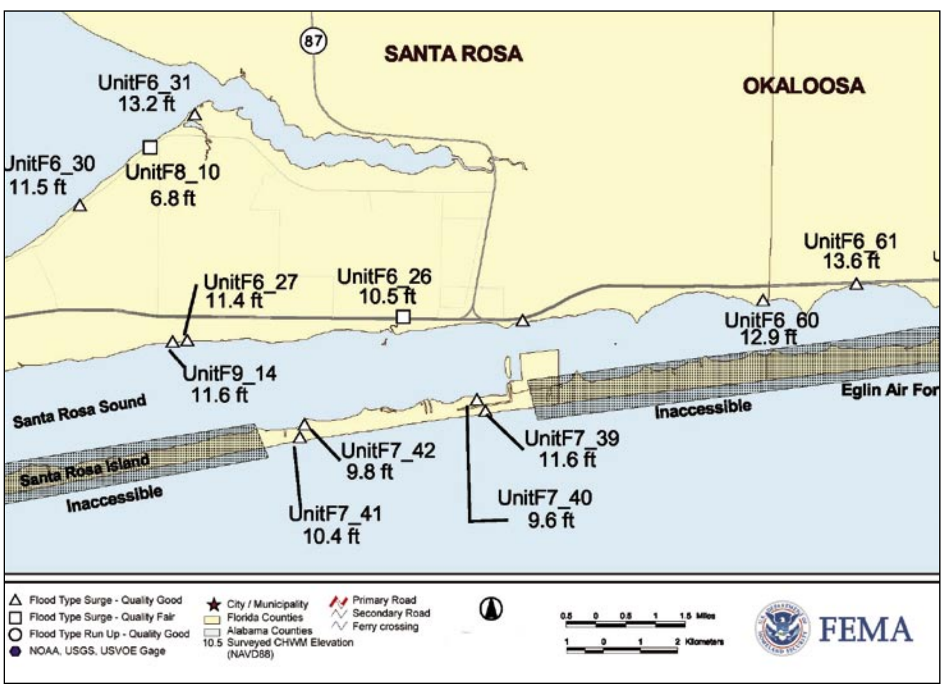
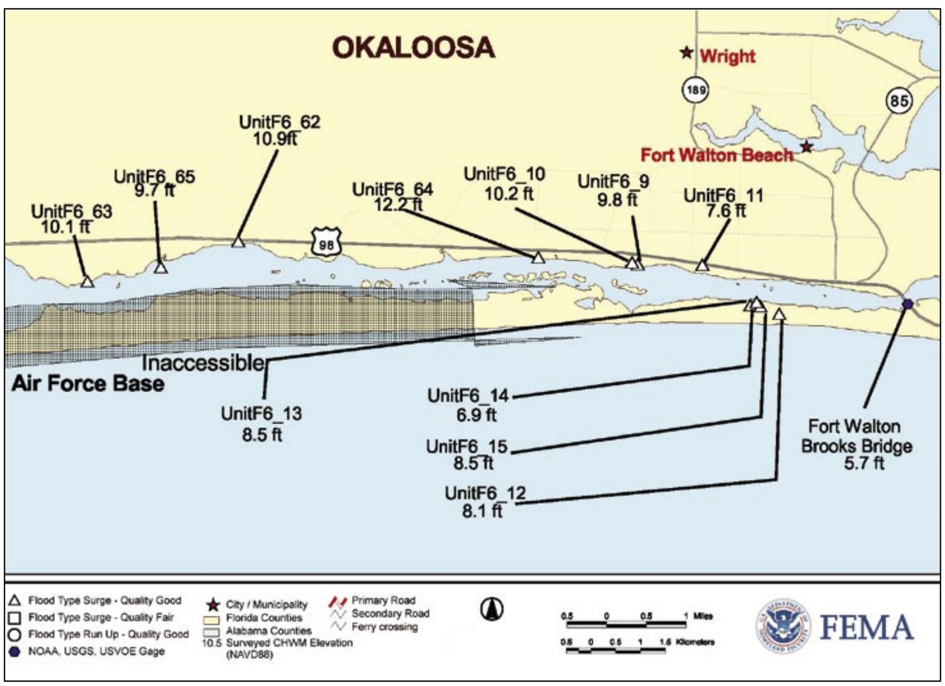


Figure 1-15. CHWM surveyed elevations for Holley Navarre area

The mainland shore of Santa Rosa Sound experienced a high surge that may have decreased slightly going east. However, this trend may be more apparent than real. It was noted that there appeared to be a correlation between the surge levels along the north shore of Santa Rosa Sound and the amount of shielding provided by the barrier island. Much of this island is part of Eglin Air Force Base and is undeveloped. The height of the dunes varies along the island, and there are patches of wooded areas. It was in the regions between the dunes and wooded areas where overtopping and overwashing occurred.

Figures 1-16 and 1-17 show data taken at the eastern end of Santa Rosa Sound and near Fort Walton Beach. Open gulf CHWMs approaching this 13-foot value have been located east of East Pass, which is the inlet into Choctawhatchee Bay, as well. This suggests that a coastal surge was generally at 12 feet or higher along more than 90 miles of the gulf shoreline between eastern Alabama and Destin, Florida. This open coast surge remained high much further to the east, but the land along the shore is high with varying relief so that the surge did not penetrate significantly behind the beach systems except at a few locations.

Figure 1-16. CHWM surveyed elevations for Fort Walton area



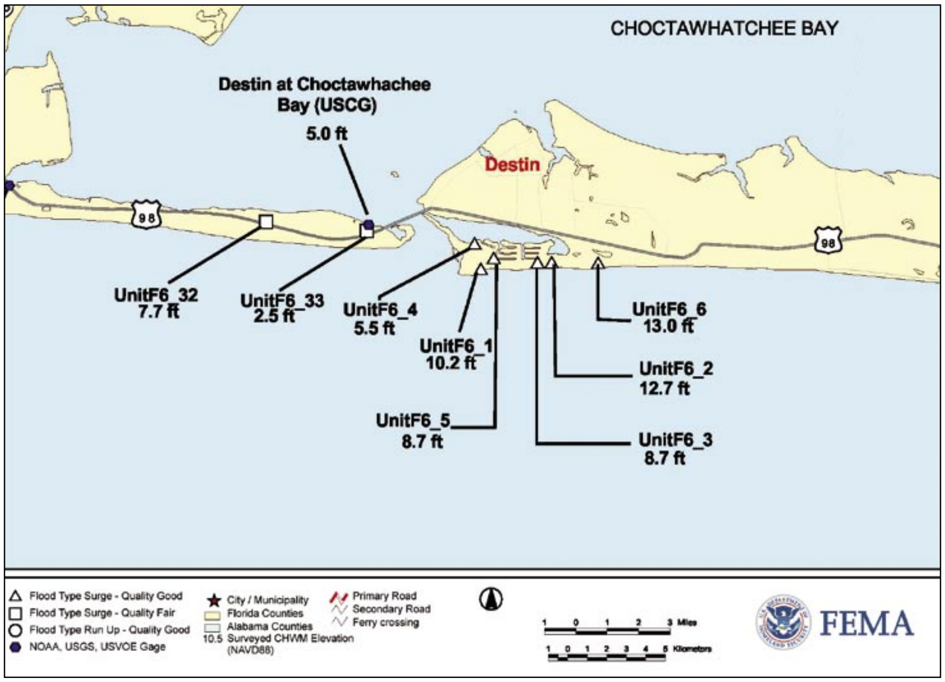


Figure 1-17. CHWM surveyed elevations for Destin area

Preliminary results of the CHWM study show that storm surge levels varied throughout the bays and that these elevations exceeded the 100-year surge elevations. Based on field observations and the CHWM study, the barrier islands were overtopped, which produced extremely high surge elevations in the back bays and, in some cases, elevations close to or nearly as high as the elevations on the open coast. The overtopping of the barrier islands was not accounted for in the surge modeling, which was performed over 20 years ago and used in the current Flood Insurance Studies (FISs). Numerous hurricanes have impacted the Alabama and Florida Panhandle coastline and severely eroded many of the high dunes that were modeled in the surge analysis. Because of the changes in the barrier islands, a new surge model would likely produce higher surge elevations, resulting in higher BFEs in the back bays.

The CHWM study had the following recommendations on how to use the CHWM information to assist in the recovery effort from Hurricane Ivan:

- Compare the Hurricane Ivan CHWMs to the flood elevation data on the effective or preliminary FIRMs. These comparisons can help determine where the updated flood hazard data was supported by the flooding or where new detailed studies should be performed to update the maps. They can help illustrate deficiencies of the existing maps.
- An evaluation is needed of the recurrence intervals of the surge conditions across the area. This will vary from place to place owing to distance from the storm track and local geographic effects. Preliminary evidence suggests that much of the area that experienced the most severe surge conditions was exposed to more than 100-year conditions.
- Compare the Ivan CHWMs to CHWMs from other significant flood events. This will identify areas of repetitive flooding that can assist in determining locations that would make good flood mitigation projects.
- Complete detailed engineering analyses to determine flood elevations in the areas where deficiencies of the existing FEMA maps have been identified, or in areas where property loss occurred and there were no previous studies.
- The locations and severity of the Ivan CHWMs can help identify areas of concern for future mitigation projects when funding for such projects becomes available.
- Use these CHWMs to evaluate the success of completed mitigation projects. The flood depths that occurred during Ivan can be used to estimate potential damage that could have occurred to buildings that have been bought out and removed as part of mitigation projects already completed. Documentation of the “damages avoided” can be used as success stories to further support the mitigation efforts.
- Use the CHWM data to calibrate and validate FEMA’s Hazards US – Natural Hazards Loss Estimating Methodology (HAZUS-MH) flood model.

1.1.2 Wind Analysis and Discussion

The NWS and the NHC reported that Hurricane Ivan made landfall just west of Gulf Shores, Alabama, on September 16, 2004, at 2:02 a.m. (Central Daylight Time). After crossing the barrier islands, Ivan turned north-northeastward across eastern Mobile Bay and weakened to a tropical storm as it crossed the central portion of Alabama.

Wind speeds at MAT investigation sites have been estimated based on a review of the wind speed measurements and the plots shown later in this section. The results listed in Table 1-3 correspond to the locations shown in Figure 1-23.

Table 1-3. Estimated Maximum 3-Second Gust Wind Speeds at 10-Meters for MAT Investigation Sites (variations for terrain are provided)

MAT Investigation Site	3-Second Gust Speed Estimate for Exposure C (Open Terrain)	3-Second Gust Speed Estimate for Exposure B (Suburban Terrain)
Alabama		
Gulf Shores	105 – 115 mph	90 – 100 mph
Orange Beach	105 – 120 mph	95 – 110 mph
Florida		
Perdido Key	110 – 125 mph	95 – 110 mph
West Gulf Beach Heights	105 – 120 mph	90 – 105 mph
Gulf Beach Heights	105 – 120 mph	90 – 105 mph
Seaglades	105 – 120 mph	90 – 105 mph
Pensacola Naval Air Station	105 – 115 mph	90 – 100 mph
West Pensacola	105 – 115 mph	90 – 100 mph
East Pensacola	105 – 115 mph	90 – 100 mph
West Gulf Breeze	105 – 115 mph	90 – 100 mph
Northeast Gulf Breeze	95 – 110 mph	80 – 95 mph
Oriole Beach	95 – 110 mph	85 – 95 mph
Floridatown	95 – 110 mph	80 – 95 mph
Avalon Beach	95 – 110 mph	80 – 95 mph
East Side of Escambia Bay Near Bridge to Gulf Breeze	95 – 110 mph	80 – 95 mph
Pensacola Beach	105 – 115 mph	90 – 105 mph

Figure 1-18 shows the approximate extent of tropical storm winds (39 to 73 mph, 1-minute sustained) and hurricane force winds (greater than 74 mph, 1-minute sustained) for Hurricane Ivan. These wind speed contours are based on a combination of actual wind readings and wind field models. The first wind field model is the H*wind program (Weather and Forecasting, September 1996) produced by the Atlantic

Oceanographic and Meteorological Laboratory's Hurricane Research Division (HRD). The second is the FEMA Hazards US – Natural Hazards Loss Estimating Methodology (HAZUS-MH) that was used by Applied Research Associates (ARA) with some adjustments. The maximum recorded Exposure C (open terrain) wind speeds for specific locations in Alabama and Florida are presented in Figure 1-19.

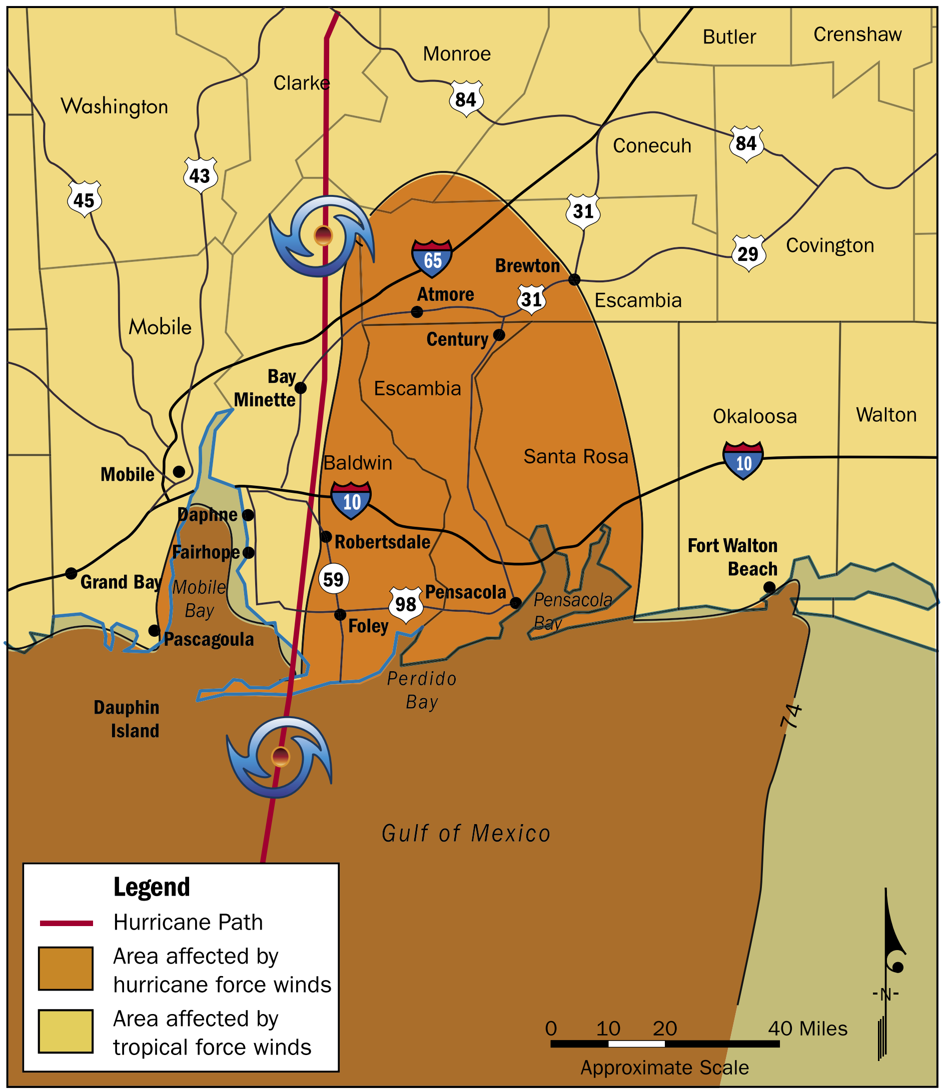


Figure 1-18.
Extent of hurricane and tropical storm force winds for Hurricane Ivan

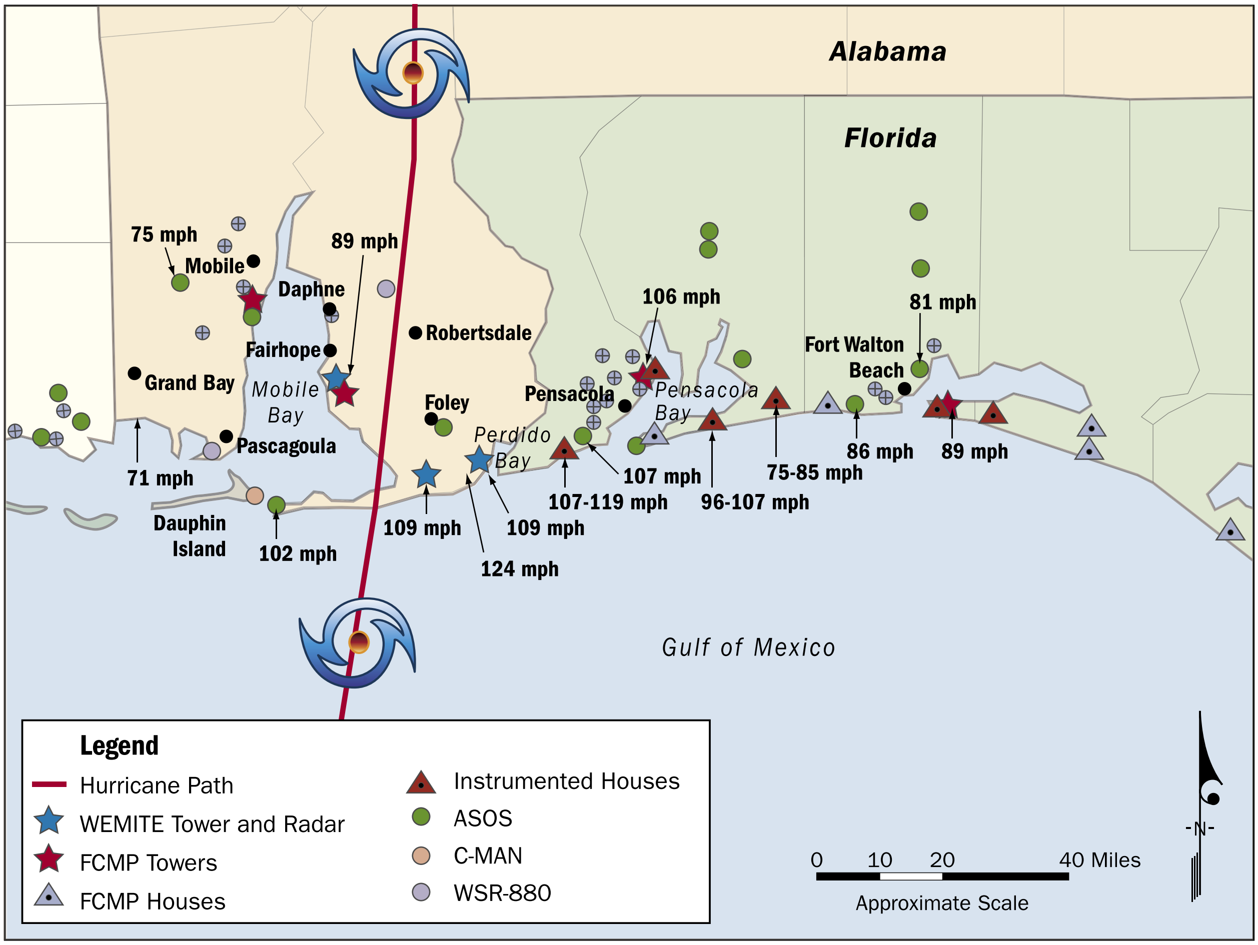


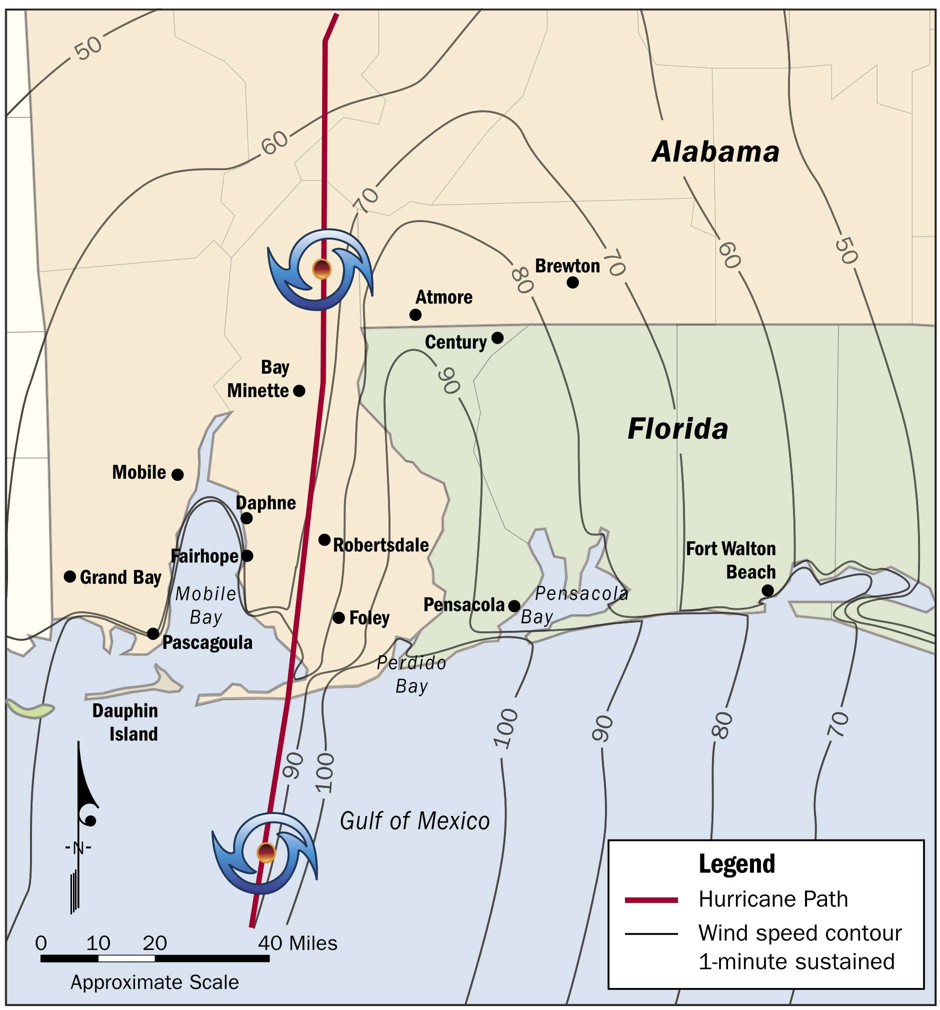
Figure 1-19.
Maximum recorded wind speeds from Hurricane Ivan normalized to 3-second peak gust at 10 meters, Exposure C (open terrain)

Despite the large number of wind speed recordings that were available throughout the area impacted by Hurricane Ivan, measurements were not available at all locations investigated by the MAT. Thus, damage investigators and weather scientists must estimate wind speeds using a variety of methods, the most reliable of which are scientifically based wind field models. The best known model for estimating wind speed variations available in the public domain is H*wind from NOAA's HRD[5]. Past experience with H*wind-based analyses suggests that the model provides reasonably accurate estimates of the maximum wind speeds seen over significant areas impacted by the storm.

[5] Powell, Mark D., Houston, Samuel H. and Reinhold, Timothy A., "Hurricane Andrew's Landfall in South Florida. Part I: Standardizing Measurements for Documentation of Surface Wind Fields," Weather and Forecasting, Vol. 11, No. 3, September 1996. Powell, Mark D., and Houston, Samuel H. "Hurricane Andrew's Landfall in South Florida. Part II: Surface Wind Fields and Potential Real-Time Applications" Weather and Forecasting, September 1996.

The largest differences between measured and predicted values typically occur for lateral distributions of winds and the decay of winds as the storm progresses inland. Contours of sustained, 1-minute, wind speeds from the H*wind analysis avre shown in Figure 1-20. A second modeling approach that usually produces reasonable estimates of maximum wind speeds and lateral distributions of winds involves use of wind field based models such as the one in FEMA's HAZUS-MH loss estimation methodology.[6] The wind field analysis conducted by ARA using this model is shown in Figure 1-21. The maximum wind speed estimates for Hurricane Ivan (when normalized) agree within about 3 mph between the H*wind and ARA analyses despite their independent approaches to making wind speed estimates. There are, however, larger differences between wind speeds at specific locations within the wind field. The estimated wind speed ranges for the various locations visited by the MAT are shown in Table 1-3.

Figure 1-20.
Wind swath contour plot (1-minute sustained winds at 10 meter elevation) based on H*wind analysis



[6] Vickery, Peter J., Skerlj, Peter, Steckley, Andrew and Twisdale Lawrence A.,"Hurricane Wind Field Model for Use in Hurricane Simulations" Journal of Structural Engineering, ASCE, Oct. 2000, pp 1203-1221.

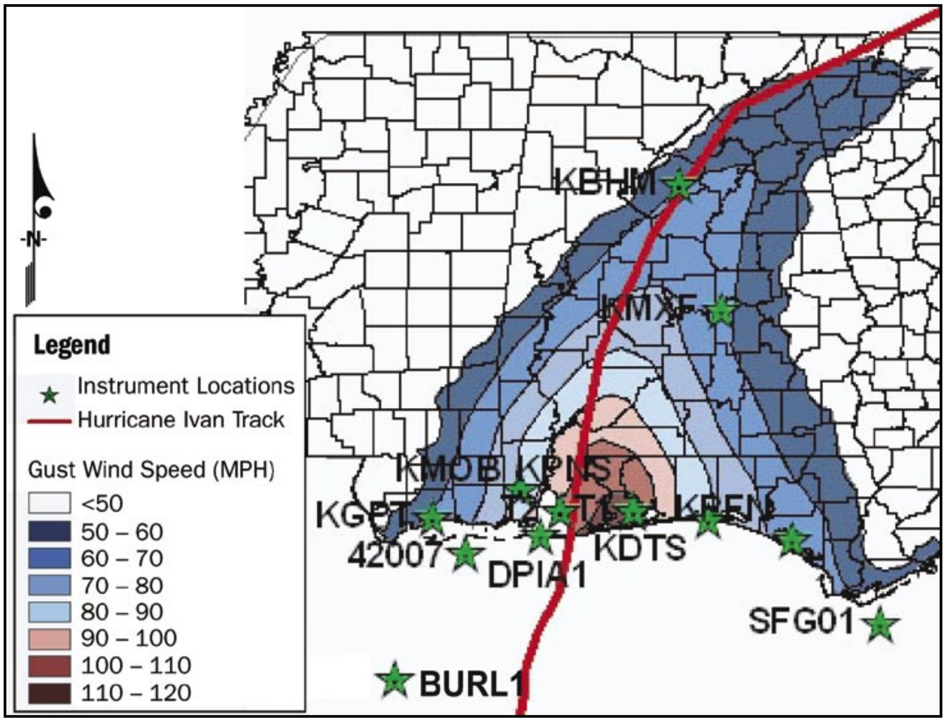


Figure 1-21.
Wind swath contour plot (3-second gust at 10-meter elevation) based on HAZUS-MH wind field methodology (ARA). The stars and letters indicate official stations reporting data for at least part of the storm.

A number of wind speed measurements were recorded at locations along the Alabama and Florida Panhandle coasts. Notable wind speeds recorded for Hurricane Ivan were obtained at the following official locations as shown in Table 1-4.

Table 1-4. Notable Wind Speeds Recorded for Hurricane Ivan

Recording Site	Location	Wind
Official Locations	**Alabama**	
	Grand Bay (AWIS)	71 mph (gust)*
	Mobile (NWS-KMOB)	75 mph
	Florida	
	Eglin Air Force Base (KVPS)	81 mph (gust)*
	Pensacola (NWS-KPNS)†	100 mph
	Pensacola Naval Air Station (KNPA)	107 mph (gust)*
	† Instrument stopped recording values after this reading and may have missed peak.	* Averaging time for gust measurements unknown. Estimated to be between 2 and 5 seconds.
Universities deploying portable 10-meter meteorological towers at various locations along the coast	**Alabama**	
	Fairhope (30.48ºN 87.87ºW) by Florida Coastal Monitoring Program Tower 2	89 mph
	Gulf Shores Airport (30.29ºN 87.67ºW) by University of Oklahoma DOW3	109 mph
	Florida	
	Pensacola Regional Airport (30.48ºN 87.19ºW) by Florida Coastal Monitoring Program Tower 1	106 mph
	Destin Airport by SBCCOM/CR5000 (30.4ºN 86.48ºW)	89 mph
Other notable measurements at non-standard heights and exposures from a number of sources	**Alabama**	
	Fairhope (30.5ºN 87.89ºW) by Texas Tech University WEMITE 2 – Obstacles for some upwind directions may have reduced the observed maximum values	73 mph
	Gulf Shores Airport (30.3ºN 87.66ºW) by Texas Tech University WEMITE 1 – (Actual values at 9.1 meter elevation of 102 mph [3-second gust])	104 mph
	Wolf Field MIPS (30.43ºN 87.54ºW) – (Actual values at 4 meter elevation of 87 mph [3-second gust])	109 mph
	Sailboat Odalisque in Wolf Bay – (Actual value at 22 meter elevation of 145 mph gust with about 2 miles of open water exposure for strong wind direction)	124 mph
	Florida	
	FCMP house ~ 1-mile east of Big Lagoon State Recreation Area – (Actual value of 91 mph [2-second gust] at 7 meters elevation in suburban area)	119 mph (107 mph for Exposure B)
	FCMP house ~ 8-miles east of Gulf Breeze – (Actual value of 82 mph [2-second gust] at 7 meters elevation in suburban area)	107 mph (96 mph for Exposure B)

Note: Wind speeds provided are 3-second peak gust wind speeds at 10 meters, Exposure C (open terrain) except where noted otherwise.

1.2 Historical Hurricanes (Frequency of Hurricanes and Tropical Storms in Eastern Coastal Alabama and Florida Panhandle

Gulf Shores and Dauphin Island, Alabama; and Fort Walton, Pensacola, and Destin, Florida, have been affected or directly hit by past hurricanes that made landfall in the vicinity of Hurricane Ivan's landfall. Historical information shows that four of these cities have been brushed or hit by a hurricane or tropical storm approximately once every 3 years; Gulf Shores has been brushed or hit approximately every 4 years. For a direct landfalling hurricane (within 40 miles), the statistics show the likelihood of such an event as once every 8.9 years for Fort Walton and Pensacola, approximately once every 12 years for Destin, and approximately once every 13 years for Gulf Shores and Dauphin Island. Figure 1-22 highlights some of these hurricanes and storms with paths similar to that of Hurricane Ivan; three of the hurricanes are described below.

Hurricane Frederic, 1979

Hurricane Frederic was the most severe hurricane to strike the Mobile, Alabama, area since 1926. It was a Category 3 hurricane, making landfall on Dauphin Island and passing to the west of Mobile. Storm tides of 8 to 12 feet above normal were reported from Pascagoula, Mississippi, to western Santa Rosa Island, Florida. Frederic was notable due to the extent and magnitude of damage to coastal construction, including the destruction of many barrier island homes that were elevated on pilings to the 100-year stillwater level as required by the NFIP at the time. The occurrence of Frederic was a driving force in modifying NFIP minimum construction standards to require elevation to the wave crest elevation rather than the stillwater level.

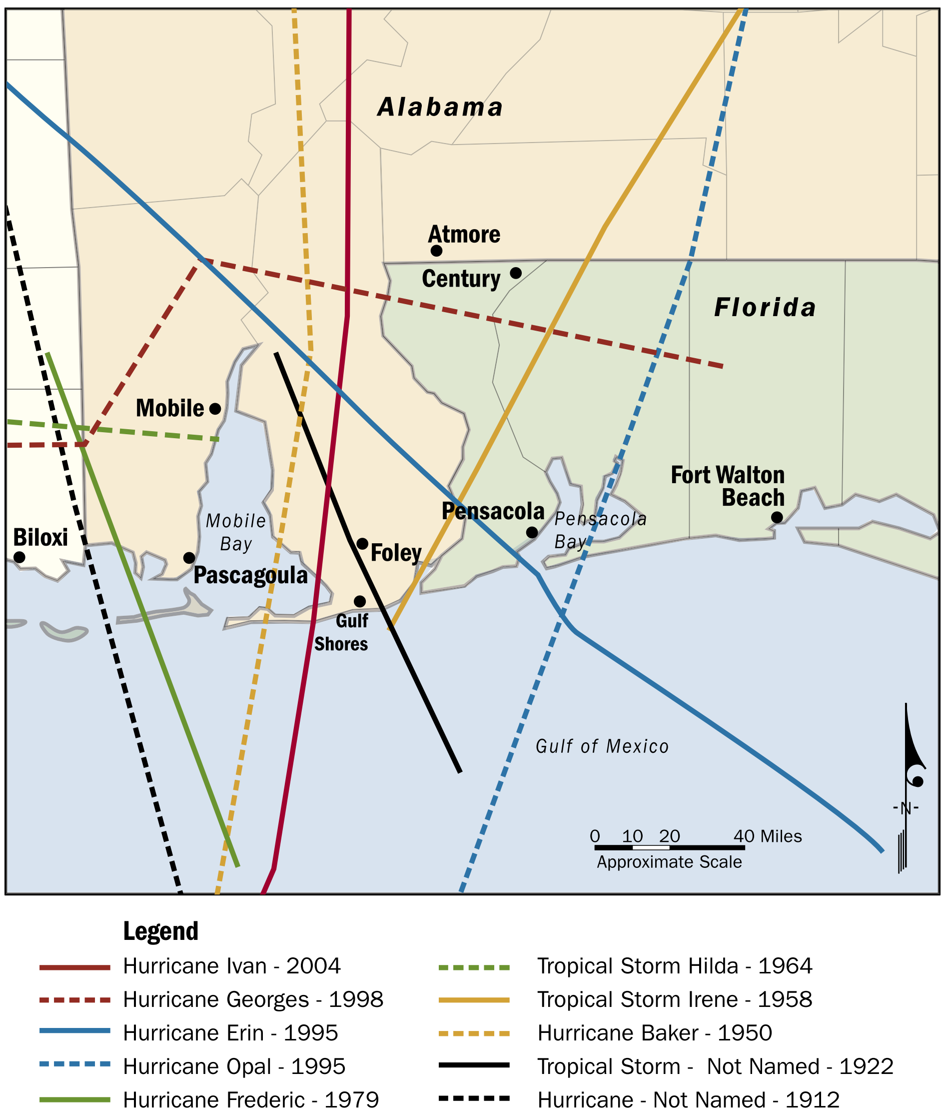
Hurricane Opal, 1995

Opal became a tropical storm near the north-central coast of the Yucatan Peninsula at the end of September 1995. After meandering over the southwest Gulf of Mexico, Opal became a hurricane and gradually accelerated toward the northeast gulf. Early on October 4th, Opal intensified explosively and, according to NHC reports, its maximum sustained winds reached 150 mph. However, the hurricane weakened when its center crossed the coast near Pensacola Beach, Florida. Fifty people died in Guatemala and Mexico, and 9 in the United States. The total damage approached $3.5 billion (year 2000 dollars) and included extensive flood damages.

Hurricane Georges, 1998

Hurricane Georges' 17-day journey resulted in seven landfalls, extending from the northeastern Caribbean to the coast of Mississippi, and 602 fatalities – mainly in the Dominican Republic and Haiti. Georges made landfall during mid-morning of September 25 in Key West, Florida, with maximum sustained winds of 104 mph, according to NHC reports. After moving away from Key West, Georges turned more to the northwest, then north-northwest, and gradually slowed down on September 26 and 27. The hurricane made landfall near Biloxi, Mississippi, on the morning of September 28 with estimated maximum sustained 1-minute winds of 104 mph. After landfall, the system meandered around southern Mississippi and was downgraded to a tropical storm on the afternoon of September 28. The total estimated damage from Georges is $5.9 billion (year 1998 dollars).

Figure 1-22. Historical hurricane and tropical storm paths



1.3 FEMA Mitigation Assessment Teams

Most people know of FEMA for its response to disasters and its assistance to the impacted people. Other important contributions of the agency are the science and engineering studies that it performs before and after disasters to better understand natural and manmade events. These studies of disasters are conducted with the intent of reducing the number of lives lost to these events and minimizing the damages and economic impact on the communities where these events occur.

Since the mid-1980s, FEMA has sent MATs to Presidentially Declared Disaster areas to evaluate building performance during hurricanes. The MAT determines the adequacy of current building codes, other construction requirements, and building practices and materials. Based on estimates from preliminary information of the potential type and severity of damages in the affected area(s) and the magnitude of the expected hazards, FEMA determines the potential need to deploy one or more MATs to observe and assess damage to buildings and structures from wind, rains, and flooding associated with the storm. These teams are deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that not only will improve the disaster resistance of the built environment in the impacted state or region, but also will be of national significance to all hurricane-prone regions.

1.3.1 Methodology

In response to a request for technical support from the FEMA Disaster Field Offices in Mobile, Alabama, and Orlando, Florida, FEMA's Mitigation Division deployed a MAT to Alabama and Florida to evaluate building performance during Hurricane Ivan and the adequacy of current building codes, other construction requirements, and building practices and materials. Hurricane Ivan approximated a design flood event on the barrier islands in an area with relatively recent development. This provided a good opportunity to assess the adequacy of NFIP floodplain management requirements as well as current construction practices in resisting storm surge damage. FEMA was particularly interested in evaluating damages to buildings in coastal AE Zones where coastal construction methods are not required.

Field investigations to assess building conditions in selected areas affected by the hurricane began on September 18 and concluded on October 3, 2004. The team conducted ground inspections across the width of the storm track from its landfall near Gulf Shores, Alabama, to Oriole Beach, Florida, as shown in Figure 1-23 below. Aerial inspections were conducted from Dauphin Island, Alabama, to the East Pass at Destin, Florida. The aerial inspections were made possible by the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) which serves as the executive agent for the Working Group for Natural Disaster Reduction and Post-Storm Data Acquisition (WG/NDR/PSDA). FEMA is a member of the WG/NDR/PSDA.

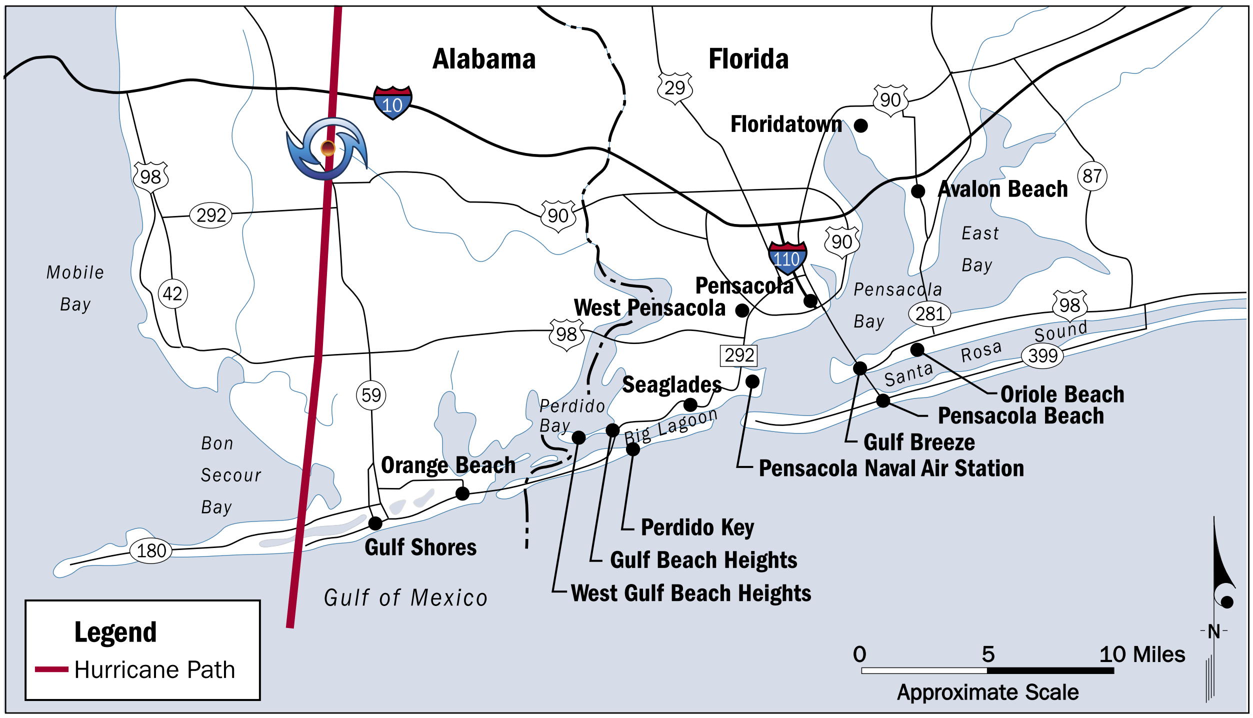


Figure 1-23. Some of the locations visited by the MAT

1.3.2 Team Composition

The MAT included engineers and other experts from FEMA Headquarters and the Regional Office and from the design and construction industry. Team members were drawn from FEMA's database of national experts. Their fields of expertise included structural, wind, and civil engineering; architecture; coastal science; and building codes.