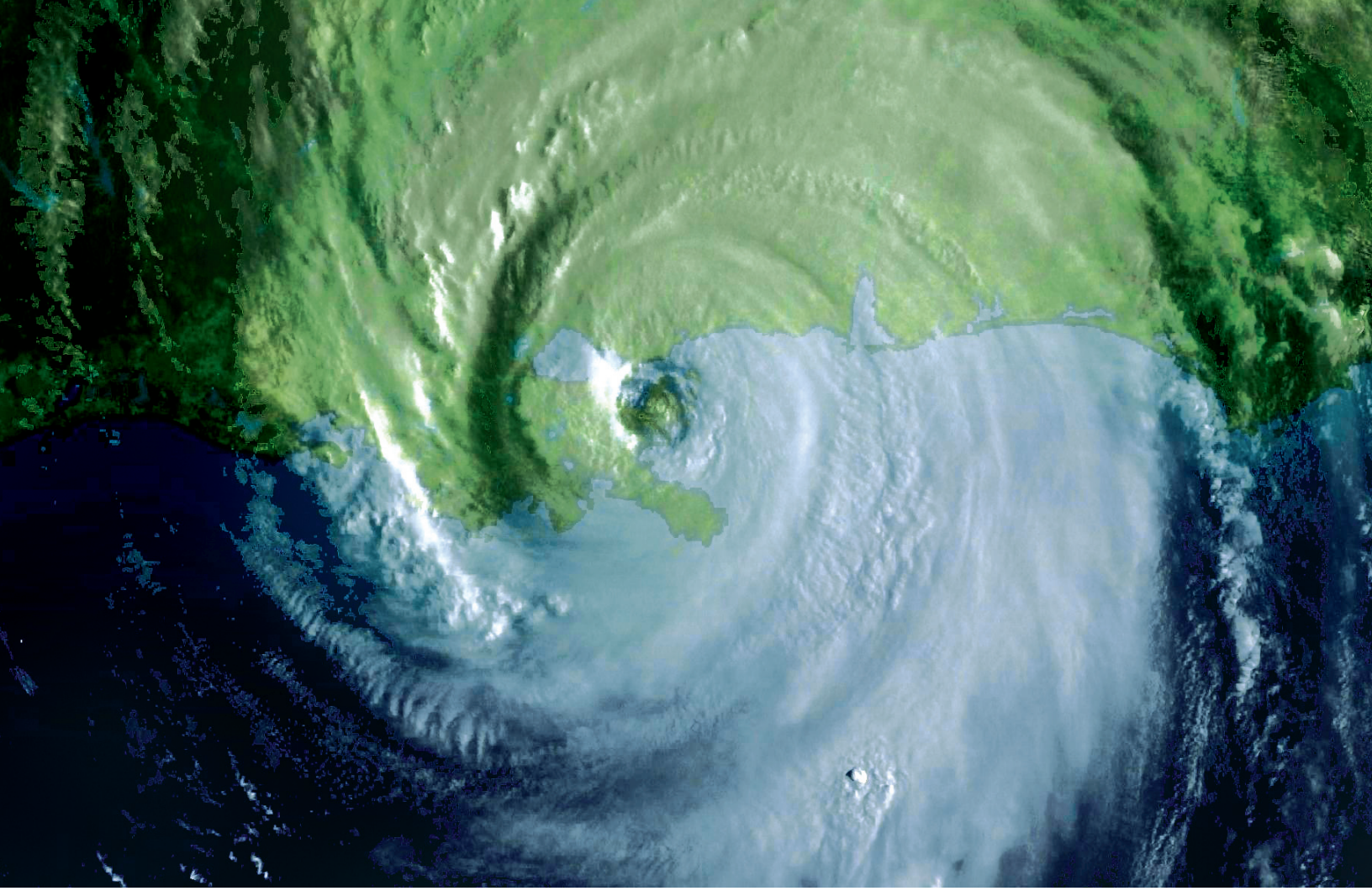

Hurricane Katrina in the Gulf Coast

Mitigation Assessment Team Report

Building Performance Observations, Recommendations, and Technical Guidance

FEMA 549 / July 2006

FEMA

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MITIGATION ASSESSMENT TEAM REPORT

HURRICANE *Katrina* IN THE GULF COAST



In response to Hurricane Katrina, the Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to evaluate and assess damage from the hurricane and provide observations, conclusions, and recommendations on the performance of buildings and other structures impacted by wind and flood forces. The MAT included FEMA Headquarters and Regional Office engineers, representatives from other Federal agencies and academia, and experts from the design and construction industry. The conclusions and recommendations of this Report are intended to provide decision-makers with information and technical guidance that can be used to reduce future hurricane damage.

About the Cover

The cover photograph is a National Oceanic Atmospheric Administration (NOAA) image courtesy of the National Environmental Satellite, Data, and Information Service (NESDIS). The NOAA Geostationary Operational Environmental Satellite (GOES)-12 satellite recorded this regional imagery of Hurricane Katrina on August 29, 2005, at 1:15 p.m. Eastern Daylight Time. This image shows a closeup of Hurricane Katrina's center of rotation.

(IMAGE COURTESY OF NOAA/NESDIS VISUALIZATION LABORATORY)

MITIGATION ASSESSMENT TEAM REPORT

Hurricane Katrina in the Gulf Coast

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FEMA 549 / July 2006

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Dedication



FEMA and the Hurricane Katrina Mitigation Assessment Team are honored to dedicate this report to the memory of Robert T. Pendley, who passed away on June 9, 2006, after a long illness.

Bob dedicated his 30-year career to FEMA mapping and mitigation programs. He began his career as a geographer preparing flood maps, but quickly began to use his talents as a technical writer for FEMA program correspondence, reports, and major publications. At Greenhorne & O'Mara, Bob assisted FEMA in writing proposed and final rule changes and had played a significant role in numerous program and technical documents, including The National Mitigation Strategy, Post-Event Building Performance/Mitigation Assessment Team reports for every major hurricane over the past 13 years, as well as the Oklahoma City bombing and the World Trade Center disaster, the *Coastal Construction Manual*, the *Homeowner's Guide to Retrofitting*, FEMA *Technical Bulletins* series, and the *Home Builder's Guide to Coastal Construction*.

Bob possessed a unique talent of understanding program regulations and requirements, and technical and engineering issues, and combined that knowledge with the ability to write documents that could be read and understood by a wide audience. He also possessed the artistic talent to create technical details and graphics to clearly depict technical and program issues.

Those who knew and worked with Bob know what a special person he was. He touched us all and his work has truly made a difference in our lives and our Nation's ability to understand our vulnerability to hazards and mitigate the potential loss of life and property.

HURRICANE *Katrina*

IN THE GULF COAST



Executive Summary

The North Atlantic hurricane season for 2005 began early and was an unusually active season, breaking the previous recorded hurricane season records for the number of named storms, hurricanes, Category 5 hurricanes, major hurricanes making U.S. landfall, early-season storms, and the strongest hurricane in the Atlantic Basin (see Table 1). On average, about six North Atlantic hurricanes occur every year; by the end of 2005, there had been 15. The annual hurricane season, which generally lasts from June 1 through November 30, was longer than average for the 2005 hurricane season with Tropical Storm Zeta (the 27th named storm) persisting until January 2006.

Table 1. 2005 Hurricane Season Records

Statistic	2005 Total	Previous Record/Year	
Number of named storms	27	21	1933
Number of hurricanes	15	12	1969
Number of Category 5 hurricanes	4	2	1960 and 1961
Major hurricanes making U.S. landfall	4	3	2004
Number of tropical storms before August 1	7	5	1997
Strongest hurricane in the Atlantic Basin	882 mb (Wilma)	888 mb (Gilbert)	1988

mb = millibars
SOURCE: NOAA, NCDC

Hurricane Katrina was one of the strongest storms to impact the coast of the United States during the past 100 years. On August 25, 2005, the storm made its first landfall on the southeast coast of Florida as a Category 1 hurricane. It then crossed south Florida and moved into the Gulf of Mexico, where it gained strength to a Category 5 hurricane, although it weakened before making its second landfall. According to the National Climatic Data Center (NCDC), Hurricane Katrina made its second landfall on August 29, 2005 as a strong Category 3 storm in southeast Louisiana near Buras, with 1-minute sustained winds estimated at 127 miles per hour (mph) or approximately 150 mph 3-second gust, and a minimum central pressure of 920 millibars (mb), the third lowest pressure on record for a U.S. landfalling hurricane. After coming ashore in Louisiana, Katrina continued to move northeastward across Breton Sound, to make a third landfall near Pearlington, Mississippi, as a Category 3 storm with sustained wind speeds estimated at approximately 120 mph or approximately 145 mph 3-second gust.

The hurricane pushed record storm surge onshore in its northeastern quadrant, which caused widespread devastation in southeast Louisiana and along the coasts of Alabama and Mississippi. The storm surge caused failures of the levee system that protects New Orleans from Lake Pontchartrain, and subsequently an estimated 80 percent of the city was flooded. Katrina was the most destructive and expensive natural disaster in the history of the United States, with estimated total economic losses in excess of $125 billion and insured losses of $35 billion, topping the losses of $26.5 billion from Hurricane Andrew in 1992.

One of the key factors of this storm was its strength 24 hours before landfall when it was a large Category 5 hurricane with a minimum central pressure of 902 mb. Although the storm began weakening, with wind speeds significantly decreasing just before making landfall in Louisiana and Mississippi as a Category 3, the storm surge maintained a level more closely associated with a Category 5 hurricane. The surge generated by the storm could not dissipate as rapidly as the wind speeds decreased. Other factors that contributed to high surge elevations were the shallow depth of the offshore shelf and the shape of the shoreline.

In most areas impacted by Katrina, the estimated wind speeds were less than current American Society of Civil Engineers (ASCE) 7-05 design wind speed (the wind standard used by the latest edition of the International Building Code [IBC]). However, along a small portion of the Mississippi coastline, the estimated wind speeds did equal current design wind speeds.

Mitigation Assessment Team (MAT)

In response to a request for technical support from the Federal Emergency Management Agency (FEMA) Joint Field Offices in Montgomery, Alabama; Baton Rouge, Louisiana; and Jackson, Mississippi, FEMA's Mitigation Division deployed a Mitigation Assessment Team (MAT) to Alabama, Louisiana, and Mississippi to evaluate both building performance during Hurricane Katrina and the adequacy of current building codes, other construction requirements, and building practices and materials.

Flood elevations in Hurricane Katrina far exceeded the current design flood elevations along a significant portion of the Gulf Coast of Mississippi and caused levee failures in Louisiana. The high surge was a near design event along some areas of Dauphin Island, Alabama, with surge elevations exceeding those of Hurricane Frederic in 1979 and Hurricane Ivan in 2004. This provided a good opportunity to assess the adequacy of National Flood Insurance Program (NFIP) floodplain management requirements as well as current construction practices in resisting storm surge damage.

Hurricane Katrina was at a design level wind event in small portion of the coast of Mississippi, but overall it was below a design wind event. However, the storm did provide an opportunity to examine building elements that failed and to determine how buildings built to new building codes performed in those areas that did experience near-design wind conditions. The team was also able to collect information about building damage that helps correlate wind speeds to building performance.

The MAT was deployed on September 26 and conducted ground and aerial observations from Dauphin Island, Alabama, along the Mississippi Gulf Coast, through the City of New Orleans to Venice and Grand Isle, Louisiana. The MAT included FEMA Headquarters and Regional Office engineers, representatives from other Federal agencies and academia, and experts from the design and construction industry.

Damage Assessment Observations

Regulatory Standards and Building Codes

All of the communities along the Mississippi Gulf Coast visited by the MAT participate in the NFIP and have adopted floodplain management regulations that meet or exceed minimum NFIP requirements. Prior to Hurricane Katrina, Alabama, Louisiana, and Mississippi did not have statewide building codes for non-state-owned buildings. Many of the communities

in areas that were heavily impacted by Hurricane Katrina had either not adopted up-to-date model building codes that incorporate flood and wind protection or had no building codes at all. A few communities in Louisiana and Mississippi had adopted the IBC where references to floodplain management issues are included in the code. Many communities in these areas had adopted only a floodplain management ordinance and had not adopted a model building code at the time Katrina came ashore. Dauphin Island, Alabama, recently adopted an amendment for deeper pile embedment, and Louisiana and Mississippi have taken steps toward adopting up-to-date building codes.

One of the goals of the MAT was to investigate building failures from flooding inside and outside the Special Flood Hazard Areas (SFHAs) that are shown on the effective Flood Insurance Rate Maps (FIRMs) for the communities. Most of the communities visited by the MAT only enforced minimum flood-resistant design and construction standards, and had not adopted more stringent requirements. One exception is Pascagoula, Mississippi, in Jackson County, which had adopted higher standards that contributed to reduced damage. However, it should be noted that the surge elevations in Pascagoula were lower than those areas farther to the west, which were closer to the storm's landfall.

Flood Damage

Given that Katrina flood levels were well above the design level, the flood damage was severe. High storm surge and waves from the storm caused severe damage to buildings along the coasts of Alabama, Louisiana, and Mississippi. Damage in coastal areas resulted from velocity flooding, wave effects, and waterborne debris impacts, and, in Alabama, severe erosion and scour. Further inland, flood damage was associated more with rising water and inundation. The MAT observed that flood elevations in many areas exceeded the 100-year Base Flood Elevations (BFEs) shown on the current FIRMs by as much as 15 feet. Typically, surge elevations exceeded 23 feet North American Vertical Datum of 1988 (NAVD 88) along the Mississippi coast from Waveland east to Long Beach. The highest recorded surge and wave height elevation was 34.9 feet (NAVD 88).

The failure of levees and floodwalls that protect the City of New Orleans resulted in catastrophic flooding in the Greater New Orleans area, with floodwaters in many areas up to 8 feet above the lowest floor of the building. The BFEs for the levee-protected area are determined based on the certification that the levee will provide protection from the base flood event. Many buildings constructed with the first floor elevation above the BFE were severely damaged or destroyed when the floodwaters rose well above the first floor. The duration of the floodwaters in New Orleans contributed to further damages, with some areas remaining under water for several weeks. This long-duration flooding saturated some types of building materials beyond the point where they could be salvaged and contaminated the materials with chemical and biological substances in the floodwaters. The rampant growth of mold in flood-saturated buildings was another effect of the long-duration flooding.

Recognizing the potential impact of increased flood elevations on long-term recovery efforts and risk reduction, FEMA issued interim Katrina Flood Recovery Maps showing Advisory Base Flood

Elevations (ABFEs) to provide guidance during the rebuilding process. The ABFEs are based on an analysis of historical flood levels throughout the region, including those observed during Katrina.

Destruction or severe flood damage to one- and two-family buildings occurred throughout the study area, especially where the waves exceeded the floor elevation, leaving nothing more than parts of foundations. Damage of this nature was observed to virtually every foundation type. Wind damage could have occurred to the buildings prior to the onset of the most severe flood conditions, but the MAT could not make such a determination; if wind damage had occurred, the evidence was largely removed when the waves and flooding struck the elevated buildings. In areas not subject to severe wave action, flood levels above the floor sometimes floated buildings off their foundations, where connections between the foundations and the buildings were inadequate.

Most one- and two-family buildings built using V Zone construction methods were built with masonry pier foundations. Many of these piers failed in one of four modes due to lateral wave forces, including:

- rotation of the shallow pier footings due to inadequate embedment
- separation of the shallow footing (or slab) at the pier connection due to inadequate reinforcement
- fracture at a mid-height point on the pier due to inadequate reinforcement or poor quality control in the masonry/concrete work
- separation at the top of the pier where the floor system was connected to the pier.

Many of these failures occurred in conjunction with flood levels above the elevated floor, but the same types of failures have been observed after less severe coastal storms.

Severe flood damage also occurred to many one- and two-family buildings elevated on pile foundations, where the flood level exceeded the tops of the piles and connections between the piles and the buildings failed. However, although some piles were cracked or broken, as a type, piles substantially outperformed masonry pier foundations.

Structural damage to multi-family dwellings varied with the severity of waves, flood levels, and construction type. Reinforced concrete and steel-framed structures were generally not significantly damaged unless they were exposed to wave action above the floor level, in which case damages were usually limited to walls and contents (with the structural frame remaining intact). Overall, damages varied from moderate to severe in such cases. On the other hand, wood-framed and masonry buildings tended to suffer more damage where waves rose above the floor level, and minimal to moderate damage in flood areas without hydrodynamic forces, as long as foundation attachments were sufficient to prevent flotation of the buildings.

Damage to commercial buildings was generally consistent with damages observed to residential buildings, and varied with location and severity of flood forces. Coastal low-rise buildings, including strip malls, individual food service/retail, and larger retail facilities also sustained damage from the storm surge and waves. Several buildings along the shoreline lost load-bearing walls, leaving no evidence of the building other than the floor slab. Larger steel-framed commercial

buildings performed better as the structural frame and roof remained intact, but curtain walls and contents were destroyed. Flood impacts on high-rise buildings were less extreme, with most damage limited to parking deck failures and non-structural damage on lower levels.

The floating casino barges and support barges represent a different class of buildings, and consistently experienced severe damage due to their location and exposure to the most extreme wave and flood forces. These barges either sank, were heavily damaged but remained attached to their moorings, or became floating debris that destroyed or damaged many other buildings on land.

Wind Damage

Although most of Katrina's damage was related to flood, widespread wind damage was observed. It was extreme in some areas, even though Hurricane Katrina did not appear to have been a design wind event in most locations. Most of the wind damage was to building envelopes and rooftop equipment.

Structural damage to buildings from wind was not widespread. Those buildings that experienced substantial structural damage typically were older and built before wind effects were adequately considered in design and construction. Newer homes that were substantially damaged were observed to have construction deficiencies pertaining to connections. Structural damage to commercial buildings depended much more on building design and construction than on building location. Relatively weak commercial buildings were destroyed in areas where wind speeds were relatively low, while stronger buildings experienced little or no structural damage in areas exposed to the highest winds.

Hurricane Katrina caused widespread damage to building envelopes and rooftop equipment. Building envelope damage was observed as far west as the New Orleans area and as far east as Dauphin Island, Alabama (a distance of approximately 140 miles). Building envelope damage was also observed as far inland as Poplarville, Mississippi (approximately 40 miles from the Gulf); however, envelope damage was reported at least as far inland as Hattiesburg, Mississippi (65 miles from the Gulf). Although the building envelope damage pales in comparison to that caused by flooding, the wind-induced envelope damage was significant, especially in light of the fact that Katrina was less than a design level storm for wind.

Critical and Essential Facilities Damage

Throughout the Gulf Coast, the poor performance of critical and essential facilities during and after Katrina was widespread. Most critical and essential facilities did not perform any better than the commercial buildings. Facilities such as hurricane evacuation shelters, police and fire stations, hospitals, and Emergency Operations Centers (EOCs) were severely damaged and many were completely destroyed. Some facilities experienced loss of function when critical support equipment such as vehicles and communications equipment was damaged or destroyed. While most of the damage to critical and essential facilities was caused by storm surge, high winds also damaged many other facilities. The poor building performance placed additional burdens on response and recovery personnel as they endeavored to provide assistance to their communities after the event.

This storm has allowed the MAT to build on the body of knowledge recently collected about the performance of critical and essential facilities during the last 2 years of hurricane events. The performance of the building envelopes, particularly for wind, has been generally poor and has allowed wind and wind-driven water to enter buildings, thereby disrupting services and, in many cases, rendering the building useless during and immediately after the storm, and for an extended period after the storm.

Recommendations

The recommendations in this report are based solely on the observations and conclusions of the MAT. They are intended to assist the States of Alabama, Louisiana, and Mississippi in the reconstruction process and to help reduce damage and impact from future storms. The recommendations are also expected to help FEMA assess the adequacy of construction standards and floodplain management requirements and determine whether changes in these standards and requirements are necessary. Lastly, they are also intended to:

- Provide the codes and standards groups and the homebuilding and building official communities with an important historical perspective of this event.
- Show how damages could have been reduced by building to higher standards currently in use in the IBC, and published in various standards, manuals, and design and testing guides.

As the people of Alabama, Louisiana, and Mississippi reconstruct their lives and the Gulf Coast rebuilds, there are a number of ways they can minimize the effects of future hurricanes. A few of the main recommendations resulting from the MAT inspections are included here; additional recommendations are included in Chapter 11.

Flood Recommendations

Based on the widespread devastation of buildings resulting primarily from floodwaters and waves that exceeded regulatory lowest floor elevations, it is strongly recommended that buildings be constructed in anticipation of flood levels that exceed the current BFE. A few of the main recommendations include:

- Adoption of modern building codes, such as the IBC, International Residential Code (IRC), or National Fire Protection Association (NFPA) 5000, is recommended. These codes include up-to-date design and construction provisions that are consistent with the NFIP. The 2006 editions of the IBC and NFPA 5000 incorporate flood load (ASCE 7-05) and flood-resistant construction (ASCE 24-05) standards.
- Follow the guidelines in FEMA's Hurricane Katrina Recovery Advisories, *The ABCs of Returning to Flooded Buildings* and *Initial Restoration for Flooded Buildings*, to facilitate restoration of flooded buildings. Appropriate safety precautions should be taken during repair and reconstruction to minimize health risks for biological and chemical contaminants.

- Use *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, publication available July 2006).
- Review the storm surge data and conduct a revised tide frequency analysis. Use modern storm surge models to estimate the BFEs throughout the Katrina impact area.
- Consider identifying and mapping Coastal A Zones onto new FIRMs. Utilize ASCE 24-05 for design and construction of buildings located in Coastal A Zones. As an interim step, use the Katrina Flood Recovery Maps to determine the approximate location of the Coastal A Zone hazard. As shown on the Recovery Maps for Mississippi, the Coastal A Zone will be the area between the approximate limit of the 1.5-foot Wave Zone line and the approximate limit of the 3-foot Wave Zone line.
- Consider evaluating and revising flood hazard mapping and levee certification procedures for areas behind levees.
- For rebuilding efforts, use the Katrina Flood Recovery Maps until the new flood maps are released.

Wind Recommendations

The wind impacts from the storm caused widespread damage to building envelopes as a result of inadequate design, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement. A few of the main recommendations include:

- Adopt the 2006 IBC and IRC, or 2006 NFPA 5000, for all jurisdictions in each state.
- Roof covering systems, soffits, wall coverings, doors, windows, and rooftop equipment need additional attention by designers, architects, and contractors as specified in Chapter 11. Testing improvements are recommended to assess the performance of exterior insulation and finish systems (EIFS), vinyl siding, and soffits.

Critical and Essential Facility Recommendations

A few of the main recommendations related to improving the performance of critical and essential facilities include:

- Locate all new critical and essential facilities that must remain operational during an event above the 500-year flood elevation and on sites that will not be isolated by floodwaters.
- Develop emergency operations plans that allow building occupants and operations of existing facilities located within the SFHA to be relocated to sites outside of SFHAs before the onset of the storm. If personnel are relocated away from the facility, relocate equipment as well.
- Evaluate flood and wind resistance of existing facilities; where inadequacies are found, either retrofit or build a new facility.
- Design to standards that exceed current code, conduct peer reviews when designing new facilities or retrofitting existing facilities, and implement special inspections during construction.

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1. Introduction

On September 26, 2005, the Mitigation Division of the Department of Homeland Security's (DHS's) Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to the States of Alabama, Louisiana, and Mississippi to assess damage caused by Hurricane Katrina. This report presents the MAT's observations, conclusions, and recommendations in response to those field investigations.

This chapter provides an introduction, a discussion of the event, historical information, and background on the MAT process. Floodplain management regulations and the building codes and standards that affect construction in Alabama, Louisiana, and Mississippi are discussed in Chapter 2. Chapter 3 provides a basic assessment and characterization of the observed flood and wind effects. Structural systems performance in residential and commercial buildings is detailed in Chapter 4. Chapter 5 presents an assessment of building envelope performance and Chapter 6 discusses damage to historic buildings. Chapter 7 presents damage to, and functional loss of, critical and essential facilities, and Chapter 8 discusses the short-term and long-duration

flood impacts in the New Orleans area. Chapter 9 documents observed hazard mitigation successes and best practices. Chapters 10 and 11 present the conclusions and recommendations, respectively, intended to help guide the reconstruction for hurricane-resistant communities in Alabama, Louisiana, and Mississippi, and other hurricane-prone regions impacted by future hurricanes. In addition, the following appendices are presented herein:

- Appendix A contains the references for the report.
- Appendix B is a list of acknowledgments.
- Appendix C defines the acronyms and abbreviations used in the report.
- Appendix D contains a glossary of terms used in the report.
- Appendix E contains the Hurricane Katrina Recovery Advisories.
  - Reconstruction Guidance Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations
  - Initial Restoration for Flooded Buildings
  - Design and Construction in Coastal A Zones
  - The ABC's of Returning to Flooded Buildings
  - Attachment of Brick Veneer in High-Wind Regions
  - Attachment of Rooftop Equipment in High-Wind Regions
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  - Designing for Flood Levels Above the BFE
- Appendix F presents high water marks reported for the storm.
- Appendix G contains a copy of FEMA Procedure Memorandum 34 - Interim Guidance for Studies Including Levees, dated August 22, 2005.
- Appendix H contains a description of Continuity of Operations (COOP) Planning and Environmental Issues for Infrastructure.
- Appendix I presents a description of sampling and analytical methods of flood-damaged buildings.
- Appendix J describes pre- and post-disaster mitigation of historic buildings.
- Appendix K contains a list of FEMA Regional Offices.

1.1 Hurricane Katrina – The Event

Hurricane Katrina was one of the strongest and most destructive storms to impact the coast of the United States during the past 100 years. The hurricane made its first landfall on August 25, 2005, on the southeast coast of Florida as a Category 1 hurricane; the storm then crossed south Florida and moved into the Gulf, where it gained strength to a Category 5 hurricane, before weakening and making its second landfall in southeast Louisiana near Buras as a strong Category 3 hurricane. After coming ashore in Louisiana, Katrina continued to move northward, pushing storm surge into coastal areas of Alabama, Louisiana, and Mississippi, and, after crossing over Breton Sound, Katrina finally made a third landfall as a Category 3 storm near Pearlington, Mississippi, along the Louisiana/Mississippi border. Figure 1-1 shows the path of Hurricane Katrina as it moved over Louisiana and Mississippi. Katrina caused widespread devastation along the Gulf Coast, with southeast Louisiana and the coasts of Alabama and Mississippi bearing the brunt of the catastrophic damage.

THE SIGNIFICANCE OF HURRICANE KATRINA

Hurricane Katrina was the most severe hurricane to strike the Louisiana/Mississippi Gulf Coast since Hurricane Camille in 1969 and the most significant hurricane to strike the New Orleans area since Hurricane Betsy in 1965. The significance of Katrina and its effects are summarized below:

- Katrina significantly exceeded the Base Flood Elevations (BFEs) by as much as 15 feet along parts of the Louisiana and Mississippi Gulf Coast. Flooding extended well beyond the inland limits of the Special Flood Hazard Area (SFHA), and the highest storm surge in U.S. history was recorded on the Mississippi coast.
- The American Red Cross estimated that Katrina destroyed over 300,000 single-family homes throughout Louisiana and Mississippi.
- Coastal flood impacts covered a wide area, with severe flood damage extending along coastal Alabama and totally destroying over 100 houses on Dauphin Island.
- Levee failures led to severe flood damage throughout the City of New Orleans and surrounding areas of Plaquemines and St. Bernard Parishes. Hundreds of thousands of people were displaced from the damage caused by the flooding.
- Katrina's wind speeds were estimated to be at the design level in only a few areas and were less than the current code-specified speeds (per the 2000/2003 International Building Code [IBC] and the International Residential Code [IRC]) in most areas. These codes use a design wind speed map developed for the 1998 and 2002 editions of the American Society of Civil Engineers (ASCE) 7.
- Wind damage to both commercial and residential buildings was widespread through the southern portions of Louisiana and Mississippi.
- In general, buildings functioning as critical and essential facilities did not perform well, and experienced significant wind and flood damage (with damages similar in nature to their commercial counterparts). Operation of many critical and essential facilities was hampered or shut down as a result of storm-induced damage or isolation due to coastal flooding.

Figure 1-1. Hurricane Katrina's path through Louisiana and Mississippi

(BASED ON HURRICANE STORM TRACK DATA FROM THE NATIONAL HURRICANE CENTER)



Katrina's storm surge caused failure of the levee system that protects New Orleans from Lake Pontchartrain and, subsequently, an estimated 80 percent of the city was flooded. This and other major damage to the coastal regions of Alabama, Louisiana, and Mississippi made Katrina the most destructive natural disaster in the history of the United States.

The estimated death toll is over 1,700, with approximately 1,500 of those deaths occurring in Louisiana and approximately 230 in Mississippi.[1] Other deaths attributed both directly and indirectly to Katrina were reported in Florida, Alabama, Georgia, Kentucky, and Ohio. Hurricane Katrina ranks as the third deadliest hurricane in the United States, surpassed only by the Texas Hurricane at Galveston in 1900, where 6,000 lives were lost, and the Florida Hurricane in 1928 where 2,500 lives were lost at Lake Okeechobee.

[1] The original toll of 1,067 issued by the Louisiana Department of Health and Hospitals included at least 14 who died prior to Katrina, and some people who were elderly or terminally ill and died outside of New Orleans after evacuation, possibly due to stress, as reported by The Times-Picayune on November 2, 2005 <http://www.nola.com/search/index.ssf?/base/library-89/113091548771970.xml?nola>.

1.1.1 Hurricane Katrina Economic Loss Summary

Estimated total economic losses from Hurricane Katrina are in excess of $125 billion and insured losses are $40.6 billion,[2] which tops Hurricane Andrew's $26.5 billion loss, Hurricane Charley's $15 billion loss, Hurricane Ivan's $14.2 billion loss, Hurricane Frances' $8.9 billion loss, and Hurricane Hugo's $7 billion loss,[3] making Katrina the most expensive natural disaster in U.S. history. As of April 2006, the number of flood insurance claims exceeded 210,000 and totaled $17 billion, covering Alabama, Florida, Louisiana, and Mississippi, with over 175,000 of those claims coming from Louisiana. Preliminary estimates indicate that Hurricane Katrina resulted in the following:

- $5.5 billion in damage to infrastructure, including roads and bridges
- 300,000 to 350,000 vehicles destroyed and approximately 2,400 ships and vessels wrecked
- 450,000 displaced people
- 800,000 Louisiana citizens requesting assistance from various Federal and State relief programs and agencies

The Small Business Administration reported that requests for $229 million in home and small business loans have been submitted. The State of Mississippi and FEMA counted the following destroyed or damaged buildings: primary homes – 157,914; multi-unit homes – 20,883; rental units – 42,187; and public housing units – 27,001.

Table 1-1 summarizes the housing damage from Hurricane Katrina as determined by the American Red Cross.

Officials estimate that, in Mobile County, 80 percent of the homes in Bayou La Batre were uninhabitable as the result of flooding; on Dauphin Island, a third of the homes on the western side of the island were destroyed and another third were significantly damaged. The worst damages in Baldwin County were along Mobile Bay south of Fairhope and along the Ft. Morgan Peninsula.

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

[2] Insurance Information Institute

[3] Estimates, not adjusted for inflation, as reported by NOAA/AOML/Hurricane Research Division, Miami, FL <http://www.nhc.noaa.gov/pastcost.shtml>.

Table 1-1. Katrina Housing Damage Summary

Location	Dwelling Type	Destroyed	Major	Minor
Alabama	Single-Family	363	966	345
	Manufactured	-	1	26
	Apartment	-	-	-
	Subtotal	**363**	**967**	**371**
Louisiana	Single-Family	241,524	38,350	40,066
	Manufactured	1,552	1,146	1,855
	Apartment	40,762	33,676	27,842
	Subtotal	**283,838**	**73,172**	**69,763**
Mississippi	Single-Family	68,466	62,981	95,468
	Manufactured	263	2,241	4,811
	Apartment*	-	-	-
	Subtotal	**68,729**	**65,237**	**100,318**
Hurricane Katrina TOTALS	Single-Family	310,353	102,297	135,879
	Manufactured	1,815	3,388	6,692
	Apartment	40,762	33,691	27,881
	Total	**352,930**	**139,376**	**170,452**

(SOURCES: AMERICAN RED CROSS, NATIONAL ASSOCIATION OF HOME BUILDERS, 10/05 <http://www.redcross.org>, <http://www.nahb.org>.)

* Data incomplete.

1.1.1.1 Hurricane Categories

Hurricanes are categorized according to their relative strength as measured by wind speed and minimum central pressure. The Saffir-Simpson Scale, presented as Table 1-2, is the standard for categorizing hurricanes and consists of five separate categories. The National Hurricane Center (NHC) reserves the term "major hurricane" for hurricanes that reach maximum 1-minute sustained surface winds of at least 111 miles per hour (mph) over open water. Therefore, Category 3, 4, and 5 hurricanes are all considered major hurricanes.

Table 1-2. Saffir-Simpson Hurricane Scale Wind Speeds and Pressures

Strength	Sustained Wind Speed (mph)*	Gust Wind Speed (mph)**	Pressure (millibars)
Category 1	74-95	89-116	>980
Category 2	96-110	117-134	965-979
Category 3	111-130	135-159	945-964
Category 4	131-155	160-189	920-944
Category 5	>155	>189	<920

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

1.1.1.2 Timeline and History of the Hurricane[4]

Hurricane Katrina began as Tropical Depression Twelve, which formed over the Bahamas on August 23, 2005. On August 24, the storm strengthened and became known as Tropical Storm Katrina, the 11th named storm of the 2005 hurricane season. The storm then traveled northwest from the Bahamas.

A few hours before making landfall in Florida on August 25, Tropical Storm Katrina was upgraded to Hurricane Katrina (Category 1, 74 mph winds). Katrina made landfall around 6:30 p.m. Eastern Daylight Time (EDT) with approximately 80 mph, 1-minute sustained winds on the Dade-Broward County line between Hallandale Beach and North Miami Beach, Florida. Port Everglades reported wind gusts to 92 mph. During its initial landfall in southern Florida, Katrina generated over 5 inches of rainfall across a large area of southeastern Florida. An analysis by the National Oceanic and Atmospheric Administration's (NOAA's) Climate Prediction Center shows that parts of the region received heavy rainfall, over 15 inches in some locations, which caused localized flooding. Katrina tracked southwest through the Everglades National Park and exited the state near the southern tip of Florida, as shown in Figure 1-2.

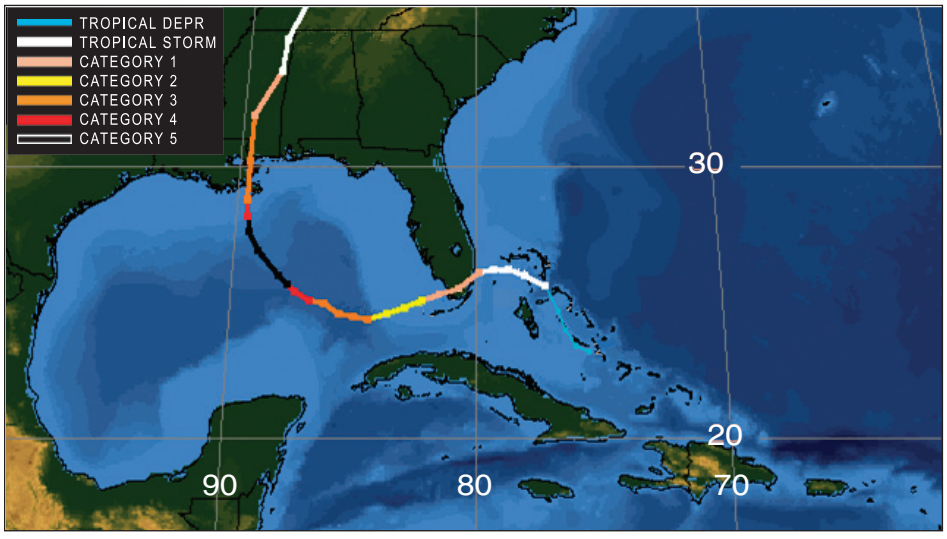


Figure 1-2. Hurricane Katrina's path

(BASED ON http://cimss.ssec.wisc.edu/tropic/archive/2005/storms/katrina/katrina.html)

[4] All wind speeds provided in this section are estimated wind speed values as provided by the National Hurricane Center.

Katrina weakened as it passed over land on August 26, and again became a tropical storm before it entered the Gulf of Mexico. However, once over the Gulf, Katrina began regaining strength and, on August 28, reached Category 5 hurricane status with sustained winds of 175 mph (gusts of 215 mph) and a central minimum pressure of 902 millibars (mb).[5] Later in the 2005 hurricane season, Hurricanes Rita and Wilma developed with minimum pressures of 897 mb and 882 mb, respectively. As a result, Katrina became the sixth most intense Atlantic Basin hurricane on record (Rita is now the third and Wilma ranks as the first). Katrina's rapid intensification was due in part to its movement over the warm Gulf waters.

At 6:10 a.m. Central Daylight Time (CDT) on August 29, Hurricane Katrina made landfall for the second time, near Buras, Louisiana, in Plaquemines Parish. According to the National Climatic Data Center (NCDC), Hurricane Katrina had 1-minute sustained winds estimated at 127 mph upon landfall, and a minimum central pressure of 920 mb, making it the third lowest landfall pressure on record for the U.S., and placing it as a strong Category 3 hurricane on the Saffir-Simpson scale. After making landfall, Katrina moved northward up the Louisiana coast, subjecting much of Plaquemines and St. Bernard Parishes, as well as Slidell in St. Tammany Parish, to the damaging effects of its storm surge and strong winds.

After passing New Orleans, Hurricane Katrina moved across the open waters of Breton Sound and the western edge of the Mississippi Sound and made landfall at 10:00 a.m. CDT for a third time near Pearlington, Mississippi, located along the Louisiana/Mississippi border. At its third landfall, Katrina was a Category 3 hurricane with 120-mph, 1-minute sustained winds. After making landfall and traveling more than 150 miles inland and reaching Jackson, Mississippi, the storm weakened, losing its hurricane strength, with sustained wind speeds dropping below 74 mph. Katrina kept moving northward, affecting weather in the central United States, until it was absorbed by a frontal boundary near southeast Quebec and northern New Brunswick, Canada, on August 31.

One of the key factors of this storm was its strength 24 hours before landfall when it was a large Category 5 hurricane with a minimum central pressure of 902 mb. Although the storm weakened from a powerful Category 5 storm to a Category 3 storm just before making landfall in Louisiana and Mississippi, the storm surge appears to have maintained a level associated with a Category 5 hurricane. The surge generated by the storm could not dissipate as rapidly as the wind speeds decreased, and the shallow depth of the offshore shelf and shape of the shoreline contributed to the high surge elevations. Storm surge pounded the coastline from southeast Louisiana to the Florida panhandle, with the Mississippi coastline experiencing the highest storm surges on record.

After landfall, the eye traveled almost 100 miles across the Louisiana Delta before reaching the Mississippi coastline. However, the highest wind areas remained largely east of the delta over open water, with little reduction in velocity before reaching the Mississippi coastline.

Katrina was a wide storm, affecting a large area and pushing record storm surge onshore in its northeastern quadrant along the Alabama and Mississippi coastlines. Typically, surge elevations

[5] Central pressure measurements are from the National Hurricane Center's *Tropical Cyclone Report* for Hurricane Katrina, dated December 20, 2005.

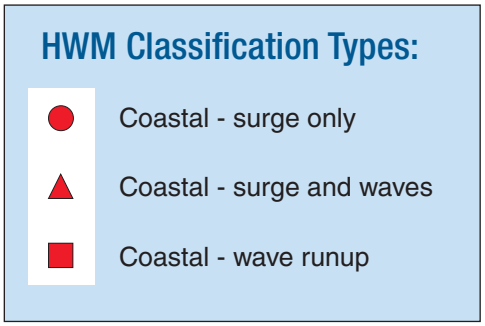
exceeded 23 feet North American Vertical Datum of 1988 (NAVD 88) throughout much of the Mississippi coastline, from Waveland east to Long Beach. The highest recorded surge and wave height elevation was 34.9 feet (NAVD 88).

Although the eye of Hurricane Katrina did not directly hit New Orleans, catastrophic destruction occurred throughout the southeast portion of Louisiana. As the eye of the storm moved farther inland to the northeast of New Orleans later in the morning of August 29, winds began to blow from the north. With surge levels already high in Lakes Pontchartrain and Borgne, additional pressure from the strong north winds was put on the levee system protecting New Orleans. The levees/floodwalls of the canals that normally channel water from the low-lying areas of the city (some below sea level) to pumping stations located along Lake Pontchartrain began to fail, allowing water to inundate large portions of the New Orleans area. Based on early investigations by the U.S. Army Corps of Engineers (USACE) Interagency Performance Task Force (USACE, 2006), there were three major levee breaches and a number of secondary breaches on Monday, August 29, 2005. The major breaches were located along the Industrial Canal in the St. Claude Avenue bridge area, the 17th Street Canal levee, and the London Avenue Canal on the east bank of the canal's flood wall and levee. Additional details on the levees may be found in the USACE Interagency Performance Evaluation Task Force Interim Status Report 1, *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System*, dated 10 January 2006.

A more detailed discussion of the storm surge and the wind analyses is provided in the following sections.

1.1.2 Storm Surge Analysis and Discussion

The storm surge in Alabama, Louisiana, and Mississippi caused severe flood damage to residential, commercial, and public buildings, and infrastructure. The surge brought high waves and carried floodborne debris, significantly impacting and destroying buildings.



To assist in the long-term recovery and mitigation effort, FEMA performed a coastal high water marks (HWMs) study to investigate the high water conditions throughout the impacted areas. The HWMs were surveyed by FEMA and the U.S. Geological Survey (USGS). HWMs were surveyed horizontally on the North American Datum of 1983 (NAD 83), Mississippi East State Plane Coordinates, and vertically in NAVD 88. The HWM elevations were also converted to the National Geodetic Vertical Datum of 1929 (NGVD 29) to aid review of data and maps available only in the NGVD 29 datum. The HWMs were classified as one of three basic types: surge only, surge and waves, or wave runup.

1.1.2.1 Mississippi – High Water Marks

The HWM data collected for this study demonstrate that the Hurricane Katrina coastal storm surge and wave-related high water conditions reached historical proportions and covered

significant portions of the Mississippi study area. A total of 402 HWMs were surveyed in the three counties investigated, as shown in Figure 1-3. Surge elevations along the open coast generally exceeded 23 feet in Hancock and Harrison Counties, and over 17 feet in Jefferson County. The highest surge HWMs along the open coast were discovered in Hancock and Harrison Counties on each side of the opening to St. Louis Bay. This high surge was evident in the communities of Lake Shore, Clermont Harbor, and Bay St. Louis in Hancock County, and Pass Christian and Long Beach in Harrison County; the highest surge elevation surveyed was 28.1 feet and the highest HWM with waves was 34.9 feet. Figure 1-4 illustrates a typical map of the HWMs in Harrison County. Maps of the all counties surveyed are provided in Appendix F.

1.1.2.2 Louisiana – High Water Marks

A total of 482 HWMs were surveyed in eastern Louisiana, as shown in Figure 1-5. The locations, elevations, and descriptions of these HWMs have been tabulated into a digital database and are summarized in Appendix F. An overall discussion of the HWM elevations for the various study areas are presented in the following sections.

1.1.2.3 Coastal Areas

Overall, the Hurricane Katrina storm surge in south-central Louisiana was lower compared to many areas of eastern Louisiana and along the entire Mississippi Coast, because the storm made landfall in the eastern part of the state. The areas of the greatest impact were those where the highest winds generated in the right-front quadrant of the storm, pushing the water toward the coast until the topography of the land surface was such that it caused a piling up of the water. These areas include St. Bernard Parish on the open Gulf Coast and the parishes surrounding Lake Ponchartrain, which include St. Tammany, Tangipahoa, Livingston, St. John the Baptist, St. Charles, Jefferson, and Orleans. The Gulf of Mexico coast forms a large embayment from Plaquemines Parish, extending north then east along the Mississippi Gulf Coast. Figure 1-6 illustrates a typical map of HWMs for Plaquemines Parish. As the storm advanced toward the coast and eventual landfall, water was pushed into this area by the high winds. HWM elevations varied in St. Bernard Parish. Typical HWM elevations ranged from 10 to 12 feet; however, some were as high as 17 to 19 feet (see Appendix F).

1.1.2.4 Lake Ponchartrain

Moderate surge levels were recorded on the western shore of the lake (see Appendix F). Due to the extensive marsh and swamp land in this area, it was difficult to collect HWMs. Surge elevations in this area ranged from 2.8 feet inland west of Lake Maurepas in Livingston Parish to 6.4 feet in St. Charles Parish (see Appendix F).

As the storm approached New Orleans, strong winds blowing from the east forced water into Lake Ponchartrain from the Gulf of Mexico, causing the elevation of the lake to rise. This increased volume of water was pushed by these winds and piled up onto the northern shore of the lake, resulting in storm surge extending north as far as U.S. Highway 190 in Slidell, to Interstate 12 north of Mandeville (see Appendix F). As the eye of the storm followed its northeast track, the wind direction shifted and began blowing to the south. This resulted in the lake water being pushed southward, allowing it to pile up on the southern shoreline.

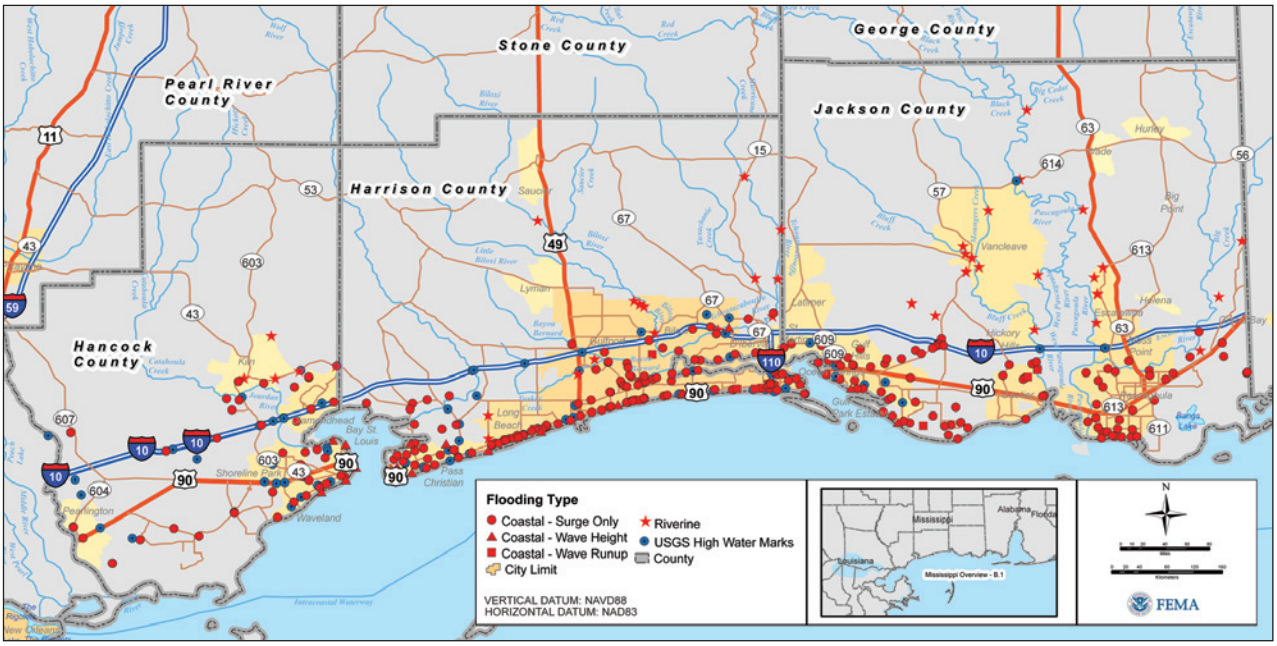


Figure 1-3. Locations of the high water marks in Mississippi

SOURCE: FEMA

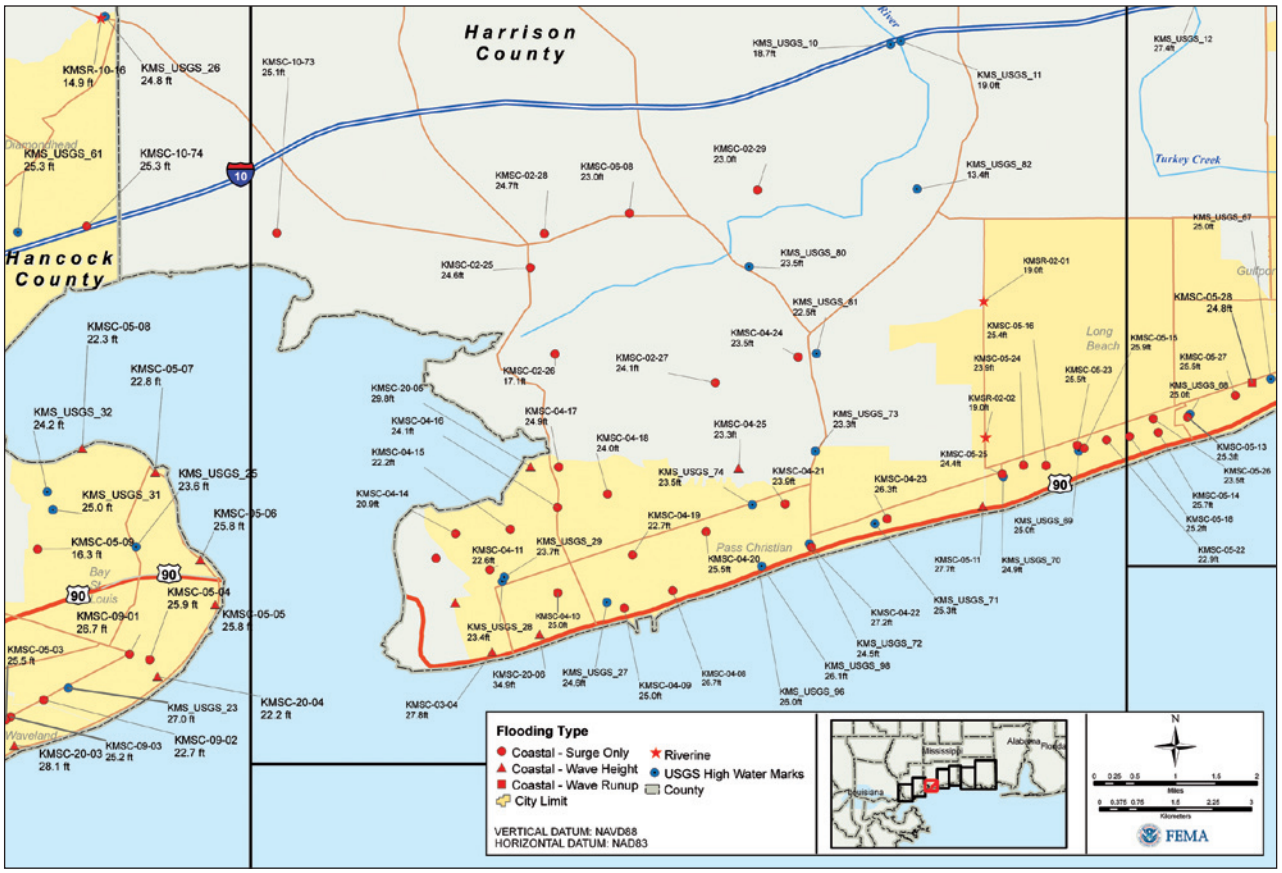


Figure 1-4. Locations of the high water marks in Harrison County, Mississippi

SOURCE: FEMA

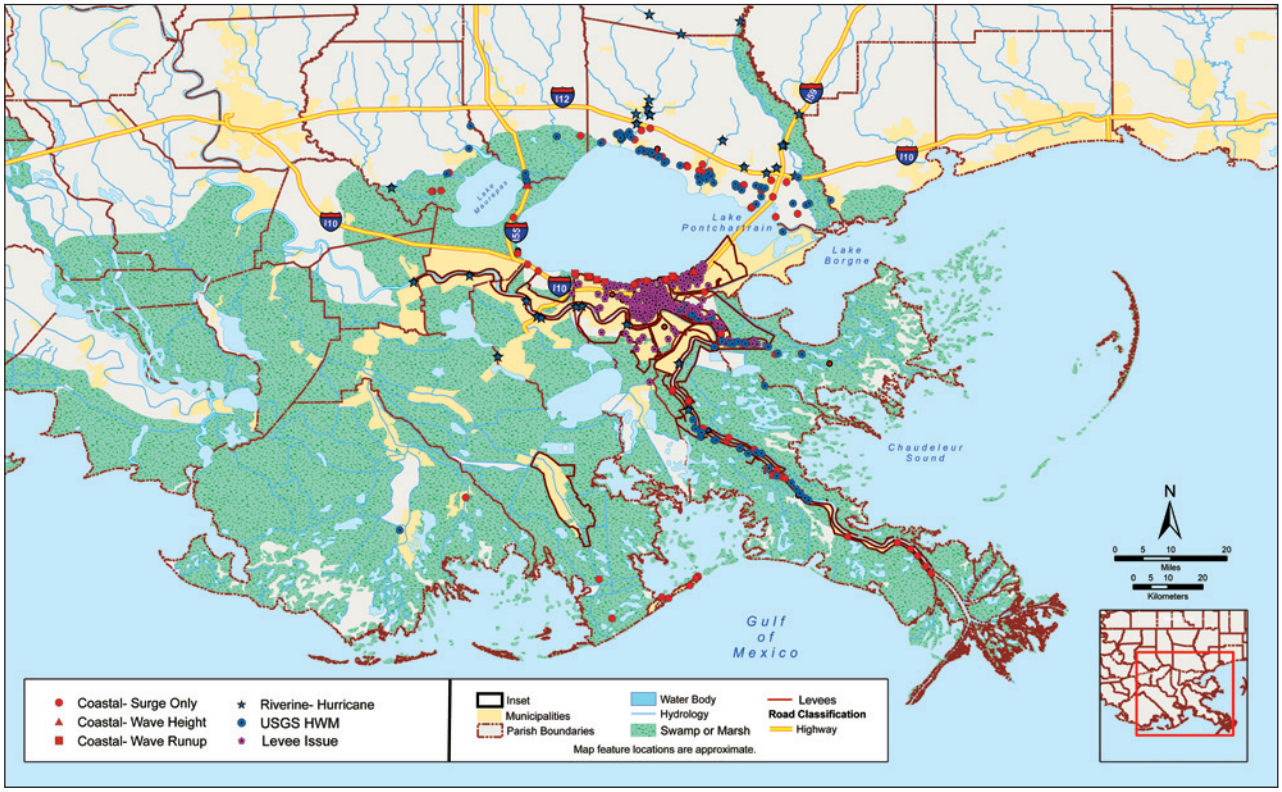


Figure 1-5. Locations of the high water marks in Louisiana

SOURCE: FEMA

On the northern shore of the lake, HWMs recorded surge levels ranging from 7 to 16 feet, with the general trend of the highest values on the east end of the north shore working westward to the lower surge values. Coastal storm surge elevations of 12.5 to 13.5 feet were recorded in the Slidell vicinity (see Appendix F). The same general pattern of higher elevations, topping at 16.6 feet, on the eastern end of Lake Ponchartrain trending to lower elevations, down to 6.8 feet, on the western end, was recorded on the southern shore of the lake (see Appendix F). These HWMs are all found on the lake side of the levee system.

1.1.2.5 Southern Area

The coastal areas least affected by Hurricane Katrina were those parishes located in the left and trailing quadrants of the storm. These include Terrebonne, Lafourche, and southern Jefferson Parishes. These parishes are sparsely populated with few roads giving access. As illustrated in Appendix F, these areas are also extensively covered by marshland and swamp. This terrain significantly lessens the impact caused by storm surge, as it applies a dampening effect to the water as it moves inland. Unfortunately, this type of terrain also lessens the availability of HWMs to be located and flagged. Appendix F shows the locations and elevations of the HWMs surveyed in these parishes. Only one HWM was found and flagged in Terrebonne Parish; seven were flagged and surveyed in Lafourche Parish. As Hurricane Katrina tracked farther inland on its northeastern path, the water in Barataria Bay was pushed southward over Grand Isle. HWM elevations were the highest in this portion of the state, measuring between 5.8 and 8.9 feet (see Appendix F).

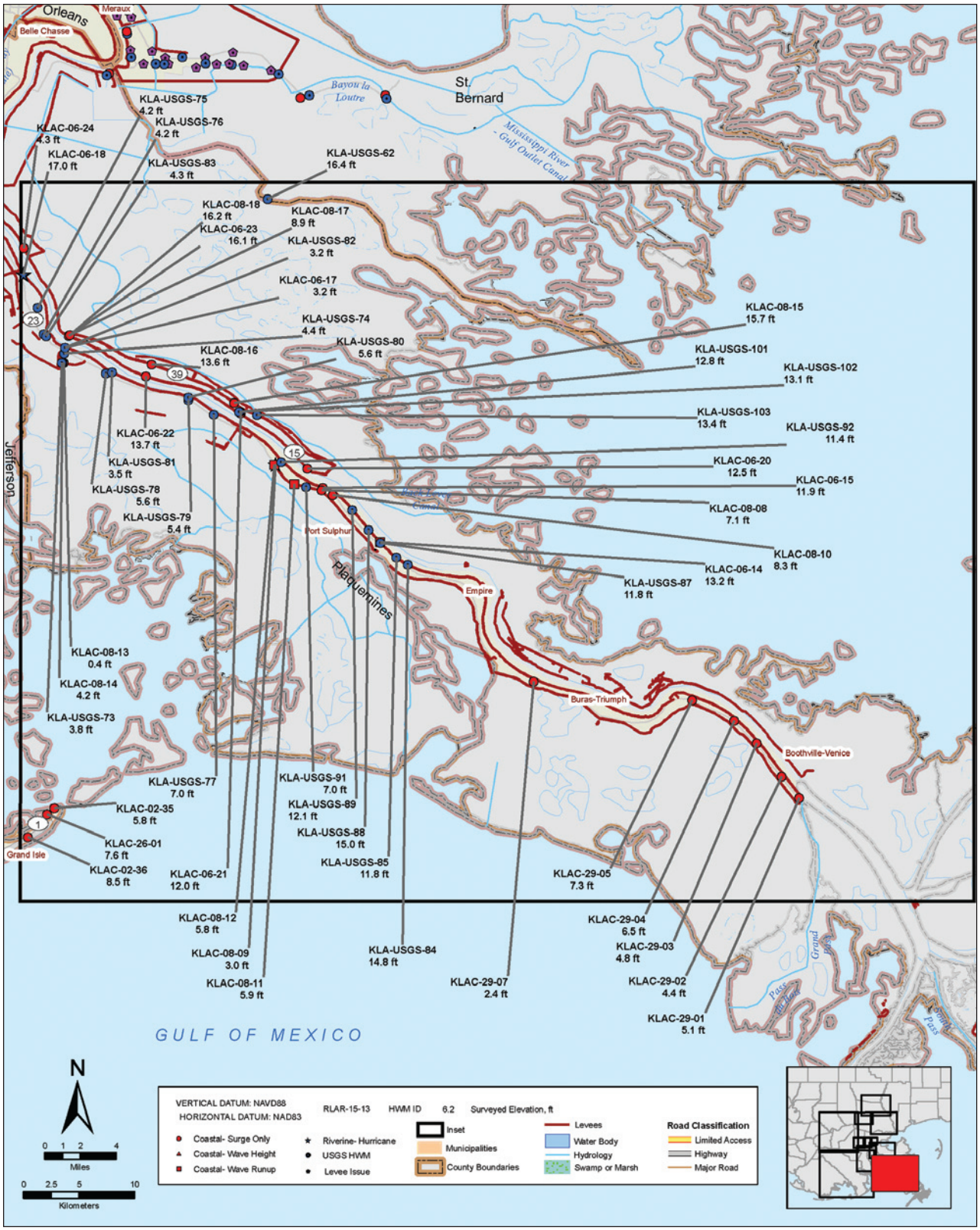


Figure 1-6. Example of map illustrating high water marks surveyed in Plaquemines Parish, Louisiana

SOURCE: FEMA

1.1.2.6 Alabama – High Water Marks

In Alabama, a total 222 HWMs were surveyed in Baldwin and Mobile Counties, as shown in Figure 1-7. The locations and elevations of the HWMs are summarized in Appendix F.

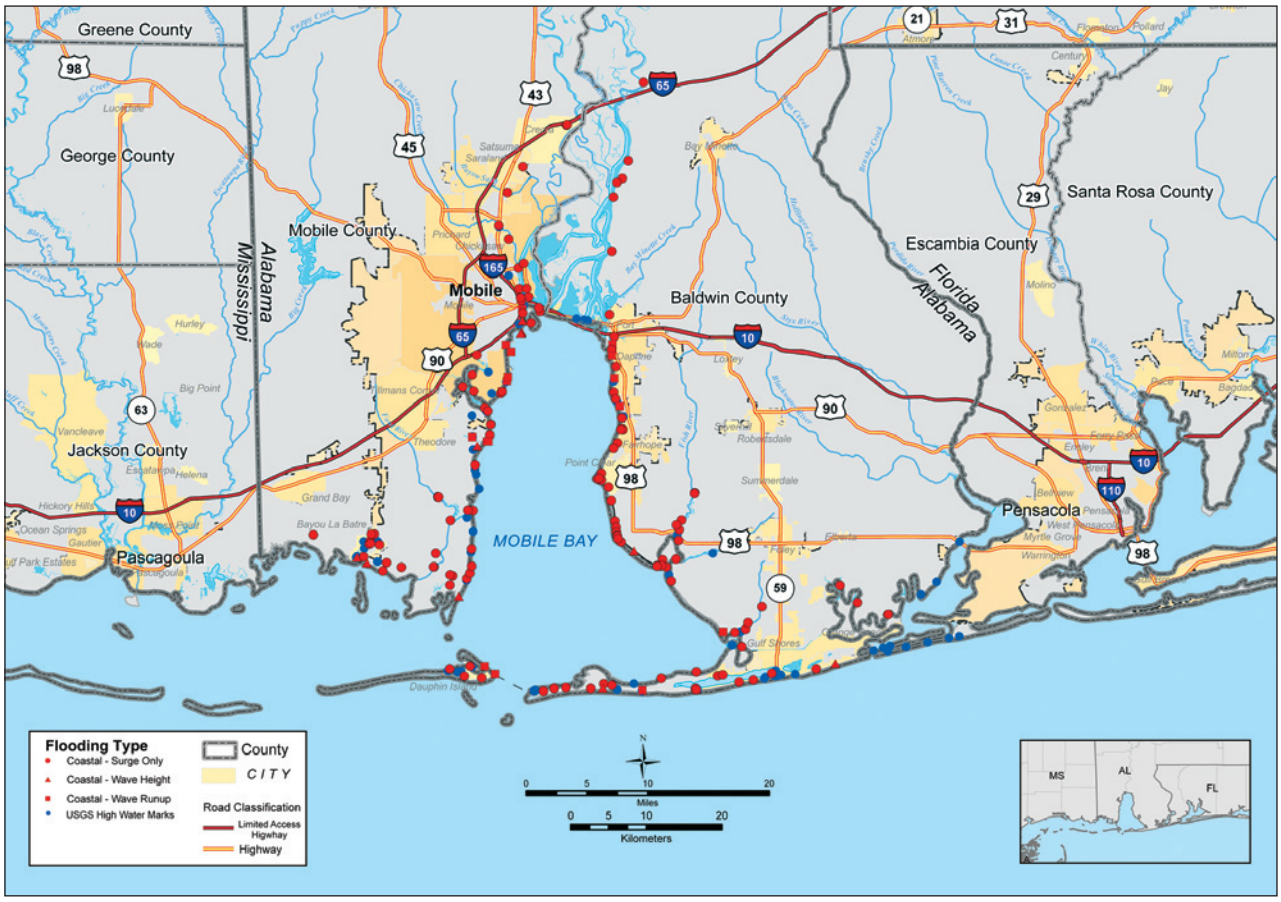


Figure 1-7. Locations of the high water marks in Alabama

SOURCE: FEMA

The Hurricane Katrina storm surge in Alabama was relatively high. The storm made landfall near the Louisiana and Mississippi state line, 65 miles west of the Alabama/Mississippi boundary. However, Katrina had a wind field that was skewed to the east and this resulted in hurricane force winds extending about 120 miles from the storm center. This caused a considerable storm surge at several places along the Alabama coast. HWMs varied throughout the two counties, typically from 10 to 12 feet on the northern end of Mobile Bay (see Figure 1-8), 8 to 10 feet along the central shorelines of Mobile Bay, and 9 to 11 feet on Dauphin Island, Alabama. Maps of HWMs in other areas of Alabama are shown in Appendix F.

1.1.2.7 Factors Affecting Storm Surge

As illustrated with the HWM data discussed in the preceding subsections, the peak storm surge in Hurricane Katrina exceeded the prior U.S. record set by Hurricane Camille, which hit in the same region of the Mississippi Coast. The fact that both records were set in the same geographic

area is not just a result of two severe hurricanes striking coastal Mississippi; storm surges there are amplified by physical features, and a hurricane of a given intensity will cause higher storm surges in coastal Mississippi than almost anywhere else along the entire coast of the United States.

The two primary factors that amplify Mississippi's storm surge are the shallow offshore depths and the shape of the shoreline. As a storm surge advances toward the shoreline, it tries to return via the bottom of the water column. Along coasts with steep offshore slopes (e.g., the southeast coast of Florida, or the Pacific Coast), return flow effectively moderates the rise in water elevation. However, the shallow depths offshore of Mississippi restrict the return flow and lead to higher surge elevations over land. The shoreline shape also determines whether and how the storm surge can escape as the hurricane approaches. On a straight shoreline, the surge can partially escape at each end of the shoreline, reducing the peak elevations. The Mississippi River Delta along the Louisiana and Mississippi shoreline forms a bay-like feature that effectively confines the surge and amplifies the elevation as a hurricane moves ashore.

These surge effects are best isolated by comparing results of the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) storm surge model prepared by NOAA. Using an array of storm tracks on local bathymetric grids, a worst-case storm surge is produced for Category 1 through 5 hurricanes. A comparison of three categories of storms along the Gulf Coast is shown in Figure 1-9.

Only the developed areas along the *open coast* areas are included in Figure 1-9, to exclude storm surge amplification in the more inland bays. Predicted worst-case storm surge elevations (without waves) are shown along the Gulf Coast from Galveston, Texas, to south of Tampa Bay, Florida. The figure shows that, for a given category storm, most areas of the Gulf Coast (i.e., Texas, Western Louisiana, Alabama, the Florida panhandle, and the lower Florida Peninsula) will experience similar storm surges, with the exception of two areas – the Mississippi Coast and the "Big Bend" area of Florida, where the surge elevations are roughly 50 to 100 percent higher than those experienced along most of the Gulf Coast. The bay effect of the Mississippi Delta can be seen as the increase from Pilot Town on the outer end of the delta to a flat peak from Pass Christian to Biloxi, dropping in Eastern Mississippi.

In addition to unusually high storm surge potential for any given storm, Mississippi has one of the highest chances of a landfalling hurricane and, in some sections, the highest design wind speeds in the country. Therefore, it is not a random coincidence that Hurricanes Katrina and Camille set storm surge records in Mississippi.

Figure 1-10 shows the NOAA SLOSH model estimating the maximum storm surge along the Gulf Coast as a result of Hurricane Katrina. The storm surge in the Gulfport-Biloxi area was estimated to exceed 23 feet.

Figure 1-11 shows the primary factors driving Katrina's storm surge as the eye of the hurricane reached the Louisiana Delta (a) and the Mississippi shoreline (b). Although the initial landfall of the eye was across Plaquemines Parish, Louisiana, the radius of maximum winds remained principally east of the delta and made landfall in Mississippi. The counter-clockwise winds around the eye forced water into the shallow, western corner of Mississippi Bay, with escape prevented by the long branches of the Louisiana Delta.

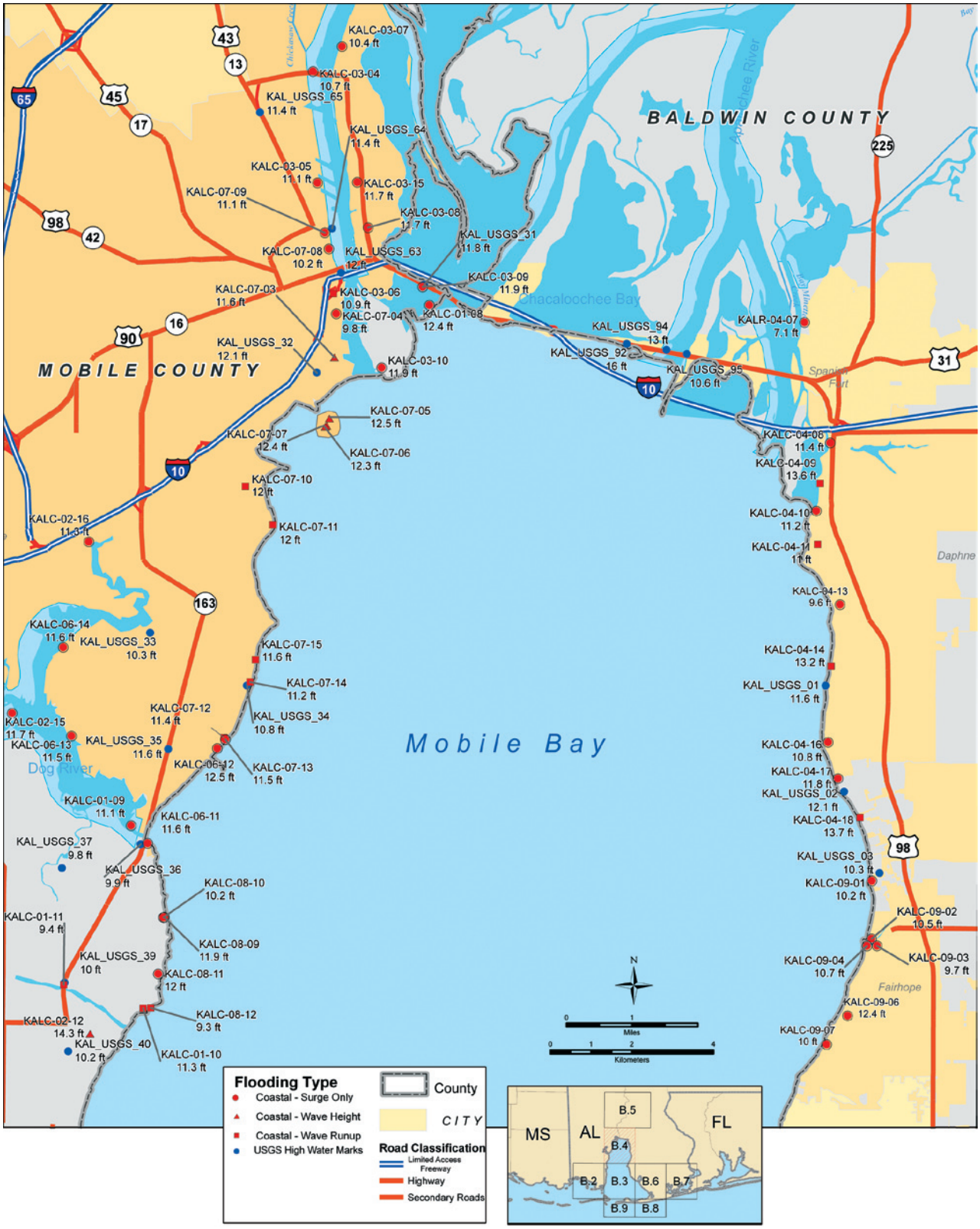


Figure 1-8. High water mark locations for area covering the northern end of Mobile Bay

SOURCE: FEMA

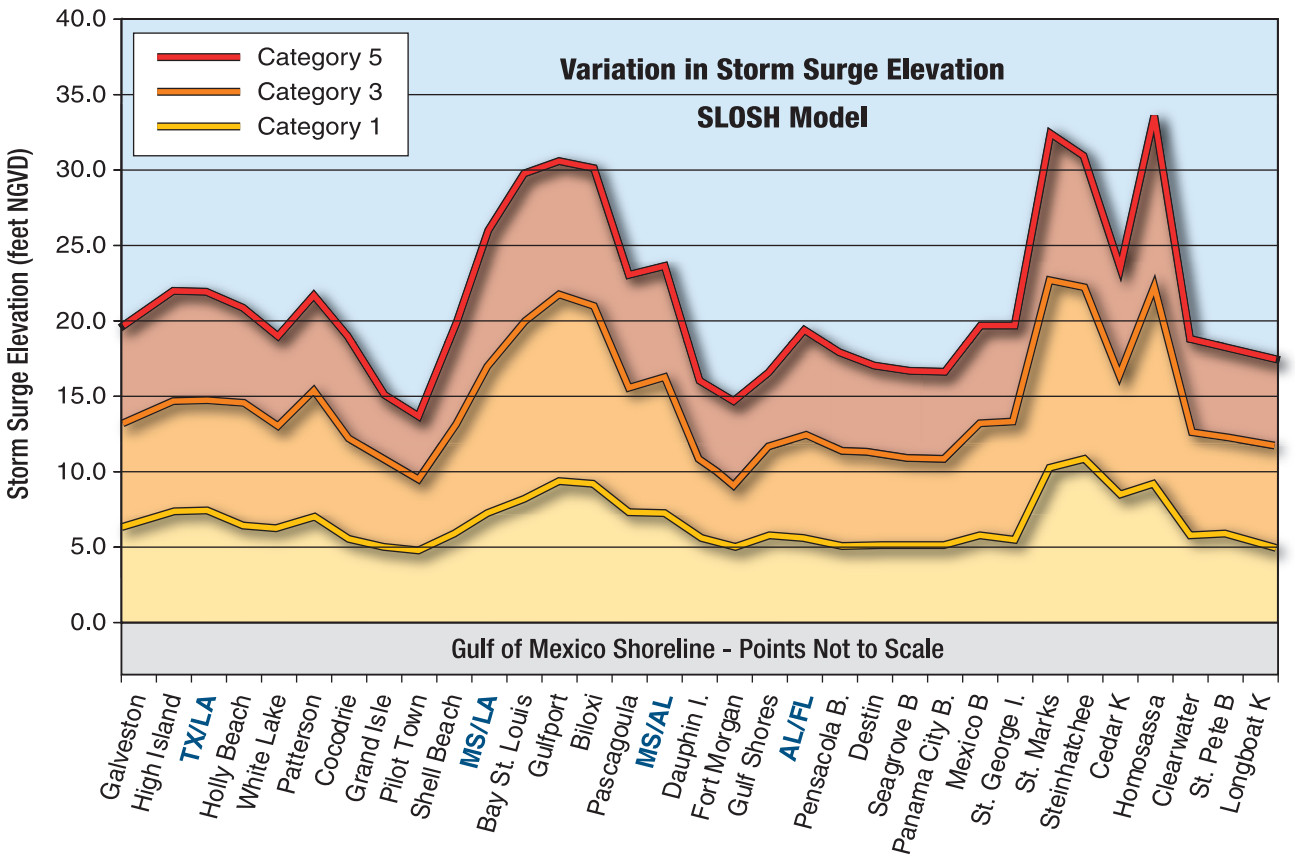


Figure 1-9. Maximum SLOSH storm surge predictions for open coast, developed shorelines

SOURCE: SLOSH DISPLAY CD-ROM/JANUARY 5, 2006/NOAA

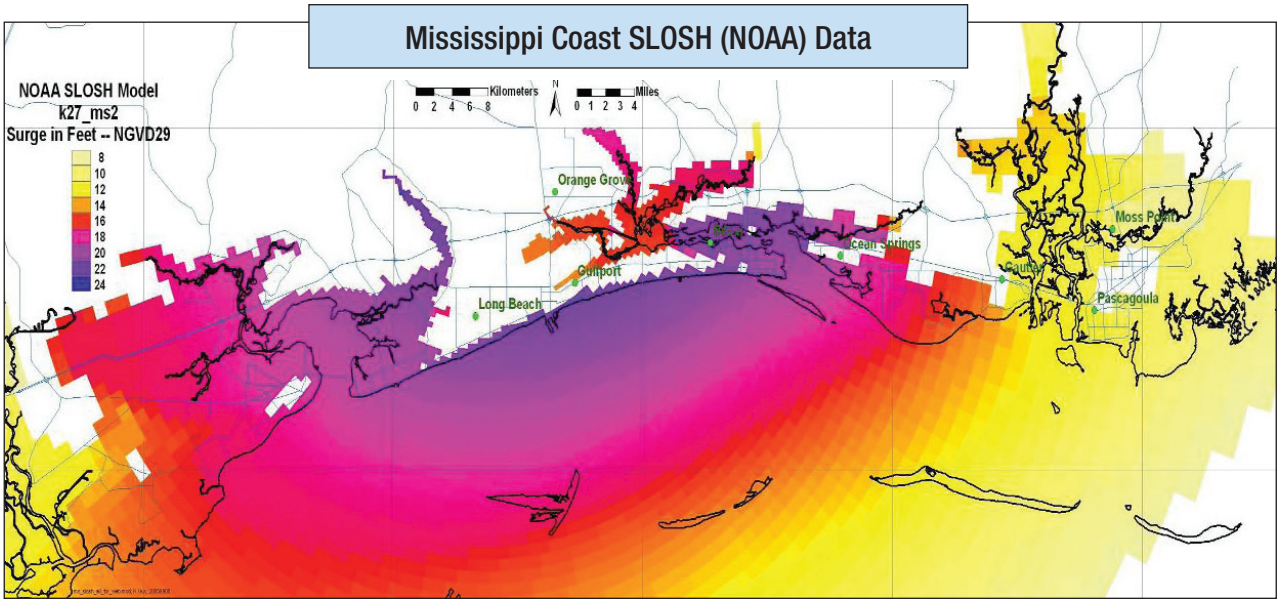


Figure 1-10. The SLOSH model of high water elevations for Hurricane Katrina

SOURCE: NOAA

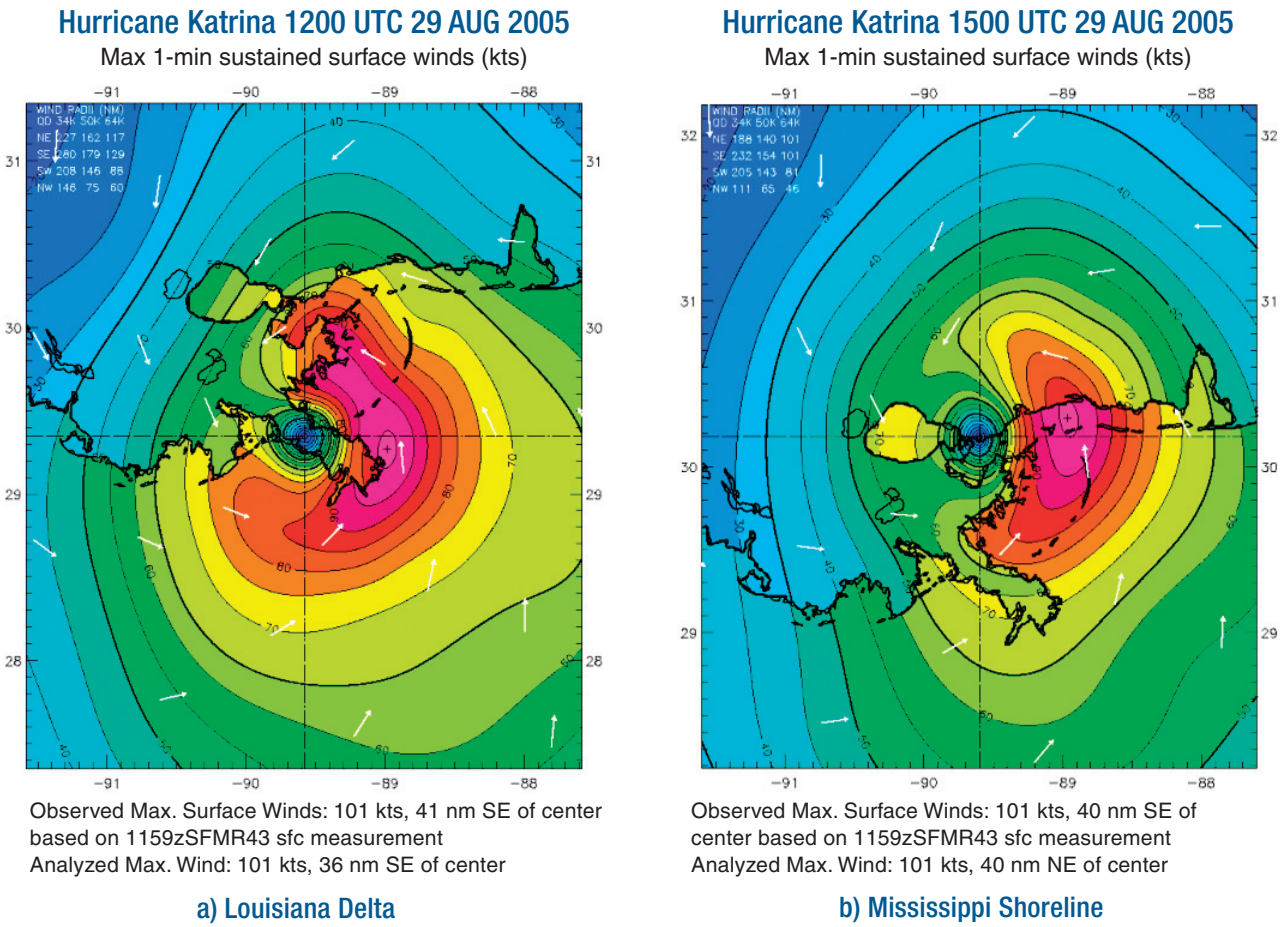


Figure 1-11.
H*Wind[6] snapshots of Katrina 1-minute winds as the eye reached the Louisiana Delta (a) and Mississippi shoreline (b). Counter-clockwise winds pushed peak storm surge into the west end of the Mississippi Bay.

SOURCE: NOAA, ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY [AOML], HURRICANE RESEARCH DIVISION [HRD]

Several other factors contributed to Katrina's record storm surge. The storm was very large, with hurricane wind speeds covering approximately 200 miles in diameter as it came ashore. As described previously, Katrina's wind speeds and central pressure were that of a very strong Category 5 hurricane within a hundred miles of the coast. The surface flow and deepwater wave heights were therefore initiated under these higher wind speeds. If the offshore conditions of the storm's strength had been similar to those at landfall, storm surge elevations would have been lower.

In short, it is not surprising that Katrina caused high storm surges along the western Mississippi coastline. The shallow offshore slope and the confining corner created by the Louisiana Delta make it predictable that a hurricane of any intensity on a similar track would result in a higher storm surge than along most other shorelines in the United States. Refer to Section 1.1.3 for more information on H*Wind.

[6] One of the better known products for representing hurricane winds is H*Wind from NOAA's Hurricane Research Division. H*Wind is an experimental research product developed by the HRD.

1.1.2.8 Coastal Flood Frequency Analysis

Under a separate Hazard Mitigation Technical Assistance Program (HMTAP) Task Order, URS was tasked to prepare Flood Advisory Maps for the three counties in Mississippi that were affected by Hurricane Katrina. Part of this task involved performing a flood frequency analysis of tidal gauge data to quickly provide information to assist in the planning and rebuilding efforts, while more detailed analyses are being conducted. The results of this study are provided in *Draft Report, Hurricane Katrina Flood Frequency Analysis,* dated September 2005. The analysis was based on 30 years' worth of tidal gauge data collected from NOAA and USGS.

The long-term gauge analysis was based on Hurricane Katrina gauge data from select NOAA and USACE stations. While the best data available were used at the time of the flood frequency analysis, the reference data had limitations. Some stations were damaged, destroyed, or malfunctioned during Hurricane Katrina and did not record the peak stage. Another limitation was that gauges with long records of data were sparsely distributed, but they did provide useful records of a long period of historic storm surge peak heights. Preliminary HWM surveys in the vicinity of the existing gauge were used in the analysis.

The historical data were analyzed using seven different methods to estimate the 2-, 10-, 50-, 100-, and 500-year elevations. Methods of the analysis include the Weibull and Cunnane plotting positions, the Pearson Type III and log-Pearson Type III distribution, the Generalized Extreme Value (GEV) distribution, and the Gumbel distribution using both untransformed and log-transformed elevation data. Details on the analysis, including the gauge data and the frequency distributions, may be found in the report.

The following is a summary of the results from the *Hurricane Katrina Flood Frequency Analysis* report:

- At Biloxi, the 100-year elevation is 15.7 feet and the 500-year elevation is 28.7 feet. Therefore, the Hurricane Katrina elevation of 24 feet is estimated to be about a 250-year event at Biloxi, Mississippi.
- At Pascagoula, the 100-year elevation is 11.9 feet and Katrina was 13 feet. Katrina is estimated to be about a 125-year event at Pascagoula, Mississippi.
- At Waveland, the 100-year elevation is 17.6 feet and Katrina was 23 feet. The 200-year event is 22.8 feet; therefore, Katrina is estimated to be about a 200-year event at Waveland. Note that the Katrina elevation of 23 feet was estimated from four HWMs obtained by USGS at a location north of Waveland near the intersection of I-10 and SR 43. It is possible that Katrina was higher than 23 feet at Waveland. The elevations of HWMs flagged at Waveland had not yet been determined when the Flood Frequency Analysis report was written.
- On the west end, bay side of Dauphin Island, the 100-year event is 7.5 feet and Katrina was 5.81 feet. The 50-year event is 6 feet; Katrina was about a 50-year event on the west end, bay side of Dauphin Island, Alabama.
- At Pensacola, the 100-year event is 7.3 feet and Katrina was 6.07 feet. The 50-year event is in the range of 5.8 feet, so Katrina is estimated to be about a 50-year event at Pensacola, Florida.

The results of the flood frequency analysis were used to develop Advisory Base Flood Elevations (ABFEs) and prepare the Katrina Recovery Maps.

1.1.2.9 Flood Recovery Maps

FEMA requested that URS evaluate coastal flood hazard conditions for Hurricane Katrina in Mississippi using data from the Flood Frequency Analysis and the High Water Mark Study, and prepare surge inundation and ABFE maps. The Hurricane Katrina Surge Inundation and ABFE maps (herein referred to as the "Katrina Recovery Maps") were provided in the form of high resolution maps that show coastal flood impacts for Mississippi and Louisiana.

These maps can be viewed at <http://www.fema.gov/hazard/flood/recoverydata/katrina/>. A sample of a Katrina Recovery Map is shown in Figure 1-12.

1.1.3 Wind Hazard Analysis and Discussion

According to the National Weather Service (NWS) December 20, 2005, report, Hurricane Katrina made landfall in Buras, Louisiana, with an estimated 1-minute sustained wind speed of 110 knots (127 mph) or approximately 150 mph 3-second gust. After landfall in Louisiana, Katrina traveled almost 100 miles across the Louisiana Delta before reaching the Mississippi coast where it made a third landfall (one in Florida and two in the Gulf) near Poplarville, Mississippi. The NWS estimated 1-minute sustained surface winds of 105 knots (120 mph) or approximately 145 mph 3-second gust.

The estimates were higher than any recorded by land-based instruments. The highest land-based wind speed recorded was 117 mph gust from a Texas Tech University tower located at the Stennis International Airport, approximately 8 miles west-northwest of Bay St. Louis, Mississippi. However, like many previous storms the MAT has investigated, ground-based anemometers either failed before they recorded maximum winds or were located great distances from the storm's path. As a result, no wind speed instruments likely recorded the maximum winds produced by Katrina.

Table 1-3 provides a summary of some of the data available from the measuring devices, including recorded wind speed, location, and the source of the data. Wind speeds have been converted from knots to mph.

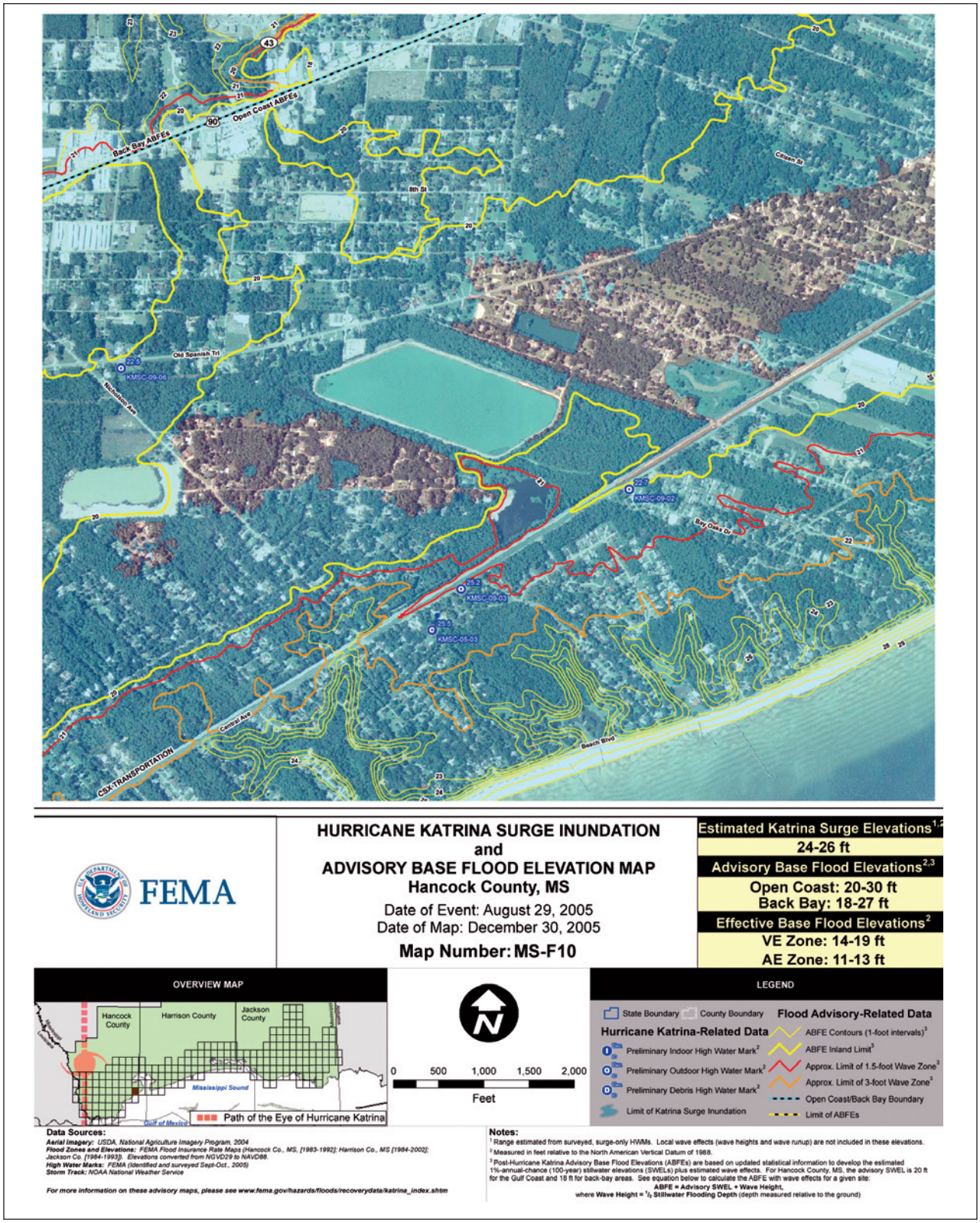


Figure 1-12.
Sample recovery map, which illustrates surge inundation and ABFEs for Hancock County, Mississippi

SOURCE: FEMA

Table 1-3. Wind Speeds Recorded for Hurricane Katrina

Location	Wind Speed
Alabama	
Dauphin Island at Coastal Marine Automated Network (C-MAN) Station DPIA1 (Source: NWS)	101 mph gust
Louisiana	
Slidell (Source: Texas Tech University mobile wind tower)	100 mph gust
Belle Chasse (Source: FCMP mobile wind tower T1)	102 mph gust
Galliano (Source: FCMP mobile wind tower T2)	96 mph gust
Vacherie (Source: Texas Tech University)	73 mph gust (data collection ceased near the storm's peak)
Grand Isle (Source: NOAA Buoy GDIL1)	114 mph gust, before gauge failed
Port Sulfur (Source: LSU AgCenter)	101 mph gust, peak before station failed
Buras (Source: University of Louisiana near Buras reporting)	114 mph gust (2 meter tower on top of a levee)
Mississippi	
Stennis International Airport (Source: Texas Tech University)	117 mph gust
Biloxi (Source: ASOS)	111 mph gust (max gust before failing)
Pine Belt Airport (12 miles NE of Hattiesburg)	Max gust 80 mph. After this, power was lost and recording stopped.
Forrest County Emergency Operations Center (EOC)	Max gust 100 mph. After this, the anemometer was blown down.
Laurel-Jones County Airport	Max gust of 110 mph. After this, the anemometer was blown down.
Jackson International Airport	Max gust of 64 mph (10 seconds), unofficial gust of 74 mph (5 seconds). After this, power was lost and recording stopped.
Pascagoula (Source: FCMP mobile wind tower T3)	95 mph gust

SOURCE: NOAA, NCDC

The wind speed data listed in this table have not been normalized to a single exposure category and instrument height.

To help fill in the gaps that exist in ground-based wind data, wind speeds are estimated using a variety of methods.

H*Wind employs estimates of surface level winds obtained from a variety of sources and yields near real-time analyses of the surface winds produced by tropical cyclones. Based on past experience of comparing modeled estimates with actual recorded wind speeds, H*Wind provides reasonably accurate estimates of maximum wind speeds over large areas impacted by a storm. Contours of 1-minute sustained wind speeds from Katrina were developed utilizing HRD's H*Wind model (see Figure 1-11). The contours are at selected "snapshots" taken as Katrina's eye passed over Plaquemines Parish and over Breton Sound.

FEMA's wind model used in HAZUS-MH (Hazards U.S. - Multi-Hazard) is also used to estimate wind speeds. HAZUS was developed as a loss estimation model, but produces reasonable estimates of maximum speed and the lateral distribution of wind. Wind swath contour plots based on HAZUS-MH methodology were modeled by Applied Research Associates (ARA) (see Figure 1-13). ARA's model uses a series of surface level observations of wind speeds and pressures obtained from portable towers, buoys, and Automated Surface Observing Systems (ASOS) stations to obtain estimates of the time variation in the storm's radius to maximum winds and the Holland B parameter (a function of the shape of the storm). Measured wind speeds are adjusted to "standard conditions" (that is 10 meter instrument height in open terrain) using either estimates of the surrounding roughness from aerial photography or from estimates of the turbulence intensity where full digital time series are available. The variation of the Holland parameter B is used with NHC position and central pressure estimates and pre-computed solutions of a numerical hurricane model to develop estimates of wind speeds as a function of time and location. Unlike the H*Wind snapshots shown in Figure 1-11, Figure 1-13 shows the highest estimated wind speeds experienced as Katrina moved through the area.

In the case of Hurricane Katrina, there were very little wind speed and pressure data inland and, as a result, estimates of wind speeds farther inland have greater uncertainty than those near the coast. Comparisons to anemometer data suggest the model has an uncertainty (estimated using the standard deviation of the observed minus modeled wind speeds) of about 6 percent, indicating that, in most cases, the modeled wind should be accurate to about 10 percent or better.

With Katrina, wind speeds generated by the HAZUS model and those estimated utilizing the H*Wind results compare favorably to each other. Also, both methods suggest that, except for a few areas along the Mississippi coast, Katrina's winds failed to reach the design wind speeds specified by ASCE 7 (the wind standard referenced by the latest building codes).

The modeled wind speeds also generally correlate with damages observed by the MAT, particularly when the model results are adjusted for exposure (HAZUS and H*Wind depict wind speeds in Exposure C (open terrain) areas; most of the MAT observations were in the more protected Exposure B areas). Exceptions to this general correlation occurred in some areas east of Gulfport and north of Picayune. In those areas, HAZUS predicted higher wind speeds than what the observed ground-based damages would appear to support. For example, HAZUS predicted wind speeds in Biloxi only 5 mph less than Bay St. Louis, but the observed wind damages in Biloxi were significantly less than those in Bay St. Louis. Also, HAZUS predicted 115 mph Exposure C wind speeds in Poplarville, but the damages observed in that area were more typical of lower wind speeds. The apparent lack of correlation between ground-based damage observations and the computer models in these areas may result from terrain effects, from construction variations, or from the uncertainty of the computer models.

DEFINITION OF WIND EXPOSURE ZONES

Exposure B. Urban, suburban, wooded areas.

Exposure C. Open terrain, flat open country, grasslands, all water surfaces in hurricane-prone regions.

Much of the wind-based damage from Hurricane Katrina occurred in areas where the wind speeds were well below the design levels specified in the latest codes. In discussing wind damage, it is important to differentiate between structural damage and building envelope damage. Many buildings experienced little or no structural damage, but may be total losses due to water entry that resulted from building envelope failure. It is also important to differentiate between the design wind speeds and their resulting design pressures specified by the latest codes and the design wind speeds/pressures specified by the older codes that were in effect when many of the buildings the MAT investigated were constructed. In many areas, the design wind pressures specified in current codes are higher than those specified in older codes.

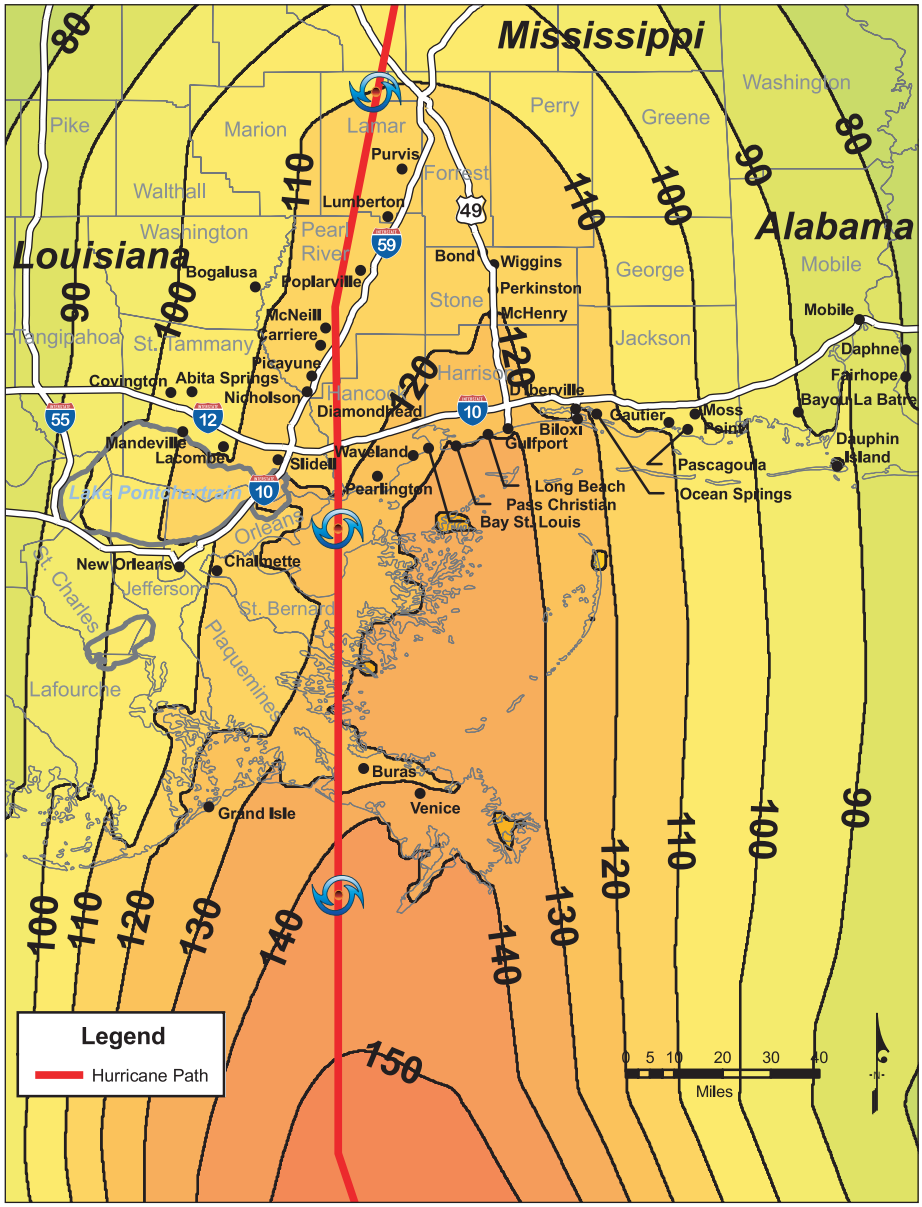


Figure 1-13.
Wind swath contour plot of 3-second gust wind speeds in mph at a height of 10 meters above ground (open exposure) based on HAZUS-MH wind field methodology

SOURCE: ARA

Table 1-4 lists the HAZUS-modeled Exposure C wind speeds in selected cities and converted wind speeds for Exposure B areas. The conversion from Exposure C to Exposure B was made using an equivalent wind pressure calculation using equations contained in ASCE 7-05.

Table 1-4. HAZUS Estimated Wind Speeds

Location	3 –Second Gust Wind Speeds* Exposure C	3 –Second Gust Wind Speeds** Exposure B
Bay St. Louis, MS	125	105
Belle Chasse, LA	110	95
Biloxi, MS	120	100
D'Iberville, MS	120	100
Dauphin Island, AL	95	80
Diamondhead, MS	120	100
Gautier, MS	110	95
Gulfport, MS	130	110
Long Beach, MS	130	110
Mobile, AL	85	70
Moss Point, MS	100	85
New Orleans, LA	105	90
Ocean Springs, MS	120	100
Pascagoula, MS	105	90
Pass Christian, MS	130	110
Poplarville, MS	115	100
Slidell, LA	115	100
Waveland, MS	125	105

* Wind speeds based on ARA wind speeds as shown in Figure 1-13.

** Calculated wind speeds, Exposure B – calculated from wind pressure conversions for components and cladding for buildings with a mean roof height of 33 feet (see ASCE 7-05 Table 6-3).

Tornadoes from Hurricane Katrina

According to the NCDC, there were 13 confirmed tornadoes in Mississippi, ranging from F1 to F2, and 11 confirmed tornadoes in Alabama, ranging from F0 to F1, as a result of Hurricane Katrina occurring on August 28 and 29, 2005. At the time the report was being developed, data for Louisiana were not available. Locations of the confirmed tornadoes are shown in Figure 1-14. Most of the tornadoes were rated F0 or F1 on the Fujita Scale, as shown in Table 1-5.

Table 1-5. The Fujita Scale

F-Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
F0	Gale tornado	40-72 mph	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	73-112 mph	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113-157 mph	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158-206 mph	Roof and some walls torn off well constructed houses; trains overturned; most trees in forest uprooted.
F4	Devastating tornado	207-260 mph	Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261-318 mph	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel reinforced concrete structures badly damaged.
F6	Inconceivable tornado	319-379 mph	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 winds that would surround the F6 winds. Missiles, such as cars and refrigerators, would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies.

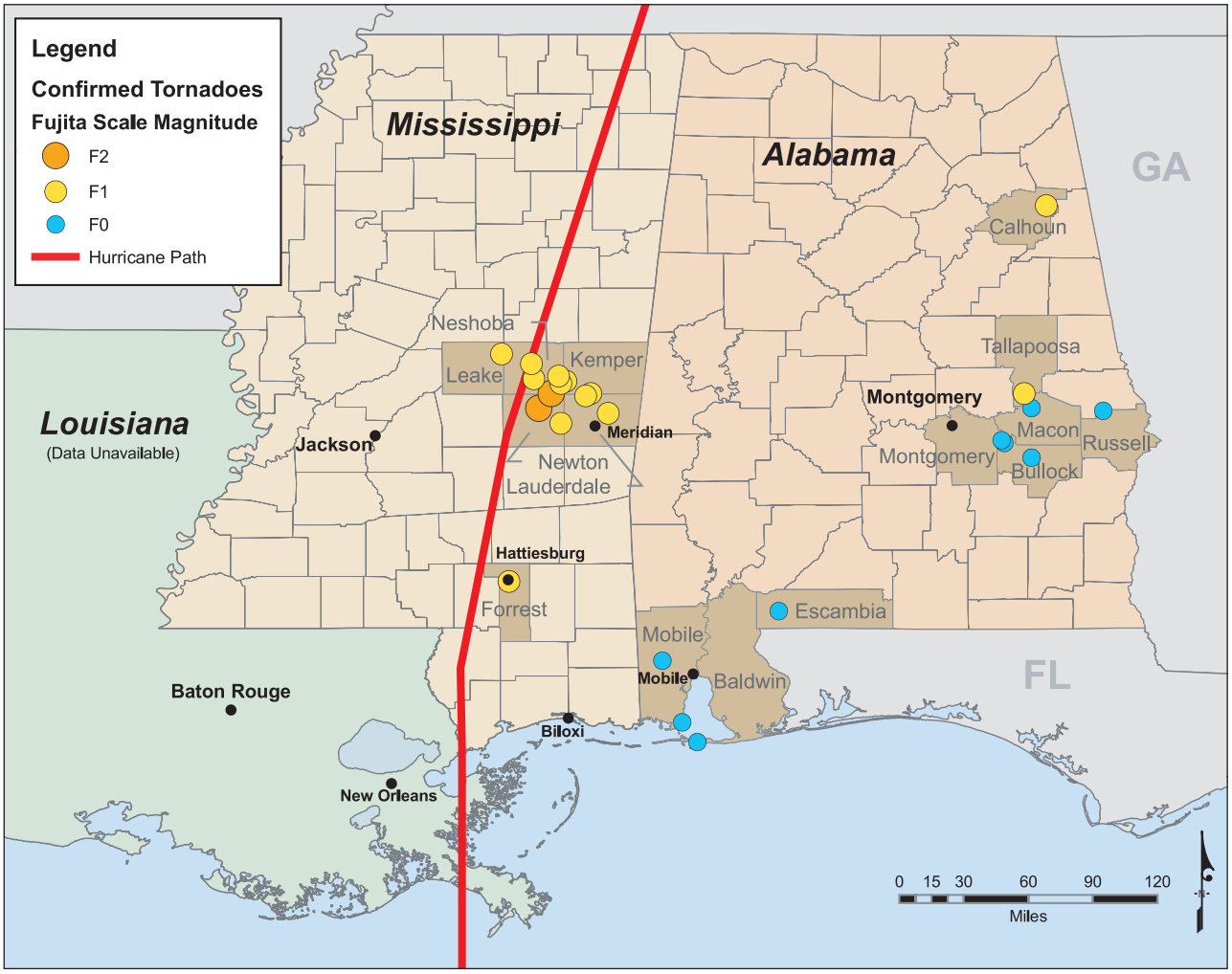


Figure 1-14. Confirmed tornadoes in Mississippi and Alabama attributed to Hurricane Katrina

(BASED ON NATIONAL CLIMATIC DATA CENTER RECORDS)

1.2 Historic Hurricanes

At its peak in the Gulf, Hurricane Katrina reached a minimum central pressure of 902 mb, although at landfall it weakened to 920 mb. Other severe hurricanes (and the minimum central pressure at landfall) were Hurricane Camille (909 mb) and the Labor Day hurricane that struck the Florida Keys in 1935 (892 mb). Hurricane Andrew in 1992 recorded a pressure of 922 mb at landfall and destroyed over 25,000 houses and damaged over 100,000 houses. Hurricanes Rita and Wilma, which occurred in 2005, recorded some of the lowest pressures in history. Table 1-6 provides a summary of the most intense hurricanes to make landfall on the U.S. mainland.

Table 1-6. Summary of Most Intense Hurricanes to Make Landfall in the United States Based on Minimum Pressure

Hurricane	Minimum Pressure (millibars)	Pressure at Landfall (millibars)	Category at Landfall	Location	Year
Wilma	882	950	3	near Everglades City, FL	2005
Unnamed Storm	892	892	5	Florida Keys	1935
Rita	897	937	3	Texas/Louisiana border	2005
Allen	899	948	3	south Texas	1980
Katrina	902	920	3	Plaquemines Parish, near Buras, LA	2005
Camille	905	909	5	Mississippi	1969
Andrew	922	922	5	southeast FL - Homestead, FL	1992

SOURCE: NOAA, NCDC, *CLIMATE OF 2005 ATLANTIC HURRICANE SEASON*

When discussing past hurricanes, many residents of southeast Louisiana and the Gulf Coast of Mississippi had always referred to the power, high surge elevations, wind speeds, and resultant damage of Hurricanes Betsy and Camille for comparison. Now the benchmark for future hurricanes has become Hurricane Katrina. In Alabama, Dauphin Island residents referred to the destruction caused by Hurricane Frederic. Table 1-7 shows the comparisons for Hurricanes Betsy, Camille, Frederic, and Katrina. Figure 1-15 shows the paths of Hurricanes Betsy, Camille, Frederic, and Katrina.

Table 1-7. Comparisons of Hurricanes Betsy, Camille, Frederic, and Katrina

Hurricane	Year	Category at Landfall	Surge Elevation (feet)	Wind Speed-gust (mph) at Landfall	Central Pressure (mb) at Landfall	Casualties	Economic Loss (billions) (adjusted 2005)	Number of Homes Damaged/ Destroyed
Betsy	1965	3	16	160	948	76	$10-12	164,000
Camille	1969	5	25	190	909	256	$6.99	19,577
Frederic	1979	3	12	145	946	5	$7.3	N/A
Katrina	2005	3	28	150	920	>1,700	$125	>300,000

SOURCE: NOAA, NCDC

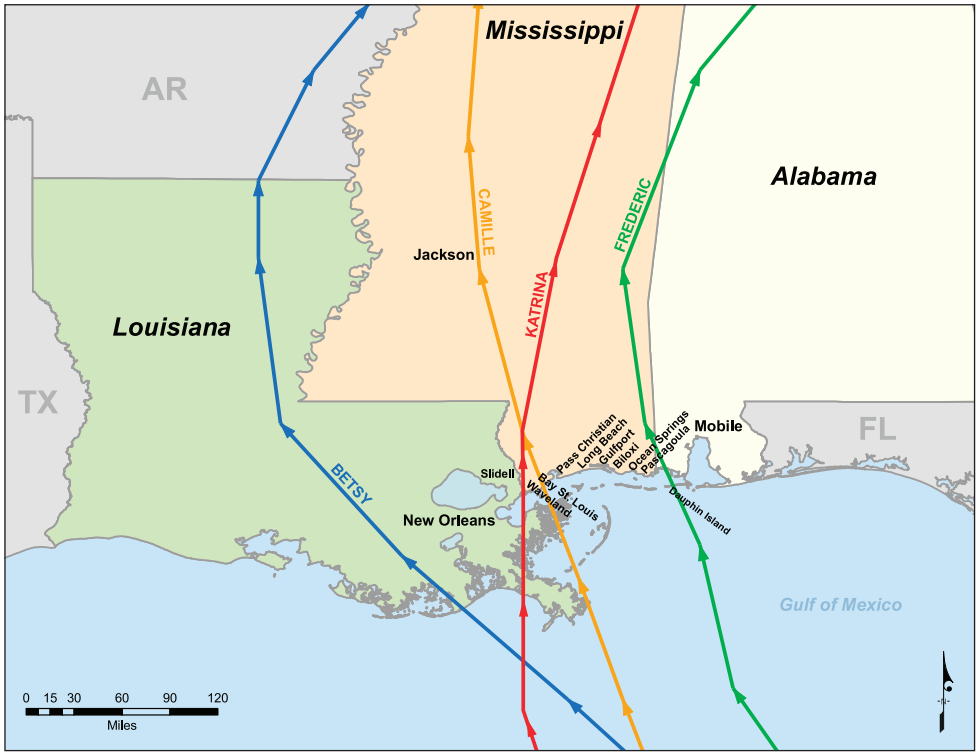


Figure 1-15. Historic hurricane storm tracks: Betsy (1965), Camille (1969), Frederic (1979), and Katrina (2005)

(BASED ON HURRICANE STORM TRACK DATA FROM THE NATIONAL HURRICANE CENTER)

1.2.1 Hurricane Betsy

A major hurricane of the 1965 hurricane season, Hurricane Betsy tracked through the Bahamas and Florida before reaching Louisiana, causing major damage along its path. Betsy made landfall on September 9, 1965, as a Category 3 Hurricane at Grand Isle, Louisiana, bringing 160-mph gusts and a 16-foot storm surge that flooded the entire island. Winds gusted to 125 mph in New Orleans and a 10-foot storm surge caused major flooding. Winds in most of southeast Louisiana reached 100 mph and, in areas as far inland as Monroe, winds exceeded 60 mph. Offshore oil rigs, public utilities, and commercial boats all suffered severe damage, resulting in approximately $1.4 billion in damage (in 1965 dollars, the equivalent of approximately $10-12 billion in 2005). Seventy-six people lost their lives as a direct result of Hurricane Betsy, the first storm to cause $1 billion in damage. Figure 1-16 shows all hurricane storm tracks in the Gulf Coast "catcher's mitt" from 1851 to the present, according to the NHC.

Like Katrina, Betsy caused surge effects in Lake Pontchartrain. The storm surge from the lake caused a section of the levee to fail, resulting in flooding within New Orleans in the Ninth Ward and in the Chalmette area of St. Bernard Parish. In most low-lying areas of the city, floodwaters reached to the roofs of houses, resulting in drowning deaths of some of those whom had sought refuge from the floodwaters in their attics. Water levels receded after approximately 10 days. It is estimated that approximately 164,000 homes were flooded in Louisiana as a result of Hurricane Betsy.

After Betsy, the USACE created the Hurricane Protection Program and constructed a new levee system both higher and stronger than the former system. This system protected New Orleans from Hurricane Camille's storm surge in 1969.

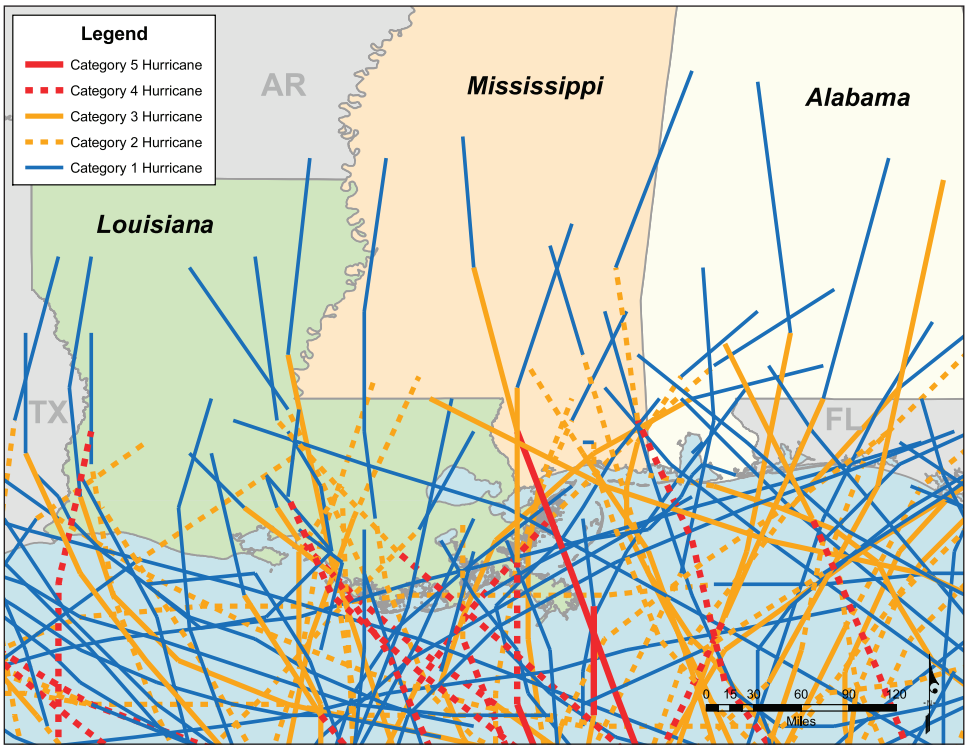


Figure 1-16. Historic hurricane storm tracks and categories (1851 – present)

(BASED ON HURRICANE STORM TRACK DATA FROM THE NATIONAL HURRICANE CENTER)

1.2.2 Hurricane Camille

Hurricane Camille (1969), the previous "hurricane of record" for the Mississippi Gulf Coast, recorded a 25-foot storm surge. At its peak strength over the Gulf (902 mb and 175 mph sustained winds), Katrina's intensity was comparable to Camille's, but at landfall Katrina's measured winds (127 mph sustained) were lower and its central pressure (920 mb) was higher than Camille's estimated landfall measurements of 190-210 mph gust speeds and 909 mb central pressure.[7] However, Katrina was a larger storm affecting a wider area than Camille, and was pushing higher storm surges onshore along the Gulf Coast.

Camille made landfall as a Category 5 hurricane in western coastal Mississippi in the Waveland/Bay St. Louis area on August 17, 1969, approximately 15-20 miles east of where Katrina made its third landfall near Pearlington, Mississippi. Like Katrina, Hurricane Camille brought severe destruction to the Mississippi Gulf Coast, causing $1.42 billion in total damage (in 1969 dollars – the equivalent of $6.99 billion when adjusted to 2005 dollars), and was directly responsible for 143 deaths in Alabama, Louisiana, and Mississippi. Many of those who died were residents along the coast who did not evacuate. After losing hurricane strength, Camille traveled north, causing major flooding in Virginia and leading to the deaths of an additional 113 people. Throughout its path, Camille caused injury to 8,931 people, destroyed 5,662 homes, and severely damaged 13,915 homes.

[7] Camille's landfall measurements are estimates because a reconnaissance aircraft was unable to estimate surface wind just prior to the storm's landfall and because terrestrial weather observation equipment did not survive the storm.

For the past 36 years, Camille has stood out as the benchmark storm for those living along the Mississippi Gulf Coast, both in their minds and in records set. However, with Hurricane Katrina's arrival in 2005, residents of the area have a new standard for devastation and destruction. Although not as powerful as Hurricane Camille according to wind speed and pressure measurements at landfall, Hurricane Katrina was a much larger diameter storm. The most overwhelming source of damage was Katrina's record-breaking storm surge along the Mississippi coast, which topped Camille's surge elevations by several feet in most areas. Although Hurricane Katrina is considered the new standard for comparing hurricanes along the Louisiana and Mississippi Gulf Coast, future storms could equal or exceed the impact caused by Katrina.

1.2.3 Hurricane Frederic

In 1979, Hurricane Frederic caused considerable damage along Dauphin Island and Gulf Shores, Alabama. Making landfall near Gulf Shores-Mobile, Alabama, peak storm surge levels reached 12 feet in Gulf Shores, destroying much of the community, and 11 feet at Dauphin Island, destroying the causeway connecting the island to the mainland. Over 50 homes were destroyed along the 22-mile reach from Fort Morgan to Gulf Shores, and 73 percent of the beachfront buildings were destroyed. In comparison, the high surge of Hurricane Katrina was similar to that of Hurricane Frederic, in some areas along Dauphin Island. Hurricane Katrina's high surge provided a good opportunity to assess the adequacy of National Flood Insurance Program (NFIP) floodplain management requirements as well as current construction practices in resisting storm surge damage.

1.3 FEMA Mitigation Assessment Teams (MATs)

Most people know FEMA for its response to disasters and its assistance to people impacted by disasters. Another important contribution of the agency is the building performance studies it conducts after disasters in order to better understand how natural and manmade events affect the built environment. These studies are conducted with the intent of reducing the number of lives lost to these events and minimizing the economic impact on the communities where these events occur. In addition, lessons learned are applied to the rebuilding effort after disasters to enhance the disaster-resistance of new building stock.

Since the mid-1980s, FEMA has sent MATs to Presidentially-declared disaster areas to evaluate building performance. The MAT studies 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 damage 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, as caused by 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 will not only improve the disaster resistance of the built environment in the impacted state or region, but will also be of national significance to all disaster-prone regions.

1.3.1 Purpose of the MAT

In response to a request for technical support from FEMA Joint Field Offices in Montgomery, Alabama; Baton Rouge, Louisiana; and Jackson, Mississippi, FEMA's Mitigation Division deployed a MAT to Alabama, Louisiana, and Mississippi on September 26, 2005, to evaluate both building performance during Hurricane Katrina and the adequacy of current building codes, other construction requirements, and building practices and materials.

The flood levels for Hurricane Katrina far exceeded the current design flood event (i.e., 100-year base flood event), as illustrated on the FEMA Flood Insurance Rate Maps (FIRMs), along the entire Gulf Coast of Mississippi, and caused levee failures in Louisiana. The wind speeds from Katrina were less than the design speeds for most areas based on the model codes (International Building Code [IBC]/International Residential Code [IRC]) and on the engineering standard (ASCE 7) referenced in the building codes.

In New Orleans, FEMA was particularly interested in the long-term impacts of flooding on the structural and non-structural elements of buildings, as well as the floodplain management issues surrounding the levee breaches.

Except at a few locations along the Mississippi coast, Hurricane Katrina was below a design level wind event. The storm provided an opportunity to examine building elements that failed even when they shouldn't have and the team had hoped to determine how buildings built to new building codes performed in those areas that did experience near-design wind conditions. However, due to a limited stock of buildings built to the newer I-codes and the fact that many areas did not experience a design wind event, it was difficult to evaluate the effectiveness of the newer codes. The team was able to collect information about building damage that helps correlate wind speeds to building performance.

1.3.2 Team Composition

The MAT included FEMA Headquarters and Regional Office engineers and experts from the design and construction industry. Team members from FEMA's database of national experts included structural engineers, architects, wind engineers, civil engineers, coastal scientists, building code experts, and flood preservation specialists. In addition, representatives from the USACE, the National Institute of Standards and Technology (NIST), Oak Ridge National Laboratory (ORNL), the Association of Floodplain Managers (ASFPM), the International Code Council (ICC), and wind engineers and scientists from Texas Tech University, Louisiana State University (LSU), and University of Mississippi also participated.

In response to the unique situation presented by the flooding in New Orleans, FEMA deployed a portion of the MAT resources (hereafter referred to as the New Orleans Flood Team) to observe and assess damage to residential buildings and critical and essential facilities from the levee breach flooding associated with the storm. Therefore, the New Orleans Flood Team also included experts from the flood restoration industry.

1.3.3 Methodology

Aerial reconnaissance was performed by MAT members to assess overall building damage in the areas affected by Katrina on September 11 and 12, 2006. As shown in Figure 1-17, the aerial observations were conducted from Dauphin Island, Alabama, along the Mississippi Gulf Coast, over New Orleans, and inland over Slidell and Mandeville, Louisiana, and Hattiesburg, Mississippi.

Preliminary field investigations to assess building conditions in limited areas were conducted between September 17 and 21. Based on the data collected by the aerial reconnaissance and the preliminary field investigations, the area of focus for the full MAT was more fully defined. The full MAT was deployed on September 26 for 2 weeks, conducting extensive ground observations from Dauphin Island, Alabama, along the Mississippi Gulf Coast, through the City of New Orleans to Venice and Grand Isle, Louisiana, as shown in Figure 1-18.

The MAT focused their efforts in Alabama, Mississippi, and St. Tammany Parish, Louisiana, from September 26 through October 3, 2005. In Alabama, the team worked on the western coastline, including Dauphin Island, collecting building damage data. In Mississippi, the team worked in the state's three coastal counties performing ground inspections from Pascagoula in Jackson County to Waveland and Pearlington in Hancock County. Field investigations to assess building conditions in Louisiana began on October 4 and concluded on October 8, 2005. The team conducted ground inspections throughout the New Orleans area, including the City of New Orleans and Orleans Parish, as well as the nearby communities of Chalmette in St. Bernard Parish and Metairie in Jefferson Parish. Additionally, the team visited affected areas in Plaquemines and Lafourche Parishes.

Damages were observed to single- and multi-family buildings, manufactured housing, commercial properties, and historic buildings. In addition, critical and essential facilities, such as Emergency Operations Centers (EOCs), fire and police stations, hospitals, nursing homes, schools, and storm shelters were also evaluated in order to document building performance as well as loss of function from Hurricane Katrina. Documentation of observations is presented in this report. Photographs and figures are included to illustrate building performance in the wind field and surge areas produced by Katrina. The conclusions and recommendations of the MAT's findings will assist in minimizing damages from future hurricanes.

Figure 1-17. Flight paths of aerial reconnaissance conducted by the MAT

(BASED ON http://www.nationalatlas.gov AND MAT GPS POINT LOCATIONS)





Figure 1-18. Locations visited by the MAT

(BASED ON http://www.nationalatlas.gov AND MAT OBSERVATIONS)

2. Floodplain Management Regulations and Building Codes and Standards

Floodplain management regulations, along with building codes and standards, are adopted and enforced to regulate construction.

The floodplain management regulations applicable to the areas affected by Hurricane Katrina are discussed in Section 2.1. Section 2.2 presents the building codes and standards used to regulate construction specific to floods and wind.

2.1 Floodplain Management Regulations

All of the communities along the Mississippi Gulf Coast visited by the MAT participate in the NFIP and have adopted floodplain management regulations that meet or exceed minimum NFIP requirements. Up until 2000, these NFIP requirements generally were contained only in local floodplain management ordinances. Starting in 2000, however, flood-resistant provisions and floodplain management requirements began to be incorporated into the model building codes. The primary model building code in the United States is developed and maintained by the ICC. The ICC's family of codes, referred to as the "I-Codes," includes the IBC, the IRC, the

International Existing Building Code (IEBC), and a series of codes for mechanical, plumbing, fuel gas, and on-site sewage installations. The National Fire Protection Association (NFPA) has recently begun to produce a building code, the *Building Construction and Safety Code* (NFPA 5000). A notable recent addition is NFPA's *Model Manufactured Home Installation Standard* (NFPA 225, 2005 Edition), the first such standard to include provisions for installation in flood hazard areas.

Communities have two avenues for enforcing flood-resistant design and construction practices that are specific to buildings and structures: the floodplain management ordinance and the building code (see Figure 2-1). The ordinance includes all requirements necessary to participate in the NFIP. The IBC contains provisions that are specific to buildings (if adopted, Appendix G adds administrative provisions and requirements for most development other than buildings). To address the coordination between the ordinances and the I-Codes, communities may wish to refer to the document, *Reducing Flood Losses Through the International Codes*, available at <http://www.fema.gov/hazard/flood/pubs/fldlossesb.shtm>.

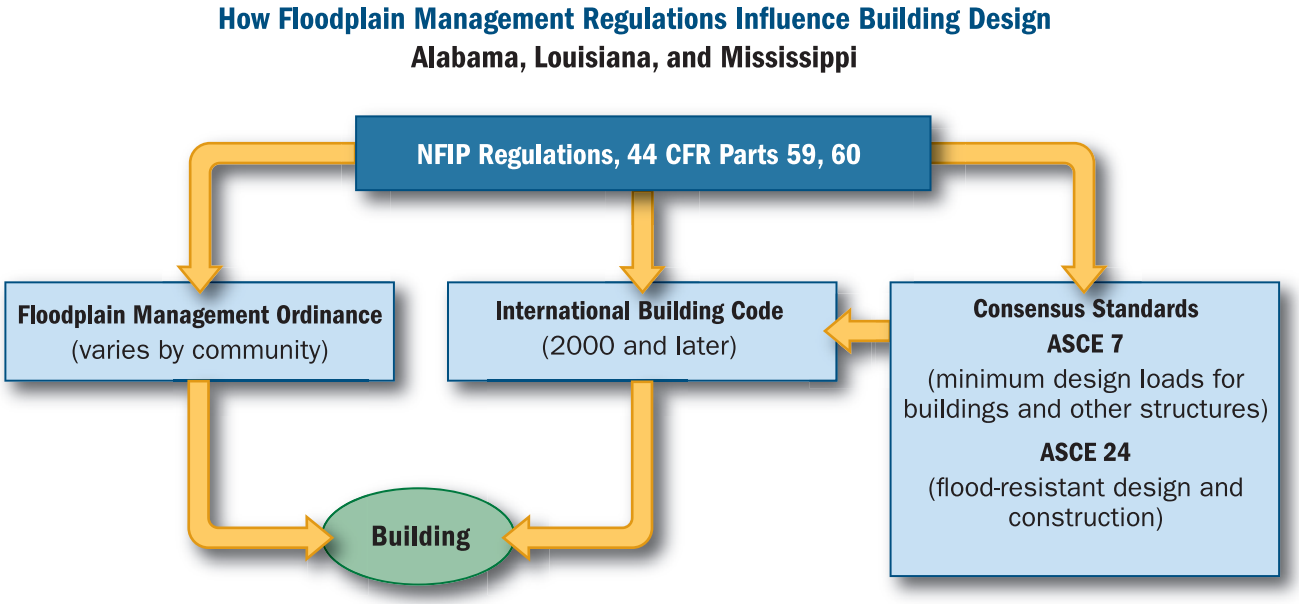


Figure 2-1.
Floodplain management regulations and building design in communities with adopted building codes

Many communities in Louisiana and Mississippi that were heavily impacted by Katrina's surge had not adopted model building codes prior to Hurricane Katrina; however, many communities had adopted a floodplain management ordinance.

Nine of the 14 Mississippi communities visited also participate in the NFIP's Community Rating System (CRS) program and range from Class 6 to Class 8 – an indication of efforts to move beyond the minimum requirements in the NFIP. In Louisiana, all six of the parishes visited participate in the NFIP, with four of the six parishes participating in the CRS program (ranging from Class 7 to Class 10). All but one incorporated jurisdiction visited by the MAT in Louisiana

participate in the NFIP, with half participating in the CRS program (ranging from Class 8 to Class 9). In Alabama, the cities of Mobile and Dauphin Island and Baldwin County, which were the most impacted areas and visited by the MAT, all participate in the NFIP and the CRS program. Table 2-1 provides a detailed breakdown of NFIP and CRS participation by jurisdiction, along with the current effective date of the community's flood maps, if applicable (refer to Chapter 1, Figure 1-18, for locations of communities visited by the MAT).

COMMUNITY RATING SYSTEM

The NFIP's Community Rating System is a voluntary incentive program that recognizes community floodplain management activities that exceed the NFIP requirements. Classes range from 1 to 10, with 1 representing the most active and the most flood hazard-resistant communities. For CRS-participating communities, flood insurance premium rates are discounted in increments of 5 percent; i.e., a Class 1 community receives a 45 percent premium discount, while a Class 9 community receives a 5 percent discount (a Class 10 receives no discount). The CRS classes for communities are based on 18 creditable activities, organized under 4 categories: (1) Public Information, (2) Mapping and Regulations, (3) Flood Damage Reduction, and (4) Flood Preparedness. Of the more than 900 communities that participate in the CRS, over 90 percent have a rating of 7, 8, or 9 <http://www.fema.gov/business/nfip>.

It is worth noting that one jurisdiction in Louisiana that does not participate in the NFIP does not have any designated flood zones identified within its jurisdiction. There is no restriction on such a community participating in the NFIP if the community chooses to do so. Many communities without designated flood zones are still subject to flooding and benefit from NFIP membership.

Table 2-1. NFIP and CRS Participation in Visited Jurisdictions

Jurisdiction	NFIP Entry Date	Effective FIRM*	CRS Status (if applicable)
Alabama			
Baldwin County	1/12/1973	6/17/2002	9
Gulf Shores	7/4/1971	6/17/2002	9
Orange Beach	1/12/1973	6/17/2002	10
Mobile County	12/11/1970	7/6/1998	Non Participating
Dauphin Island	12/11/1970	7/6/1998	8
Mobile, City of	9/15/1972	7/6/1998	10
Escambia County	3/31/1998	10/27/1978	Non Participating
Atmore	6/24/1977	6/24/1977	8

Table 2-1. NFIP and CRS Participation in Visited Jurisdictions (continued)

Jurisdiction	NFIP Entry Date	Effective FIRM*	CRS Status (if applicable)
Louisiana			
Jefferson Parish	10/1/1971	3/23/1995	7
Grand Isle	10/30/1970	3/23/1995	Non Participating
Gretna	6/18/1971	3/23/1995	8
Lafitte	10/1/1971	3/23/1995	Non Participating
Kenner	6/25/1971	3/23/1995	8
Lafourche Parish	4/17/1985	5/4/1992	10
Orleans Parish	8/3/1970	3/1/1984	8
Plaquemines Parish	5/1/1985	9/30/1993	Non Participating
St. Bernard Parish	3/13/1970	6/30/1999	Non Participating
Chalmette	Non Participating	Non Participating	Non Participating
St. Tammany Parish	4/23/1971	4/21/1999	9
Madisonville	12/2/1980	3/16/1983	Non Participating
Mandeville	9/28/1979	4/4/1983	8
Slidell	12/16/1980	4/21/1999	9
Mississippi			
Hancock County	9/9/1970	8/18/1992	Non Participating
Bay St. Louis	9/11/1970	11/16/1983	7
Waveland	9/11/1970	11/16/1983	6
Harrison County	6/15/1978	10/4/2002	8
Biloxi	9/11/1970	3/15/1984	7
D'Iberville	11/14/1988	8/04/1998	Non Participating
Gulfport	9/11/1970	10/4/2002	8
Long Beach	9/11/1970	5/4/1988	8
Pass Christian	5/26/1970	8/19/1987	6
Jackson County	4/3/1978	4/16/1993	Non Participating
Gautier	11/13/1986	8/18/1992	8
Moss Point	9/18/1970	9/4/1987	Non Participating
Ocean Springs	9/18/1970	8/18/1992	8
Pascagoula	9/18/1970	3/15/1984	Non Participating

SOURCE: NFIP, CRS

Under Executive Order 11988, Federal agencies shall take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural beneficial values served by floodplains in carrying out its responsibilities for the following:

1. acquiring, managing, and disposing of Federal lands and facilities;
2. providing Federally undertaken, financed, or assisted construction and improvements; and
3. conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities.

2.1.1 Flood Studies and Flood Maps

FEMA conducts Flood Insurance Studies (FISs) to develop the data upon which FIRMs are based. FEMA provides printed copies of FISs and FIRMs to participating communities. FIRMs identify areas of varying flood hazard as flood zones. Zones A and V comprise a special area known as the Special Flood Hazard Area (SFHA). The SFHAs are expected to be inundated by the flood event with a 1-percent probability of being equaled or exceeded in any given year. This flood is also referred to as the base flood or 100-year flood. Within these special flood hazard areas are areas that may experience more frequent but less severe flooding. One of the goals of the MAT was to investigate failures from flooding to buildings located both inside and outside the SFHAs, as shown on the effective FIRMs.

SFHAs labeled as Zone AE (as well as A1-30, VE, and V1-30) have been studied by detailed methods and show Base Flood Elevations (BFEs), which are the minimum elevations to which lowest floors, as defined by the NFIP, are required to be elevated.[1] SFHAs labeled as Zone VE are along coasts and are subject to additional hazards due to storm-induced velocity wave action (the BFE in Zone V is the top of the wave crest). BFEs derived from detailed hydraulic analyses are shown within

[1] A Zone BFEs apply to the top of the lowest floor elevation; V Zone BFEs apply to the bottom of the lowest horizontal structural member. In A Zones, the lowest floor is to be elevated to or above the BFE; in V Zones, the bottom of the lowest horizontal structural member is to be elevated to or above the BFE.

DESCRIPTION OF FLOOD ZONES

V Zones. The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action (3 feet and higher) from storms or seismic sources. The FIRMs use Zones VE and V1-30 to designate these Coastal High Hazard Areas.

A Zones. The portion of the SFHA not mapped as a V Zone. Although FIRMs depict A Zones in both riverine and coastal floodplains (as Zones A, AE, A1-30, and AO), the flood hazards and flood forces acting on buildings in those different floodplains can be quite different. In coastal areas, A Zones are subject to wave heights less than 3 feet and wave run-up depths less than 3 feet.

Coastal A Zones. Though not shown on FIRMS, Coastal A Zones are referenced in ASCE 24-05 and ASCE 7-05. This is an area within the SFHA, landward of a V Zone, where flood forces in A Zones in coastal areas are not as severe as in V Zones, but are still capable of damaging or destroying buildings on shallow foundations. During the base flood conditions, the potential for breaking wave heights shall be greater than or equal to 1.5 feet. For this reason, different design and construction standards are recommended (by the MAT and others) in Coastal A Zones that are different than those used in Riverine A Zones.

DESCRIPTION OF FLOOD ZONES (continued)

A1-30. Areas of 100-year flood; BFEs and flood hazard factors are determined.

AO. Areas of 100-year shallow flooding where depths are between 1 and 3 feet.

AH. Shallow flooding SFHA.

A99. An area inundated by 100-year flooding, for which no BFEs have been determined. This is an area to be protected from the 100-year flood by a Federal flood protection system under construction.

Zones X, B, and C. These zones identify areas outside of the SFHA. Zone B and shaded Zone X identify areas subject to inundation by the flood that has a 0.2 percent probability of being equaled or exceeded during any given year. This flood is often referred to as the 500-year flood. Zone C and unshaded Zone X identify areas above the level of the 500-year flood. The NFIP has no minimum design and construction requirements for buildings in Zones X, B, and C.

For NFIP flood zone definitions, refer to 44 CFR 59.1.

For an explanation of zone designations, please refer to the FIRM for your community.

the V Zones. (Zone VE is used on new and revised maps in place of Zones V1-V30.) Mandatory flood insurance purchase requirements apply in all SFHAs. Figure 2-2 shows the relationship between the stillwater elevation, wave effects, BFEs, and the zone designations. Further discussion of flood zones, including Coastal A Zones, can be found in Section 3.1.

The zone designation and the BFE are critical factors in determining what requirements apply to a building and, as a result, how it is built. NFIP regulations provide minimum building requirements for structures built in each of the zones; when a community joins the NFIP[2] and adopts its FIRM, the community is also adopting minimum floodplain standards. Some examples of the NFIP minimum requirements for buildings built in Zone VE (Coastal High Hazard Areas) are:

- The building must be elevated on pile, post, pier, or column foundations.
- The building must be adequately anchored to the foundation.
- The building must have the bottom of the lowest horizontal structural member at or above the BFE.
- The building design and method of construction must be certified by a design professional.
- The area below the BFE must be free of obstructions; if enclosed, the enclosure must be made of breakaway walls that are designed and certified to give way under certain flood loads.

ADVISORY BASE FLOOD ELEVATIONS

FEMA established Advisory BFEs after Hurricane Katrina to help expedite the rebuilding process in areas that were most severely impacted by coastal flooding. Communities are not required to adopt the advisory maps, but when the official maps are completed, adoption will be required. See Section 11.1 for further details on flood-related recommendations.

Web site for Advisory BFEs: <http://www.fema.gov/hazard/flood/recoverydata/index.shtm>

[2] Additional information on the National Flood Insurance Program can be found at <http://www.fema.gov/plan/prevent/fhm/hm_nfip.shtm>.

In Zone AE, the NFIP has the following requirements:

- The top of the lowest floor of a building must be at or above the BFE; however, there are no specific design standards or certification requirements for foundations other than the general performance standard that the building must be anchored to resist flotation, collapse, and lateral movement.
- Unfilled foundation walls below the BFE must have openings to allow for the automatic inflow and outflow of floodwaters to equalize hydrostatic pressure and prevent wall failures.

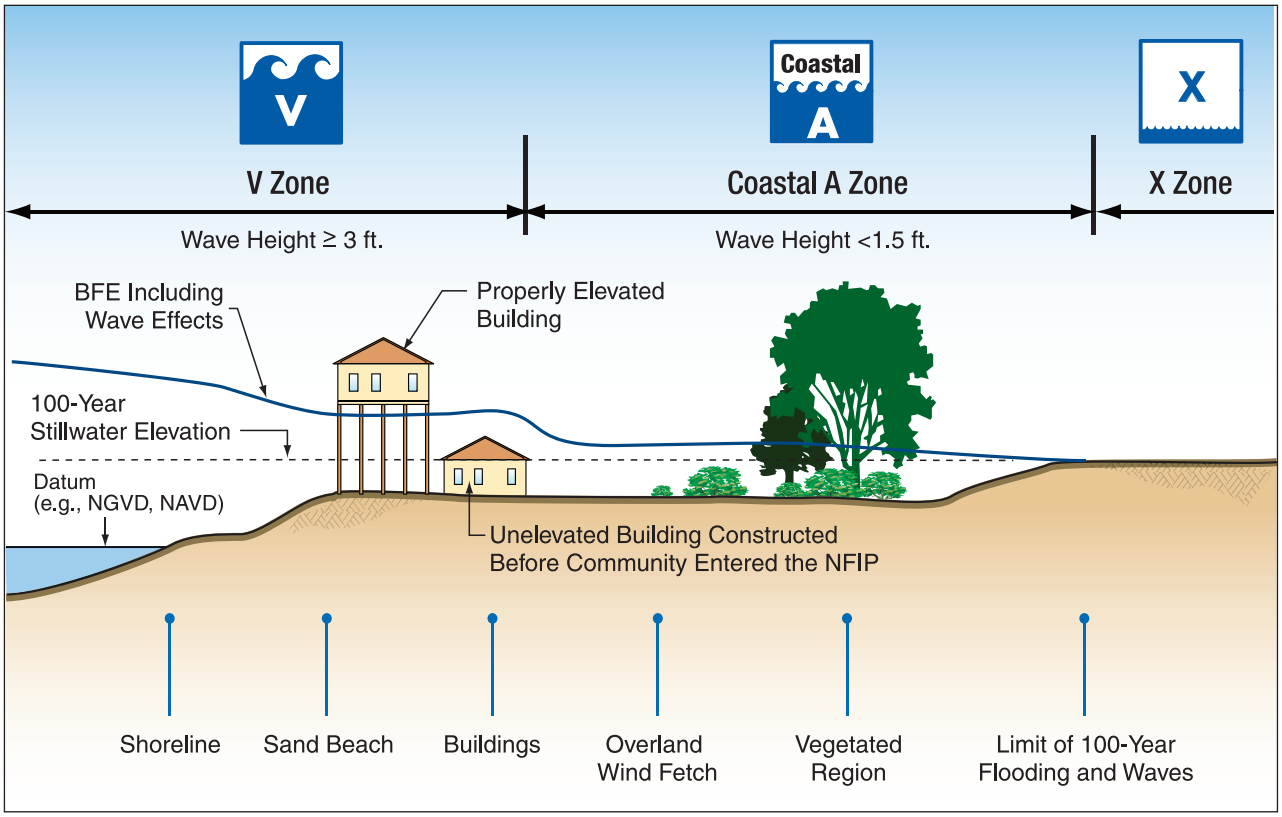


Figure 2-2.
Illustration of the relationship between the stillwater elevations, BFE, and wave effects

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*

For buildings constructed in Zones X, B, and C (areas of moderate or minimal hazard from the principal source of flood in the area), there are no NFIP building requirements, even for buildings built on barrier islands, because these buildings are outside of the SFHA.

In Louisiana, many buildings were constructed behind levees that were intended to protect them from the 100-year flood. Areas that were protected by the levees are shown by various zone designations, depending upon the unique flood hazard for that specific area. Zone designations for these areas may fall into one of the following designations: A1-30, AO, or A99 (see pages 2-5 and 2-6). As an example of the variations of the BFE for areas impacted by Hurricane Katrina,

the BFE outside the levee was 14 feet in some areas; however, inside some areas protected by the levee, the BFE was 1.5 feet.[3] In many areas impacted by Hurricane Katrina, the mapped BFE was below mean sea level (msl). In some areas, the BFE was as low as -4.5 feet NGVD.[4] As a result of levee failures, widespread flood damage to residential neighborhoods occurred throughout the New Orleans area. Flood depths observed in residential buildings, for example, reached more than 8 feet in some cases, with the largest flood depths observed on the north side of New Orleans near Lake Ponchartrain, the Lower Ninth Ward, and Chalmette. A more detailed discussion of the issues in the New Orleans area can be found in Chapter 8.

2.1.2 Higher Regulatory Standards

One of the goals of the MAT was to investigate building failures from flooding (principally, waves and storm surge) inside and outside the SFHAs shown on the effective FIRMs. One issue the MAT identified during its investigation was that almost all the communities visited only enforce minimum flood-resistant design and construction standards; few have adopted more stringent requirements.

2.1.3 Mississippi – Relating Observed Flood Damage to the FIRMs

Along the Mississippi Gulf Coast, many newer buildings, apparently constructed in compliance with the minimum requirements of the NFIP per the effective FIRMs for each community, failed due to storm surge and wave crest elevations far in excess of BFEs (refer to Figure 2-4). Water marks and building damage thresholds throughout the region, especially in Hancock and Harrison Counties, show that storm surge/wave crest elevations exceeded 23 feet and were as high as 25 to 30 feet NGVD in some areas along the shore, while BFEs shown on the effective FIRMs were generally 11 to 15 feet NGVD.

The following three examples (Figures 2-3 through 2-5) show residential buildings in three Mississippi communities that relate observed flood damage to the FIRMs.

2.1.4 Louisiana – Relating Observed Flood Damage to the FIRMs

In many areas observed by the MAT, water levels were well above mapped BFEs due to levee failure, most notably in Orleans, St. Bernard, Plaquemines, and Jefferson Parishes. Flooding caused severe damage to both pre-FIRM and post-FIRM buildings, with flood depths in various neighborhoods ranging to more than 8 feet above the lowest floor (refer to Figure 2-6).

The two-part New Orleans levee/floodwall system was certified by the USACE as providing at least 100-year flood protection in accordance with the NFIP requirements. Due to this certification, the FIRMs for the area, which are the basis for the flood insurance and floodplain management, did not reflect direct flooding from the Gulf of Mexico, Lake Pontchartrain, or the Mississippi River. The FIRMs did reflect some internal flooding in the areas protected by the levee/floodwall system; the source of this flooding was not a levee/floodwall breach, but rainfall

[3] The 1.5-foot BFE referenced here is to account for rain within the area protected by the levee.

[4] NGVD is the national datum used by the NFIP. NGVD is based on msl.

EXAMPLE: BUILD SAFE! 13.1 FEET MSL PASCAGOULA ELEVATION STANDARD
PASCAGOULA, MISSISSIPPI

Following Hurricane Georges in 1998 (a storm that heavily impacted Jackson County), the City of Pascagoula, as an example of one community that has enforced more than minimum standards, established higher elevations requiring new construction be built to 13.1 feet msl. In some cases, this represented up to a 5-foot increase above mapped BFEs. As a result of this local decision to enforce higher standards, buildings impacted by Hurricane Katrina that were built to this elevation suffered less flood damage than older housing units built to previous requirements. In order to increase public awareness surrounding the program, homes built to the new standard were identified with a sign that read, "Build Safe! 13.1' msl Pascagoula Elevation Standard." One specific example of this success was also the first application of Increased Cost of Compliance funds in the State of Mississippi. Funded out of the Hazard Mitigation Grant Program (HMGP) at a 75 percent Federal share, Increased Cost of Compliance funds provided part of the 25 percent non-Federal match. Elevation allowed this house to survive Hurricane Katrina. The estimated flood depth from Katrina was approximately 1 foot above the regulatory lowest floor and reportedly caused only minor damage to the house. According to the effective FIRM at the time of Hurricane Katrina, the building is located in Zone AE with a BFE of 11 feet. For more information on Increased Cost of Compliance refer to http://www.fema.gov/business/nfip/icc.shtm.



Figure 2-3.
This elevation project was designed to the higher elevation standard of 13.1 feet msl adopted by the City of Pascagoula. Note the "Build Safe!" public awareness sign posted in the front yard of the house following the completion of the project. The estimated flood depth of 1 foot above the floor is shown by the red line.

EXAMPLE: COLUMN-ELEVATED HOUSE
PASS CHRISTIAN, MISSISSIPPI

One surviving building located on Shadowlawn Avenue in Pass Christian, Mississippi, is situated, according to the effective FIRM at the time of Hurricane Katrina, in Zone A with a BFE of 13 feet. The parking slab of this building is at 14.7 feet NGVD, with the bottom of the floor beams at 22 feet NGVD. The homeowner, a structural engineer who also designed and built the structure, based the elevation of the house on the storm surge caused by Hurricane Camille in 1969. The MAT observed the remains of other buildings that had been located along Shadowlawn Avenue within approximately 1,000 feet of East Beach Boulevard (Highway 90). All of the houses surrounding this surviving building had been destroyed by surge, waves, and debris. The estimated surge/wave damage elevation inside the surviving house was +/- 29 feet NGVD (4 feet above elevated first floor slab). Although the flood line was around 7 feet above the bottom of the floor beams, there was no structural damage because of the robustness of the structural system, which consists of a reinforced concrete frame with insulated concrete form walls.

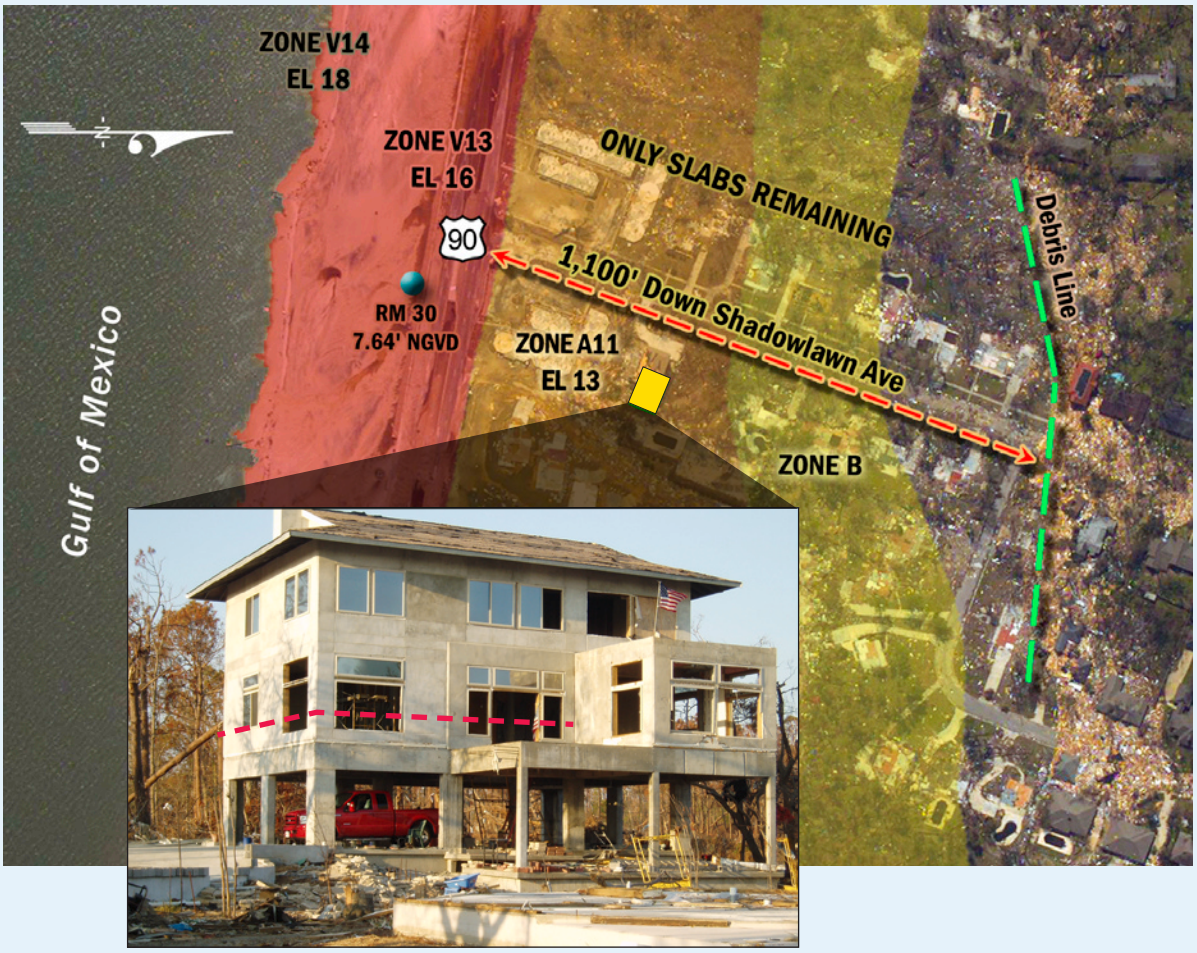


Figure 2-4.
The surviving building on Shadowlawn Avenue (yellow highlight and inset) in relation to aerial observations of post-Katrina damage and approximate flood zone delineations. The red line in the inset illustrates the depth of flooding at the building.

EXAMPLE: SLAB-ON-GRADE HOUSE
OCEAN SPRINGS, MISSISSIPPI

Several buildings in Ocean Springs, Mississippi, which were visited by the MAT, exhibited varying conditions with regard to observed damage from Hurricane Katrina and the effective FIRMs. One such building, located on Arbor Circle, was a single-family residential property on the Back Bay with the regulatory lowest floor elevation 1 foot above the BFE.



Figure 2-5.
The slab of this house is at 14 feet NGVD. According to the FIRM for this area, the building is located in Zone AE with a BFE of 13 feet. The building sustained severe flood damage and wave impacts, with water rising 4 feet above the slab.

within the protected area, which generated runoff and produced localized flooding.

The following two examples (Figures 2-6 and 2-7) show residential buildings in two Louisiana communities that relate observed flood damage to the FIRMs.

PRE-FIRM AND POST-FIRM

For insurance rating purposes, a pre-FIRM building was constructed or substantially improved on or before December 31, 1974, or before the effective date of the initial FIRM of a community, whichever is later. Most pre-FIRM buildings were constructed without taking the flood hazard into account.

A post-FIRM building was constructed or substantially improved after December 31, 1974, or after the effective date of the initial FIRM, whichever is later. For a community that participated in the NFIP when its initial FIRM was issued, post-FIRM buildings are the same as new construction and must meet the NFIP's minimum floodplain management standards.

EXAMPLE: WOOD-FRAMED HOUSE
NEW ORLEANS, LOUISIANA

One representative residential building in New Orleans/Orleans Parish visited by the MAT, located on Memphis Street, was a wood-framed building constructed in 2003. The structure experienced flood depths from the 17th Street Canal levee breach that were 6 feet above the first floor, which was at a BFE of –2.5 feet NGVD.



Figure 2-6.
Note the actual flood depth from Hurricane Katrina (dashed line) vs. the BFE (solid line).

2.1.5 Alabama – Relating Observed Flood Damage to the FIRMs

Severe flooding occurred in many areas within Mobile County, including areas in the cities of Mobile, Bayou La Batre, Fairhope, and Daphne as well as the town of Dauphin Island. Many buildings, except those on Dauphin Island, were pre-FIRM and were constructed to much lower elevations compared to the current BFE. In Bayou La Batre, the FIRMs along two roads (Shell Belt and Coden Belt) indicate that the BFEs vary between 14- to 16-feet NGVD, VE Zone, depending on location along the beach from east to west, respectively. At no point does the regulatory BFE fall below 14 feet NGVD. Many of the lower elevated buildings (pre-FIRM) along

EXAMPLE: HOUSE ELEVATED ON FILL
MYRTLE GROVE, LOUISIANA

The house shown in is located between the levee and Highway 23 in Myrtle Grove in Plaquemines Parish (the body of water in the top left corner of the photo is the Mississippi River). The area was inaccessible at the time of the MAT ground investigation, so it is unknown whether the structure received flood damage. It is easy to presume, however, especially given that this photo was taken more than a month after the event, that the house would definitely have been flooded had it not been elevated on fill.



Figure 2-7.
Parts of Highway 23 remain under water as does much of the surrounding area more than a month after the event. Note the location of the levee behind the surviving structure (red line).

these roads were destroyed; the higher elevated buildings, built to the current floodplain regulations, performed well. In Fairhope and Daphne, damages were limited to water-dependent structures (e.g., piers and boat houses) and older pre-FIRM residences.

2.2 Building Codes and Standards

Model building codes have long included requirements for designers to identify anticipated environmental loads and load combinations, including wind loads, seismic loads, snow loads, and soil conditions. The 2000, 2003, and 2006 editions of the IBC and the IRC, and the 2003 and 2006 editions of the NFPA's *Building Construction and Safety Code* (NFPA 5000) are the first model codes to include comprehensive provisions that address flood hazards. These codes are consistent with the minimum provisions of the NFIP that pertain to design and construction of buildings (see Section 2.2.1).

The MAT report references the 2000 and 2003 editions of the IBC and the IRC published by the ICC. In 2006, the ICC issued their latest editions of the IBC and IRC. These editions became available after much of the MAT report had been completed, so detailed discussions of those codes have not been included.

Once a community has joined the NFIP and adopts its NFIP regulations, that community has adopted minimum floodplain standards for buildings constructed in the SFHA. These standards provide the minimum elevation for the regulatory lowest floor of a building. Building codes and standards, on the other hand, cover a wide range of areas, including electrical, mechanical, and fire, and provide specific provisions for wind. The newer model codes now also include flood provisions.

The IBC is a performance code that, for the most part, requires buildings and structures to be individually designed to meet the requirements of the code and various referenced standards. The two referenced standards (ASCE 7 and ASCE 24) that include provisions pertaining to flood hazards are briefly described in Sections 2.2.2 and 2.2.3.

The IRC addresses environmental loads in a more prescriptive approach so that many one- and two-family homes can be built without individual designs prepared by architects and engineers.

With respect to managing flood hazard areas as required by the NFIP, communities traditionally haven't relied solely on the building codes because they lacked requirements on basic development issues (other than buildings and structures). However, with the arrival of the I-Codes floodplain requirements for development issues, which include some aspects of site development, floodways, coastal setback lines, erosion-prone areas, and other environmental constraints, can also be found in NFPA 5000 and the appendices and annexes of these codes.

At the time of Hurricane Katrina, each of the three states visited by the MAT had adopted building codes on a statewide basis only for state-owned buildings; local jurisdictions have the authority to adopt building codes for non state-owned buildings.

2.2.1 Flood Requirements in the IBC and the IRC

The IBC is applied to multi-family buildings (with a few exceptions) and to non-residential buildings. In the terminology of the NFIP, the IBC is used for engineered structures. The IBC addresses flood loads and flood-resistant construction primarily in Section 1612 (*Flood Loads*), which refers to the consensus standards ASCE 7 and ASCE 24. Flood loads and load combinations are specified in Section 1605. The designer must identify the pertinent, site-specific characteristics and then use ASCE 7 to determine the pertinent specific loads and load combinations. In effect, it is similar to a local floodplain ordinance that requires determination of the environmental conditions (in/out of the mapped flood hazard area, BFE/depth of water) and then specifies certain conditions that must be met during design and construction. The body of the IBC, together with Appendix G, addresses all of the key building and development requirements of the NFIP. If communities participate in the NFIP, they should coordinate their floodplain ordinances with the I-Codes to ensure that all requirements are addressed.

The scope of the IRC is more limited than the IBC. The IRC applies to one- and two-family dwellings and to some townhouses. In the terminology of the NFIP, the IRC is used for residential structures. The IRC addresses flood-resistant construction primarily in Section R323 (*Flood-Resistant Construction*; renumbered to R324 in the 2006 edition), although provisions for the mechanical and plumbing installations are included in pertinent sections of the code.

It is important that communities coordinate their ordinances with the I-Codes to ensure that all requirements are addressed. A crosswalk of the NFIP regulations and the IRC provisions is found in *Reducing Flood Losses Through the International Codes*.

There are some commonalities between the IBC and the IRC:

- They specify information related to special flood hazard areas that are to be included in permit applications and shown on plans.
- They specify that an inspection is required upon placement of the lowest floor, including basement, and prior to further vertical construction, at which time the building official is to require submission of documentation, prepared and sealed by a registered design professional or surveyor, of the elevation of the lowest floor, including the basement.

2.2.2 Flood Requirements in ASCE 7

The ASCE develops and maintains the consensus standard for *Minimum Design Loads for Buildings and Other Structures* (ASCE 7). Since the 1995 edition, ASCE 7 has included flood load provisions. The provisions have changed with each succeeding edition. ASCE 7-98 is a referenced standard in the 2000 and 2003 editions of the IBC, and the 2006 edition refers to ASCE/SEI 7-05.

Design loads used by the IBC (2003) are taken from ASCE 7 (2002). The following sections of ASCE 7 deal with flood:

- Section 2.3 (*Load Combinations*, including different load combinations for V Zones and Coastal A Zones).
- Section 5.3 (*Flood Loads*, which covers hydrostatic, hydrodynamic, and wave and impact loads.) Load criteria for breakaway walls are also included in this section.

The standard requires designers to determine if a site is susceptible to erosion (general lowering of the ground surface) or scour (localized lowering due to interaction of waves and currents with a building element).

In recognition of the growing awareness that wave heights between 1.5 feet and 3 feet (the cutoff used to delineate FEMA's V Zone) cause considerable damage, ASCE 7 incorporates the concept of the Coastal A Zone and specifies that designers determine loads on structures in these areas. For the most part, Coastal A Zones are treated as V Zones.

The IRC does not refer to ASCE 7 for flood loads because the code is a prescriptive code that, for the most part, does not require individual designs for buildings that are built in compliance with the provisions of the code. However, for buildings located in V Zones, individual designs for buildings must be prepared and sealed by a registered design professional.

2.2.3 Flood Requirements in ASCE 24

The ASCE develops and maintains the consensus standard for *Flood Resistant Design and Construction* (ASCE 24). It is referenced by Section 1612 of the IBC (2003). The first edition of ASCE 24 was published in 1998 and it is referenced in the 2000 and 2003 editions of the IBC. The 2005 edition is a major revision and expansion of the standard, which is referenced in the 2006 IBC. The IBC states, "The design and construction of buildings and structures located in flood hazard areas, including flood hazard areas subject to high velocity wave action, shall be in accordance with ASCE 24."

ASCE 24 specifies minimum requirements for flood-resistant design and construction of buildings and structures located in flood hazard areas, including floodways, coastal high hazard areas, and other high-risk flood hazard areas such as alluvial fans, flash flood areas, mudslide areas, erosion-prone areas, and high velocity areas. It applies to new structures and substantial repair or improvement of existing structures that are not designated as historic structures. Basic design requirements address flood loads and load combinations, elevation of the lowest floor, foundation requirements and geotechnical considerations, use of fill, and anchoring and connections. As a function of the type of flood hazard area, enclosures are to have breakaway walls or meet requirements for flood openings (prescriptive or engineered).

For buildings in coastal high hazard areas (V Zones) and Coastal A Zones, ASCE 24 includes specifications for the design of pile, post, pier, column, and shear wall foundations. Considerable detail is specified for pilings as a function of pile types and connections.

Additional sections of ASCE 24 include the following elements: materials, dry and wet floodproofing, utility installations, building access, and miscellaneous construction (decks, porches, patios, garages, chimneys and fireplaces, pools, and above- and below-ground storage tanks).

The IRC does not refer to ASCE 24 because the code is a prescriptive code that, for the most part, does not require individual designs for buildings that are built in compliance with the provisions of the code. The exceptions for V Zone buildings (which do require design) was listed above. Communities must, therefore, reference ASCE 24 directly for its provisions to apply to small residential buildings. However, Section R323 of the IRC states that buildings in floodways shall be designed in accordance with the IRC, thereby mandating use of ASCE 24 for buildings in floodways as shown on the FIRMs.

2.2.4 Wind Requirements in Building Codes and Standards – Mississippi

The wind speeds recorded in Hurricane Katrina, though high in some areas, were for the most part less than the design wind speed given in IBC/ASCE 7-02. Much of Mississippi sustained wind damage to building envelopes; however, the strongest effects were felt along the coast in Hancock, Harrison, and Jackson Counties. Exceptions occurred where severe damage was

caused by either uprooted trees or by tornadic activity spawned by the hurricane. Impacted cities in the coastal counties include those listed in Table 2-2.

Table 2-2. SBC and I-Codes in Effect at the Time of Hurricane Katrina for Impacted Counties and Cities in Mississippi

County/City	Standard Building Code (SBC)	International Codes (IBC/IRC)
Hancock County	**No Code Adopted**	**No Code Adopted**
Bay St. Louis		2003 IBC and IRC
Waveland		2003 IBC and IRC
Harrison County	**1997 SBC**	
Biloxi	1997 SBC	
D'Iberville		2000 IBC and IRC
Gulfport	1997 SBC	
Long Beach		2000 IBC and IRC
Pass Christian		2000 IBC and IRC
Jackson County		2003 IBC and IRC
Gautier		2003 IBC and IRC
Moss Point		2003 IBC and IRC
Ocean Springs		2003 IBC
Pascagoula		2003 IBC and IRC

Mississippi adopts building codes on a statewide basis only for state-owned buildings. Most of these buildings are concentrated in the state capital of Jackson, while others are spread throughout the state (for example, in regional mental health centers and on university campuses). Only fire-related code provisions were required by statute prior to Katrina making landfall.

Local jurisdictions determine the adoption of building codes for all other buildings. Some jurisdictions in Mississippi had not adopted a building code, usually because inhabitants were not willing to pay the added expense of permitting and inspection or viewed any code as an invasion of privacy. Most jurisdictions in Mississippi have traditionally adopted the 1997 editions of the Standard Building Code (SBC) published by the Southern Building Code Congress International (SBCCI); however, a number of jurisdictions have adopted the 2003 editions of the IBC and IRC. The IBC requires the use of wind provisions given in ASCE 7 – *Minimum Design Loads for Buildings and Other Structures.*

As shown in Table 2-2, the 1997 SBC, 2000 and 2003 IBC, and 2000 and 2003 IRC codes were in effect prior to Hurricane Katrina for most impacted counties, except for Hancock County, which had not adopted any building codes. Clearly, the potential existed for variability in design and construction practice, as well as inspection and enforcement.

Katrina's landfall and impact on the coastal communities created a favorable climate for promoting the more recent codes. A short list of actions taken is given below to represent some positive steps in this regard:

- A workshop was held in Hattiesburg on December 19, 2005, to promote adoption of a state-wide building code. It was organized and sponsored by The Mississippi Construction Coalition, composed of material suppliers, general contractors, engineers, and architects, which formed in response to the Governor's Commission for Recovery, Rebuilding, and Renewal. At the workshop, a regional ICC representative outlined the history of building code adoption in the United States, including recent steps taken in Alabama and Louisiana; summarized some of the benefits; and recommended appropriate steps and mechanisms for adoption and management of building codes at the state level.
- The Governor's Commission issued its final report on December 31, 2005. Recommendation 4 was to adopt and enforce building codes as a primary hazard mitigation strategy.
- Building officials maintain communications with one another and FEMA regarding developments in the lessons learned from Katrina. On January 25, 2006, a meeting of building officials in communities having adopted the IBC and IRC was held in Moss Point.
- Senator Chaney of Vicksburg and others introduced Senate Bill SB2807 on behalf of the Coalition to adopt the IBC and IRC throughout the state in response to the Governor's Commission. The bill passed the Senate on February 15, 2006, and was then sent to the House Ways and Means Committee.
- Representative Compretta of Bay St. Louis and others introduced House Bill HB1406 as an emergency measure for the three coastal counties plus Pearl River County. The bill passed the House on February 4, 2006, and was sent to the Senate Committee on Insurance.
- House Bill 1406 was passed on April 9, 2006, and subsequently signed by the Governor. The new law requires that Jackson, Harrison, Hancock, Stone, and Pearl River Counties and municipalities therein enforce, on an emergency basis, all wind and flood mitigation requirements prescribed by the 2003 IRC and 2003 IBC as supplemented. A county board of supervisors may within 60 days formally resolve not to be subject to these codes. A Mississippi Building Codes Council was created to establish which codes counties may adopt.

The City of D'Iberville recently adopted the 2006 IBC, and Harrison and Hancock Counties, and the cities of Biloxi, Long Beach, and Pass Christian adopted the 2003 IBC. Unfortunately, the City of Gulfport did not adopt a new building code, and will continue to enforce the 1997 SBC.

2.2.4.1 Comparing Basic Design Wind Speeds

Current codes and standards (IBC and ASCE 7) standardize wind speed measurements as the 3-second gust. This differs from the fastest-mile wind speed measure that was previously used

by the SBC, as well as the wind speed measure of 1-minute sustained that is used in the Saffir-Simpson Hurricane Scale and referenced by the NHC. The Saffir-Simpson Hurricane Scale was presented in Table 1-2. Table 2-3 provides a comparison of wind speeds for 3-second gust, fastest mile and 1-minute sustained.

Table 2-3. Wind Speed Comparison (in miles per hour)

*$V_{3\text{-second gust}}$	85	90	100	110	120	130	140	150
*$V_{\text{fastest-mile}}$	70	75	80	90	100	110	120	130
**$V_{\text{sustained}}$	67	71	79	87	95	102	110	118

* 3-second gust and fastest mile based on 2003 IBC table 1609.3.1.

** 1-minute sustained based on the ESDU gust factor curve.

The IBC specifies higher wind speeds for coastal Mississippi than any of the previous editions of the SBC. Hancock, Harrison, and Jackson Counties in Mississippi extend inland approximately 30 miles from the Gulf of Mexico coastline. Therefore, variation exists in the design wind speeds for areas throughout these counties. At the time of Hurricane Frederic in 1979, the SBC design wind speeds were 100-year recurrence of fastest-mile speeds, varying from 110 mph at the coast to 90 mph inland; if these are converted to equivalent 3-second gust speeds, they would be 130 mph at the coast to 110 mph inland.

The 1985 SBC modified the required speeds to match those in American National Standards Institute (ANSI) A58.1 -1982, the predecessor to the ASCE 7. For Hancock, Harrison, and Jackson Counties, that range of speeds was 90 to 95 mph based on 50-year recurrence fastest-mile values, or 110 to 115 mph measured as a 3-second gust. The wind speed map remained unchanged for all the subsequent editions of SBC, including the last edition in 1999.

The maps used by the 2003 IBC are taken directly from ASCE 7-02. The 3-second gust wind speeds for Hancock, Harrison, and most of Jackson Counties increased significantly to approximately 120 mph (north end) to 150 mph (at the coast), as shown in Figure 2-8. For portions of Jackson County seaward of the 150-mph wind speed contour, ASCE 7-02 recommends that the 150-mph value be used.

DEFINITION OF WIND EXPOSURE ZONES

Exposure B. Urban, suburban, wooded areas.

Exposure C. Open terrain, flat open country, grasslands, all water surfaces in hurricane-prone regions.

Table 2-4 summarizes the progression over time of the basic design wind speeds for the counties in Mississippi visited by the MAT. Table 2-5 presents a summary of the design wind pressures on wall and roof areas for a typical residence in Pass Christian. The IBC calculations are based on Exposure B. The required design pressures are given for both a building's structure (referred to in codes and standards as the main wind force resisting system or MWFRS) and for a building's envelope (referred to as components and

cladding or C&C). In instances where Exposure C is applicable, the tabulated pressures would be approximately 30 percent higher than the values shown in the table. SBC loads were based on Exposure B (the SBC did not provide different criteria for Exposure C conditions).

Table 2-4. Approximate Range of Basic Design Wind Speeds in the Coastal Counties Visited by the MAT (3-second gust, Exposure C, at 33 feet above ground)

County	SBC 1979 Edition*	SBC 1997 Edition*	2003 IBC and ASCE 7-98 and Later
Hancock	110-130 mph	110-115 mph	120-130 mph
Harrison	110-130 mph	110-115 mph	120-135 mph
Jackson	110-130 mph	110-115 mph	125-150 mph

* Code wind speeds reported as fastest-mile wind speeds in the SBC were converted to 3-second gust for comparison. The lower values correspond to the edge of the county farthest from the coast, and the higher values correspond to the coastal value or the edge of the county closest to the coast.

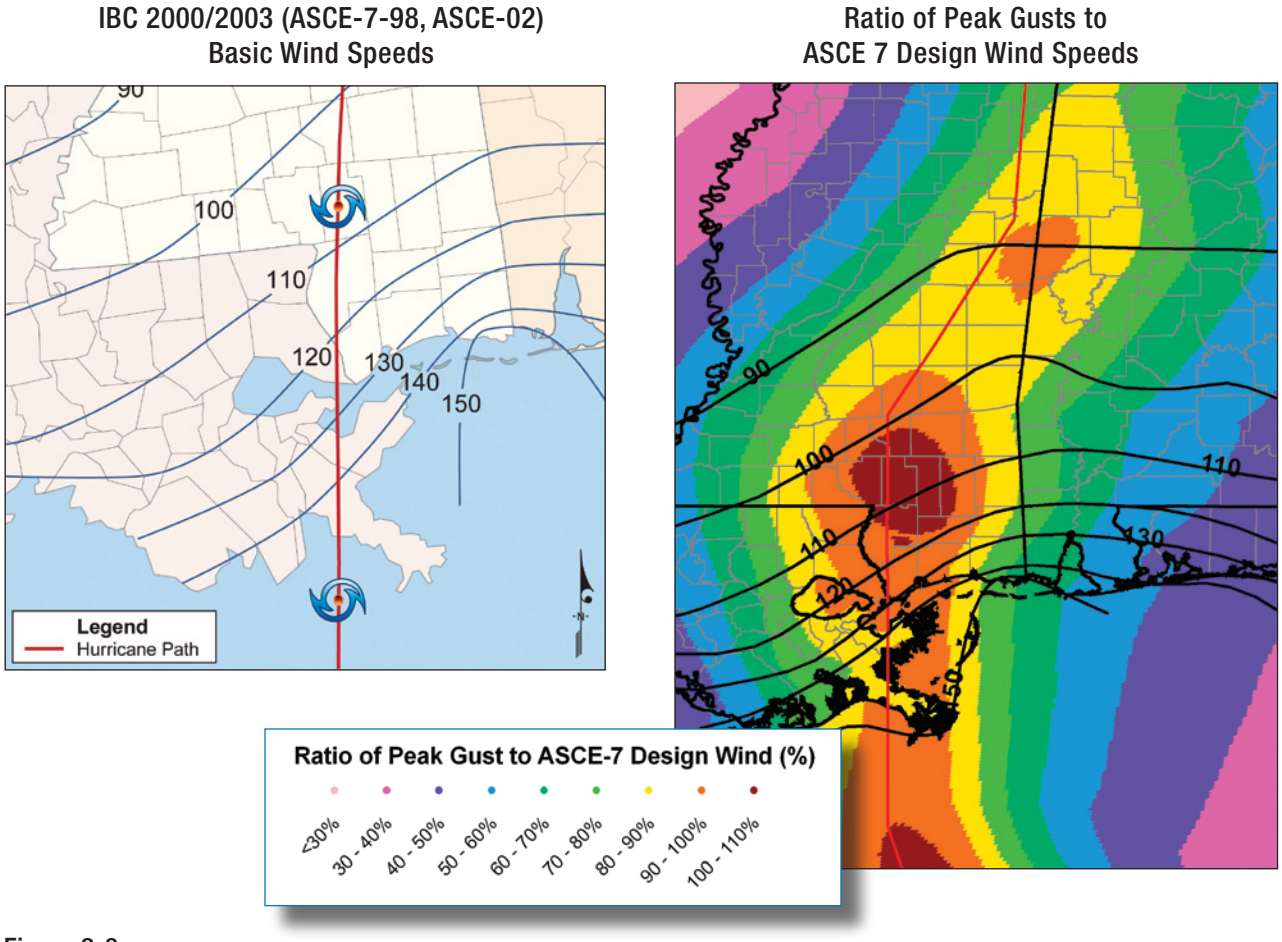


Figure 2-8.
Comparison of code and Katrina peak gust wind speeds

Table 2-5. Design Loads for a Typical Single-Family Residence in Pass Christian, Harrison County, Mississippi

Description	SBC 1979 Edition	SBC 1997 Edition	2002/2003 IBC and ASCE 7-98 and Later Editions
Basic Design Wind Speed	110 mph	95 mph	130 mph*
Equivalent Wind Speed (3-Second Gust)	130 mph	115 mph	130 mph*
Wind Design Pressures on Exterior Walls (psf)			
As MWFRS			
Edge	20/-18	21/-18	26/-23
Middle	20/-18	15/-13	19/-16
Net Edge	33	32	37
Net Middle	33	21	25
As C & C			
Middle	27/-27	25/-25	31/-34
Corner	27/-27	25/-29	31/-42
Wind Design Pressures on Roof (4 in 12 slope) (psf)			
As MWFRS			
Windward Edge	-25	-26	-33
Leeward Edge	-19	-19	-23
Windward Middle	-25	-19	-23
Leeward Middle	-19	-14	-18
As C & C			
Middle	-23	15/-23	18/-29
Corner	-23	15/-52	18/-59

Notes:

1. The pressure calculations under each code for both MWFRS and C&C were calculated using building design coefficients in wind zones that provide the maximum wind pressure for any area on that building surface.

2. Positive value pressures indicate pressures acting inward toward building surfaces. Negative value pressures indicate pressures acting outward from building surfaces.

3. Pressures calculated from the 1979 and 1997 SBC were calculated using their appropriate fastest-mile wind speed and design methods in the code that were in effect at the time. The 3-second gust wind speed is shown for comparative purposes only and was not used in the calculation of the design wind pressures.

4. The 1979 and 1997 SBC and ASCE 7-98 simplified design procedures used in this comparison account for effects of internal pressure implicitly through the selection of pressure coefficients that vary depending on the degree of enclosure provided by the building envelope. The ASCE 7-02 and ASCE 7-05 (Method 2) detailed design procedures consider the effect of internal pressure explicitly by requiring that multiplicative external pressure coefficients be adjusted by 0 (open) to +/-0.18 (full enclosure) to +/-0.55 (partial enclosure).

psf = pounds per square foot

Net edge = the net pressure contributing to the shear force for the wall edge strips; equal to the sum of the external pressures from edge wall Zones 1E and 4E (see ASCE 7-98 Figure 6-4; internal pressures cancel).

Net middle = the net pressure contributing to the shear force for the interior wall zone; equal to the sum of the external pressures from wall Zones 1 and 4 (see ASCE-98 Figure 6-4; internal pressures cancel).

* = maximum estimated HAZUS modeled wind speed (see Table 1-4)

2.2.4.2 Comparing Design Wind Pressures

The methodology required for calculating wind loads in the 2003 IBC is that prescribed in Chapter 6 of ASCE 7-02. Using ASCE 7 for determining wind loads ensures that designers are using state-of-the-art methodology to calculate wind loads. The ASCE 7-02 provisions provide the same loads as ASCE 7-98 for the cases discussed previously. In addition to the improved load computations, ASCE 7-02 also provides performance and testing requirements for windborne debris protection of glazing. For the purpose of the loads listed in Table 2-5, the 1998 and 2000 editions of the ASCE 7 are indicated.

2.2.5 Wind Requirements in Building Codes and Standards – Louisiana

Similar to Mississippi, Hurricane Katrina's wind speeds (see Section 1.1.3) in Louisiana were less than design wind speeds given in IBC/ASCE 7-02. Wind damage was the most severe near where the storm made landfall in Plaquemines Parish. The rest of the populated areas in Louisiana were to the left of the storm track (i.e., on the weak side of the storm). Wind damage in Jefferson, Orleans, and St. Tammany Parishes was clearly more intense in the eastern portions of those communities, which were closer to the west side of the eyewall. Modest levels of wind damage extended as far east as Baton Rouge, where minor wind damage to roof coverings and damage due to falling trees was not uncommon.

Prior to Katrina, Louisiana communities had various building and residential codes, and, in many communities, no codes at all. The State Uniform Construction Code, which took effect on January 1, 2004, required only that communities choosing to enforce a code must use the 2000 IBC (Louisiana Act 387 of the 2003 Legislative Session, which supplanted the 1997 SBC as the State Uniform Construction Code). There were no state-level provisions relating to residential building codes. Most of the larger cities and parishes in the state had adopted the IBC in compliance with the state requirements (e.g., New Orleans, Baton Rouge, Lafayette, Lake Charles, Shreveport, and others), but many other communities had not adopted the IBC, and were still enforcing various editions of the SBC.

Even more variation was present in adoption of residential codes that provide specific residential design and construction guidance typically not provided in a commercial building code. When adopted, the form and guidance provided by these residential codes varied widely, including various editions of the IRC, SBC, and Council of American Building Officials (CABO) codes. The lack of a residential code, or use of older versions of the residential codes, is often a clear indicator that the residential buildings in these areas were designed and constructed without the guidance and criteria of the newer hazard-resistant codes. It should be noted that, if a residential code has not been explicitly stated as adopted, it is likely that no residential code has been adopted. Table 2-6 shows the building codes in place in the most severely impacted parishes in Louisiana at the time when Katrina made landfall. In some cases, municipalities within a parish enforced different codes than the rest of the parish.

Table 2-6. SBC and I-Codes in Effect for Impacted Parishes and Cities in Louisiana

Parish/City	SBC	International Codes (IBC/IRC)
Plaquemines Parish	1997 SBC	
Jefferson Parish	1997 SBC and 1995 CABO	
Gretna	1997 SBC	2000 IBC and IRC
Harrahan	1997 SBC and 1995 CABO	
Kenner	1997 SBC and 1995 CABO	
Westwego	1997 SBC and 1995 CABO	
St. Bernard Parish	1994 SBC	
Orleans Parish	1997 SBC	2000 IBC
St. Tammany Parish	1997 SBC and 1995 CABO	
Covington	1997 SBC	
Mandeville	1997 SBC	2000 IRC
Slidell	1997 SBC	2000 IBC and IRC

Prior to Hurricane Katrina, in response to the lessons learned in Florida from the 2004 hurricane season, the state had taken steps toward improving building codes. Louisiana House Concurrent Resolution 135 called for creation of a Uniform Building Code Task Force, under the Commissioner of Insurance. The charge for this task force was "…to study current laws and regulations related to the construction of buildings and structures and make recommendations regarding legislation that would best insure maintenance of buildings and structures throughout the state and to adequately protect the health, safety, and welfare of the people." The task force was to have reported its findings, recommendations, and drafts of proposed legislative changes to the governor and legislature not later than March 1, 2007. Ironically, the first meeting of this task force was scheduled to take place on August 31, 2005, 2 days after Katrina made landfall.

Because of the devastation caused by Hurricane Katrina, the focus of a state building code has been a major priority; therefore, the State has taken the following actions:

1. The first (and only) meeting of the Uniform Building Code Task Force was held at the Louisiana Department of Insurance on October 4, 2005. This meeting provided a forum to open the building code reform discussion in the wake of Hurricane Katrina. A second meeting was scheduled for mid-November, but this meeting was later cancelled, as the legislature was subsequently called into special session and was considering building code reform (see item 2).

2. Governor Blanco called the legislature into a special session (November 6-22, 2005) focused on hurricane recovery, where one of the items in the call for the special session was building code reform. The House and Senate Commerce Committees considered code reform bills and amendments through many days of hearings. The legislature ultimately passed SB44, requiring enforcement of the IBC and IRC statewide. It also created the Louisiana State Uniform Construction Code Council, whose purpose is to "… review and adopt the state uniform construction code, provide for training and education of code officials, and to accept requests for amendments to the code, except the La. State Plumbing Code." On November 29, 2005, Governor Blanco signed SB44 into law as Act 12 of the 1st Extraordinary Session of the 2005 Legislature.

The provisions of the newly revised State Uniform Construction Code are to be implemented in several phases. The new law contains emergency provisions requiring Calcasieu, Cameron, Iberia, Jefferson, Lafouche, Orleans, Plaquemines, St. Bernard, St. Tammany, Terrebone, and Vermilion Parishes to enforce all wind and flood mitigation requirements prescribed by the 2003 IBC and the 2003 IRC, as modified and amended by Section 301.2.1.1(2) to replace "Southern Building Code Congress International Standard for Hurricane-Resistant Construction (SSTD 10)" with the *Guidelines for Hurricane Resistant Residential Construction* as published by the Institute for Business and Home Safety, 2005.

The emergency wind and flood provisions were required to be effective within 30 days of the new law (i.e., December 29, 2005) for parishes and municipalities in the affected areas that are already enforcing building codes, and within 90 days for other communities. The emergency wind and flood mitigation requirements remain in effect until the Louisiana State Uniform Construction Code Council adopts the latest editions of both the IBC and the IRC. The initial codes adopted by the Council go into effect statewide on January 1, 2007.

2.2.6 Wind Requirements in Building Codes and Standards – Alabama

On a statewide basis, Alabama adopts building codes for state-owned buildings, including schools. Local jurisdictions determine the adoption of building codes for private buildings. All Alabama jurisdictions have traditionally adopted editions of the SBC. Mobile County adopted the IBC 2000 in 2000, and the City of Mobile adopted it on May 15, 2001. The city of Orange Beach adopted the IBC 2003 in the summer of 2004. The City of Gulf Shores adopted the IBC 2003 as an emergency measure after Hurricane Ivan in 2004 to improve the quality of the reconstruction. After Hurricane Katrina, Dauphin Island adopted the IBC and recently adopted provisions requiring deeper pile embedment. Most other affected Alabama communities, such as those in unincorporated Baldwin County, were still enforcing the 1997 or 1999 SBC at the time of Hurricane Katrina.

The IBC 2000 was the first model code to address windborne debris protection. Many communities in Mississippi enforced the SBC, which has no requirements for windborne debris. Some communities that had adopted the IBC had deleted the windborne debris requirements by local amendment. The IBC defines the windborne debris region as:

- Areas where the basic wind speed is 120 mph or greater.

- Areas within 1 mile of the coastal mean high water line where the basic wind speed is 110 or greater.

If windows and glazed doors are not protected, they may be damaged and allow wind and water into a building, which could lead to significant water damage and development of high internal air pressure, which could result in structural damage or damage to the building envelope, interior partitions, or ceilings.

2.3 HUD Manufactured Housing Design Standards

The design and construction of manufactured homes have been governed at the Federal level by HUD since the National Manufactured Housing and Construction Safety Standards Act was passed in 1974.

Beginning in 1976, the Manufactured Home Construction and Safety Standards, 24 Code of Federal Regulations (CFR) 3280, established the minimum requirements for the construction, design, and performance of a manufactured home. These standards are preemptive over any state or local standard for home construction, provided that the HUD standards cover that aspect of performance of the home. The HUD standards cover body and frame requirements; thermal protection; plumbing; electrical; heating, ventilation, and air conditioning (HVAC); fire safety; and other performance aspects of the home.

Currently, the HUD standards define a manufactured home as a dwelling unit, transportable in one or more sections, that, when erected on site, is of at least 320 square feet in size, with a permanent chassis to assure the initial and continued transportability of the home. In the traveling mode, a manufactured home is 8 feet or more in width or 40 feet or more in length.

In August 1992, when Hurricane Andrew hit southern Florida, over one third of all site-built homes were substantially damaged and almost all manufactured homes were destroyed. As a direct consequence, HUD developed improved wind-resistance requirements for the hurricane-prone coastal areas of the United States. Contained in Final Rule 59 FR 2456 (1994), these changes included defining three separate wind zones – Zone I, Zone II, and Zone III.

For wind Zones II and III, this rule also designates higher wind loads. Specifically, the updated HUD standard requires that the manufactured home, each of its wind-resisting parts, and its C&C materials be designed by a professional engineer or architect to resist either the design wind loads for Exposure C specified in American National Standards Institute (ANSI)/ASCE 7-88, *Minimum Design Loads for Buildings and Other Structures,* for a 50-year recurrence interval; or a fastest-mile design wind speed of 100 mph, as specified for pressures in the Table of Design Wind Pressures (24 CFR 3280.305).

In addition, the new rule requires that each manufactured home have a support and anchoring or foundation system that, when properly designed and installed, will resist overturning and lateral movement (sliding) of the manufactured home, as imposed by the respective design loads.

Federal, state, and local governments and the manufactured home industry strive to institute construction practices and regulations to increase the safety of manufactured homes in natural hazards environments. The following list summarizes some of the recent regulations that have been passed or are in the process of being developed to improve the resistance of manufactured homes to natural hazards:

- Section 605 of the National Manufactured Housing Construction and Safety Standards Act of 1974 (42 U.S.C. 5401) required the Secretary of HUD to establish and implement a national manufactured housing installation program by December 27, 2005. This installation program must include: (1) installation standards, (2) the training and licensing of manufactured home installers, and (3) the inspection of manufactured home installations. The HUD program will be implemented in any state that does not have its own program, which includes all three of the previous components, established by state law. Further, to be exempted, a state must have adopted standards that equal or exceed the protection provided by HUD's national manufactured housing installation program. More information on the development of this new program can be found at http://www.hudclips.org.

- The National Fire Protection Association currently maintains three documents on the subject of manufactured housing: (1) NFPA 501, *Standard on Manufactured Housing*, a consensus document on the design and construction of manufactured homes that provides a source for revisions to the Federal regulations (24 CFR 3280); (2) NFPA 501A, *Standard for Fire Safety Criteria for Manufactured Home Installations, Sites and Communities;* and (3) NFPA 225, *Model Manufactured Home Installation Standard*, a consensus document that governs the installation of manufactured homes. Both the 2005 editions of NFPA 501 and NFPA 225 have wind-related requirements based upon ASCE 7-02.

- The HUD program only requires that Zone III units be constructed to receive high-wind shutters to protect openings; there is no requirement to provide window protection in areas where other one-and two-family dwellings are constructed.

Additional information may be found in Section 4.1.2.

3. General Overview of Storm-Related Damage

One of the goals of a MAT is to observe buildings that effectively withstood design flood and/or wind conditions with little or no damage and document successes.

This chapter presents a general overview of typical types of damage that resulted from Hurricane Katrina, as well as the effects caused by flood and wind damage. Section 3.1 characterizes flood damages observed by the MAT, with additional discussion and examples provided by different types of building occupancy (e.g., one- and two-family residential buildings, multi-family residential buildings, commercial buildings, critical and essential facilities, and historic buildings). Section 3.2 includes a similar treatment and breakdown for wind effects. More detailed discussions of the observations are presented in Chapters 4, 5, 6, and 7.

Katrina's wind speeds were generally below the design winds in most areas, and yet wind damage was still observed. Flood conditions, however, were far in excess of design conditions over a large area. Flood damage was so widespread that there were relatively few successful (flood-resistant) buildings in the coastal SFHAs of Alabama, Louisiana, and Mississippi. The MAT documented the successes it observed, but also expanded its scope to document *survivors* (buildings that were damaged, sometimes heavily, but stood out from the destruction around them). Many of these survivors provide useful

information about the benefits of designing and constructing for flood conditions in excess of the base flood conditions shown on the FIRMs. The terms "successes" and "survivors" will be used throughout this report, and are more fully described and compared in Table 3-1.

Table 3-1. Building Classifications Used by the MAT: Successes and Survivors

Building Element Characteristic	Success	Survivor
Overall	No structural damage, with minimal non-structural damage during design event.	Building is recognizable - structural system (foundation and frame) intact, with no more than minor damage. Damage to envelope and non-structural elements may be severe.
Foundation	Building foundation is intact and functional.	Foundation may have sustained minor damage; any damage or displacement is repairable.
Structural Frame	Structural frame is intact and functional.	Frame may have sustained minor damage; any damage or displacement is repairable.
Envelope (walls, openings, roof, and lowest floor)	Envelope is structurally sound and capable of minimizing penetration by wind, rain, and debris.	Envelope may be breached, damaged, or destroyed by flooding or waves allowing interior damage by wind, rain, and debris. Interior may have been damaged or destroyed by wind, rain, and debris.
Lowest Floor Elevation	Lowest floor elevation was sufficient to prevent floodwaters from entering the elevated building envelope during the design event.	Lowest floor elevation may have been insufficient to prevent floodwaters from entering the building.
Utilities	Utility connections (e.g., electricity, water, sewer, natural gas) are intact or restored easily.	Utility connections (e.g., electricity, water, sewer, natural gas) are severed, but restorable.
Access and Usability	Building is accessible and usable following a design-level event.	Restoration of building access and use is possible.
Below DFE Enclosures	Damage to enclosures below the design flood elevation (DFE) did not result in damage to the foundation, the utility connections, or the elevated portion of the building.	Below-DFE enclosures are destroyed.

3.1 Flood Effects

As discussed in Chapters 1 and 2, high storm surge and waves from Hurricane Katrina caused severe (often catastrophic) damage to buildings on the Alabama, Louisiana, and Mississippi Gulf Coast. Damage in coastal areas primarily resulted from wave effects, velocity flooding, floodborne debris impacts, and, to a lesser extent, erosion and scour. Further inland, flood damage was associated principally with storm surge inundation.

Storm Surge and Wave Damage

The MAT observed that flood elevations in many areas exceeded the 100-year BFEs shown on the FIRMs by as much as 15 feet or more.[1] The team observed that storm surge and wave damage typically associated with V Zones also occurred in Coastal A Zones and in areas outside the SFHA (refer to Section 2.1.1 for definitions of zones). Pre-FIRM buildings and buildings constructed to comply with pre-Katrina flood standards were subjected to unanticipated levels of flooding. The resulting destruction of buildings and infrastructure in the coastal areas along the Gulf was unprecedented, as was the damage resulting from long-duration flooding behind the failed levees in New Orleans and surrounding areas.

Figure 3-1 illustrates the general relationship observed by the MAT between flood depth (relative to the lowest floor) and damage resulting from waves and storm surge striking typical light frame construction where erosion and scour were not sufficient to undermine or destroy the building foundation. Note the increase in damage when the wave crest elevation rose above the bottom of the lowest horizontal member.

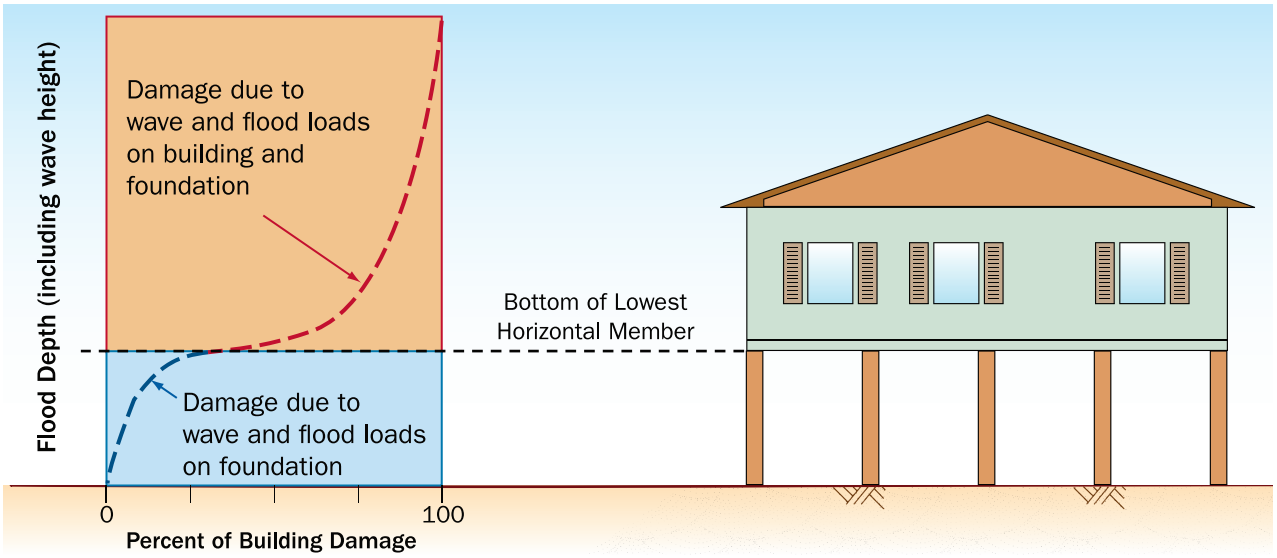


Figure 3-1. Idealized building damage vs. flood depth relative to lowest horizontal member

[1] Recognizing the potential impact of increased flood elevations on long-term recovery efforts and risk reduction, FEMA issued Flood Recovery Maps in 2006 to provide guidance during the rebuilding process. The Flood Recovery Maps provide ABFEs that were based on a statistical analysis of the high water marks and the wind-water damage boundary surveyed in Katrina's aftermath, plus an additional 25 years of historical flood data not available when the earlier FIRMs were published in the 1980s.

Floodborne Debris

Besides waves and storm surge flooding, floodborne debris was a significant and widespread contributor to building damage in coastal Mississippi (and to a lesser extent in Alabama and Louisiana). Floodborne debris included small pieces of destroyed buildings, intact buildings washed off their foundations, vehicles and shipping containers, and casino barges. Although it is difficult to separate the specific effects of floodborne debris from those of waves and velocity flow, it is likely that the presence of the debris increased flood damage in some areas; in other areas, large piles of debris could have sheltered landward buildings from damaging waves. Examples of floodborne debris and debris damage are shown in Figures 3-2 through 3-4.



Figure 3-2.
Displaced casino barge floated inland, struck and came to rest near a hotel along U.S. 90 (Biloxi, Mississippi)



Figure 3-3.
A major element of debris in this debris field was shipping containers from the port (arrows indicate examples) (Gulfport, Mississippi).



Figure 3-4. Floodborne debris, including shipping containers and sections of destroyed buildings (Gulfport, Mississippi)

3.1.1 Flood Effects on One- and Two-Family Residential Buildings

Severe flood damage occurred to one- and two-family residential buildings throughout the study area. In areas close to the shoreline, the damage was principally a result of waves, velocity flow, and floodborne debris, while in areas distant from the shoreline damage was primarily a result of inundation by storm surge. Since Katrina's flood elevations greatly exceeded mapped BFEs, flood damage was more extensive and severe than would be expected from a design level flood event. Typical flood damages are shown in Figures 3-5 through 3-11.

In the New Orleans area, severe building damage near levee breaches as well as some areas in Plaquemines Parish (with many buildings washed off their foundations) resulted from rapidly rising, fast-moving water flowing through breaches. Within the levee-protected areas, but away from the breaches, flood damage to buildings was typically a result of slowly rising water, which inundated houses for long periods (most of these buildings were heavily damaged, but remained structurally intact). Refer to Chapter 8 for a more detailed discussion of the effects of long-term flooding.

Most one- and two-family residential buildings in the Katrina-affected area were built on shallow foundations such as slabs, stem walls, crawlspaces, or piers. In some cases, more deeply embedded pile or column foundations were used. Masonry pier foundations were the most common foundations in V Zones and in A Zones near the shoreline, followed by timber pile foundations. When properly designed and constructed, all of these foundations were effective for those buildings where waves and surge remained below the floor system and erosion and scour did not undermine the foundations. However, in areas where Katrina's surge and waves exceeded the floor elevation, many buildings were destroyed, often leaving only foundations behind. In areas subject to erosion and scour, shallow foundations usually failed. Detailed discussions about the performance of the various foundation types are provided in Chapter 4.



Figure 3-5.
House on verge of collapse due to shallow embedment of timber pile foundation (Dauphin Island, Alabama)



Figure 3-6.
Elevated house atop masonry pier foundation was lost, probably due to waves and storm surge reaching above the top of the foundation (Long Beach, Mississippi)



Figure 3-7.
Building floated off of foundation (Happy Jack, Louisiana)



Figure 3-8.
Wave and surge damage to load-bearing walls atop stem wall foundation. The house was located in flood hazard zone C, approximately 1/4 mile from the shoreline (Pointe Aux Chens area, Jackson County, Mississippi).



Figure 3-9.
Interior damage and mold from prolonged flooding (New Orleans, Louisiana)



Figure 3-10.
This new public housing neighborhood (not yet occupied) was flooded by storm surge to the first floor ceilings. Houses closest to the bay also sustained damage to walls by waves and floodborne debris. The arrows indicate the locations of the inset photos (Biloxi, Mississippi).



Figure 3-11.
Wave, floodborne debris, and surge damage to some Gulf-front neighborhoods was extreme. Arrows indicate locations of buildings in both photos (Waveland, Mississippi).

SOURCE: UNITED STATES GEOLOGICAL SURVEY [USGS]

Like site-built homes, manufactured homes sited in Katrina's path were damaged and often destroyed. Damage resulted from the hydrodynamic effects of rapidly moving floodwaters (storm surge) and also from submergence (inundation). Many manufactured homes floated or washed off of their supports or had supports collapse due to velocity flow and scour (see Figure 3-12).



Figure 3-12. Manufactured home washed off its supports by moving floodwaters (Ocean Springs, Mississippi)

3.1.2 Flood Effects on Multi-Family Residential Buildings

Structural damage to multi-family residential buildings varied with the severity of flooding and construction type. Multi-family buildings sustained flood damage consistent with that observed for one- and two-family buildings, which is further discussed in Chapter 4. As observed with multi-family buildings, such as apartments, reinforced concrete and steel-framed buildings generally sustained less structural damage than light-framed wood or masonry construction, but were still subject to wall collapse in instances where wave action was present. Examples of multi-family building flood performance are shown in Figures 3-13 through 3-18.



Figure 3-13. Apartments damaged by storm surge, floating automobiles, and wave action (Biloxi, Mississippi)



Figure 3-14.
Apartments on slab foundations destroyed by waves, storm surge, and wind (Long Beach, Mississippi)



Figure 3-15.
Aerial photo of apartment complex shown in Figure 3-14 and the surrounding area (Long Beach, Mississippi)



Figure 3-16.
Wood-framed and masonry multi-family residential buildings damaged by storm surge (limited wave action). The building in foreground sustained flooding to a level approximately 30 inches above the elevated floor. The building in the background was flooded to the ceiling of the lower floor units (Ocean Springs, Mississippi).



Figure 3-17.
Wave and surge damage to Gulf-front apartments. Note the poured concrete foundation columns and slab performed well, but the waves rose above the slab and attacked the wood-framed buildings, destroying the building closest to the Gulf, and severely damaging the landward building. The severity of damage to the remaining building resulted in demolition (Biloxi, Mississippi).

SOURCE: USGS



Figure 3-18.
Waves and storm surge washed through the lowest floor of this condominium building, but the building reportedly sustained no structural damage (Gulfport, Mississippi).

3.1.3 Flood Effects on Commercial Buildings

Damage to commercial buildings, like other building types, varied with location and flood conditions. Low-rise buildings close to the Gulf, including strip malls, individual food service/retail, and larger retail stores, were often destroyed or severely damaged by storm surge, waves, and floating debris. Several buildings along the shoreline lost load-bearing walls, leaving no evidence of the building other than the floor slab. Larger steel-framed commercial buildings performed better, as the structural frame and roof remained intact, but curtain walls and contents were destroyed. Flood impacts on high-rise buildings were less extreme, with most damage impacting parking decks located on the lower floors.

Figures 3-19 through 3-21 illustrate typical flood damage to commercial buildings observed by the MAT.



Figure 3-19.
Strip mall with walls destroyed by waves and storm surge (Biloxi, Mississippi)



Figure 3-20.
Marine Education Center, which lost most of its walls due to wave action, storm surge, and floating debris (Biloxi, Mississippi)

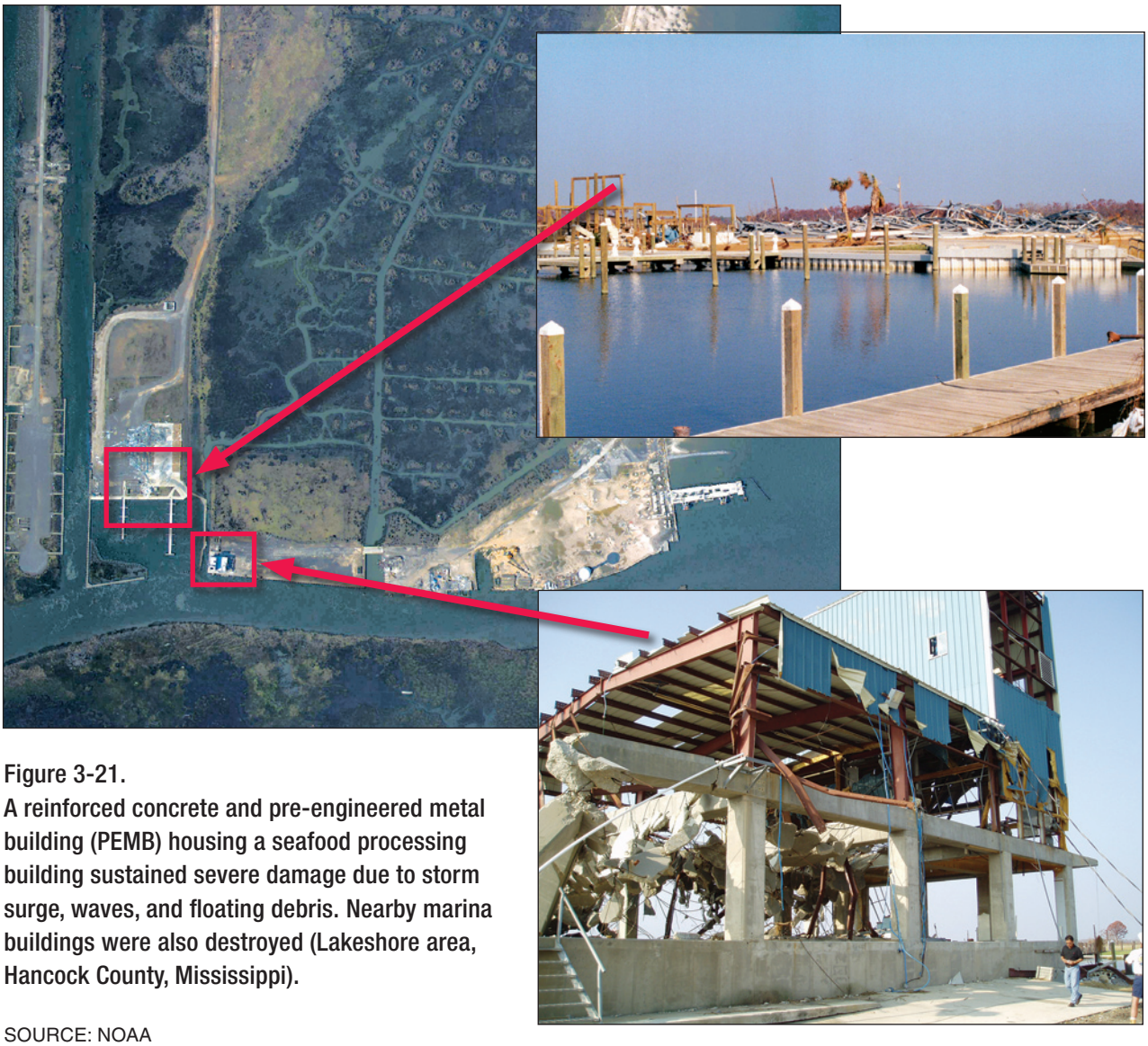


Figure 3-21.
A reinforced concrete and pre-engineered metal building (PEMB) housing a seafood processing building sustained severe damage due to storm surge, waves, and floating debris. Nearby marina buildings were also destroyed (Lakeshore area, Hancock County, Mississippi).

SOURCE: NOAA

3.1.4 Flood Effects on Critical and Essential Facilities

Critical and essential facilities did not perform any better than the commercial buildings, despite the importance attached to these facilities. More information on damage to these facilities is presented in Chapter 7. Figures 3-22 through 3-25 illustrate flood damage sustained by these facilities.



Figure 3-22. Newly constructed Gulfport Fire Station #7 destroyed by waves and storm surge (Gulfport, Mississippi)



Figure 3-23. Pass Christian Police Department destroyed by storm surge (Pass Christian, Mississippi)



Figure 3-24. Storm surge damage to the St. Bernard Parish Coastal Government Complex (Delacroix, Louisiana)



Figure 3-25. Floodwater isolated Charity Hospital and incapacitated its emergency generator (New Orleans, Louisiana)

3.1.5 Flood Effects on Historic Buildings

Throughout the impacted area, the MAT reviewed damage to an extensive number of historic buildings, which had fared well in past major hurricanes. Damage to historic buildings varied based on their elevation, structural system, foundation type, and, in some cases, the amount of retrofitting integrated while maintaining the facility. Most historic buildings survived inundation by floodwaters, but, like other buildings, those that were near the open coast were often damaged by waves and floodborne debris. More information on the damages and observations to historic buildings is contained in Chapter 6. Figures 3-26 through 3-28 illustrate flood damage sustained by several historic structures.







Figure 3-26.
a. This house (actually, one of three houses that make up the Milne Boys Home) had an interior flood depth of 3 feet.

b. and c. Water marks on the interior and exterior of the Milne Boys Home indicate the level of flooding that occurred as a result of Hurricane Katrina (New Orleans, Louisiana).





Figure 3-27.
Before (a.) and after (b.) photos of Beauvoir (Jefferson Davis' home), built in 1848. The building sustained severe surge damage from Hurricane Katrina's waves and storm surge (Biloxi, Mississippi).

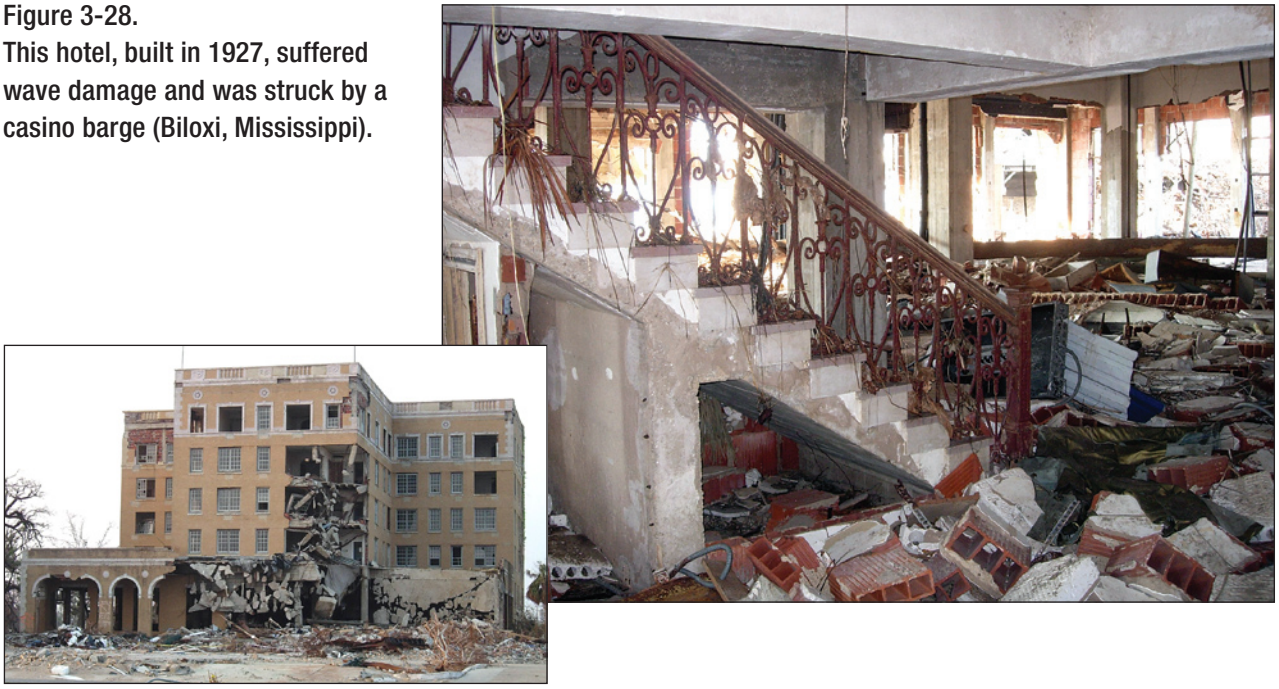


Figure 3-28.
This hotel, built in 1927, suffered wave damage and was struck by a casino barge (Biloxi, Mississippi).

3.2 Wind Effects

As documented in Chapter 1, Hurricane Katrina's flood levels were significantly higher than the design level; however, Hurricane Katrina's wind speeds were below current design wind speeds in most areas, but the wind pressures exceeded some of the older code-level wind pressures. The MAT did observe damage to structural elements but, most noticeably, observed widespread wind damage to building envelopes along the entire coasts of Alabama, Louisiana, and Mississippi, and extending several miles inland. The MAT also observed numerous examples of building damage due to tree-fall and windborne debris (most windborne debris damage was a result of aggregate blowing off roofs and blown-off vinyl siding and asphalt shingles). Many buildings that experienced envelope breaches also suffered from internal pressurization, which resulted in additional building damage and damage to non-structural elements and contents from rainfall penetration.

Wind Damage

As expected, wind damage generally was greater in areas where wind speeds were higher and in areas where the housing inventory included many older homes or homes that lacked sufficient quality of construction. High-wind areas like the towns of Buras and Boothville in Plaquemines Parish, Louisiana, and Bay St. Louis, Waveland, and Pass Christian, Mississippi, were particularly hard hit. In areas like Biloxi and Pascagoula, Mississippi, and Slidell, Louisiana, where wind speeds were lower, wind damage was common, but typically not as extensive or severe as in areas exposed to higher wind speeds. However, wind damage was also common in some areas many miles from areas exposed to the highest winds. For example, some homes on Dauphin Island, Alabama, over 100 miles east of the storm's track, were damaged severely by Katrina's winds.

Windborne Debris

Structural and building envelope failure resulted from windborne debris, which included roof aggregate (see Figure 3-29); roofing panels, tiles, shingles, and rooftop equipment; vinyl siding; tree limbs; and falling trees. Fallen tree damage was widespread and even affected areas where wind speeds were relatively low. Buildings surrounded by tall dense forests had reduced wind loads compared with buildings that were not protected by trees. However, as wind speed increases, trees fall (see Figure 3-30) and/or are stripped of leaves and branches, which then reduces some of the protection they may initially provide.



Figure 3-29.
Roof aggregate was the primary windborne debris source for the window damage (New Orleans, Louisiana).



Figure 3-30.
Tree-damaged home (Diamondhead, Mississippi)

3.2.1 Wind Effects on One- and Two-Family Residential Buildings

Many one- and two-family residential buildings observed by the MAT experienced no wind damage, while others sustained varying degrees of non-structural or structural damage due to wind. The most common type of wind damage was to the building envelope, including loss of asphalt shingles and vinyl siding, soffit blow-out, and broken glazing. When loss of glazing or other damage created breaches in building envelopes, building interiors were pressurized and the damage was greater. When a building lost soffit materials or roof sheathing, the loss of the roof or other structural damage typically followed. Usually, structural damage typically was limited to loss of a few sheets of roof sheathing (see Figure 3-31) but, in some cases, there was extensive loss of sheathing (see Figure 3-32), which resulted in loss of trusses or joists. Typical examples of wind damage to one- and two-family residential buildings are shown in Figures 3-32 through 3-37.

While most of the damage to manufactured housing was from flooding, wind damage was noted in both older and newer manufactured housing. Wind damage to manufactured homes included loss of asphalt shingle roofing, loss of vinyl siding, loss of large overhangs, and damage to window and door glazing (see Figure 3-38).



Figure 3-31. Roof sheathing was a source of windborne debris (Waveland, Mississippi).



Figure 3-32.
Relatively new home damaged from internal pressurization and lack of adequate connections (Pass Christian, Mississippi)



Figure 3-33.
Loss of shingles and chimney failure caused by inadequate attachment (Slidell, Louisiana)



Figure 3-34.
Row house with failed gable end wall and roof (gable end wall was being replaced when this photo was taken) (Biloxi, Mississippi).



Figure 3-35.
House constructed in 2001 on Gulf side of Dauphin Island, Alabama, was destroyed by wind (Dauphin Island, Alabama)



Figure 3-36.
Roof sheathing damage to an older home (Gulfport, Mississippi)



Figure 3-37. A home under construction racked severely when exposed to Katrina's winds. Its attached garage also collapsed (Slidell, Louisiana).



Figure 3-38. Manufactured home lost a gable roof over its entrance, asphalt shingles, and metal fascia along its eaves (Plaquemines Parish, Louisiana)

3.2.2 Wind Effects on Multi-Family Residential Buildings

As was the case with one- and two-family residential buildings, wind damage to multi-family residential buildings varied with wind speed, building shape, structural design, and construction quality. Examples of wind damage to multi-family residential buildings are shown in Figures 3-39 through 3-42, and a more detailed discussion of wind damage can be found in Chapters 4 and 5.

Damage was greatest when building envelopes were breached at "soft" portions of the building exteriors, like soffits and lightly constructed ceilings over covered corridors or breezeways, which resulted in pressurization and structural failures.



Figure 3-39.
Apartment complex severely damaged by wind. Although wind speeds were less than current code-specified values, widespread and severe damage occurred at this development, a result of poor construction quality (Ocean Springs, Mississippi).



Figure 3-40.
Multi-family, wood-framed residential building damaged by high winds (Waveland, Mississippi)



Figure 3-41.
Wind damage to wood-framed, multi-family residential building (Long Beach, Mississippi)



Figure 3-42.
Gable end wall and roof sheathing loss to apartments near the City of Toca (St. Bernard Parish, Louisiana)

Multi-family residential buildings constructed with reinforced concrete or steel frames performed well structurally (see Figure 3-43). Unfortunately, many of those buildings had weak envelopes covered with materials like exterior insulation finishing systems (EIFS) (see Figure 5-8 for typical EIFS assemblies). Although the structural systems performed well, many sustained extensive damage due to water entry through failed building envelopes (see Figures 3-44 and 3-45).



Figure 3-43.
Multi-family residential building constructed with reinforced concrete frame showed no visible structural damage (Ocean Springs, Mississippi)



Figure 3-44. Reinforced concrete frame building that performed well structurally, but sustained extensive damage due to water intrusion from EIFS failure (Biloxi, Mississippi)



Figure 3-45. Damage to EIFS on hotel and casino (Biloxi, Mississippi)

3.2.3 Wind Effects on Commercial Buildings

Wind damage to commercial buildings' structural systems depended much more on building construction than on building location. Relatively weak (i.e., non-engineered or not structurally reinforced) commercial buildings were destroyed in areas where wind speeds were relatively low, while stronger (i.e., engineered or structurally reinforced) buildings experienced little or no structural damage in areas exposed to the highest winds.

In general, high- and medium-rise buildings performed much better than low-rise structures. MAT team members investigated few buildings over three stories that experienced significant structural wind damage, but did observe envelope damage (see Figures 3-46 and 3-47). No wind-induced collapses of high- and medium-rise buildings were noted, but deck failure was observed on a 400-foot tall building (see Figure 3-48).[2] In comparison, several one- and two-story commercial structures sustained severe structural damage due to wind.



Figure 3-46. Closeup of high-rise building whose structure performed well, but experienced widespread damage to its EIFS envelope and some glazing damage (Biloxi, Mississippi)



Figure 3-47. Roof aggregate was the primary windborne debris source for the glazing damage to the hotel and office building (New Orleans, Louisiana).

[2] In discussing wind damage to buildings, it is important to differentiate between structural components and envelope components. Many commercial buildings experienced little or no structural damage, but may be total losses due to failure of the building envelope and the resulting water entry. In this report, structural components are limited to those required to resist lateral and vertical loads and those that provide structural stability to the building. Generally, structural components in commercial buildings are limited to foundations and footings, beams, columns, load-bearing and shear walls, structural frames, and roof decks. Roof coverings, wall coverings, and non-load-bearing walls are not considered structural components.



Figure 3-48.
The deck on this 400-foot tall building was lightweight insulating concrete over steel form deck. The form deck was blown from the deck supports (New Orleans, Louisiana).

The low-rise commercial buildings observed by the MAT to have sustained significant wind damage were older, pre-engineered metal buildings. While many older PEMBs were heavily damaged, newer ones performed much better. At St. Ansyslem's School in Bay St. Louis, a PEMB constructed in 2001 was not visibly damaged by wind (however, it did experience severe flood damage). Figures 3-49 through 3-52 show examples of damage to PEMBs.

Newer, low-rise commercial buildings generally performed well, but like their high-rise counterparts, several sustained damage to their envelopes (see Figures 3-52 and 3-53).



Figure 3-49.
Low-rise PEMB that was severely damaged by wind. The building was constructed with steel moment frames and purlins, metal roof and wall panels, and unreinforced masonry infill walls (Gulfport, Mississippi).



Figure 3-50.
Low-rise PEMB at the Gulfport-Biloxi Airport severely damaged by winds. The building was constructed with steel moment frames and purlins, and metal roof and wall panels (Gulfport, Mississippi).



Figure 3-51.
Wind, wave, and surge damage to St. Thomas Catholic Church. Destruction of the PEMB envelope likely reduced wind damage to the structure itself (Long Beach, Mississippi).



Figure 3-52.
Newer low-rise PEMB that performed well structurally, but experienced some envelope damage. Metal coping along the top of the left wall (circle) was lifted by high winds (Bay St. Louis, Mississippi).



Figure 3-53.
This bank building performed well structurally, but its envelope, specifically the metal roofing and brick, failed (Gulfport, Mississippi).

3.2.4 Wind Effects on Critical and Essential Facilities

The poor performance of critical and essential facilities was widespread throughout the Gulf Coast. Almost without exception, critical and essential facilities such as hurricane evacuation shelters, police and fire stations, hospitals, nursing homes, schools, and EOCs were damaged, and many were completely destroyed. While much of the damage to critical and essential facilities was caused by surge or stillwater flooding, high winds caused damage to many facilities, impacting the use and operations of the facility (see Figures 3-54 through 3-61).



Figure 3-54.
The Long Beach Police Station was severely damaged by high winds (Long Beach, Mississippi).



Figure 3-55.
Wind damage to the New Orleans Fire Department 3rd District Headquarters (New Orleans, Louisiana)



Figure 3-56.
The Harrison Central Elementary School was used as an evacuation shelter during Katrina. Portions of its roof covering were blown off by high winds and many of its windows were broken by windborne aggregate from its own roof (Gulfport, Mississippi).



Figure 3-57.
Ceiling damaged by wind and rain entry due to soffit failure (Gulfport, Mississippi)

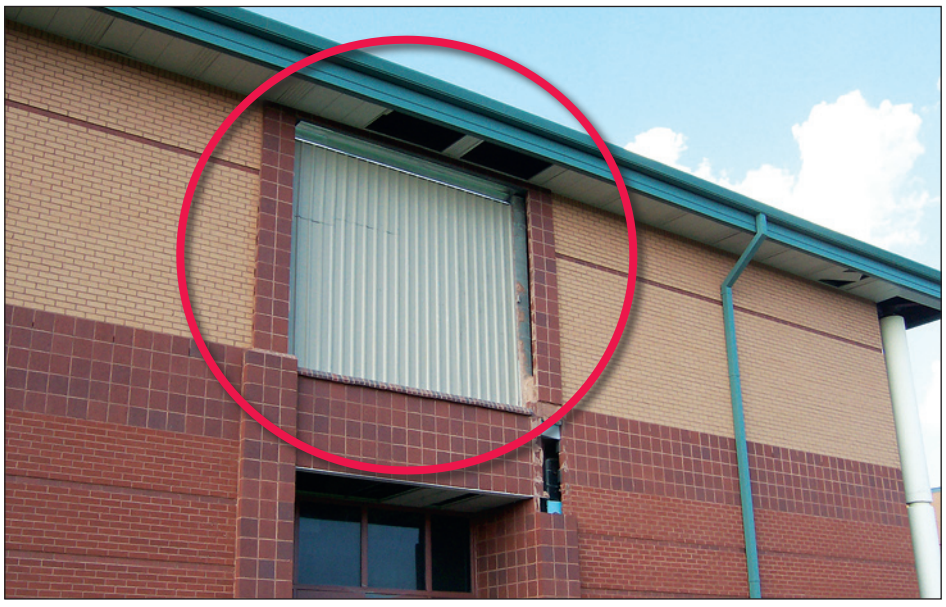


Figure 3-58.
Window failed due to wind pressures, resulting in water entry into the building and damage to ceiling boards. After the failure, metal panels were installed for temporary protection (circled) (Gulfport, Mississippi).

Though not completely destroyed, most of the hospitals were damaged and other types of critical and essential facilities performed poorly. Most of the fourteen hospitals observed by the MAT experienced building envelope damage and a few were flooded. Often their ability to operate during and after the storm was due to the heroic efforts of their staff. Several of the hospitals had to contend with the loss of windows (see Figure 3-59), failed roofs and rooftop equipment (see Figures 3-60 and 3-61) and other exterior elements, loss of water, and, occasionally, loss of emergency power and communications.



Figure 3-59.
Temporary repairs for broken windows in Memorial Hospital. The black panels are painted plywood installed after the spandrel panels were damaged by windborne roof aggregate from the hospital's own roofs (Gulfport, Mississippi).



Figure 3-60.
Temporary repairs required after combustion air louvers for emergency generators were blown off of the roof at the Garden Park Medical Center (Gulfport, Mississippi)



Figure 3-61.
The equipment on this new Federal courthouse blew away because it was resting on vibration isolators that provided lateral resistance, but no uplift resistance. Two large openings through the roof were left after the duct work blew away (temporary covers had been placed over the openings) (Gulfport, Mississippi).

3.2.5 Wind Effects on Historic Buildings

Wind effects on historic buildings were primarily limited to the removal of roof covering, sheathing, and limited curtain wall damage. Figure 3-62 is an example of a wood window that blew in. Even though these structures pre-date the building codes, buildings that had sufficient connection details in their design and construction, or were retrofitted, performed well against Hurricane Katrina's winds. More detail may be found in Chapter 6.



Figure 3-62.
Wind damage to a New Orleans church built in 1886 (New Orleans, Louisiana)



4. Structural Systems Performance

The dominant causes of structural failure observed by the MAT included storm surge, waves, floodborne debris, and wind. Structural damage due to erosion was also common on the barrier islands. Damage occurred to residential buildings (single- and multi-family housing), commercial buildings, and critical and essential facilities.

Section 4.1 discusses flood impacts on single-family, manufactured housing, and low-rise multi-family residential buildings, low-rise commercial buildings, and high-rise buildings. Wind impacts are addressed in Section 4.2, including wind impacts on wood-framed buildings; concrete, steel, and masonry buildings; PEMBs; and manufactured housing.

4.1 Flood

Storm surge stillwater elevations varied from approximately 10 feet (at the eastern end of the study area, on Dauphin Island, Alabama), to over 20 feet in coastal Louisiana and Mississippi. Associated flood conditions (e.g., wave heights, floodborne debris, shoreline erosion, and localized scour) varied widely by location.

The performance of structural systems was closely tied to the severity and variability of the storm surge, erosion, and wave and debris impacts. In particular, there were significant differences in building performance between those areas where flood conditions were near or below the previously predicted design conditions, and regions where the flood conditions exceeded design flood levels. Structural damage was less in areas where flooding was near or below design conditions. As typically is the case, older, low-elevation buildings were the most likely to be flooded and more severely damaged.

The MAT observed differences in building damage based on the structural system and foundation type employed. These observations have been generalized and are shown in Figures 4-1 (a-c). Flood damage states (ranging from 1 = no damage to 5 = destroyed) are plotted against floor elevation and foundation type for three different combinations of flood and erosion conditions. As defined herein, damage states 1 and 2 would be "successes" and damage states 3 and 4 would generally be classified as "survivors."

- Figure 4-1(a) shows observed damages for the case where inundation by storm surge occurred, but where waves and erosion were not present. In this case, damage tends to vary by floor elevation and be similar for all foundation types, as long as buildings are firmly attached to their foundations, buildings with the floor elevation far above the surge elevation tend to be undamaged and, as the floor elevation drops relative to the surge elevation, damage increases. This scenario is representative of much of the New Orleans area and in the areas of coastal Alabama and Mississippi where buildings are distant from the shoreline, and waves have dissipated.

- Figure 4-1(b) shows observed damages for the case where inundation by storm surge occurred and damaging waves were also present (erosion in these cases was non-existent or minor). A comparison with Figure 4-1(a) shows the effects of waves on buildings; as the wave crest rises to and above the floor level, building damage increases. Building damage does depend on foundation type in this case, with buildings supported on shallow foundations tending to sustain the greatest damage. The scenario depicted in Figure 4-1(b) was probably the most common situation observed by the MAT.

- Figure 4-1(c) shows observed damages for the case of inundation by storm surge with damaging waves and moderate erosion.[1] In this case, building damage is more closely associated with foundation type, even for situations where the floor level is far above the wave crest. Comparison of Figure 4-1(c) with Figure 4-1(b) shows that, when moderate erosion occurs to buildings with typical slab, crawlspace, foundation wall, pier, and stem wall foundations, severe building damage or destruction generally occurs, regardless of the floor elevation. Virtually all one-and two-family and other light-frame buildings will be destroyed when the floor level is far below the wave crest, with the possible exception of buildings with continuous structural frame systems; these buildings may survive, but will sustain severe damage.

[1] Moderate erosion is defined as up to a few feet of erosion, sufficient to undermine shallow foundations, but not enough to cause collapse of buildings supported on deep foundations.

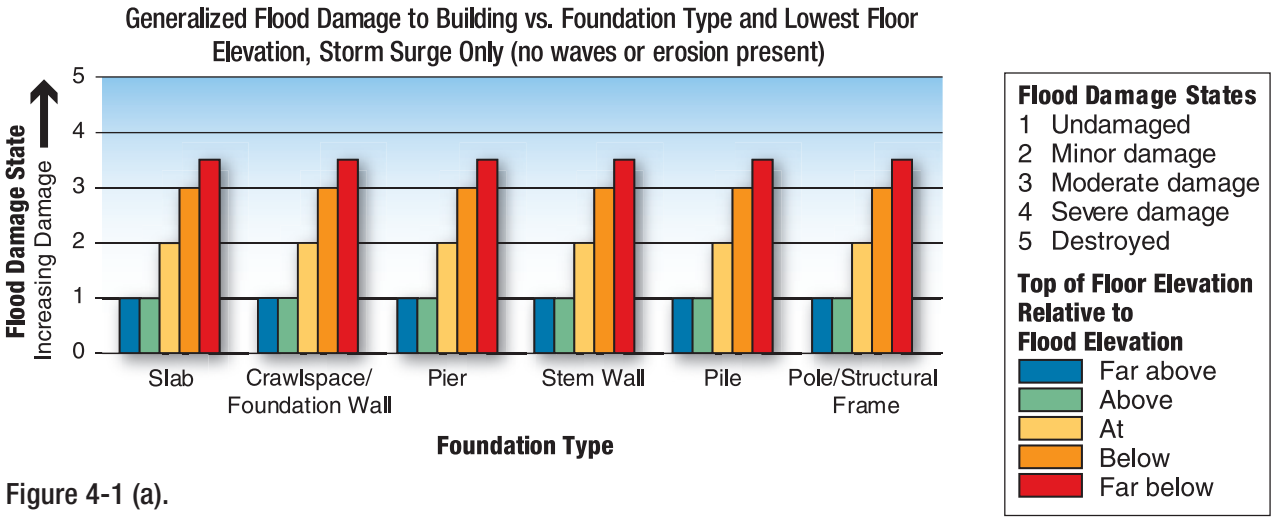


Figure 4-1 (a).
Flood damage vs. foundation type and floor elevation (no waves or erosion)

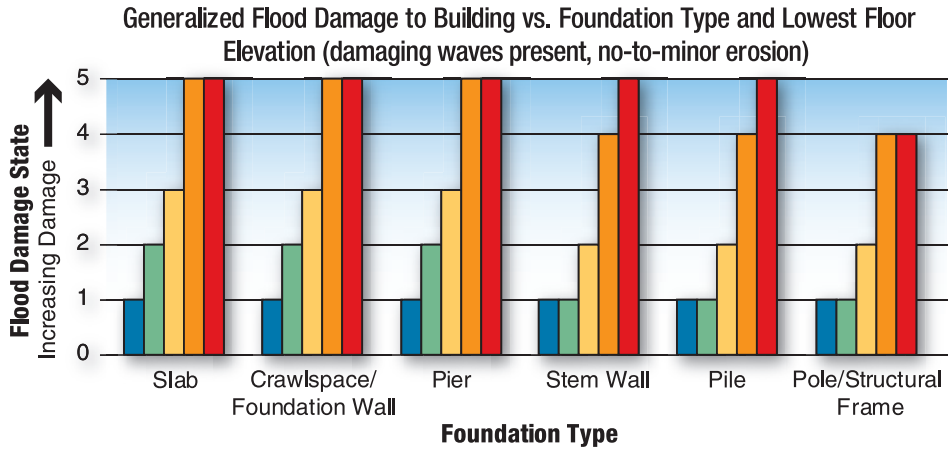


Figure 4-1 (b).
Flood damage vs. foundation type and floor elevation (waves present)

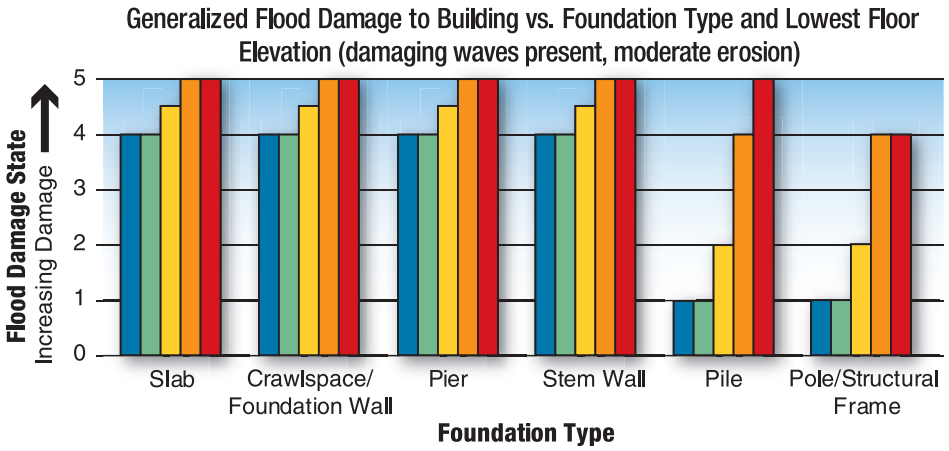


Figure 4-1 (c).
Flood damage vs. Foundation type and floor elevation (waves and moderate erosion present)

4.1.1 Single-Family Residential Buildings

Single-family and other light-frame buildings are generally incapable of resisting coastal flood loads and, therefore, are designed to *avoid* those flood loads through elevation above the design flood level (including wave effects), and by limiting flood loads to the building foundation. In coastal areas, foundations must be designed to resist wave forces, wave-induced erosion and localized scour, and floodborne debris, all of which can threaten the stability of the foundation (and the building). Thus, the foundation type makes a significant difference in the ability of the structure to resist a variety of flood conditions and flood loads. Where Hurricane Katrina's storm surge level exceeded the lowest floor level and waves were present, virtually all of the buildings were destroyed or heavily damaged, regardless of foundation type. However, some foundation types exhibited clear advantages during Katrina, such as those buildings constructed with foundations that are integral to the structural building frame.

4.1.1.1 Pile Foundations

Deep pile foundations are generally the most effective choice on barrier islands and open bay shorelines where waves, high velocity flow, and storm-induced erosion and scour are anticipated, provided the top of the pile foundation is at or above the wave elevation. Where Katrina's storm surge and waves exceeded the floor elevations of pile-supported buildings, building destruction or significant building damage usually occurred.

Where Katrina's storm surge and waves were below the building's first floor elevation, pile foundations consistently supported a wide range of small building designs. The slender cross-section of piles minimizes the wave force transferred to the elevated building until the wave crest reaches the floor beams and joists. The most commonly observed piles were wooden, but piles made of concrete and other materials were also observed. Piles consist of a continuous structural unit along the embedded and exposed length, which, unlike piers, does not contain splices or joints. Splices and joints were identified as common failure points for piers in areas subject to high flood levels, wave effects, and large floating debris loads. This indicates that better pier designs are needed in the region. In areas where the BFEs are approximately 6 feet above exterior grade (including erosion effects), homes supported by pile foundations can be elevated 3 to 5 feet above the BFE with only moderate cost increases. Elevating above the BFE is desirable because the freeboard created provides an added safety factor against flood damage. In areas where homes need to be elevated more than 10 feet above grade, pile foundations are still a viable method of providing reasonably-priced freeboard if longer piles are readily available in the area. The ability to deeply embed the pile makes it the most reliable support in areas subject to the deeper erosion commonly found on barrier island and ocean dune exposures.

To perform successfully, piles must be adequately embedded. Where piles were not adequately embedded, pile foundation failure occurred and resulted in destroyed or missing houses or racked piles and leaning buildings.

Erosion compounded the stress from the surge and caused pile foundations that were not adequately embedded to fail even when the surge did not exceed the first floor elevation. On Dauphin

Island, Alabama, more pile-supported houses were destroyed by Katrina (108) than by Hurricane Ivan (17). Two-thirds of the 150 houses on the far west side of the island were totally destroyed and many of the remaining houses were significantly damaged. Many of these homes were not flooded to the first floor level. The failure of the pile systems was likely due to erosion and loss of foundation support from successive storms (Hurricanes Ivan, Dennis, and Katrina) that made the buildings more susceptible to pile failure.

Isolated shoreline erosion and localized scour of a foot or two were widely observed throughout the Katrina impact area. Local geology dictates that there are few coastal dune systems where deeper erosion is commonly found. Erosion depths greater than 10 feet, which were recently noted in Hurricanes Ivan (2004) and Dennis (2005), were not observed following Katrina. The closest exception was the developed area on the west end of Dauphin Island, Alabama. USGS ground elevation comparisons based on light detection and ranging (LIDAR) surveys are shown in Figure 4-2. The figure compares erosion and accretion trends and building losses along part of Dauphin Island for the pre Ivan to post Ivan period, and for the post Ivan to post Katrina period. The dark red points in the figure indicate the footprints of destroyed houses. The pink area shows erosion, and the green areas show accretion.

The top figure shows erosion closest to the Gulf and accretion along the center of the island (where the road was buried by 2 to 3 feet of sand) during Ivan. Approximately 17 houses were lost in this region during Ivan. The middle figure shows that erosion occurred across the entire barrier island during Katrina (surveys showed that grade elevations on the island dropped 2 to 5 feet), with deposition in the sound. Approximately 108 houses were lost in this region during Katrina. The bottom figure shows a post Katrina aerial photo of the same area.

When pile foundations elevated single-family houses above the storm surge/waves and the piles were adequately embedded to tolerate the erosion, they performed well, as shown in Figures 4-3 and 4-4.

Flood maps identified the area seaward of the beach road as a V Zone with BFEs of +10 to +12 feet NGVD. Preliminary water level estimates indicate that the west end of Dauphin Island experienced storm surge and wave heights several feet above the predicted BFE. Many of the newer houses received minimal damage when constructed in the +14 to +20 NGVD range like those in Figures 4-3 and 4-4. However, many older buildings had shallower pile embedments and prior storm-induced erosion of the dunes had already lowered the ground elevations. The consequences of building too low or on too shallow a pile for Katrina's conditions were severe. Some of the surviving buildings were substantially damaged. The successes received little or no flood damage, but generally required new stairs and/or utility connections to return to normal use.

Damage and failures caused by inadequate pile embedment are shown in Figures 4-5 and 4-6. Wave damage to elevated buildings is shown in Figures 4-7 and 4-8. Once the storm surge and wave heights rose above the bottom of the floor beams and joists, either on stable foundations or when the foundation was undermined, the buildings were quickly destroyed by the waves, leaving little debris on the island.

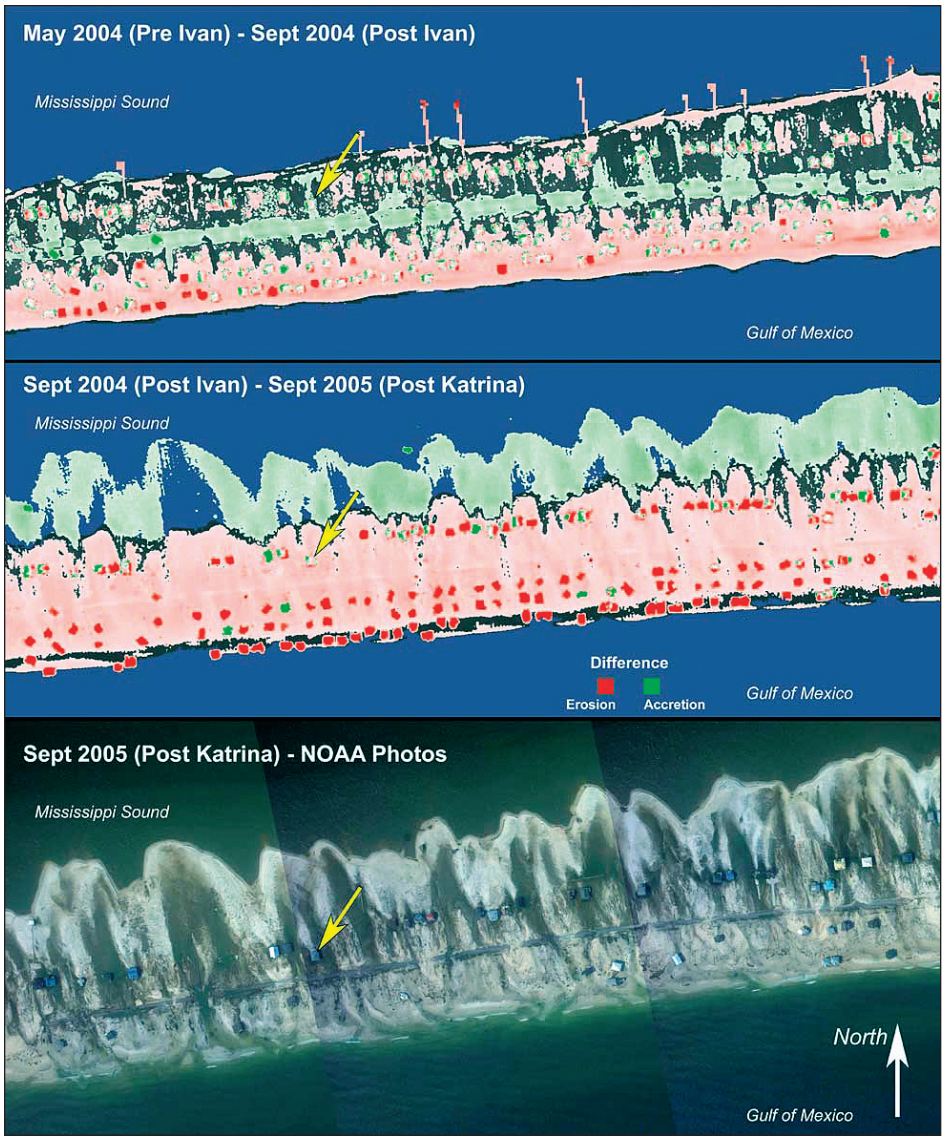


Figure 4-2.
Comparison of erosion patterns and building losses on Dauphin Island, Alabama, due to Hurricanes Ivan (2004) and Katrina (2005)

SOURCE: USGS

In contrast to Dauphin Island, few other areas affected by Katrina experienced significant erosion losses around building foundations. Therefore, the lack of embedment and piling rotation was a rare cause of damage other than on Dauphin Island.

Storm surge and wave elevations were significantly higher than the BFEs shown on the FIRMs for much of the Mississippi Coast and sections of the Louisiana Delta. Successful, pile-elevated buildings that remained above Katrina's waves were observed in the fringes of the high storm surge areas, as shown in Figure 4-9.

Examples of survivor building designs were relatively rare along the Mississippi Coast and sections of the Louisiana Delta. When waves exceeded the floor elevations of the pile-supported buildings, many were destroyed, as shown near the Mississippi Gulf shoreline in Pass Christian

(see Figure 4-10) and on the north-facing bay shoreline in Bay St. Louis (see Figure 4-11). In most cases, the waves destroyed the floor beams, joists and above, but left the piles in place where erosion was not a significant factor.



Figure 4-3.
Successful example of well-elevated and embedded pile foundation following Katrina (Dauphin Island, Alabama)



Figure 4-4.
Another successful example of well-elevated and embedded pile foundation following Katrina. Note adjacent building failures where foundations were not high enough or where pile embedment was inadequate (Dauphin Island, Alabama).



Figure 4-5.
Near failing house due to inadequate pile embedment (Dauphin Island, Alabama)



Figure 4-6.
Leaning piles indicate building failures due to shallow embedment (Dauphin Island, Alabama).



Figure 4-7.
Partial wave damage after wave heights exceeded the floor elevations (Dauphin Island, Alabama)



Figure 4-8.
Total wave damage after wave heights exceeded the floor elevations (Dauphin Island, Alabama)



Figure 4-9.
Successful house on high pile foundations, well above the local BFE (Shell Beach, Louisiana)



Figure 4-10.
Failure at connections between pile foundations and buildings (Pass Christian, Mississippi)



Figure 4-11.
Pile and connection failure (Bay St. Louis, Mississippi)

4.1.1.2 Foundations Integral with Structural Frames

Where Katrina's breaking waves rose above the foundation and impacted floor beams and walls, most houses quickly disintegrated into debris. Residential buildings that survived Katrina's worst storm surge and wave conditions typically had heavier than normal open foundations that were part of the building's structural frame. Examples of other surviving buildings that had foundations that are integral to the structural frames include steel-framed buildings in Mississippi that survived storm surge and wave action above the first floor level, wood-framed buildings along Mississippi's Jourdan River, and

Pole construction is a type of construction where the pilings extend from the ground to the roof system. It differs from platform construction where the piles terminate at the lowest floor.

houses with reinforced concrete frames and walls in Long Beach, Mississippi. These houses, though heavily damaged, survived next to destroyed houses on slab, pier, or pile foundations that had first floor elevations below the wave elevation.

Figures 4-12 through Figure 4-14 show an example of a house with timber pole-type construction. Wave heights exceeded the elevated floor level by approximately 4 feet, lateral wave forces destroyed many of the exterior and interior walls, and wave uplift damaged the floor (Figure 4-14) and interior floors. However, the upper portion of the structure and the roof remained stable due to the nature of the foundation and structural frame.



Figure 4-12.
Aerial view based on USGS imagery of the surviving pole constructed house shown in Figures 4-13 and 4-14 (circle). Note the many slabs and foundation remnants of destroyed houses nearby (Waveland, Mississippi).



Figure 4-13.
Ground view of same building circled in Figure 4-12. Storm surge and waves reached at least 4 feet above the elevated floor (red line) (Waveland, Mississippi).



Figure 4-14.
Wave damage to floors and walls, but pole construction left a repairable, surviving building (Waveland, Mississippi)

Other examples of single-family buildings surviving Katrina surge and wave levels above the elevated floor are shown in Figures 4-15 through 4-21. In each case, the buildings were damaged by Katrina, but the buildings were not destroyed like most of the neighboring homes, which were on slab foundations, or elevated on piers or piles below the wave elevation. Figure 4-17 shows the devastation in the area where only two buildings survived.



Figure 4-15.
Steel-framed building on St. Louis Bay survived storm surge and wave action above the elevated floor level (Pass Christian, Mississippi)



Figure 4-16.
Wood-framed survivor exposed to storm surge and waves (Jourdan River shoreline of Bay St. Louis, Mississippi)



Figure 4-17.
Destruction of pile-and pier-supported homes (platform type construction) adjacent to the house shown in Figure 4-16. Only two homes out of approximately 100 survived in the neighborhood (Bay St. Louis, Mississippi).



Figure 4-18.
Surviving house constructed with a reinforced concrete frame and walls. Note storm shutters on upper level damaged by waves (Long Beach, Mississippi).



Figure 4-19.
Another surviving house constructed with a reinforced concrete frame. The wave elevation was approximately 2 to 3 feet above the elevated floor (Long Beach, Mississippi).

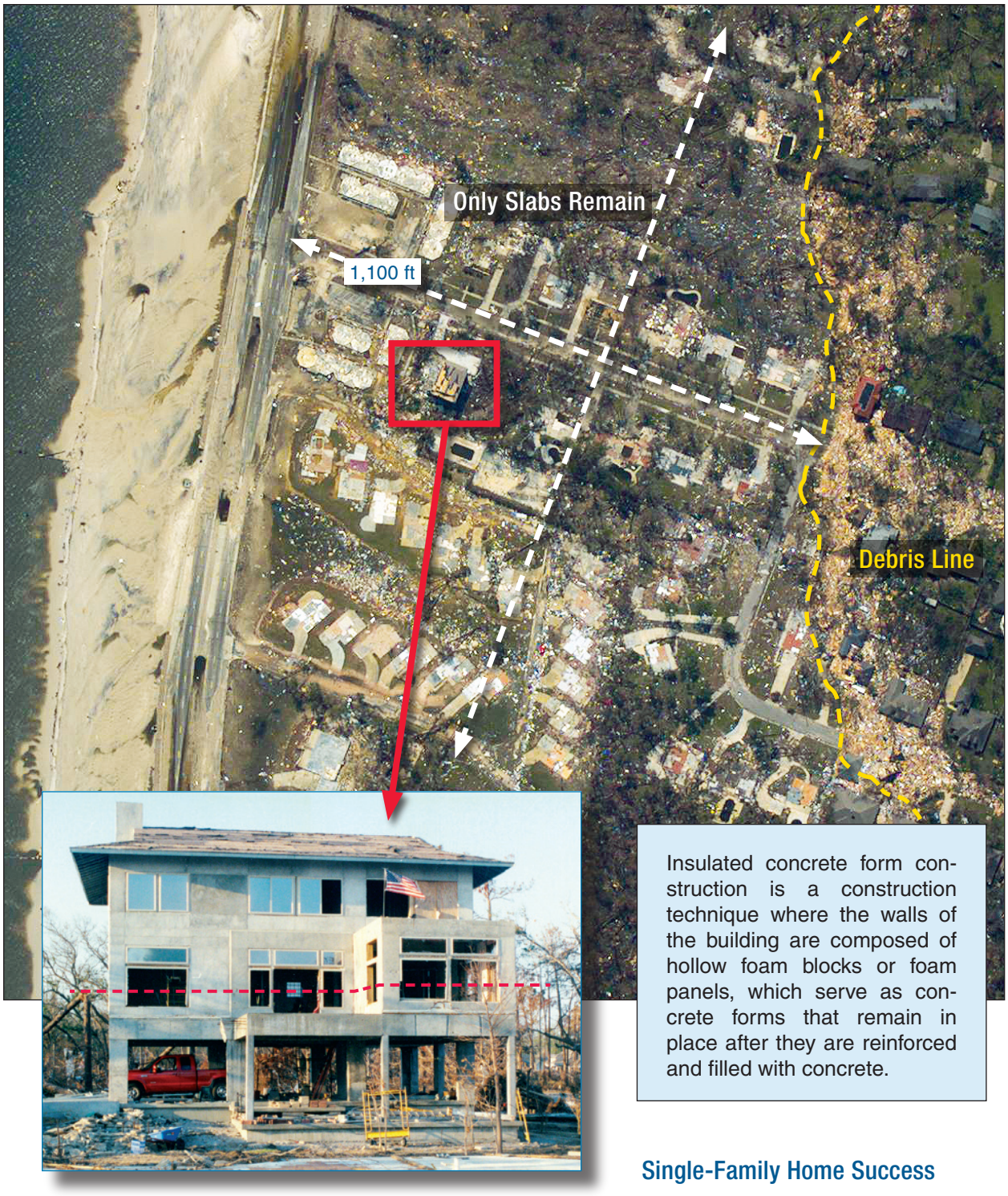


Figure 4-20.
Success amidst dozens of destroyed homes; the house was constructed with a reinforced concrete frame and insulated concrete form walls. Waves during Katrina washed through the elevated portion of the house (white dashed lines on aerial indicate total destruction of all houses except the one in the insert; red line on house indicates flood level) (Pass Christian, Mississippi).



Figure 4-21. Successful pole construction home (background) near Old Fort Bayou. The top photo was taken approximately 3 weeks after Hurricane Katrina. The lower photo was taken during Katrina (the water level had dropped approximately 6 feet from its peak when the photo was taken) (Ocean Springs, Mississippi).

SOURCE: OCEAN SPRINGS FIRE CHIEF

4.1.1.3 Masonry Pier Foundations

Masonry piers were the most common foundation type used to elevate small buildings above grade in Louisiana and Mississippi. Materials and designs varied widely, but most were concrete-filled masonry units or cast-in-place, reinforced concrete. Piers were used to elevate floors from a couple feet to more than 10 feet above grade. Most piers appeared to have been supported on shallow concrete footings or slabs. Discussions with local contractors indicate that pier foundations constructed on reinforced concrete beams are also common. The footings on grade beam foundations are interconnected to create an integral mat that is structurally superior to discrete pad footings.

When properly designed and constructed, piers were effective foundations as long as storm surge and waves remained below the floor beam and floor system components, and erosion and scour did not undermine the foundations. In Mandeville, Louisiana (see Figures 4-22 and 4-23), on the north shoreline of Lake Pontchartrain, storm surge in the lake was close to the predicted BFEs. Many buildings along the lakefront experienced storm surge and waves ranging from 2 to 6 feet above existing grade; however, buildings were adequately set back from the shoreline such that erosion was not a threat around most building locations.



Figure 4-22. Pier-supported house with minimal flood damage (Mandeville, Louisiana)



Figure 4-23. This 100-year-old building is on the National Register of Historic Places. It sustained minimal flood damage due to elevation on taller piers (an architectural choice, not a requirement when the building was constructed in 1905). Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).

Piers have been used to support buildings in the United States for centuries. In 1905, long before BFEs became a requirement, the builder of a house in Mandeville (see Figure 4-23) made the architectural choice to elevate on brick piers approximately 9 feet above grade. The foundation contained arches that provided some fixity and resistance to lateral forces. The building had damage to a few recently added under-house, breakaway walls, and minor damage to several columns, but was otherwise undamaged compared to older, lower houses.

As with pile foundations, when Katrina's storm surge and even small waves exceeded the pier foundation height and impacted the elevated building, damage was severe. Total building loss is shown in Figures 4-24 and 4-25. Such losses of houses elevated on piers 9 to 12 feet above grade were widespread across coastal Louisiana and Mississippi near the Gulf and around larger bays.

Compared to piles, traditional pier foundations have several disadvantages in storm surge and wave conditions. Some can be overcome with conservative design, but others are inherent in their construction. Piers constructed on shallow discrete footings are the most vulnerable and can be undermined by shallow erosion or localized scour, or the pier and footing can fail as a unit and rotate when exposed to lateral forces from flood and wind loads as shown in Figure 4-26. For similar support capacities, piers must generally have larger cross-sections and, therefore, are subject to higher wave forces as compared to piles.[2] In Figure 4-27, the porch roof supports have failed and the building piers have rotated landward due to lateral wave and wind forces.



Figure 4-24. Typical building failures when surge and waves exceeded pier foundation height (Long Beach, Mississippi)

[2] Piers are commonly constructed on shallow footings for one or more of the following reasons: 1) pier construction on shallow footings can be accomplished with labor and hand tools (no large equipment needed); 2) codes typically require footing depths based on frost considerations, and the designer/contractor has either underestimated erosion and scour, or has "determined" that erosion and scour will not be a problem; and 3) designers and contractors have traditionally used piers on shallow footings.



Figure 4-25.
Another typical example of building failures when surge and waves exceeded pier foundation height (Long Beach, Mississippi)



Figure 4-26.
Failure of masonry piers on shallow footings (Pass Christian, Mississippi)



Figure 4-27.
Tops of piers have been pushed landward, probably due to wave effects on the foundation and lateral wind loads on the building. Note reinforcing bars hanging from the porch roof overhang (circle). These bars were placed through wood columns and attached to the foundation, apparently as a way of providing wind uplift resistance for the wide overhang (Belle Fontaine Point, Jackson County, Mississippi).

Piers with discrete footings are much more prone to failure than piers constructed with continuous grade beams. Grade beams allow the foundation to respond as an integral system. While discrete footings can rotate and fail with relatively low lateral loads, properly designed foundations using grade beams can withstand much higher lateral loads since the entire grade beam matrix must rotate as an entity. Although grade beam foundations can resist much greater lateral loads than foundations using discrete footings, they are just as vulnerable to erosion- and scour-induced failures as foundations with discrete footings.

Compared to continuous piles that are manufactured off site, most piers are constructed on site, where the quality of construction is more difficult to control. Since piers typically consist of numerous individual components and steps in construction, there are many opportunities for error, assuming the pier is designed properly. Common pier failures observed by the MAT were due to a combination of factors, such as insufficient reinforcement (size or number or placement of bars) or inadequate splicing, shallow footings, or poor connections between the pier and the footing. Failures usually took the form of pier breakage or pier separation from the footing (see Figures 4-28 through 4-30).



Figure 4-28.
Pier connection failure (Belle Fontaine Point, Jackson County, Mississippi)



Figure 4-29.
Pier breakage (Long Beach, Mississippi)



Figure 4-30. Failure from a poorly detailed pier to beam connection (Long Beach, Mississippi)

The MAT also observed instances where lateral flood and wind forces acting on a building caused failure in the connections between the piers and the building before the foundation itself failed (see Figure 4-31). The result was foundations standing after the storm with no buildings atop the foundations.

Pier performance was best in stillwater flood conditions where erosion was minimal and waves were small. However, when the stillwater elevation exceeded the floor elevation, buoyant forces acted on the buildings, in conjunction with lack of adequate uplift anchoring in floor framing, causing some to float off their pier foundations. For example, 19 of 32 new houses in a Pass Christian subdivision (approximately 1 mile from the Gulf shoreline) floated off their pier foundations due to flood heights approximately 10 feet above the BFE and poor connections between the building and the floor beams or the floor beams and the piers (see Figures 4-32 and 4-33)[3]. Floated buildings experienced a variety of structural damage when the water receded, and appeared to be total losses. Buildings that remained attached were flooded to approximately 8-9 feet above the floor elevations, but received minimal structural damage and appeared repairable.

Each of the failures noted points out the importance of a continuous load path, from the top of the building, through the foundation, and into the ground. A continuous load path would have reduced flood damage to many buildings subject to storm surge only (no damaging waves), such as those shown in Figure 4-32, and would have had a mitigating effect on some of the buildings subject to wave forces (turning some failures into survivors).

[3] A better connection to resist flotation and lateral loads can be made using heavy beam seats, such as those shown in Figure 4-34.



Figure 4-31.
Failure of pier-to-beam connections due to wave and flood forces acting on the elevated building (Long Beach, Mississippi)



Figure 4-32.
Buildings floated off of pier foundations (Pass Christian, Mississippi)



Figure 4-33.
Poor pier-to beam connection. Although this particular connection did not fail (because the wall and floor-to-beam connections failed first), this connection is poor. Note use of light gauge metal straps and nailing of strap at a joint in the beam (Pass Christian, Mississippi).

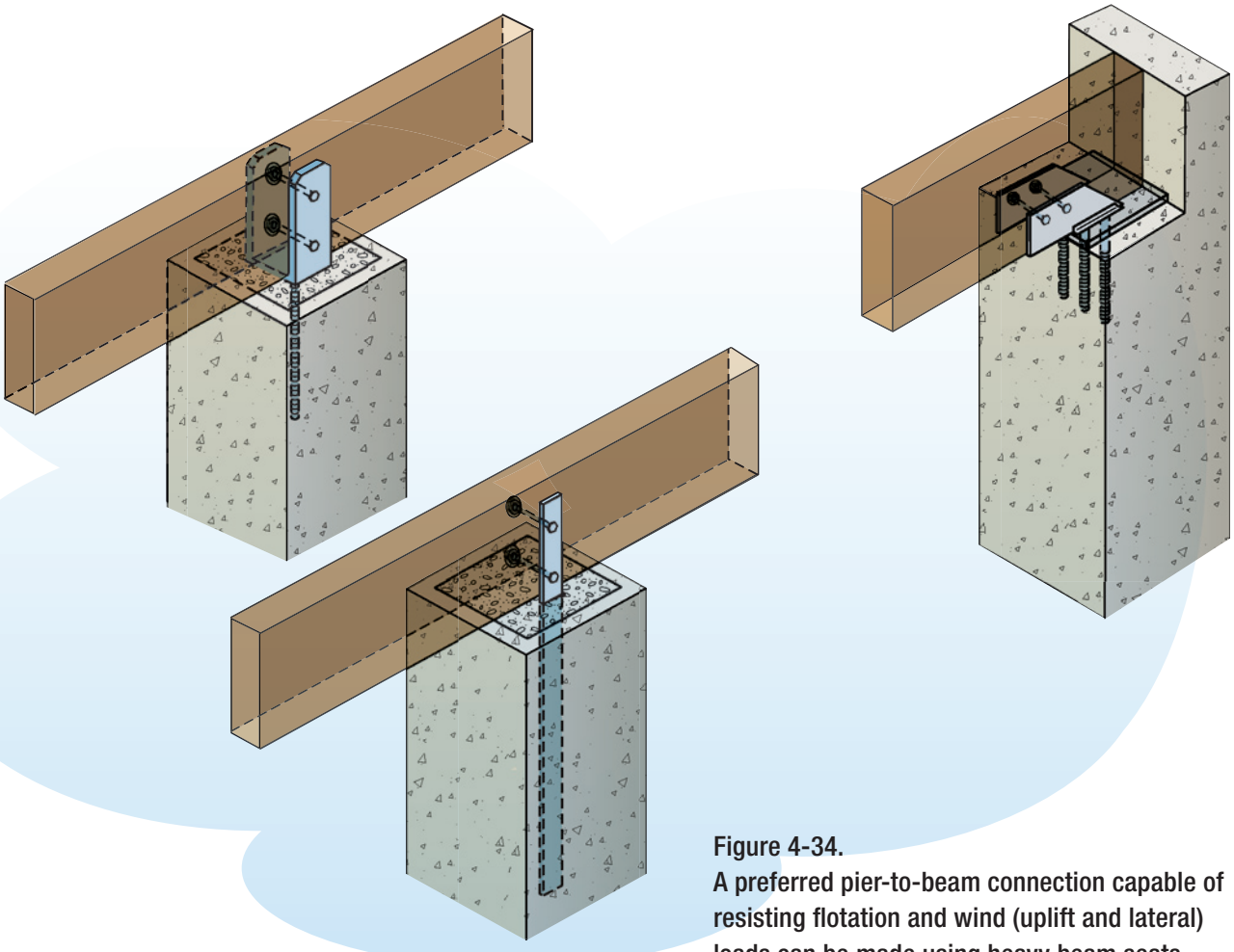


Figure 4-34.
A preferred pier-to-beam connection capable of resisting flotation and wind (uplift and lateral) loads can be made using heavy beam seats.

4.1.1.4 Slab-on-Grade Foundations

Slab-on-grade foundations were very common in coastal Louisiana and Mississippi, especially for pre-FIRM buildings and buildings outside the SFHA where the ground elevation was above the BFE. During Katrina, as long as flood heights and wave runup remained below the adjacent ground elevation, there was little flood damage to buildings supported by slab foundations. Unlike most coastal storms, Katrina was not accompanied by widespread erosion, which could have undermined slab foundations just above the flood level. Buildings constructed with slab-on-grade designs were severely damaged when floodwaters and waves reached above the slab (see Figure 4-35). Where storm surge exceeded the slab elevation by more than about 3 feet and where breaking wave heights are believed to have exceeded 1.5 feet, wave damage to load-bearing walls resulted in severe building damage (see Figure 4-36) or total loss (see Figure 4-37). Total building loss, leaving nothing but the floor slab, was common in areas experiencing wave crest elevations several feet above the slab elevation. Figure 4-38 shows the wide zone of destruction of buildings supported on slab-on-grade foundations and subject to high waves and deep flooding in Pass Christian, Mississippi. All that remains of houses in the zone closest to the shore are the slab foundations. As buildings were destroyed, the resulting floating debris moved progressively farther inland. The debris zone represents the separation between total losses and deep, stillwater flooding, with little structural damage shown at the top of the photo.



Figure 4-35. Slab-on-grade undermining (Ocean Springs, Mississippi)



Figure 4-36.
Wave and surge damage to a house supported by load-bearing wood-frame walls atop a slab foundation. The house was approximately 1/4 mile from the Gulf, in mapped flood Zone C (1992 FIRM), and was probably exposed to Coastal A Zone conditions (3-4 feet stillwater depth and small waves) during Katrina (Pointe Aux Chenes area, Jackson County, Mississippi).



Figure 4-37.
Waves, surge, and floating debris destroyed many single-family homes on slab foundations. Note debris from houses washed landward into other buildings (Biloxi, Mississippi).



Figure 4-38. Typical zones of damage to homes supported on slab-on-grade foundations (Pass Christian, Mississippi)

4.1.1.5 Stem Wall Foundations

Stem walls typically use a masonry wall to contain and elevate compacted fill, which, in turn, supports a slab. The higher elevation above surrounding grade makes the foundation preferable to a slab-on-grade, and adds a safety factor against local stormwater flooding. Stem wall foundations are frequently used to meet the elevation requirements when the BFE is several feet above grade. The earth-filled wall also provides more initial wave capacity than typical crawl space perimeter walls. However, as with other shallow foundations, stem wall foundations are susceptible to

undermining due to erosion or localized scour. If undermined, the contained fill can be lost, removing support for the slab floor, as shown in Figure 4-39. Similar to buildings with slab-on-grade foundations, buildings with stem wall foundations experienced severe damage when flood levels and wave heights far exceeded the top of the slab (see Figure 4-40).



Figure 4-39.
Shallow foundation failure due to localized scour and damage to walls by surge and wave impacts (Ocean Springs, Mississippi)



Figure 4-40.
Stem wall foundation survived intact, but waves and surge above the floor destroyed the house, sweeping it off the foundation (Waveland, Mississippi).

4.1.2 Manufactured Housing

Most of the damage to manufactured housing observed by the MAT was from flooding.[4] Many of the manufactured homes that experienced damage were separated from their foundations or the foundations shifted (see Figures 4-41 through 4-48 for examples of damage to manufactured homes). In all cases, however, homes were likely substantially damaged wherever the floodwaters rose above the floor of the homes.[5]

In other words, once flood levels rose above the floor, the MAT would classify no manufactured homes as "successes" and relatively few manufactured homes as "survivors," even if the foundation remained intact and the home remained attached to the foundation. The manner by which manufactured homes are constructed makes their repair difficult, if not impossible, once the floor is flooded. Thus, a successful manufactured home installation will require: 1) elevation of the floor system above the actual flood level, 2) attachment of the home to the foundation, and 3) anchorage of the home and foundation to the ground, capable of resisting wind loads experienced by the home.

Foundation type tended to affect whether or not manufactured homes were displaced from their foundations. Manufactured homes placed on, and secured to, poured concrete foundations generally remained intact (although with flood damage from inundation). Homes placed on dry-stacked (unmortared) piers and secured with helical ground anchors were often pushed off of their foundations and destroyed.

Wind provisions for manufactured homes are included in Section 305 of the Manufactured Home Construction and Safety Standard promulgated by HUD's Manufactured Housing Consensus Committee (MHCC).

There are three wind classifications of U.S. Department of Housing and Urban Development (HUD) homes: Zone I, Zone II, and Zone III. Each classification has specific requirements for wind resistance. HUD Zone I homes are not designed to a listed wind speed, but rather are required to resist specified horizontal loads and net roof uplift loads. HUD Zone II homes are designed for 100 mph (fastest mile) wind speeds (approximately 115 mph 3-second gust wind speed). HUD Zone III homes are designed for 110 mph (fastest mile) (approximately 125 mph 3-second gust wind speed).

The MHCC HUD Zone II and Zone III homes are required to be constructed to resist the wind pressures listed in CFR 24 Part 3285. The requirements extend to the "anchorage equipment" provided with the home, but the foundations that manufactured homes are placed on are not specified in the MHCC standard.

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[4] Readers should note that flood damage to manufactured homes was common, both inside and outside the SFHA.

[5] Manufactured homes are particularly vulnerable to flood damage when the flood level rises above the floor. FEMA depth-damage functions generated by flood insurance claims data show that manufactured homes in areas not affected by waves are likely to be substantially damaged by between 1 and 2 feet of stillwater flooding above the floor. If high velocity flow or waves are present, substantial damage can result from flooding at or below the top of the floor. These damage patterns are in contrast with conventional site-built homes, where the entire structure must be inundated by stillwater flooding before substantial damage is likely or, in the case of waves and high velocity flow, where flood levels must reach above the top of the floor before substantial damage is likely to occur.

HUD homes in all Mississippi counties along the Gulf Coast and many of the parishes in Louisiana that the MAT visited are in HUD Zone II. Other Louisiana parishes (e.g., Jefferson, St. Bernard, Plaquemines, La Fouche, and Terrebone) are in the higher HUD Zone III.

The new HUD standards, which have not yet been released, do include provisions for local floods.

Where nameplates could be viewed, all of the newer HUD style homes investigated were identified as HUD Zone II homes. Most were installed on dry-stacked masonry piers and were secured



Figure 4-41.
Collapse of manufactured home due to loss of anchorage and pier settlement (indicative of soil saturation under flooded conditions) (Pass Christian, Mississippi).



Figure 4-42.
Dry-stacked pier under home rotated 20 degrees from vertical (Pass Christian, Mississippi).

with ground anchors. Ground anchors in many structures were spaced at approximately 8-foot centers, but ground anchor spacing could not be determined on all homes. Ground anchor spacing requirements are not contained in the MHCC, but must be included in the manufacturer's installation instructions. Other homes were placed on more substantial foundations like cast-in-place concrete strip footings.



Figure 4-43. Manufactured home placed on and secured to poured concrete strip footing had floodwaters 6 feet above its floor, but was not moved from its foundation. Although this indicates good foundation performance, the cost of repairing may exceed the value of the residence because of the significant inundation damage (Ocean Springs, Mississippi).



Figure 4-44. Interior photo of manufactured home shown in Figure 4-43 (Ocean Springs, Mississippi)



Figure 4-45.
A manufactured home near the home shown in Figure 4-43, but placed using a "standard set" installation of ground anchors and dry-stacked masonry piers (Ocean Springs, Mississippi).



Figure 4-46.
Foundation of manufactured home in Figure 4-45. Although the home did not collapse, the ground anchors were partially pulled out of the ground (probably by flotation and lateral flood forces on the home under saturated soil conditions) and it shifted laterally on its piers (Ocean Springs, Mississippi).



Figure 4-47. Flood-damaged manufactured home (St. Bernard Parish, Louisiana)



Figure 4-48. Foundation of home shown in Figure 4-47. The flood level rose above the floor, the ground anchors were apparently pulled up from the saturated soil, and the piers were displaced (St. Bernard Parish, Louisiana).

4.1.3 Low-Rise, Multi-Family Residential Buildings

Low-rise, multi-family residential buildings were constructed on the same types of foundations used for single-family houses. Performance of these buildings during flooding was similar to that of single-family houses. With stillwater levels, storm surge, and wave elevations well above the BFEs, flood damage to affected multi-family structures was widespread and severe. The pile-supported Pascagoula condominium unit in Figures 4-49 and 4-50 lost bearing walls due to lateral wave forces, and elevated floors due to wave uplift. The unit was the only remaining one out of 20 (Figure 4-50).

The condominium in Figures 4-51 and 4-52 was supported on heavy reinforced concrete columns and beams, but progressively failed from lateral and uplift wave loads on the lower unit load-bearing walls and floors. Note that wind impacts to the building, apparent at the roof and upper stories, may have also contributed to building damage.

Katrina's high surge levels (and associated wave debris and wind conditions) completely destroyed apartment buildings constructed on slab foundations. Figure 4-53 shows multiple views of an apartment complex in Pass Christian. The red arrows on the aerial view indicate the point of view of the labeled closeups. The deepest flooding extended from the Gulf shoreline to the elevated railroad tracks at the top of the aerial image. The extent of the progressive failures moving inland from the Gulf is graphically identified by the upper limits of the debris field. The floating debris (a) consisted primarily of lumber from the destroyed buildings. All that remained of the seaward buildings were the slab foundations (b). The leading edge of the debris field combined with wave forces to progressively destroy the first- and second-story bearing walls



Figure 4-49. Severely damaged condominium unit was the only one remaining of 20 units (Pascagoula, Mississippi)



Figure 4-50.
Another view of the severely damaged condominium unit shown in Figure 4-49 (Pascagoula, Mississippi)



Figure 4-51.
Condominium on heavy concrete foundation severely damaged when wave elevations exceeded lower floor elevations (Gulfport, Mississippi)



Figure 4-52
Another view of the condominium shown in Figure 4-51 (Gulfport, Mississippi)

of the next remaining row of buildings (c). By the end of the storm, the floating debris field is thought to have grown so massive that it functioned as a breakwater, damping the waves from reaching the deeply flooded units, as shown by the watermark in (d), just landward of the debris field. Wind damage is apparent to the structures standing in (d), indicating that wind might have contributed to damage of the destroyed buildings seaward of the debris line.



Figure 4-53.
Multiple views of an apartment complex on slab foundations. The red arrows on the aerial image indicate the point of view of the labeled closeups (Pass Christian, Mississippi).

4.1.4 Low-Rise Commercial Buildings

A wide variety of commercial buildings experienced flooding and severe damage from the storm. These buildings included downtown storefronts in the older business districts, stand-alone food service/resort retail, motels, churches, seafood handling/processing facilities near the harbors, strip malls, and larger retailers. No type of commercial buildings constructed on slab foundations near the coastline escaped damage when the storm surge or wave elevations exceeded the floor levels. In denser development such as the downtown central business areas, those buildings farther from the shoreline experienced widespread stillwater flooding, but were protected by increasing ground elevations and the density of buildings closer to the Gulf. Most of the commercial buildings had light gauge metal stud exterior walls or masonry walls on slab foundations. As seen in other types of buildings (i.e., residential), the buildings closest to the shoreline that were exposed to waves lost load-bearing walls and were swept clean to the floor slab (see Figure 4-54). Steel-framed construction with in-fill masonry walls was more common in larger retail buildings and some churches. When exposed to waves, the heavier steel frame continued to support the roofs, but walls and contents were destroyed (see Figures 4-55 through 4-58).

A very unusual commercial structure investigated by the MAT was the Biloxi Harbor Master Administration Building (see Figure 4-59). The building structure was a hybrid. Its lower level consisted of a reinforced concrete frame; the upper levels and roof were constructed with heavy steel structural columns and joists. The building was constructed in a designated V Zone, and the first floor walls of glass behaved like breakaway walls and were sacrificed with the storm surge.



Figure 4-54. Commercial building destruction along the Mississippi coast

SOURCE: USGS



Figure 4-55.
Steel-framed strip mall construction with exterior and interior wave damage (Gulfport, Mississippi)



Figure 4-56.
Interior of steel-framed strip mall construction shown in Figure 4-55 (Gulfport, Mississippi)



Figure 4-57.
Steel-framed church that was gutted by waves, but the roof remained in place (Biloxi, Mississippi)



Figure 4-58.
Large retail store that was gutted by waves, but most of the roof remained in place (Pass Christian, Mississippi)



Figure 4-59.
Biloxi Harbor Master Administration Building with a hybrid structural system, concrete and steel (Biloxi, Mississippi)

4.1.5 High-Rise Buildings

High-rise buildings subject to stillwater flooding in Katrina included downtown office buildings and hospitals that were located more distant from the shoreline. Structural damage from the flooding was rare, but water damage to equipment and contents was severe in some cases. High-rise buildings close to the shoreline experienced some of the worst storm surge depths and wave heights. Shoreline erosion was rare compared to most recent storms (FEMA 489, 2005 [Ivan]). The foundation stability of the large buildings was not affected; most were cast-in-place, reinforced concrete. A few were steel-framed construction. Although sited near the shoreline and experiencing the worst flood conditions, the high-rises were some of the better examples of successes.

A concrete-framed building in downtown Gulfport (see Figure 4-60) sustained surge damage to its first floor and glazing damage from flying debris, but remained structurally sound and easily repairable.

An unusual failure of a concrete structure was the multi-family complex located outside of Pass Christian (see Figure 4-61). The project was under construction when Katrina hit. The structure consisted of concrete columns with post-tensioned slabs and integral drop pan beams. Like many post-tensioned concrete structures, the beams and slabs were likely cambered (intentionally curved upward) to counteract the natural downward deflection that occurs after a building is constructed and fully loaded.

Post-tensioned slabs are strong under gravity loading, but can be weak when exposed to uplift. The MAT believes failure resulted when the unloaded and post-tensioned cambered slab and



Figure 4-60. Concrete-framed building sustained non-structural damage to lower portions from storm surge (Gulfport, Mississippi)



Figure 4-61. Multi-family property on Beach Boulevard with failed post-tensioned slabs and columns. Note the post-tensioning tendons (circles) (Pass Christian, Mississippi).

beams were lifted and further cambered when surge and waves struck the bottom of the floor slab and beams. This lifting appeared to produce failure in portions of the slab and in some of the beams and resulted in localized collapse.

Most of the affected floating casinos located along the Gulf and bay shorelines were associated with high-rise hotels on adjacent land. It was common practice to elevate main entrances one or two stories above the low, adjacent ground elevations (see Figure 4-62). Lower level parking decks supported (see Figure 4-63) or were adjacent to the hotels. In some cases, the floor elevations were high enough to avoid flood and wave damage, or at least limit damage to the lowest finished-entrance floor level. The higher foundation elevations allowed several hotels on exposed shorelines to return to operation sooner than more sheltered lodging farther inland and outside the flood area.

Other post-storm inspection groups noted that the construction techniques used for the parking decks made a significant difference in the performance (MCEER, 2005). Cast-in-place concrete designs performed the best. Pre-stressed parking deck designs frequently experienced wave damage to horizontal structural members and the floor panels of the first elevated level. The designs frequently relied on gravity connections that failed when exposed to lateral and uplift wave forces, as shown in Figures 4-64 and 4-65. Cast-in-place designs integrated better component connections and performed better when exposed to waves. The performance of parking decks under and around the casino hotels indicated that the large buildings could be designed for Katrina's similar conditions if appropriate wave forces were considered.

Although the flood resistance of the casino hotels was better than many other building classes, the performance of floating casino barges was poor. Along the Gulf and exposed bay shorelines, the storm surge and waves either sank the barges at their docks or separated the

barges from their moorings to become massive floating debris. An example of barge damage to a hotel parking deck in Biloxi is shown in Figure 4-66. The consequences of other barge impacts is described in Chapters 3 and 6.



Figure 4-62. Elevated entrance driveway in casino hotel (Biloxi, Mississippi)



Figure 4-63. Elevated lower level parking deck in casino hotel (Biloxi, Mississippi)



Figure 4-64.
Collapse of first elevated level of pre-stressed parking decks due to poor column-to-beam gravity connections that failed when exposed to lateral and uplift wave forces (see Figure 4-65) (Biloxi, Mississippi)



Figure 4-65.
Another view of the collapse of first elevated level of pre-stressed parking decks shown in Figure 4-64 (Biloxi, Mississippi)



Figure 4-66.
Parking deck collapse due to impact by casino barge, on left (Biloxi, Mississippi)

The MAT observed generally good structural performance of high-rise buildings located near the Gulf shoreline. The buildings observed included casinos/hotels, office buildings, and condominiums. High-rise foundation systems were generally not impacted by storm surge and wave impacts due to their location on high ground and building elevations. As an example, a high-rise building in Gulfport was sited on higher ground with a lower level office floor at elevation 20 feet NGVD (see Figures 4-67 and 4-68). One building was almost complete and the second tower was nearing completion. The cast-in-place concrete shear walls, aligned perpendicular to the shoreline, allowed waves to pass through the lower level, damaging only the office and other non-structural walls on the ground floor. The higher floors were undamaged.



Figure 4-67.
High-rise building along Beach Boulevard received non-structural flood damage to lower floors, but no apparent flood or wind damage to higher residential floors (Gulfport, Mississippi)



Figure 4-68. Another view of the high-rise building along Beach Boulevard shown in Figure 4-67 (Gulfport, Mississippi)

4.2 Wind

While damages from Hurricane Katrina's storm surge devastated the Gulf Coast, Hurricane Katrina's winds also caused damage throughout the impacted area. Some of the damage was in areas that experienced wind speeds that approached current design wind speeds. However, much of the damage was in areas where the wind speeds were well below the design levels specified in the latest codes and standards.

Most of the damage was to building envelopes (discussed in Chapter 5), but structural damages occurred as well. Common types of structural damage included roof decking blow-off; gable end wall failures; collapse of unreinforced, load-bearing masonry walls, and purlin and moment frame failure of older (pre-1980) PEMBs. These damages were observed on all types of buildings with older residential and commercial buildings generally affected the worst.

In discussing wind damage, it is important to differentiate between structural damage and building envelope damage. Many buildings experienced little or no structural damage, but may be total losses due to water entry that resulted from building envelope failure. It is also important to differentiate between the design wind speeds and their resulting design pressures specified by the latest code and the design wind speeds/pressures specified by the older codes that were in effect when many of the buildings the MAT investigated were constructed. In many areas, the design wind pressures specified in current codes are higher than those specified in older codes.

4.2.1 Wood-Framed Buildings

Most of the wood-framed buildings observed by the MAT were residential buildings (both single-family and low-rise apartment buildings). The predominant wind related damage to these types of buildings was structural failure of wall and roof elements.

The construction type for these structures is known as light framed with superstructures supported by load-bearing, wood-framed walls. Building floors and roofs are supported by wood joists, rafters or trusses, and plywood or oriented-strand board (OSB) decks. Typical framing members are nominal 2-inch-thick lumber with widths ranging from nominal 4 inches to 12 inches, depending upon the member's use. Members are typically spaced at 12 inches, 16 inches, and 24 inches in order to accommodate building loads and 4x8-foot sheet material (i.e., gypsum board, plywood, and paneling).

Wood is a favored material of residential building contractors for its economy, architectural flexibility, and aesthetics. Small work crews can handle most wood members without special lifting equipment, cutting and fastening can be accomplished on site with hand-held or portable power tools, and the skills needed for wood construction are easily learned. The ease and flexibility of wood construction also leads to one of the major problems it has as a system (i.e., it can be assembled or modified in so many different ways).

Structural framing systems must be designed to transfer all gravity, uplift, and lateral loads to the foundation, as shown in Figure 4-69. The integrity of the overall building depends not only on the strength of these components, but also on the adequacy of the connections between them to properly transfer the forces. Critical connections occur in the following locations where the roof systems are supported by the top plate of the wall, there are openings and headers in the walls that collect forces, floors connect to each other, and the base of the wall connects to the foundation system. In buildings with trusses or rafters for roof framing, the roof sheathing typically works with the framing to create a roof diaphragm. The roof diaphragm in turn transfers lateral loads to the foundation through the building's shear walls.

Observations of hurricane damage during the past few decades have revealed that a common failure point was wood-framed gable end walls. These were commonly under designed, improperly constructed, and unbraced. Often, a typical roof truss is the only support element behind the wall covering of the gable, as shown in Figure 4-70. Properly designed, fabricated, and installed trusses are usually designed to carry gravity loads across their strong axis. However, when a truss is used alone as the wall framing for the gable end wall, the truss members must resist the wall's wind forces along its weak axis. In many cases, the gable end may be as tall as a story high and, even if wall studs are added to the truss, the truss may still be inadequate to carry the shear and bending forces produced by the lateral wind load. Lateral bracing must also be considered in buildings using scissor trusses. Scissor trusses have sloped bottom chords that create vaulted ceilings. If the wall framing below the gable assembly is not continuous, a hinge can form and the wall framing can fail under lateral loads. The MAT observed new construction where inadequate wall framing was being provided (see Figure 4-71).

In cases where adequate wall stud framing is present in the gables, the problem is typically the absence of adequate bracing of the gable end wall, which sits on top of the wall below, as shown in Figure 4-72. Without adequate bracing, a hinge is produced between the bottom of the truss and the top of the wall, as seen in Figure 4-73. In most cases, the only bracing is the roof diaphragm, and when removed by the wind, total collapse of the roof and wall occurs as shown in Figure 4-74.

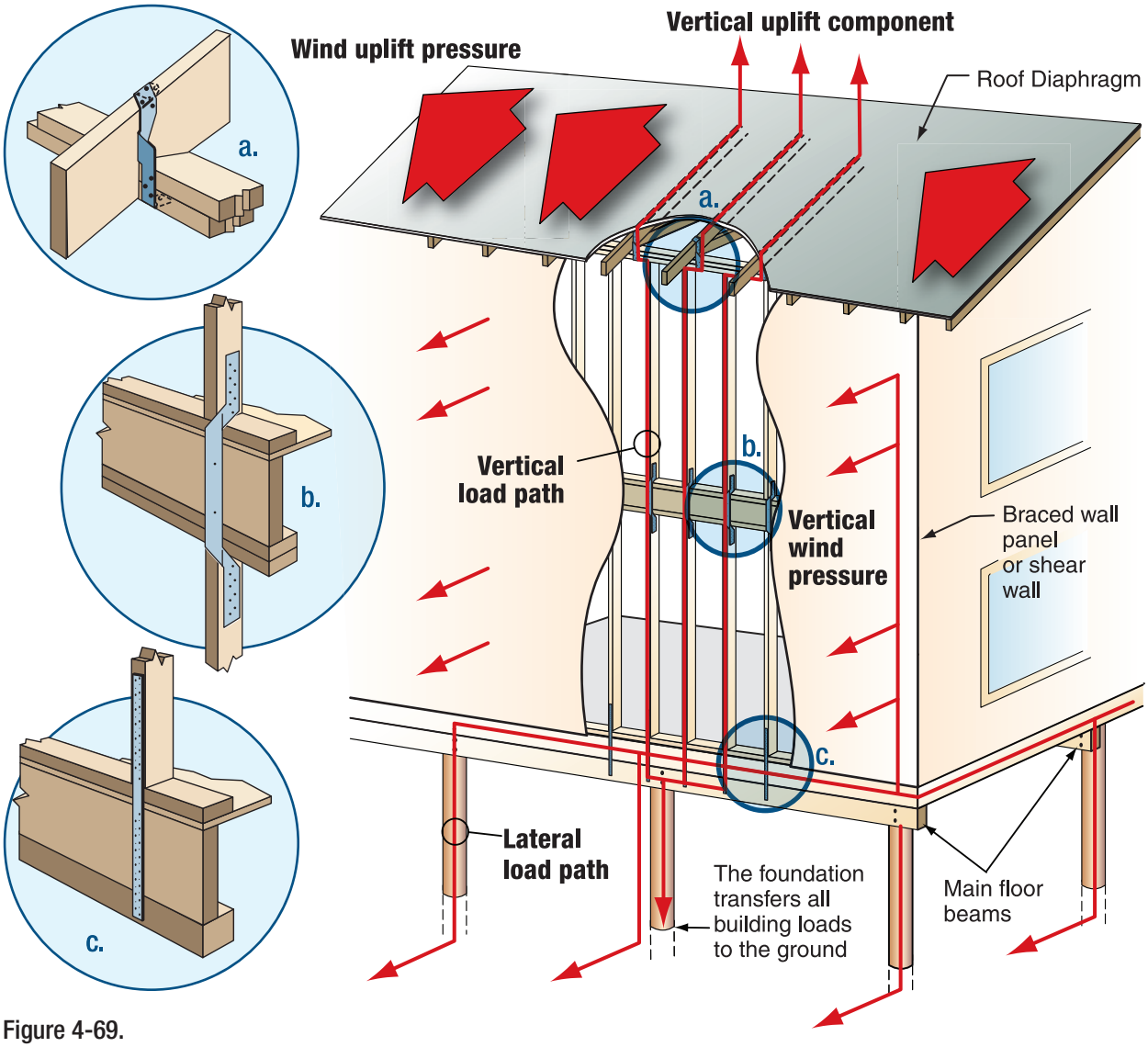


Figure 4-69.
Load path of a two-story building with a primary wood-framing system: walls, roof diaphragm, and floor diaphragm

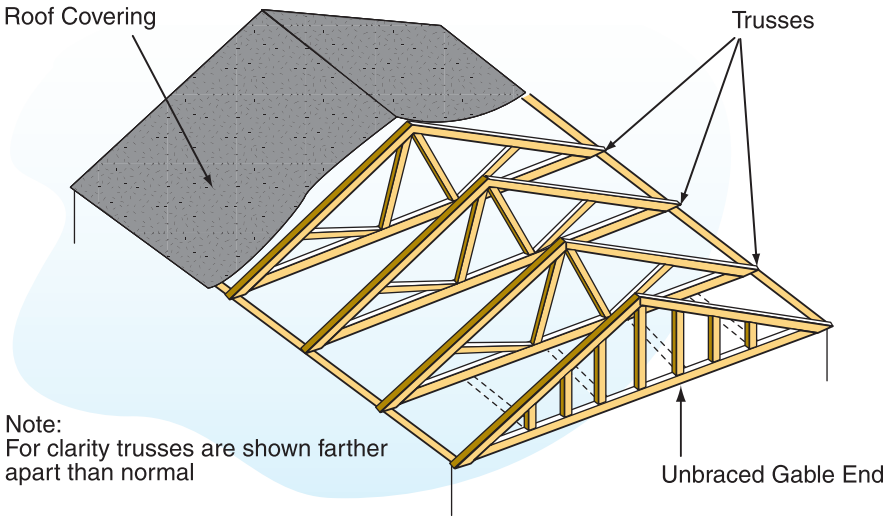


Figure 4-70.
Gable end wall framing diagram



Figure 4-71
Inadequately braced gable on a building under construction (the building was not in place during Katrina). The trusses have sloped bottom chords (scissor style trusses) to create a cathedral vaulted ceiling. While the gable truss has a flat bottom chord, the wall studs below the bottom of the gable assembly are interrupted, which creates a weak hinge that will not adequately brace the top of the wall or the bottom of the gable truss above (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 4-72.
Apartment with typical gable end wall truss with stud infill. Note the loss of gable sheathing and the lateral displacement of the bottom chord of the truss (circle) (estimated wind speed: 120 mph.[6] Ocean Springs, Mississippi).

[6] Estimated speeds given in this chapter are based on Figure 1-13. These are for a 3-second gust at a 10-meter elevation for Exposure C. Unless otherwise noted, the buildings for which estimated speeds are given are located in Exposure B. See Table 1-4 for the estimated speed conversion for buildings located in Exposure B. For example, the 130-mph Exposure C speed given for Figure 4-71 is equivalent to 110 mph in Exposure B.



Figure 4-73.
Hinge formed between gable end and top of wall (hinge circled) (estimated wind speed: 120 mph. Ocean Springs, Mississippi)



Figure 4-74.
Two-story apartment building that lost its roof diaphragm and load path connections (estimated wind speed: 120 mph. Ocean Springs, Mississippi)

The most common wind-related structural failures observed in light-framed construction were roof framing failures. Failures were observed in both new and old construction. Insufficient attachment of roof sheathing panels to the supporting framing was the most common problem. Before the 1982 SBC, the code did not account for higher uplift pressures that occur at roof perimeters and corners. Much closer nail spacing was required after implementation of the 1982 SBC criteria. Once the sheathing attachments fail, a variety of other failure modes can occur. Attics that have been breached can become pressurized and other structural elements may then become overstressed. This can lead to an "unzipping" effect of progressive failure where one failure leads to a series of subsequent failures, as seen in Figure 4-75.



Figure 4-75.
Failure of the gable end wall of this apartment building led to pressurization of the attic and the release of sheets of plywood sheathing. Note the plywood roof sheathing "unzipped" by wind pressures (arrows) (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

Zones of increased wind pressure occur at wall and roof corners, roof edges, roof ridges, hips, and overhangs. Failures of building structural and/or envelope components usually begin in these zones. Breaches of the building envelope (such as door or window failure) can result in increased internal pressure, which can damage interior partitions and ceilings and increase the wind load on structural and envelope components. Increased pressure can cause failure if the structure and envelope possess inadequate wind resistance. Figures 4-76 and 4-77 are illustrative of these zones of high pressure.



Figure 4-76.
Roof corners, edges, and ridges are zones of increased wind pressures (arrows), as seen in this apartment complex (estimated wind speed: 120 mph. Ocean Springs, Mississippi).



Figure 4-77.
High pressures under overhangs often lead to progressive structural failures. Note the vinyl soffit material removed by high-wind pressures (arrows) (estimated wind speed: 130 mph. Pass Christian, Mississippi).

The MAT observed numerous examples of failures of building soffits that led to attic internal pressurization and subsequent loss of decking and roof framing members, as seen in Figure 4-78. Soffits supported by solid substrate, seen in Figure 4-79, often prevented significant air pressure from entering inside the building envelope.



Figure 4-78.
Pressurization of the second floor porch ceiling of this apartment led to soffit failure and loss of roof decking and other structural components (estimated wind speed: 120 mph. Ocean Springs, Mississippi).



Figure 4-79. Properly attached gypsum board substrate avoided attic pressurization and entrance of wind-driven rain when the finish soffit material was lost (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

4.2.1.1 Single-Family Homes

In the areas damaged by Hurricane Katrina, the MAT observed few houses new enough to have been built under the 2000 or 2003 IBC. Newer wood-framed houses generally performed well structurally. However, in most of the areas struck by Katrina, the actual wind pressures were below the code-prescribed pressures and Katrina could not be considered a true "code design-level test." [7] Therefore, it is difficult to evaluate the effectiveness of new codes because newer homes were not fully tested.

Efforts in the last 15 years to increase the quality of coastal construction using best practices and most current research, such as discussed and illustrated in the Standard Building Code (SBC) SSTD-10, *Hurricane Resistant Residential Construction Standard*, and FEMA 55, *Coastal Construction Manual*, have been successful. Many newer houses observed by the MAT had significant damage due to storm surge below their elevated floors and into first habitable floors, but remained structurally connected, as seen in Figures 4-80 and 4-81.

SSTD 10-99 is a high-wind standard first published by the Southern Building Code Congress International (SBCCI) in 1990. The standard references ASCE 7-88. ASCE 7 has been revised five times since 1988 and wind provisions have been significantly changed. To address those changes and other state-of-the-art research, the ICC will be releasing *Revised Standard for Hurricane Resistant Construction*.

[7] Hurricane Charley (2004) was a near code design-level test in some of the areas it impacted. For structural performance of new residential construction during that event, see *FEMA Mitigation Assessment Team Report: Hurricane Charley in Florida* (FEMA 488).



Figure 4-80.
Coastal home located in Exposure C received significant surge damage into the habitable level and, although it lost its porch and three porch columns, the basic load path remained connected. Red circle indicates location of Figure 4-81 (estimated wind speed: 120 mph. Ocean Springs, Mississippi).



Figure 4-81.
Coastal home located in Exposure C that is well connected with beam-to-column lap joints and galvanized bolts and straps (estimated wind speed: 120 mph. Ocean Springs, Mississippi)

Good connections are essential in maintaining structural integrity of structures. For many years, metal framing connectors have been available for residential construction and are required by the various codes in coastal areas. If properly installed, the connectors, which have been engineered by industry, will transfer roof loads to foundations, thereby maintaining a continuous load path. The home shown in Figures 4-82 and 4-83 was still under construction and, although the first floor was completely inundated by floodwater, it remained fully connected.



Figure 4-82.
Home under construction subjected to flood and wind damage (estimated wind speed: 130 mph. Pass Christian, Mississippi)



Figure 4-83.
Home located in Exposure C with rafter-wall connectors and top plate-stud connectors. Note the rafter-top plate connector (arrow) is more effective to install on opposite side of wall, and the top plate stud connector (circle) (estimated wind speed: 130 mph. Pass Christian, Mississippi).

Frequently, the MAT found structures (including houses under construction) without proper connectors, or with inconsistently spaced, insufficient, or poorly attached connectors. Figures 4-84 and 4-85 illustrate floor-to-floor connectors that were adequately spaced, but improperly attached. They do not fully extend across the floor framing and several nails were missing from the connection. Furthermore, the sheathing was not installed in a fashion that best takes advantage of its potential to transfer lateral and vertical forces. As a best practices approach, sheathing should extend 2 feet above and below the floor level. When metal connectors are used, manufacturers usually recommend filling all holes with the proper-sized nails in order to maximize the strength of the fastener. Figure 4-86 shows a floor-to-floor strap that does not extend to the upper wall system. Figure 4-87 shows a plate-to-stud connector that is attached with the incorrect size of nail, which has been bent over to prevent pull-through.



Figure 4-84.
Two-story structure with floor-to-floor connectors (arrows) that are adequately spaced, but improperly attached (see Figure 4-83) (estimated wind speed: 120 mph. D'Iberville, Mississippi).

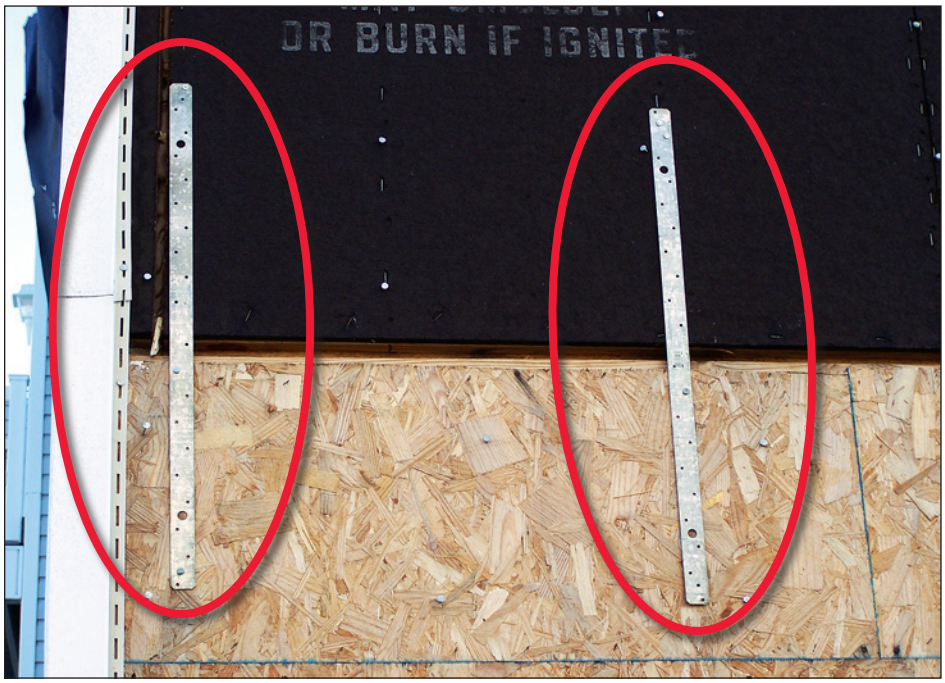


Figure 4-85.
Two-story structure with floor-to-floor connectors that were adequately spaced, but were too short to extend into the wall framing above and below the floor level and were missing several fasteners (circles) (estimated wind speed: 120 mph. D'Iberville, Mississippi).



Figure 4-86.
Floor-to-floor straps are intended to keep the load path connected (proper strap location in red). The strap installed in this Biloxi office condominium does not extend to the upper wall system and is insufficiently nailed (estimated wind speed: 120 mph. Biloxi, Mississippi).

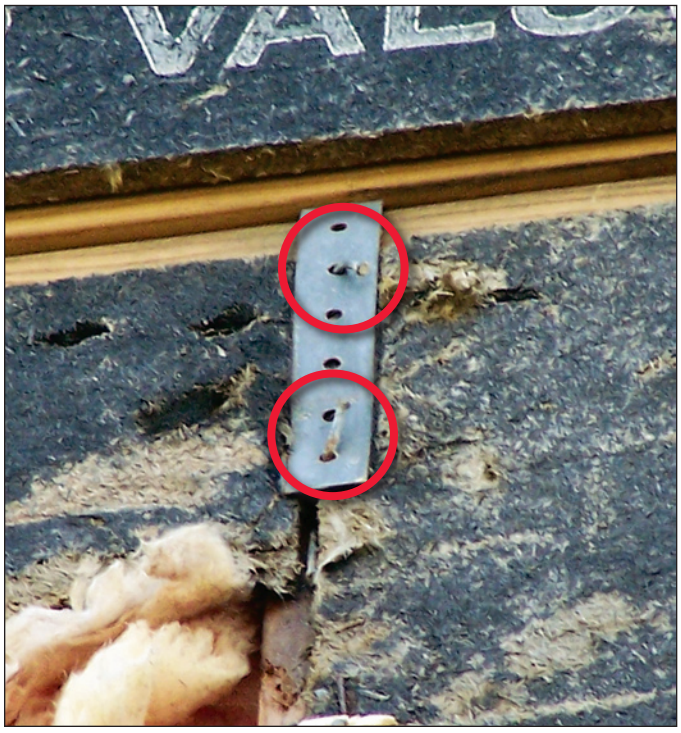


Figure 4-87.
Stud strap connected to top plate with improperly sized nails with bent heads (circles). The strap did not extend far enough down the stud and several fasteners were missing (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

Some homes under construction were severely damaged or destroyed by Katrina's winds even though wind speeds were well below current design levels. Figure 4-88 shows a home in St. Tammany Parish with failed shear walls and a collapsed garage. The complete destruction of the garage prevented the MAT from determining the mode of failure, but the failure of the home could be attributed to inadequate shear wall nailing. The home had shear walls that were only stapled and the staples were widely spaced. Several staples missed the wall framing.



Figure 4-88.
Home under construction whose garage collapsed and that racked laterally approximately 1 foot. Sheathing in the shear walls in the front of the home were found to be inadequately fastened to the wall framing (estimated wind speed: 120 mph. St. Tammany Parish, Louisiana).

Figure 4-89 shows another home under construction that experienced partial failure of the roof framing systems. The roof framing was fastened to the wall's top plate with framing anchors, but no fasteners were used to connect the top plate to the wall framing (see Figure 4-90).

Figures 4-91 (a) and 4-91 (b) show a home in St Bernard Parish, Louisiana, that did not experience significant damage during Katrina (it is possible that the home was constructed after Katrina), but was indicative of improper construction methods found in several new homes the MAT visited. Wall sheathing in the home was fastened to the bottom wall plate at 32 inches on center while prescriptive codes would require nailing at 6 to 8 inches. The presence of building wrap on the outside walls indicates that no additional nailing was to be installed.



Figure 4-89.
Home located in Exposure C that lost portions of its roof structure (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana)



Figure 4-90.
Framing anchors were used to connect rafters to top plate, but no framing anchors connected top plate to wall framing at this house located in Exposure C (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana).





Figure 4-91 (a) and 4-91 (b).
Wall framing was inadequately secured to the bottom plate with fasteners spaced over 32 inches on center. The presence of building wrap shows that no additional nailing was planned (estimated wind speed: 130 mph. St. Bernard Parish, Louisiana).

4.2.1.2 Multi-Family Residential Buildings

As reported in Chapter 3, the structural performance of multi-family dwellings varied with construction type. Reinforced concrete- and steel-framed structures performed well, while extensive damage was observed in many wood-framed, multi-family structures. The severity of wind damage did not vary significantly with foundation style. Structures with shallow foundations performed similarly to those with deeper foundations. Deeper foundations, like piers or pilings, were typically used in coastal sites where wind speeds were higher; thus those

buildings had greater wind damages, but the difference in damages attributed to wind cannot and should not be attributed to foundation style.

Wood-framed, multi-family buildings fared the worst. Many buildings were severely damaged or destroyed. As stated in Chapter 3, breaching of the building envelope through soffits or other soft portions in the exterior contributed to failure. Weaknesses often involved inadequate roof sheathing attachment, inadequate connections between roof and wall framing, and other weaknesses in the vertical load path between roofs and foundations.

The MAT observed several damaged buildings where roof sheathing was tacked at corners with nails and fastened with staples in all other areas of the sheet (see Figures 4-92 and 4-93). Staple placement varied greatly and often one leg of the staples missed the roof framing. Where staples were squarely fastened to roof framing, some staples tore through the sheathing when the roof sheathing experienced pull-through failure, as shown in Figure 4-94. The 2003 IRC allows cellulosic fiberboard wall sheathing to be stapled along panel edges at 3-inch centers (on 6-inch centers within the panel), but specifies nails for fastening structural wall and roof panels.

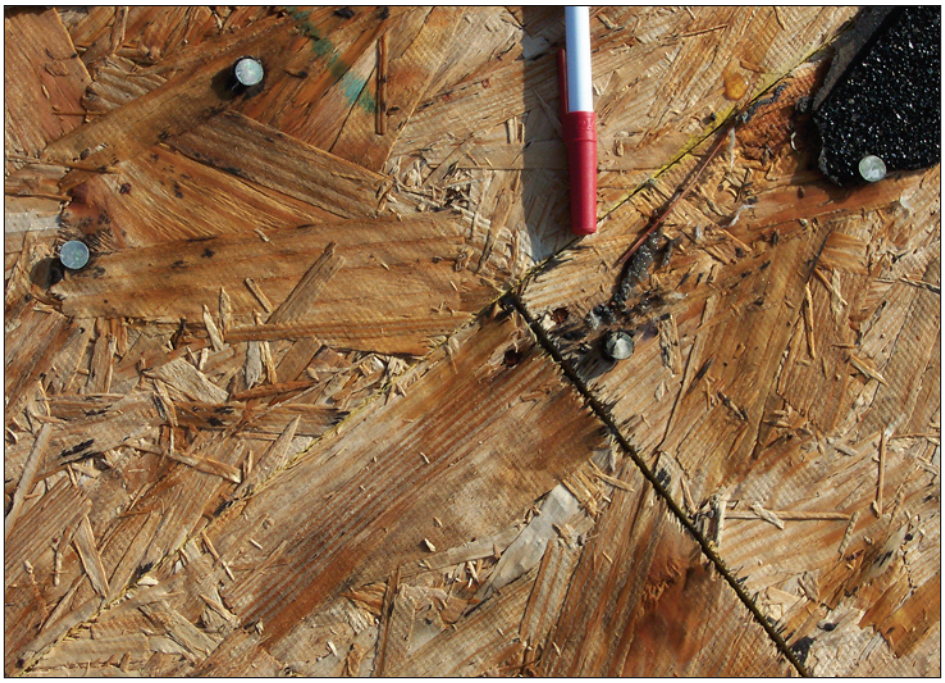


Figure 4-92.
Roof sheathing nailed only at corners, and stapled in other areas (estimated wind speed: 130 mph. Long Beach, Mississippi)



Figure 4-93.
Roof sheathing beneath the gable roof (that blew off) was tacked at corners with nails. No other fastening was used (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 4-94.
Roof sheathing attachment was inadequate. Several staples were missing, some staples missed framing, and inland the sheathing pulled over the staples (estimated wind speed: 130 mph. Long Beach, Mississippi).

Metal connectors were frequently left out, or were installed improperly. In a Long Beach apartment complex, connectors were used to anchor the main trusses to the bearing walls, but none were used on the gable trusses above the entrances and porches (see Figures 4-95 through 4-98). In those areas, the wide eaves and open breezeways were subjected to uplift forces on the trusses on several buildings in the complex. Connections failed and entire roof structures above the entrances and porches blew off of the buildings.

Gable end walls were often constructed with vinyl siding over rigid insulation sheathing, which is vulnerable to damage from wind and windborne debris. If the gable walls are penetrated, internal pressurization occurs and uplift forces on the trusses increase. Properly fastened plywood sheathing on the gable walls would have improved performance and may have prevented failure.

Figure 4-99 shows a similar apartment building whose gable end walls were OSB. The sheathing failed during Katrina. Resulting attic pressurization likely contributed to the loss of sheathing near the ridge. Vinyl siding was blown off, but the gable wall and the roof above remained intact.



Figure 4-95.
Metal connectors (arrow) were used on main trusses (estimated wind speed: 130 mph. inland Long Beach, Mississippi).



Figure 4-96.
Metal connectors were lacking on the gabled roofs over the porches and entrances. Several roof structures were blown off (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 4-97.
Another example of metal connectors lacking on the gabled roof that once existed over the entrance (estimated wind speed: 130 mph. inland Long Beach, Mississippi)



Figure 4-98.
Apartment building's gable walls sheathed with insulation failed during Katrina (estimated wind speed: 130 mph. inland Long Beach, Mississippi)



Figure 4-99. Apartment building with gable end walls that were constructed with OSB sheathing under housewrap (estimated wind speed: 120 mph. D'Iberville, Mississippi)

4.2.1.3 Manufactured Housing

While most of the damage to manufactured housing was from flooding, wind damage was noted in both older and newer manufactured homes. Figure 4-100 shows an older manufactured home in St. Bernard Parish, Louisiana, that was rolled over and destroyed by wind forces. The home's frame was once secured with metal straps spaced approximately 13 feet on center. No wall ties for improved resistance to uplift were visible (see Figure 4-101). The strapping and lack of wall/vertical ties does not meet HUD Zone II requirements for newer homes. Even though the home was older and likely not constructed to current wind standards, proper anchorage may have prevented the home from being destroyed.

Figures 4-102 and 4-103 show damage to newer manufactured homes. The home in Figure 4-102 lost a gable roof over its entrance, asphalt shingles, and metal fascia along its eaves. Wind speeds were insufficient to displace the home from its foundation. Temporary roof repairs completed prior to the MAT's visit prevented full assessment of the extent of roof damage.

The styles of manufactured home installations impacted performance during Hurricane Katrina. When properly anchored, manufactured home damage under wind loads was less significant. Unanchored or improperly anchored homes or homes with damaged anchors were prone to wind-related damage. The home in Figure 4-104 was installed with ground anchors. The heads of the ground anchors extended several inches above the ground (see Figure 4-105). The straps that connect the ground anchors to the frame were loose and would allow the home to move several inches before the ground anchors would begin to resist wind loads.



Figure 4-100.
Manufactured home rolled over by Hurricane Katrina's winds (estimated wind speed: 110 mph. Chalmette, Louisiana)



Figure 4-101.
The metal straps were spaced approximately 13 feet on center on a manufactured home located in Exposure C (estimated wind speed: 110 mph. Chalmette, Louisiana).



Figure 4-102.
Newer manufactured home located in Exposure C that lost the gable roof over its entrance (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana)



Figure 4-103. Newer manufactured home located in Exposure C with roof covering damage (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana)



Figure 4-104. Manufactured home located in Exposure C installed with ground anchors (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana)



Figure 4-105. Ground anchors at manufactured home located in Exposure C (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana)

Figure 4-106 shows an older manufactured home secured with straps that connect both the home's frame and its walls to the anchors set in the concrete slab. The older home was within 10 miles of the storm's path, but remained on its foundation piers and did not experience significant damage. Most of the straps were tight and there was no evidence of home movement.

4.2.1.4 Wood-Framed Non-Residential Buildings

Wood-framed commercial buildings failed similarly to wood-framed residential buildings. Roof structure uplift failures and gable wall end failures like the ones shown in Figures 4-107 through 4-109 were observed. In Figure 4-109, the bottom chords of the roof trusses appear to have buckled under uplift forces. Insufficient truss bracing is suspected.



Figure 4-106. Manufactured home located in Exposure C secured to taut anchors in the concrete slab (estimated wind speed: 110 mph. Plaquemines Parish, Louisiana)



Figure 4-107. Failure in a wood-framed commercial building. Trusses lost roof sheathing, allowing trusses to tip over (estimated wind speed: 120 mph. Ocean Springs, Mississippi).



Figure 4-108. Roof uplift failure in wood-framed commercial building (estimated wind speed: 115 mph. Slidell, Louisiana)



Figure 4-109. Three-story wood-framed commercial building lost roof sheathing and the exterior wall collapsed (estimated wind speed: 105 mph. New Orleans, Louisiana)

SOURCE: NIST

4.2.2 Engineered Buildings

Engineered buildings include buildings that are designed by registered architects and professional engineers. The amount of design professional involvement in engineered buildings can vary. In general, fully engineered buildings include schools, larger office buildings, hospitals, correctional institutions, and critical and essential facilities where great attention is given to compliance with building codes and standards. Fully engineered building types are typically designed with heavy structural elements such as concrete, steel, and masonry. In fully engineered buildings, design professionals are often involved with nearly all aspects of design and may be involved with construction to ensure that the designs are properly implemented.

Partially engineered buildings include those that receive limited engineering. Often, engineering involvement is limited to the minimum required by local building officials. Partially engineered (or sometimes called lightly engineered) buildings typically include fast food restaurants, strip malls, or large department stores.

While Katrina's winds caused widespread damage to engineered structures, most of the damage was to building envelopes. Structural damage was much less common.

4.2.2.1 Reinforced Concrete, Heavy Steel, and Masonry Buildings

Reinforced concrete is a favored method of construction for resistance to wind loads. In general, reinforced concrete and heavy steel buildings observed by the MAT performed well structurally. While the MAT noted little structural damage to most buildings constructed with reinforced concrete frames, extensive damage to unreinforced masonry buildings was observed. Most of the beach-front casino hotels were constructed of reinforced concrete and survived Katrina's winds, but were inundated with water and experienced envelope failures (see Figure 4-110). Though reinforced concrete buildings are normally quite expensive to construct, new methods have been developed to facilitate the ease of forming, reduce the sizes of members, and reduce the amount of labor required.

A flying form is a large reusable form for pouring multiple floors in high-rise buildings. The form is used on one floor and then "flown" into place on a higher level with an on-site crane.

Pre-stressing strengthens concrete by reducing potentially damaging tension stresses in concrete. Post-tensioning is a type of pre-stressing where tension is introduced after (or post) the concrete cures. Post-tensioning involves placing steel cables (tendons) in special ducts (or sheaths) before the concrete is placed. After the concrete is placed and cured, the tendons are tensioned to pre-stress and strengthen the concrete. The small dots at the ends of the floor slabs in Figure 4-111 are the ends of the pre-stressing tendons.

Probably the most successful concrete structures observed by the MAT were the buildings shown in Figures 4-110 through 4-112. At the building shown in Figure 4-111, reinforced concrete shear walls and post-tensioned concrete slabs constructed on "flying forms" were used on this luxury condominium complex. The folded concrete shell and circular plan of the Catholic church on Highway 90 in Biloxi (Figure 4-112), though subjected to storm surge, was resistant to Katrina's winds.

4.2.2.2 Unreinforced Masonry Buildings

Damage to unreinforced masonry buildings was typically initiated when wind forces exceeded the strength of connections between roof framing and bearing walls or exceeded the tensile strength of the top of the walls themselves. Overloading the connections allowed the roof structures to lift. Once the roof structures lifted, lateral support was lost for the top of the bearing walls, and the walls collapsed (see Figure 4-113). This mode of failure is often observed after wind events. Because the weight of many roof systems is less than the total uplift forces from wind, a structural failure takes place whenever the connections are not designed to resist the net uplift forces.

The MAT observed wind-related damage to many buildings with unreinforced masonry walls; however, the MAT did not concentrate their efforts in documenting collapsed unreinforced masonry walls because the failure mode is well understood, and improvements have been incorporated into the current codes. Therefore, only a few examples of these failures are included in this report.



Figure 4-110.
This casino located in Exposure C suffered water inundation and wind damage to wall finishes (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 4-111.
East tower located in Exposure C under construction with reinforced concrete and post-tensioned floor slabs. The east tower was water-inundated on the first floor and suffered only minor wind damage to the roof covering of the finished tower (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 4-112.
St. Michael's Catholic Church on Beach Boulevard (Highway 90), with its concrete shell roof and supporting concrete columns, was undamaged by Katrina's winds, but was severely damaged by the storm surge (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 4-113.
Wind-induced damage to older unreinforced masonry building located in Exposure C (estimated wind speed: 130 mph. Gulfport, Mississippi)

Other failure modes were observed in unreinforced masonry construction. In Figure 4-114, the parapet failed and visibly rotated toward the center of the building. The parapet portion of the wall acts as a cantilever above the roof structure. In this structure, the roof side of the parapet was exposed to the relatively high eave zone wind pressures and to bending moments. With no reinforcing steel present, the parapet failed in bending. Like other failures in unreinforced masonry, this type of failure is well known and is easily avoided with better construction measures.

The MAT investigated numerous heavy masonry buildings, most 30 years old or older. The Hancock County Courthouse in Bay St. Louis, Mississippi (see Figure 4-115) received wind damage to its roof and most of its windows. The Hancock Bank Building in Pass Christian, Mississippi (see Figure 4-116), an early 20th century building, successfully survived Katrina, but suffered water inundation and wind damage to glazing, and loss of one suspended

awning. The First Presbyterian Church of Gulfport, Mississippi (see Figures 4-117 and 4-118) was constructed of grouted multi-wythe brick masonry. Though the chapel lost its roof covering and decking, the heavy timber purlins and steel trusses remained firmly attached to the load-bearing masonry walls.



Figure 4-114. Unreinforced masonry parapet failure on a building located in Exposure C (estimated wind speed: 130 mph. Gulfport, Mississippi)



Figure 4-115. Hancock County Courthouse located in Exposure C with roof and windows damaged by wind and windborne debris (estimated wind speed: 125 mph. Bay St. Louis, Mississippi)



Figure 4-116. Heavy masonry Hancock Bank Building located in Exposure C on Highway 49. Note the location of a missing awning (circle) and damaged windows (arrows) (estimated wind speed: 130 mph. Pass Christian, Mississippi).



Figure 4-117. Gulfport First Presbyterian Church with wind damaged roofs. Note the wind damaged roof covering (circle) and the missing roof decking (arrow) (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 4-118. Grouted multi-wythe masonry walls. Note loss of roof decking (estimated wind speed: 130 mph. Gulfport, Mississippi).

4.2.3 Pre-Engineered Metal Buildings

PEMBs are normally used for purposes such as warehouses, storage facilities, airplane hangars, and other similar open interior uses. Due to their relatively low cost and relatively short construction time, PEMBs are being used for other facilities like schools, retail, and low-rise commercial buildings. These buildings are easily recognized by their metal walls and roof coverings, tapered rigid frames, and long spans with open spaces. Secondary structural members consisting of girts and purlins are installed to support the metal siding and roofing panels.

Some components in PEMBs must perform more than one function (e.g., roof panels in PEMBs must function both as the roof deck and as the roof covering); in other styles of construction, two separate systems function as the roof deck and roof covering. This dual function reduces redundancy in a building and can increase its vulnerability to damage from wind, windborne debris, and water entry.

Like previous post wind event assessments, the MAT observed failures in several older buildings and PEMBs were no exception. Older PEMBs are generally those constructed before the mid-1980s when less attention was given to wind forces and less was known about wind effects on buildings. Although many older PEMBs were heavily damaged, newer ones performed much better.

Figures 4-119 through 4-121 show the relative performance of newer versus older PEMBs. In Figure 4-119, the PEMB on the left (built in 2001), was not damaged significantly by wind, but it was flooded; the building on the right (estimated to be 30 years old) lost its roof panels and was significantly damaged.



Figure 4-119.
Relative performance of older and newer PEMBs located in Exposure C. The 5-year old building on the left was not damaged by winds; the 30-year old building (estimated) on the right lost its roof (estimated wind speed: 130 mph. Pass Christian, Mississippi).



Figure 4-120.
Undamaged newer PEMB constructed in 2001 (estimated wind speed: 130 mph. Pass Christian, Mississippi)



Figure 4-121
Severely damaged PEMB estimated to be 30 years old (estimated wind speed: 130 mph. Pass Christian, Mississippi)

Most failures either involved connections between the metal roof panels and their supporting purlins, or between the purlins and the steel moment frames, as shown in Figures 4-122 through 4-125. Connection failures between the base of the moment frames and supporting footings were observed, but were much less common than connection failures higher up in the structure (Figure 4-124).

Though not a commercial-use structure, the airplane hangar with a second floor residence was constructed of a light steel pre-engineered frame (see Figure 4-126). This home/hangar, along with others in the Diamondhead, Mississippi, fly-in residential community, was devastated by wind and water.



Figure 4-122. Failure of older (1974) pre-engineered metal building (estimated wind speed: 130 mph. Gulfport, Mississippi)



Figure 4-123. Connection failures between roof panels and purlins and between purlins and rigid frames (estimated wind speed: 130 mph. Gulfport, Mississippi)



Figure 4-124.
Anchor bolt connection failure between steel base plate of the pre-engineered metal building frame and foundation (estimated wind speed: 130 mph. Gulfport, Mississippi)



Figure 4-125.
Wall and roof covering failure in pre-engineered metal building. Moment frames not visibly damaged (estimated wind speed: 125 mph. Stennis Airport, Hancock County, Mississippi).

SOURCE: NIST



Figure 4-126.
Residence/hangar constructed of a light-steel pre-engineered frame (estimated wind speed: 120 mph. Diamondhead, Mississippi)

5. Building Envelope Performance

Although Hurricane Katrina's winds were not nearly as powerful as those of other catastrophic hurricanes that have struck the Gulf Coast (such as Hurricane Camille [1969] or Hurricane Charley [2004]), the storm's winds caused widespread damage to building envelopes and rooftop equipment.

The MAT observed building envelope damage as far west as the New Orleans area and as far east as Mobile (see Figure 5-1) and Dauphin Island, Alabama (a west-to-east distance of approximately 140 miles). The MAT also observed building envelope damage as far inland as Poplarville, Mississippi (approximately 40 miles from the Gulf); however, building envelope damage was also reported at least as far inland as Hattiesburg, Mississippi. Although the building envelope damage was less severe than that caused by flooding, the wind-induced envelope damage was significant.

Sections 5.1 through 5.6 describe building envelope performance (e.g., sheathing on the underside of elevated buildings; doors; non-load-bearing walls, and wall coverings and soffits; roof systems; windows, shutters, and skylights; and exterior-mounted mechanical, electrical, and

communications equipment) during Hurricane Katrina as observed for residential, commercial, and critical and essential facilities. (Note: see Chapters 3 and 7 for additional photos of damaged building envelopes and rooftop equipment.)



Figure 5-1. Blow-off of a modified bitumen roof membrane at a service station. Note: The cantilevered canopy over the pumps was flipped upside down (estimated wind speed: 85 mph. Mobile, Alabama[1]).

In addition to the costs associated with repairing building envelope and rooftop equipment damage, even greater costs are typically incurred due to wind and/or water damage to interiors and contents once a building envelope is breached (see Figure 5-2). Because of Katrina's widespread devastation, emergency repairs were not made to large numbers of damaged buildings for many weeks, or even months, after the storm. Thus, during subsequent rains, further wetting of interiors occurred. (Note: At the time the school shown in Figure 5-2 was investigated [about 4 weeks after the hurricane], the damaged roof had not been repaired.) When breached envelopes remain open for several weeks, even small breaches can allow a significant amount of water to leak into buildings and allow mold to develop.

Blow-off of building envelope components and rooftop equipment also frequently results in damage to adjacent buildings and vehicles, as well as the building itself. Common windborne building envelope debris during Hurricane Katrina included roof coverings (particularly aggregate surfacings and asphalt shingles) and vinyl siding. Figure 5-3 illustrates the magnitude of building envelope debris that occurred in some areas.

In addition to the costs associated with repairing damaged building envelopes and subsequent water infiltration damage, when families, businesses, and critical and essential facilities are forced to vacate damaged buildings, the costs associated with the interruption and temporary relocation often exceed the direct costs of repairing the damaged buildings and their contents. Thus, while good structural system performance is critical to avoiding injury to occupants and minimizing damage to a building and its contents, good structural system performance does not ensure occupant or building protection. Good performance of the building envelope is also critical.

[1] Estimated speeds given in this chapter are based on Figure 1-13. These are for a 3-second gust at a 10-meter elevation for Exposure C. Unless otherwise noted, the buildings for which estimated speeds are given are located in Exposure B. See Table 1-4 for the estimated speed conversion for buildings located in Exposure B. For example, the 85-mph Exposure C speed given for Figure 5-1 is equivalent to 70 mph in Exposure B.



Figure 5-2.
After the roof membrane blew off this school, water saturated the fiberglass insulation and ceiling boards, and several of the ceiling boards collapsed (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 5-3.
A substantial amount of siding (the white lines scattered around the ground) blew off this housing complex (estimated wind speed: 105 mph. Harvey, Louisiana area).

The most notable building envelope issues pertaining to Hurricane Katrina were the widespread poor performance of asphalt shingles, vinyl siding, and exterior insulation and finish systems (EIFS) on several mid- and high-rise buildings. Rooftop equipment anchorage and glazing breakage by aggregate from roof surfaces was also prevalent.

Considering that the estimated actual wind speeds were typically less than the design speeds given in ASCE 7, had the buildings been designed and constructed in accordance with a current model building code such as the International Building Code (IBC), the extent and magnitude of the envelope damage would have been reduced. However, many wind-related issues associated with building envelopes are not addressed or are inadequately addressed in current model codes. Therefore, in order to minimize building envelope damage, in addition to complying with codes, designers and contractors need to voluntarily incorporate a variety of best practices, as discussed in this chapter and in Chapter 11.

5.1 Sheathing on the Underside of Elevated Buildings

Sheathing is typically installed on the underside of lowest-floor joists on elevated buildings. Besides protecting batt insulation that is placed between joists, sheathing can also protect electrical and plumbing lines from floodborne debris. A variety of sheathing materials are used, with vinyl siding and plywood the most common. Because storm surge destroyed most of the buildings along the coast, there were few observations of sheathing on the underside of buildings. Figure 5-4 is an example of one of the vinyl-sheathed buildings observed. Houses with corrugated metal panel and fiber-cement panel sheathings were also observed. The house with the fiber-cement panels was located in Saint Bernard Parish, Louisiana. All of the 1/8-inch-thick 4x8-foot panels were blown off. They had been attached with nails spaced at 7-1/2 to 8 inches on center along the panel edges and ends. Nails were also spaced at 15-1/2 to 16 inches on center along two intermediate rows parallel to the edges.



Figure 5-4. Loss of vinyl siding from the underside of an elevated residence in Exposure C. Note the large floodborne pole debris near the steel cable "x" brace (estimated wind speed: 130 mph. St. Bernard Parish, Louisiana).

Fast-moving floodwater and breaking waves can cause sheathing loss and floodborne debris can cause gouging. However, the loss of the fiber-cement sheathing appeared to be caused by wind accelerating as it passed beneath the elevated building. Neither ASCE 7, IBC, or IRC provide guidance for determining design wind loads for sheathing on the underside of elevated buildings. Therefore, professional judgment in specifying attachment is needed.

For further information on the performance of sheathing on the underside of elevated buildings, see FEMA 489, *Mitigation Assessment Team Report, Hurricane Ivan in Alabama and Florida.*

5.2 Doors

Failure of an exterior door has two important consequences. First, failure can cause a rapid increase in internal pressure, which may lead to exterior wall, roof, interior partition, ceiling, or structural failure. Second, wind can drive rainwater through the opening, causing damage to interior contents and finishes, and leading to the development of mold. The essential elements of good high-wind door performance include product testing to ensure sufficient factored strength to resist design wind loads (both static and cyclic loading); suitable anchoring of the door frame to the building; proper flashing, sealants, tracks, and drainage to minimize water intrusion into wall cavities or into occupied space; and, for glazed openings, the use of laminated glass or shutters to protect against windborne debris damage, as discussed in Section 5.5.2.

5.2.1 Personnel Door Damage

Personnel door damage was observed on a limited number of buildings. Observed damage included door frames that detached from the building (likely caused by inadequate fastening to the building) and doors that blew from their hinges (likely caused by use of inadequately sized screws) as illustrated by Figure 5-5. One door on a new residence under construction blew off when the hinges detached from the frame. The door/frame was a pre-hung assembly that used very short screws to attach the hinges to the frame (otherwise, the screws would have projected from the frame and been a potential safety hazard during installation). After the frame was installed in accordance with most manufacturers' instructions, the short screws should have been replaced with stronger permanent screws.

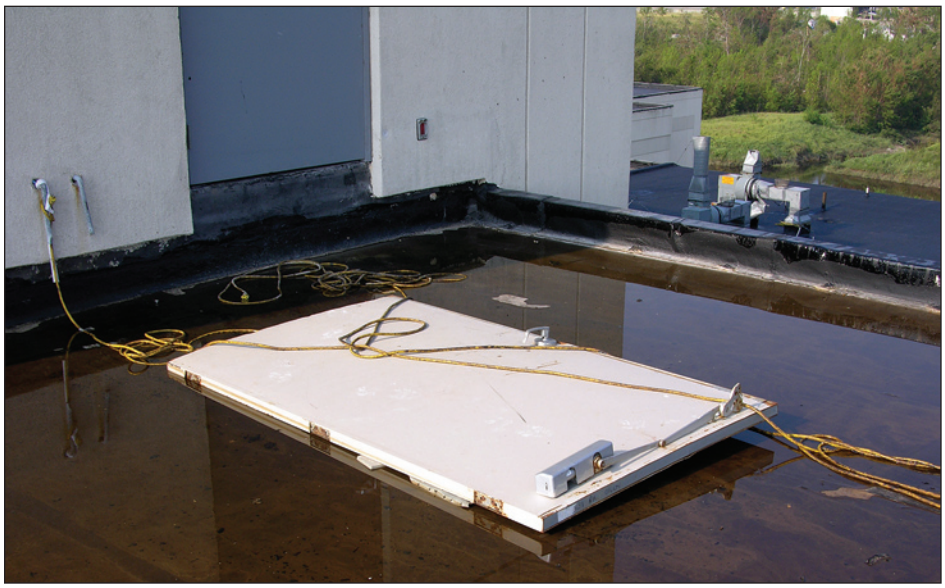


Figure 5-5.
A penthouse door on this hospital blew off its hinges. Blown-off doors allow entrance of rain, and tumbling doors can puncture roof membranes (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.2.2 Garage Door Damage

Several damaged residential garage doors were observed, some of which were damaged by floodwater, while others were damaged by wind. Figure 5-6 shows wind-induced damage at a house under construction. Damaged doors were typically displaced from their tracks, but in some

instances the track fasteners were pulled out. (Note: Where breakaway walls are installed, collapse of the garage doors is intended.) For further information on garage door performance, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida.*



Figure 5-6. Positive pressure blew this garage door from its tracks. At some other residences, negative pressure blew doors outward. Note the damage to the asphalt shingles (estimated wind speed: 110 mph. Belle Chase, Louisiana).

5.2.3 Rolling and Sectional Door Damage

Water- and wind-induced damage to rolling and sectional doors (e.g., service garage doors, loading dock doors, and fire station apparatus bay doors) was observed (see Figure 5-7). In some cases, the doors were dislodged from their tracks, while in others the tracks pulled away from the wall. At a fire station in Gulfport (constructed in 1977), all three windward (eastern) doors were blown in (see Figure 7-8). One of the doors pulled from its tracks, but at the other



Figure 5-7. Wind-induced damage to several roll-up doors (estimated wind speed: 130 mph. Gulfport, Mississippi)

two doors the tracks pulled from the wall. The tracks were fastened with 1/4-inch diameter lag screws spaced at 2 feet on center. The tracks were lag-screwed to 1x wood framing, which was inadequately nailed to the 6x columns.

5.3 Non-Load-Bearing Walls, Wall Coverings, and Soffits

Hurricane Katrina caused damage to a large number of non-load-bearing walls, wall coverings, and soffits. Non-load-bearing walls included brick veneer/concrete masonry unit (CMU) cavity walls, EIFS, and panelized wall systems. Wall coverings included brick veneer, fiber-cement siding, metal panels, stone veneer, vinyl, and wood. Vinyl was typically used for soffits; however, several metal panel soffits were also observed. The following factors are essential to good, high-wind performance of non-load-bearing walls, wall coverings, and soffits: product testing to ensure sufficient factored strength to resist design wind loads; suitable anchoring of the wall, wall coverings, and soffits to the building; use of moisture barriers (e.g., asphalt-saturated felt or housewrap) where appropriate; and proper flashing, sealants, and drainage to minimize water intrusion into wall cavities or into occupied space.

5.3.1 Non-Load-Bearing Walls

Non-load-bearing walls that were investigated included brick cavity walls, brick veneer/CMU cavity walls, EIFS over studs, and panelized wall systems. Pre-cast concrete wall panels were also observed and none were damaged by wind. A large number of EIFS failures were observed, including failures as far east as Moss Point, Mississippi. With loss of the EIFS (and other types of coverings), wind-driven rain was often able to enter the wall cavity or the building itself and initiate mold growth. EIFS (and other types of coverings) that became windborne debris were capable of breaking unprotected windows. Figure 5-8 shows typical EIFS assemblies.

5.3.1.1 Exterior Insulation and Finish Systems

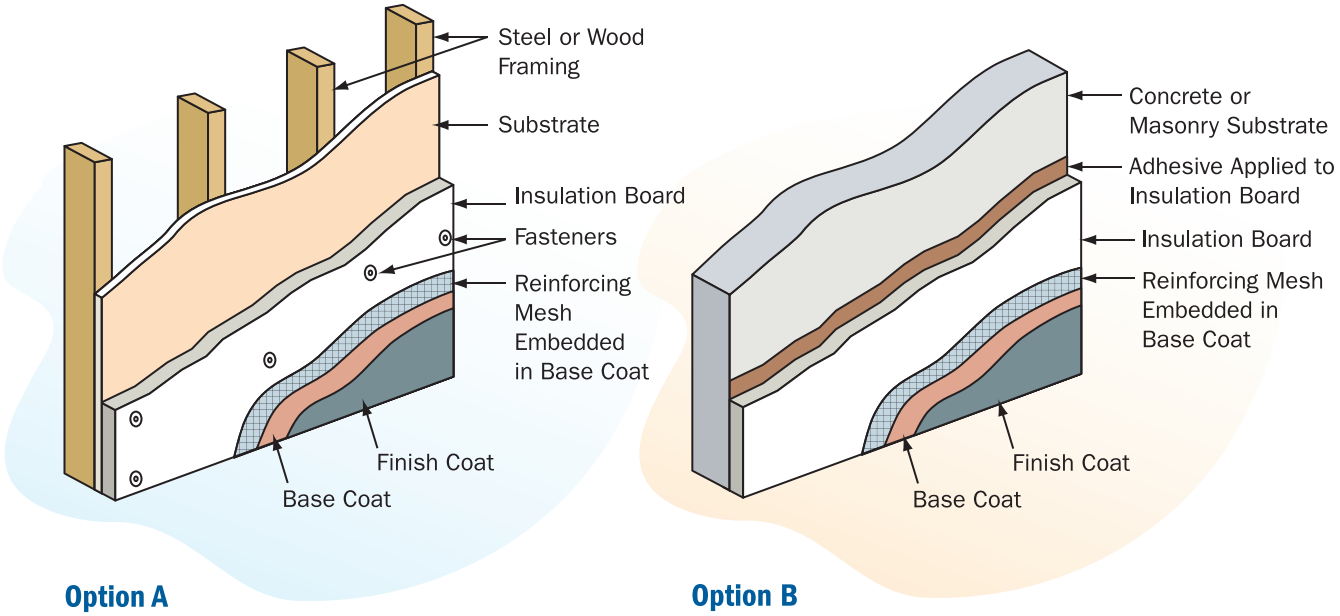
Hurricane Katrina produced large areas of EIFS failure on many low-rise and multi-story buildings (see Figure 5-9). In addition to puncture by windborne debris, common planes of failure of EIFS assemblies included (typically as a secondary failure plane) separation of the synthetic stucco from the insulation and (as primary failure planes) detachment of the insulation from the gypsum board substrate, detachment of the gypsum board from the studs, and failure of the studs. When the insulation detaches from the gypsum board, the gypsum board can suffer strength reduction due to wetting from the wind-driven rain, and it too often will then blow off during a hurricane.

Figure 5-10 shows loss of EIFS on a penthouse on a new 13-story building (there was also extensive loss at the main walls). The gypsum board detached from the 8-inch-deep steel studs spaced 16 inches on center. The gypsum board was attached with screws that were irregularly spaced. Along one stud near the corner, the screws were spaced at 8, 25-1/2, and 12-1/2 inches. Along another stud in the corner region, the screws were spaced at 14, 12, and 21-1/2 inches. Away from the corner region, the screws along one stud were spaced at 12, 10-1/2, 12-1/2, and

10-1/4 inches. Along another nearby stud, the screws were spaced at 10, 12, 8-1/4, 4-3/4, and 11 inches. Surprisingly, the screws were typically spaced farther apart in the corner region (where the wind loads are the highest). Away from the corners, the screws should have been spaced in the range of a maximum of 6 inches on center. In the corner areas, the screws should have been spaced in the range of a maximum of 4 inches on center and the studs should have been at a maximum of 12 inches on center. Because contract documents were not available, it is unknown whether the spacing deficiencies were due to design or workmanship errors.

Along another wall of the penthouse in an area outside of the corner region, the screws along the end of a gypsum board panel were spaced at 5, 9-1/2, 6, 6, 4, and 4-1/2 inches. Along the next stud, the intermediate row was spaced at 21-1/2, 10, and 13 inches. As shown in Figure 5-11, in one area the molded expanded polystyrene (MEPS) insulation detached from the gypsum board. The MEPS had been adhered with vertical lines of adhesive. Adhesive should have been continuously applied throughout the entire board area.

Figure 5-12 shows a building that had been re-skinned with EIFS (new metal framing had been installed over the original walls). In some areas, the gypsum board blew off the new metal framing, but in other areas the metal framing was blown away because it was inadequately attached to the building.



Option A

Steel or Wood Framing
EIFS may be attached by mechanical fasteners (as shown) or by adhesive (as shown right)

Option B

Concrete or Masonry
EIFS attached to concrete or masonry using adhesive. Mechanical fasteners may also be used.

Figure 5-8. Typical EIFS assemblies



Figure 5-9.
Multi-story building in Exposure C, showing severe EIFS damage. The gypsum board typically detached from the studs. In some areas, the gypsum board on the interior side of the studs was also blown away (estimated wind speed: 120 mph. Biloxi, Mississippi).

SOURCE: NIST



Figure 5-10.
Loss of EIFS on penthouse of a new 13-story building in Exposure C. The gypsum board was attached with irregularly spaced screws and detached from the steel studs (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 5-11.
The MEPS had been set in rows of adhesive rather than in a continuous layer of adhesive. Note the inadequate edge distance of the fasteners along the end joint. The building was located in Exposure C (estimated wind speed: 120 mph. Biloxi, Mississippi).

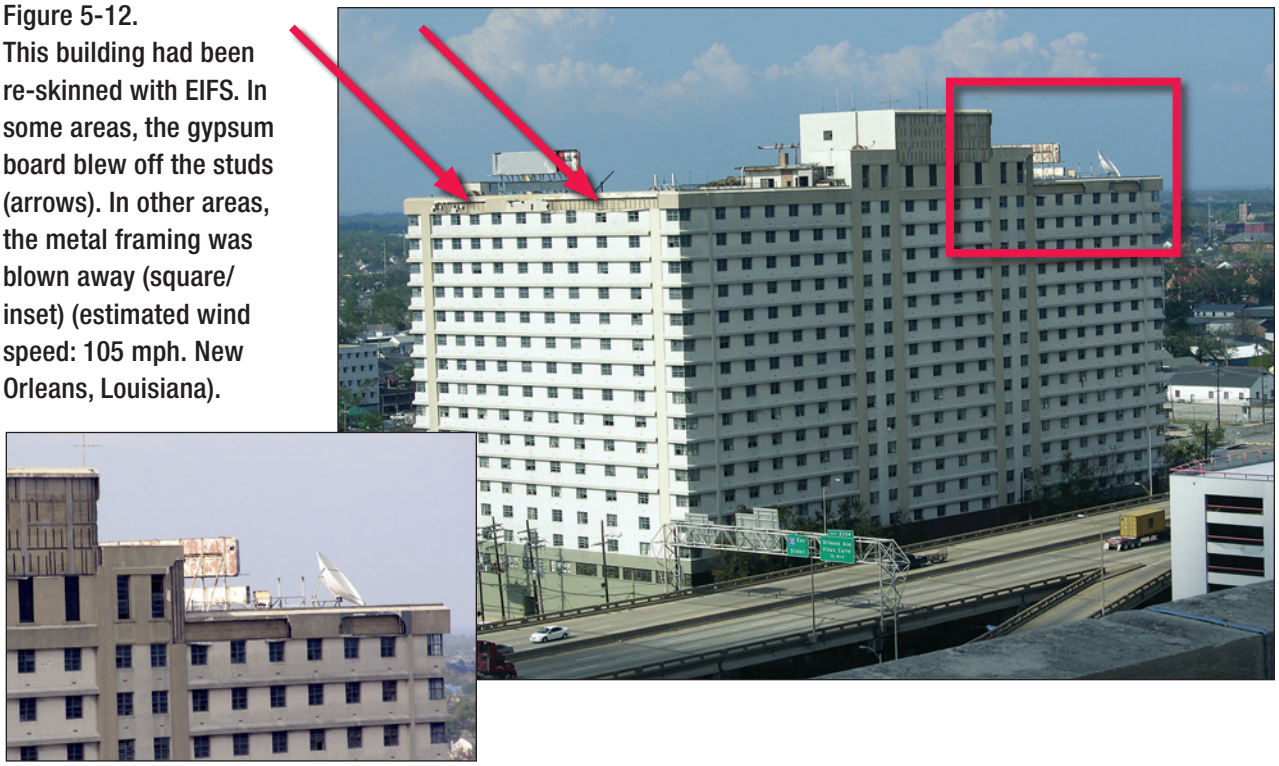


Figure 5-12.
This building had been re-skinned with EIFS. In some areas, the gypsum board blew off the studs (arrows). In other areas, the metal framing was blown away (square/inset) (estimated wind speed: 105 mph. New Orleans, Louisiana).

For many buildings, the ramification of damage to EIFS assemblies was significant. With several of these failures, the cost of repairing the EIFS was minor in comparison to the cost of damage to other building components; the cost of rainwater damage and mold remediation to building interiors, furnishings, and equipment; and the cost due to loss of use of the building while repairs

were made. EIFS installed over studs is susceptible to disproportional failure, wherein a relatively minor deficiency (such as an inadequate number of screws to attach gypsum board) results in loss of the exterior wall, as shown in Figure 5-9. Typical EIFS assemblies (i.e., studs, gypsum board, insulation, and synthetic stucco) lack redundancy to protect the building from extensive wind and rainwater infiltration when wind initiates failure somewhere within the assembly.

The EIFS damage was primarily related to application and/or design deficiencies. Lack of design guides likely contributed to the design problems. The test method used to determine wind resistance of EIFS assemblies may have also contributed to some of the damage. These issues are discussed below:

- **Application:** In all cases that were investigated where adhered insulation boards separated from the gypsum board, there was a significant lack of adhesive. EIFS manufacturers currently specify that the entire surface of the insulation boards is to be covered with adhesive applied with a notched trowel.

  In all cases that were investigated where gypsum board was mechanically attached, the fasteners were spaced too far apart. Because contract documents were not available, it is unknown whether the spacing deficiencies were due to design or workmanship errors.

- **Testing:** The EIFS industry uses American Society for Testing and Materials (ASTM) E330 to evaluate the wind resistance of EIFS assemblies. Load is applied to the specimen for 10 seconds before being released. The load is then increased and applied for another 10 seconds, and then released. This process is repeated until failure occurs. While none of the investigated failures were specifically attributed to deficiencies in the test method, the test method's load duration of only 10 seconds appears to be inadequate. ASTM E1592 (a test for metal roof and siding panels) specifies that each load increment be maintained for a minimum of 60 seconds and until the gauges indicate no further increase in deflection. The load duration and deflection criteria in E1592 appear prudent for EIFS.

- **Design guides:** The EIFS Industry Members Association (EIMA) has a *Guide to EIFS Construction*, but the guide doesn't discuss wind-related issues. Manufacturers of EIFS materials have specifications, but they are typically lacking in wind-related criteria. For example, to determine fastener spacing for gypsum board (which is a critical element in the load path), designers are referred to gypsum sheathing manufacturers. Also, ultimate load values based on ASTM E330 typically are given, but guidance on the magnitude of the safety factor is often not given to the specifier.

- **Codes:** The IBC does not have specific wind-related criteria pertaining to EIFS. However, the International Code Council's (ICC's) Evaluation Service does have the AC24 *Interim Criteria for Exterior Insulation and Finish System* for evaluating EIFS. AC24 uses ASTM E330 for the wind resistance evaluation. AC24 requires at least six load increments with a 10-second load duration for each increment. AC24 also requires a minimum safety factor of 3. (Note: The Standard Building Code Congress International's Evaluation Service previously used a safety factor of 2. Therefore, systems designed in accordance with those criteria would be much weaker than systems designed in accordance with the ICC criteria.)

5.3.1.2 Panelized Wall Systems

Figure 5-13 shows collapsed wall panels. The tracks at the top of the panels were inadequately anchored to the concrete floor slabs. Figure 5-14 shows collapse of non-load-bearing walls at a hotel. These types of failures can be avoided by designing and constructing the wall panels and their connections to the structure to resist the design wind loads.



Figure 5-13. Collapse of panelized wall system (estimated wind speed: 115 mph. Slidell, Louisiana)



Figure 5-14. Collapse of non-load-bearing walls at a hotel (estimated wind speed: 105 mph. New Orleans, Louisiana)

5.3.2 Wall Coverings and Soffits

This section covers wall coverings, which include brick veneer, fiber-cement siding, metal panels, stone veneer, and vinyl siding (and soffits). Soffits included vinyl, aluminum, and lay-in panels in a suspended grid. In some instances, with loss of the coverings/soffits, wind-driven rain was able to enter the wall/attic cavity and initiate mold growth. Some of the blown-off coverings/soffits became windborne debris that was capable of breaking unprotected glazing.

5.3.2.1 Brick

Several buildings with failed brick veneer were observed. The majority of the failed brick veneers were applied over wood stud framing; however, some of the failed veneers were applied over CMU (in some instances, the CMU also failed). Figure 5-15 shows failed brick at a house that was under construction. The ties were typically spaced at 16 inches on center horizontally. Vertical spacing varied. The first row was 19 and 21 inches above the footer. The second row was 22 and 24 inches above the first row, and the third row was 18 inches above the second row. Some of the smooth-shank tie nails pulled from the studs. Many of the ties had never been embedded into the mortar joints, which was a major workmanship error.



Figure 5-15. Collapsed brick veneer wall that was under construction. Several of the ties had not been embedded into the mortar joints (square/inset) (estimated wind speed: 125 mph. Waveland, Mississippi).

The Brick Industry Association's (BIA's) *Technical Notes 28 (2002) – Anchored Brick Veneer, Wood Frame Construction* specifies a maximum tie spacing of 24 inches in each direction. The ties at the house described previously complied with the spacing specified in *Technical Notes 28*. For this house, the 2005 edition of *Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/ TMS 402*, specifies a maximum vertical and horizontal tie spacing of 16 inches (based on a basic wind speed of 130 mph). Therefore, the ties at this house complied with the ACI 530 specification for horizontal spacing, but did not comply with the vertical spacing requirement.

At a house under construction in Ocean Springs, Mississippi, brick had not been installed, but the corrugated ties had been placed. At a narrow strip of wall between a door and window, the ties were spaced 16 inches apart along one row. A tie along the first row was up 22 inches from the footer. The next row was up 41-1/4 and 42-1/4 inches from the footer. Along another wall, the first row was up 35 inches from the footer. The first tie along this row was 34 inches from the corner. A tie along the second row was up 54 inches from the footer. Ties along this row were 30 and 37 inches apart. The first tie was about 14 inches from the corner. A tie along the third row was up 78 inches from the footer and another was up 80-1/4 inches. These ties were 32 and 31 inches apart. The first tie was about 2 inches from the corner. Figure 5-16 illustrates the layout of ties at this wall.

The ties at this house did not comply with the vertical or horizontal spacing specified in *Technical Notes 28*. This house is located in an area with a basic wind speed of 140 mph; ACI 530-02 does not provide prescriptive tie spacings for this speed. The FEMA Hurricane Katrina Recovery Advisory *Attachment of Brick Veneer in High-Wind Regions* (Appendix E) recommends a maximum horizontal tie spacing of 16 inches and a maximum vertical spacing of 13.7 inches for a 140-mph design wind speed. Figure 5-16 also illustrates location of ties as recommended in the advisory.

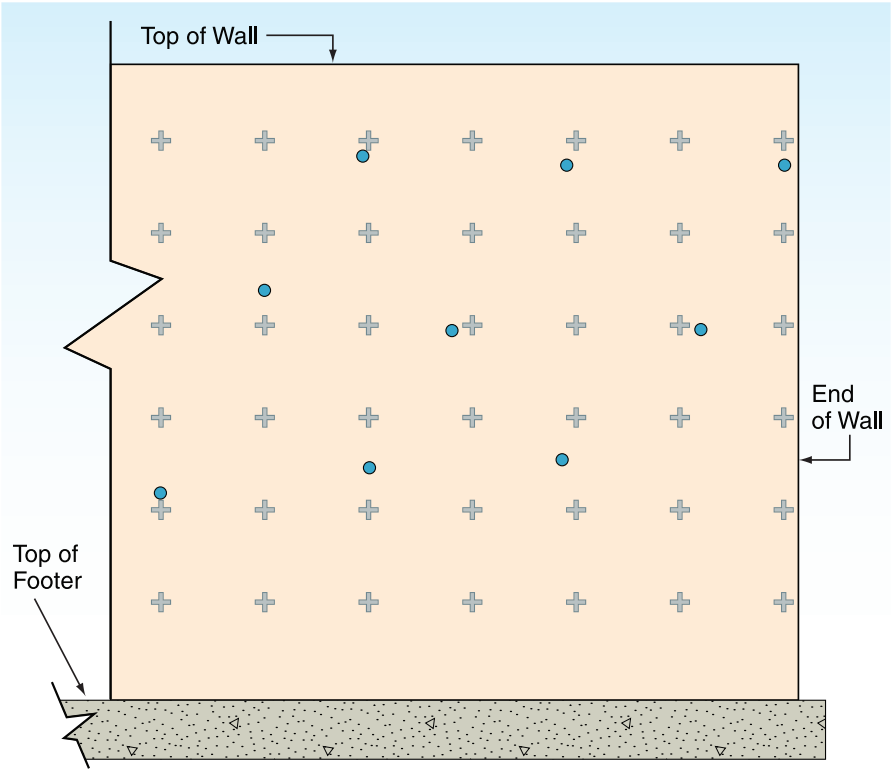


Figure 5-16.
Brick ties at house under construction in Ocean Springs, Mississippi. At this wall, nine ties were installed (blue circles); however, 42 ties ("+" symbol) are needed to comply with the advisory.

Most of the failed brick veneers that were investigated failed because of inadequate tying between the brick and studs. Inadequacies included excessive vertical and/or horizontal spacing of ties, inadequate pull-out resistance of tie nails (all nails observed were smooth-shank, with a length of either 1-3/8 or 1-3/4 inches), failure to embed ties into the mortar joints, and poor bonding between ties and mortar. However, some of the failures were due to tie corrosion as shown in Figures 5-17 and 5-18. The apartment building shown in Figure 5-17 was occupied at the time of the investigation. The area in the vicinity of the partially collapsed walls had not been barricaded, leaving pedestrians and vehicular traffic susceptible to injury if further collapsing occurred.



Figure 5-17. Partial collapse of brick veneer at an apartment building; the ties were corroded (inset) (estimated wind speed: 115 mph. Slidell, Louisiana).

At the old church shown in Figure 5-18, the ties between the roof framing and brick wall, and the continuous wire truss type horizontal joint reinforcement between the two wythes were severely corroded.

FEMA Hurricane Katrina Recovery Advisory *Attachment of Brick Veneer in High-Wind Regions* (Appendix E) provides recommended practices for brick veneer attachment. This advisory was based on observations from Hurricanes Ivan and Katrina.



Figure 5-18.
The ties and wire truss type horizontal joint reinforcement in this double-wythe cavity wall were severely corroded (inset) (estimated wind speed: 105 mph. Pascagoula, Mississippi).

5.3.2.2 Fiber-Cement Siding

Only a very small number of buildings with fiber-cement siding were observed. Figure 5-19 shows a newly constructed house that experienced wind-induced loss of fiber-cement siding. Along one of the 6-1/4-inch-wide siding panels, the concealed nails were located 1 inch from the end of the panel, then 12, 14, and 12 inches. One of the nails was 5/8 inch from the top of the panel and another was 3/4 inch. At a house in Saint Bernard Parish, Louisiana, along one of the 7-1/4-inch-wide siding panels, the concealed nails were spaced at 8 inches on center and were located 7/8 inch from the top of the panel. At both of these buildings, the siding pulled over the nail heads. The manufacturer recommends that, when using the concealed nailing method, the nails be placed at studs spaced at a maximum of 24 inches on center and that the nails be located 1 inch from the top of the panel.

5.3.2.3 Metal Wall Panels

The MAT observed a limited number of metal wall panel failures. A massive failure occurred at the penthouse on a 15-story office building (Figure 5-20). With loss of the wall panels, the elevators were no longer operational due to wind-driven rainwater damage to the elevator controls.

A few high-rise buildings in New Orleans also lost metal panels from equipment screen walls (see Figure 5-21). Blown-off panels from tall buildings can damage other buildings and vehicles, and cause injury. The panels at one of these buildings were composite panels (i.e., inner and outer metal skins with a plastic foam insulation core).



Figure 5-19.
Blow-off of fiber-cement siding. Note the broken window at the right (arrow) (estimated wind speed: 125 mph. Bay St. Louis, Mississippi).



Figure 5-20.
The metal wall panels blew off the penthouse on this 15-story building. Rainwater infiltration damaged the elevator controls (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 5-21.
Loss of metal panels from equipment screen walls (arrow). Note the broken window (circle) (estimated wind speed: 105 mph. New Orleans, Louisiana).

Figure 5-22 shows panels at a police station that unlatched and were blown away. The panels were attached with concealed staples to 1x wood nailers.



Figure 5-22.
Loss of metal panels at a police station. In addition to generating windborne debris, loss of panels allowed rainwater infiltration (estimated wind speed: 130 mph. Long Beach, Mississippi).

Another wall panel failure was observed at a university building (Figure 5-23). New metal panels had been installed over older metal panels. The newer panels were attached with concealed clips installed over the older panels. The clips were placed at horizontal girts that were far apart. At a corner area both the newer and older panels blew off; the blow-off may have initiated with failure of the older panels, or the failure of the older panels may have been a secondary failure.



Figure 5-23. The white metal panels had been installed over a previous metal panel system. Most of the underlying original panels (red arrow) remained in place, but many of the newer panels (yellow arrow) blew off due to inadequate attachment (green double-arrow shows the area that is missing the newer overlying panels). Note that the girts (red double-arrow) were very far apart (estimated wind speed: 125 mph. Waveland, Mississippi).

5.3.2.4 Stone Veneer

Several mid- and high-rise buildings in New Orleans were sheathed with stone veneer. No buildings were observed to have experienced widespread loss of stone veneer; however, a small number of buildings lost a few panels, as shown in Figure 5-24. Blown-off panels can damage buildings and vehicles, and can cause injury.

The tallest building in New Orleans (670 feet to the main roof level) lost several stone panels at the penthouse (see Figure 5-25). The blown-off panels severely punctured the roof membrane. Some of the penthouse panels had loosened a few years earlier and corrective action was planned, but had not been implemented prior to Hurricane Katrina.

5.3.2.5 Vinyl Siding

Vinyl was the predominant siding and soffit material observed on residences in the areas investigated by the MAT. Performance of the siding and soffit was extremely poor (see Figure 5-26) and there were numerous significant failures on both new and old buildings. When vinyl siding was blown off, the underlayment (either asphalt-saturated felt or housewrap) was also often blown away. With loss of the siding and underlayment, wind-driven rainwater was then able to enter the wall cavity, causing water damage and initiating mold growth. Vinyl siding and soffits that became windborne debris were capable of breaking unprotected glazing.

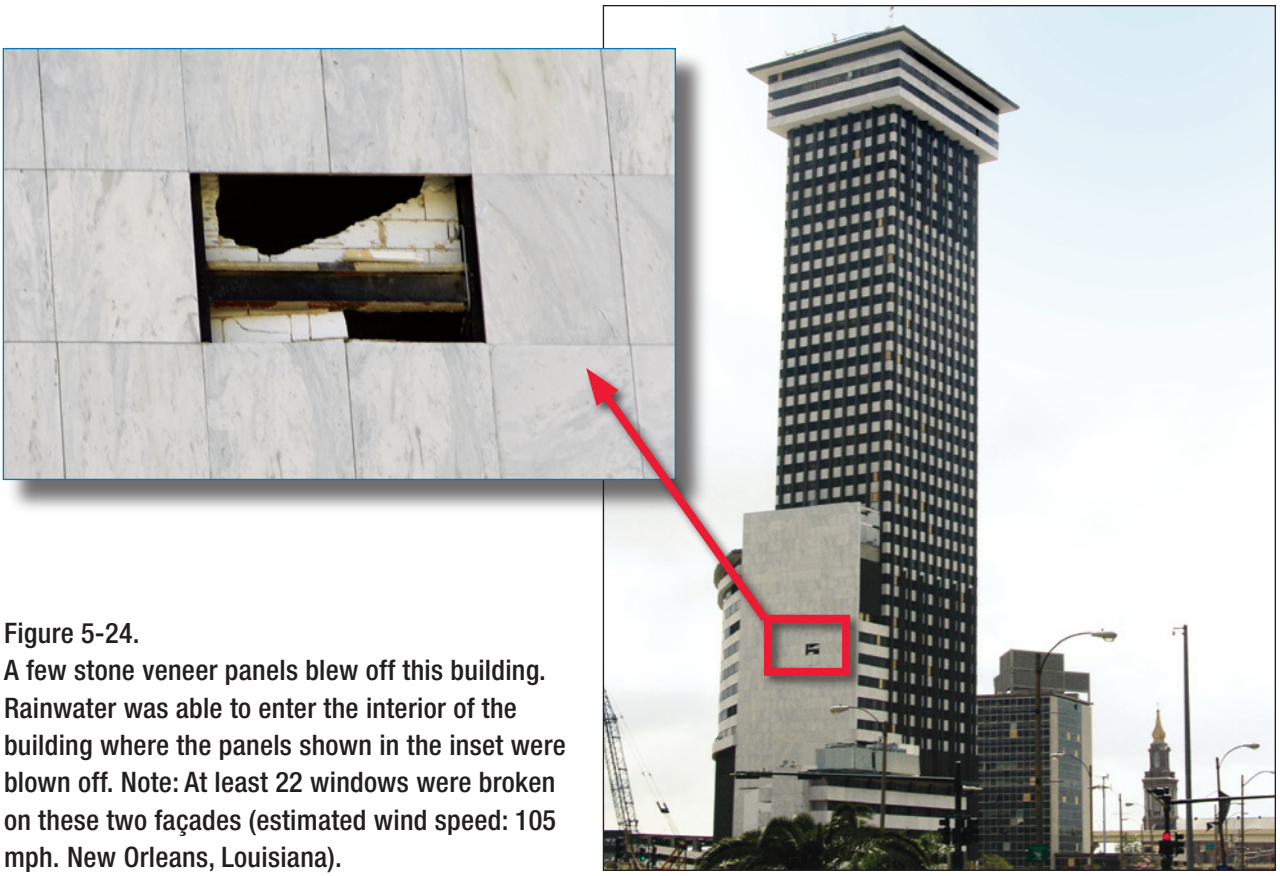


Figure 5-24.
A few stone veneer panels blew off this building. Rainwater was able to enter the interior of the building where the panels shown in the inset were blown off. Note: At least 22 windows were broken on these two façades (estimated wind speed: 105 mph. New Orleans, Louisiana).

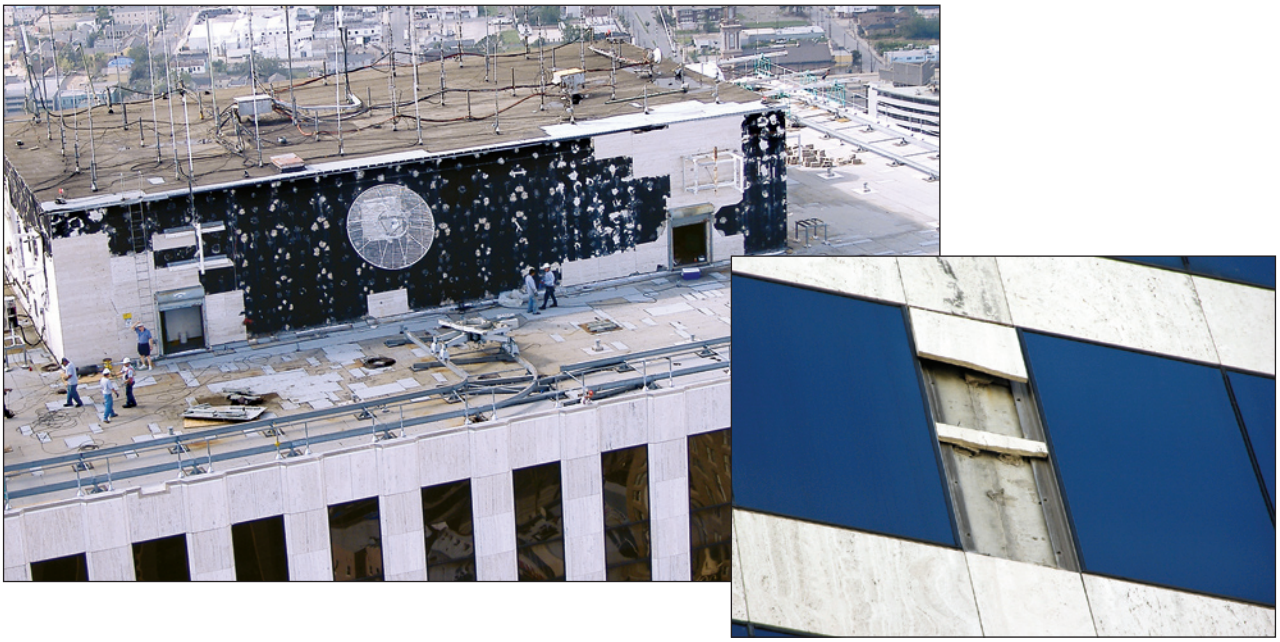


Figure 5-25.
Several stone veneer panels blew off the penthouse and caused significant puncturing damage to the modified bitumen membrane roof. A few panels were also blown off the main walls (inset) (estimated wind speed: 105 mph. New Orleans, Louisiana).

Many of the windows in the apartment complex shown in Figure 5-26 were broken (see Figure 5-27), which is not surprising considering the large amount of vinyl siding, vinyl soffit, and asphalt shingles that were blown off of these buildings.

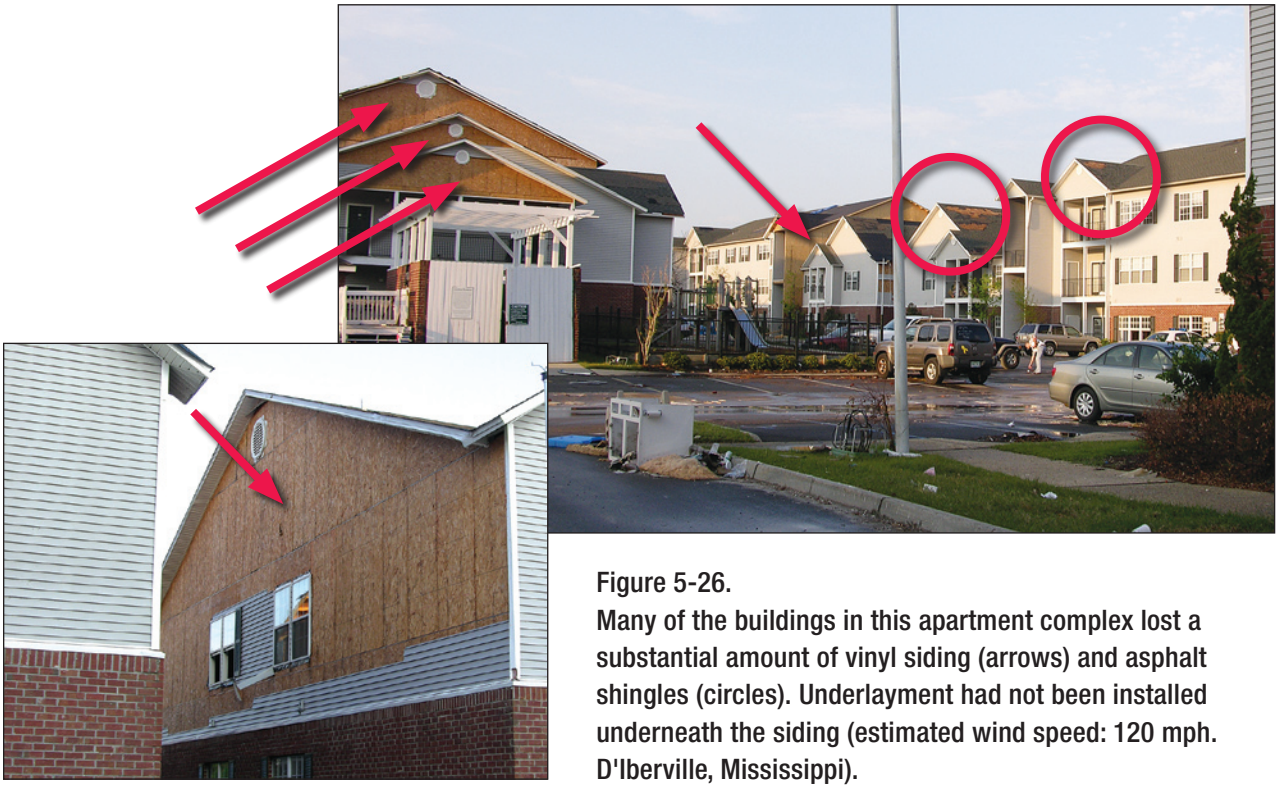


Figure 5-26.
Many of the buildings in this apartment complex lost a substantial amount of vinyl siding (arrows) and asphalt shingles (circles). Underlayment had not been installed underneath the siding (estimated wind speed: 120 mph. D'Iberville, Mississippi).



Figure 5-27.
These windows were broken by windborne debris (inset and arrows). Note the missing vinyl siding and soffit (estimated wind speed: 120 mph. D'Iberville, Mississippi).

In several areas investigated by the MAT, siding at gable end walls had been installed over plastic foam insulation (i.e., there was no plywood or oriented-strand board [OSB]). With blow-off of the vinyl siding, the foam insulation was typically also blown away (see Figure 5-28). With loss of both the siding and foam insulation, wind-driven rainwater was free to enter the attic space. When this occurred, typically the attic insulation became saturated and the ceiling collapsed.

On several buildings, siding was also installed over foam insulation at portions of walls, as shown at the apartment complex in Figure 5-29. At this complex, OSB had been installed in corner areas (in order to provide shear walls), but between the corner areas only plastic foam insulation occurred between the studs and vinyl. With loss of both the siding and foam insulation, wind-driven rainwater was free to enter the wall cavity. Also, where the wood sheathing was not present, wind-blown debris of only moderate energy could easily penetrate the building and injure occupants. With the vinyl in place, the center area of the walls shown in Figure 5-29 consisted of vinyl siding, foam insulation, stud cavity, and gypsum board on the interior side of the studs. As shown in the inset in Figure 5-29, in one area the vinyl, foam insulation, and interior gypsum board were blown away and there was no protection of occupants from windborne debris.

Vinyl siding manufactured for high-wind areas is available, but was not observed. (With high-wind siding, the nailing flange is folded over, so there is a double thickness of vinyl at the fastener points.) Vinyl siding that was blown off typically tore around the fastener points, which in all the cases investigated were large-headed nails. The 2003 IBC requires a maximum fastener spacing of 16 inches. ASTM D 4756, *Standard Practice for Installation of Rigid Poly (Vinyl Chloride) (PVC) Siding and Soffit*, also specifies a maximum spacing of 16 inches.

The fastener spacing was measured at a few buildings. The spacings on each of the buildings were quite variable. At the complex shown in Figures 5-28 and 5-29, along one of the siding panels, the nails were located 4 inches from the end of the panel, then 29, 14, 18, 31, and 17 inches. At another building in this complex, along one of the panels the nails were located 20 inches from the end of the panel, then 37 and 39 inches (this last fastener was 9 inches from the end of the panel).



Figure 5-28.
Loss of vinyl siding and foam insulation at a gable end wall. Note the missing vinyl soffit (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 5-29.
OSB was installed at the corner areas, but only foam insulation was present over the studs in the field of the wall. Most of the foam was blown away at this end wall (arrow). At some areas in this complex, the gypsum board on the interior side of the studs was also blown away (circle) (estimated wind speed: 130 mph. Long Beach, Mississippi).

ASTM D 4756 specifies that the fasteners are to be driven into framing or furring members, rather than just into plywood or OSB. Most of the fasteners that were investigated by the MAT were merely driven into sheathing. Although this practice did not comply with ASTM D 4756, no fastener pull-out problems were observed. In some cases, the MAT believes that the blow-off was triggered by unlatching of the buttlock, which is the bottom portion of the panel (see Figure 5-30). Once the panel unlatches from the retainer slot just below the nailing flange, the panel is free to rotate outward where it can be caught by the wind and blown off. The magnitude of the unlatching issue, compared to the strength of the nailing flange and fastener spacing, is unknown. When unlatched, panels are very susceptible to blow-off.

Underlayment had not been installed at all on some residences (see Figures 5-26, 5-28, and 5-29). Not installing underlayment is a poor practice because vinyl siding (like many other types of wall coverings) does not prevent rainwater from getting behind the siding. Underlayment should always be installed to intercept the leakage and drain it out of the wall. ASTM D 4756 does not currently require underlayment underneath vinyl siding; however, the 2003 IBC does require underlayment.

Some vinyl siding was damaged by windborne debris, and some vinyl soffit damage was observed (see Figures 5-27 and 5-28). Where soffits were blown away, a significant amount of water was often driven into the attics and ultimately into living spaces. (Debris damage and soffit failure was more commonly observed by the MAT that investigated Hurricane Charley. Further discussion

and analysis of debris damage and soffits are presented in FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida.*)

The vinyl siding damage was related to application deficiencies (i.e., excessive spacing between fasteners). However, other factors also likely contributed to the damage. In all of the failures investigated by the MAT, it did not appear that the siding was any stronger than that used in areas of the United States that have a 90-mph basic wind speed. There also appear to be weaknesses in the ASTM product and testing standards. ASTM D 3679, *Standard Specification for Rigid Poly Vinyl Chloride) (PVC) Siding*, which specifies a 1.5 safety factor. Considering the simplicity of the test method and the number of wind failures, the 1.5 factor appears to be too low.

ASTM D 5206, *Standard Test Method for Windload Resistance of Rigid Poly (Vinyl Chloride) (PVC) Siding*, requires holding the test load for only 30 seconds before increasing to the next pressure level. ASTM E 1592 (a test for metal roof and siding panels) specifies that each load increment be maintained for a minimum of 60 seconds and until the gauges indicate no further increase in deflection. The load duration and deflection criteria in E 1592 appear prudent for vinyl siding. Another weakness is that D 5206 is a static test. Static tests can overestimate the wind resistance of systems that experience significant deformations and/or fatigue failure. Considering the flexible nature of vinyl siding and the dynamic nature of wind loading, a dynamic test appears to be prudent for vinyl siding.



Figure 5-30. When a panel becomes unlatched, it becomes very susceptible to blow-off (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

5.3.2.6 Wood Siding

Buildings with wood siding were not investigated by the MAT. However, wood siding was investigated by the Hurricane Ivan MAT. For discussion and analysis of those investigations, see FEMA 489, *Mitigation Assessment Team Report, Hurricane Ivan in Alabama and Florida.*

5.3.2.7 Soffits

Vinyl soffits were discussed in the vinyl siding section, and damaged soffits were shown in Figures 5-27 and 5-28. Figure 5-31 shows loss of metal soffit at a school that was completed in 1997. Some of the soffit panels were perforated. In one area, the soffit support angle was attached to the top row of brick veneer (inset in Figure 5-31). Wind created positive (i.e., upward-acting) pressure on the soffit panels. This load was transferred to the support angle and then to the bricks, which lacked sufficient strength to carry the uplift load. This failure illustrates the importance of soffits being designed and constructed to carry positive and negative pressures, and the importance of load-path continuity. With loss of the soffit, wind-driven rainwater was able to enter the ceiling space, whereupon several ceiling boards became saturated and collapsed. Soffit failure can also increase the magnitude of positive pressure within attics and exert more load on the roof structure and coverings (see Section 10.2.3.1 for further discussion).



Figure 5-31.
Loss of metal soffit at a school. At the area shown in the inset, the soffit support angle was inadequately anchored (estimated wind speed: 130 mph. Gulfport, Mississippi).

Figure 5-32 shows loss of metal soffit from an elevated walkway at a courthouse in downtown New Orleans. Figure 5-33 shows loss of soffit boards from a suspended grid system. The grid system did not have compression struts to resist positive pressure. In addition to the soffit damage itself, windblown soffit panels can break windows.



Figure 5-32.
Loss of metal soffit from an elevated walkway (estimated wind speed: 105 mph. New Orleans, Louisiana)



Figure 5-33.
Loss of soffit at canopy. The grid support did not have compression struts (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.4 Roof Systems

Historically, damage to roof coverings and rooftop equipment is the leading cause of building performance problems during hurricanes. In the rains accompanying a hurricane, rainwater entering a building through damaged roofs can cause major damage to the contents and interior. Unless quick action is taken to dry a building, mold bloom can quickly occur in the hot, humid southern climate. Drying of buildings was hampered after Hurricane Katrina by the lack of electrical power to run fans and dehumidifiers. These types of damage

are frequently more costly than the roof damage itself. Rainwater leakage can also disrupt the functioning of critical and essential facilities, and weaken ceilings and cause them to collapse. Although ceiling collapse is unlikely to result in death, it can cause injury to occupants and further frighten them as they ride out the hurricane.

5.4.1 Asphalt Shingles

Throughout the areas observed by the MAT, most of the residences had asphalt shingle roof coverings. The vast majority of the observed roofs experienced damage, ranging from loss of a few hip trim shingles or tabs to loss of a large number of shingles and underlayment. For example, asphalt shingles were damaged on seven of the houses shown in Figure 5-34. Spotty damage occurred at the house on the upper left of Figure 5-34, while nearly all of the shingles and part of the underlayment were blown away at the house on the lower left.

A large number of relatively new shingle roofs (including several houses still under construction) experienced shingle damage. Figure 5-35 shows a new house that lost many shingles. The starter course was incorrectly installed (as discussed later) and there was no metal drip edge. Some of the shingles were superficially bonded to one another, underlayment was not lapped over a portion of the hip, the underlayment along the hip was cut in several locations (apparently while the shingles were being trimmed), the hip nails were incorrectly located, and several of the hip shingles did not bond, or were only superficially bonded, to one another. These shingles had a 1-1/2-inch-wide nailing strip and the majority of the nails were placed within the strip. The end nails were too far from the end (ranging from about 2 to 4 inches rather than 1 inch from the end). The field nails were somewhat uniformly distributed between the end nails; however, the manufacturer's literature indicates a different nailing pattern. These shingles had a Miami-Dade County (Florida) product approval label.



Figure 5-34. Asphalt shingles were damaged on seven of these houses. The two houses on the lower right had built-up or modified bituminous cap sheets. The blow-off at the lower right was likely initiated by blow-off of a deck panel from the corner (estimated wind speed: 105 mph. New Orleans, Louisiana area).



Figure 5-35.
An incorrectly installed starter course was the likely cause of failure at the left and right portions of the damaged roof. Water was able to leak into the building where the underlayment was not lapped over a portion of the hip (estimated wind speed: 130 mph. Long Beach, Mississippi).

Performance of the self-seal adhesive is a key factor. If the bonding is inadequate to prevent the shingle tab from lifting, winds of even moderate speed can lift the tabs. Depending upon physical properties of the shingle, number of fasteners, and fastener location, when tabs are lifted they are susceptible to being torn off, or entire portions of shingles being blown away. New Underwriters Laboratories (UL) and ASTM standards have been developed in recent years to provide better evaluation of wind resistance of shingles. UL has also implemented a new wind classification; however, it is unlikely that most of the damaged roofs that were observed were constructed with shingles that met the new classification system.

While sufficient bonding of the tabs is a critical performance factor, there are other key issues that influence wind performance. Throughout the areas observed by the MAT, failures of hip/ridge trim shingles, and failures along the eaves and rakes were common. Enhancement of hip/ridge, eave, and rake details, such as that shown in the FEMA 55, *Coastal Construction Manual* (2000), were not observed (see Technical Fact Sheet No. 20 in FEMA 499, *Home Builder's Guide to Coastal Construction*, for these details and other items pertaining to shingle roof coverings). Fastener mislocation and an inadequate number of fasteners were also common. These issues are discussed in the following paragraphs.

5.4.1.1 Hips/Ridges

Hip or ridge shingles were often blown off while all or many of the remaining shingles were undamaged (Figures 5-34 to 5-36 and 5-39). The fasteners on all of the hip and ridge shingles that were observed were located in or above the self-seal adhesive, rather than below the adhesive,

as recommended by the industry. However, the hip and ridge shingles were blown off because of lack of bonding of the adhesive. Sometimes a limited amount of bonding occurred, but frequently none of the adhesive had bonded (Figure 5-37). Lack of bonding of hip and ridge shingles is common due to substrate irregularity along the hip/ridge line. Use of asphalt roof cement, as recommended in Technical Fact Sheet No. 20 in FEMA 499, ensures bonding.



Figure 5-36.
Loss of hip shingles. The underlayment above the dormer was likely blown off due to increased turbulence caused by the dormer (estimated wind speed: 115 mph. Slidell, Louisiana).





Figure 5-37.
At the hip on the left, the self-seal adhesive only made contact at a small area on the right side of the hip (red circle). At the hip at the right, no adhesive bonding occurred. The nails at both of these hips were above, rather than below, the adhesive line (estimated wind speed: 105 and 130 mph. Pascagoula and Gulfport, Mississippi, respectively).

5.4.1.2 Eaves

None of the observed starter courses of damaged roofs complied with industry recommendations. The typically observed practice was to turn the starter shingle 180 degrees, rather than cut off the tabs (see Figure 5-38). By turning the starter 180 degrees, the tabs of the first course of shingles were not bonded to the starter course, thereby making them susceptible to lifting and progressive peeling (see Figures 5-39 and 5-47). One recently installed roof used a factory precut starter strip and did not experience any damage along the eaves (however, the wind speeds in this area were only about 120 mph). On this roof there was some limited hip damage, loss of one shingle from the field of the roof, and some loss of laminated tabs (see Figure 5-42).



Figure 5-38.
Rather than cutting off the tabs of the starter, the starter was rotated 180 degrees (red arrow). The exposed portion of the first course of shingles (yellow arrow) was unbonded because the self-seal adhesive (dashed line) on the starter was not near the eave (estimated wind speed: 130 mph. Long Beach, Mississippi).





Figure 5-39.
These two failures likely initiated at the eave due to an incorrectly installed starter course. Note that, at both roofs, a portion of the underlayment and some of the hip shingles were blown away (estimated wind speed: 115 and 105 mph. Slidell, Louisiana, and Pascagoula, Mississippi, respectively).

In addition to correctly installing the starter, use of asphalt roof cement to ensure bonding along the eave is recommended in Technical Fact Sheet No. 20 of FEMA 499. Due to substrate irregularities along the eave line, even when the starter is correctly installed, insufficient tab bonding can occur unless asphalt roof cement is applied.

Another commonly observed problem was excessive overhang. The *Residential Asphalt Roofing Manual* (published by the Asphalt Roofing Manufacturers Association [ARMA]) recommends that the shingles overhang the eave and rakes by 1/2 to 3/4 inch. Eave overhangs of 3/4 to 1-1/2 inches were often observed. The greater the overhang, the greater the uplift load on the shingle. Therefore, Technical Fact Sheet No. 20 in FEMA 499 recommends a 1/4-inch overhang at eaves and rakes.

5.4.1.3 Rakes

As with eaves, lifting and peeling failure often initiates at rakes and propagates into the field of the roof, as shown in Figure 5-40. Rakes are susceptible to failure due to the additional load exerted on the overhanging shingles (thus it is important to minimize the overhang as discussed above) and the configuration of the self-sealing adhesive. Along the long dimension of the shingle (i.e., parallel to the eave), the tab is sealed with self-sealing adhesive that is either continuous or nearly so. But along the rake, the ends of the tab are only sealed at the self-seal lines; therefore, the tabs are typically sealed at about 5 inches on center. Therefore, under high-wind loading, the adhesive at the rake end is stressed higher than the adhesive farther down along the tab. With sufficient wind loading, the corner of the tab at the rake can begin to lift up and progressively peel.



Figure 5-40.
These shingle blow-offs likely were initiated by lifting and peeling of shingles along the rake. Note the loss of vinyl siding at the right photograph (estimated wind speed: 130 and 115 mph respectively. Long Beach, Mississippi, and Slidell, Louisiana, respectively).

To enhance the wind resistance of shingles along the rake, Technical Fact Sheet No. 20 in FEMA 499 recommends application of asphalt roof cement along the rake. By adding dabs of cement, as shown in Technical Fact Sheet No. 20 (and Figure 5-41), uplift load across the ends of the rake

shingles is distributed to the cement as well as the self-seal adhesive, thus minimizing the possibility of tab uplift and progressive peeling failure.

On several damaged roofs, including the one shown on the left side of Figure 5-40, bleeder strips had been installed. Bleeder strips are shingles that are applied along the rake, similar to the starter course at the eave, as shown at Figure 5-41. A bleeder provides an extended straight edge that can be used as a guide for terminating the rake shingles. At first glance, it might be believed that a bleeder enhances wind resistance along the rake. However, it does not significantly enhance resistance because the concealed portion of the overlying rake shingle is the only portion than makes contact with the self-seal adhesive on the bleeder. As can be seen in Figure 5-42, the tab does not make contact with the bleeder. Hence, if the tab lifts, the shingle is placed in a peel mode, which can easily break the bond with the bleeder. Also, if the tabs are not cut from the bleeder and the cut edge placed along the rake edge (which was seldom done on the observed roofs), the bleeder's adhesive is too far inward to be of value.

If bleeder strips are installed for alignment purposes, use of asphalt roof cement, as shown in Technical Fact Sheet No. 20 of FEMA 499, is still recommended.

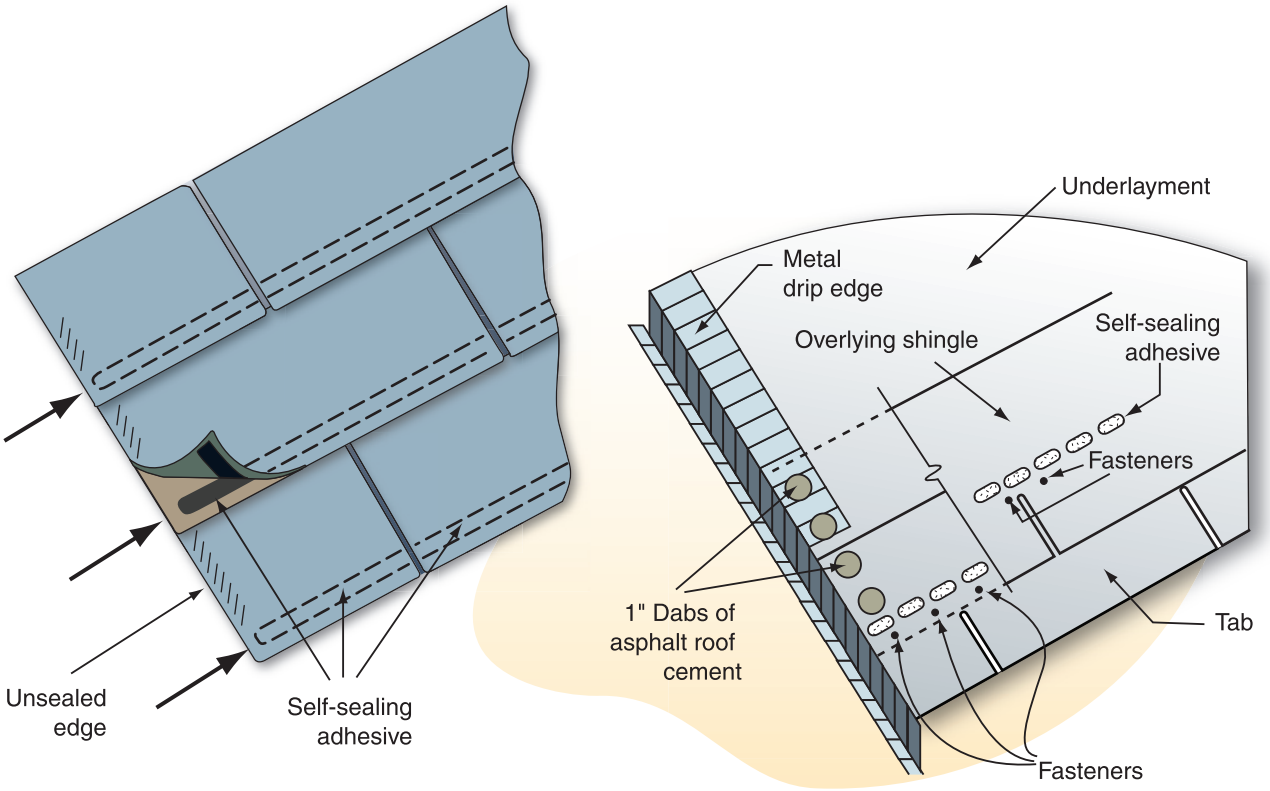


Figure 5-41.
Uplift loads along the rake are transferred (illustrated by the arrows) to the ends of the rows of self-sealing adhesive. When loads exceed resistance of the adhesive, the tabs lift and peel. The detail at the right is from Technical Fact Sheet 20 in FEMA 499. It shows installation of asphalt roof cement along the rake. The cement adheres the unsealed area shown by the hatched lines of the drawing to the left.



Figure 5-42. Blow-off of shingles at a new house under construction. A bleeder strip (double-arrow) was used along the rake. Note that the tab of the overlying shingle cannot make contact with the bleeder's self-seal adhesive (upper arrow) (estimated wind speed: 125 mph. Waveland, Mississippi).

5.4.1.4 Fasteners

Where fasteners were visible due to shingle blow-off, it was found that roofing nails were typically used. Several of the damaged roofs had been installed with six nails per shingle, but it was more common to see four or five nails per shingle. (Use of five nails per shingle is not a recognized practice.) ARMA advises that six nails per shingle "should be considered" in high-wind areas. (All of the areas investigated by the MAT are high-wind areas.)

Significant fastener mislocation occurred on nearly all of the damaged roofs observed (see Figures 5-43 and 5-44). Fasteners were typically located 1 to 2 inches above the nailing line (i.e., the line printed on the shingle by the manufacturer). End fasteners were often 2 to 3 inches from the end, rather than the industry-recommended 1 inch. Minor deviations from intended fastener locations should be expected; however, the deviations on nearly all of the damaged roofs were excessive.

When nails are too high above the nail line, they can miss the underlying shingle headlap or have inadequate edge distance as shown by the nail that is right of the circle in Figure 5-43 and illustrated in Figure 5-45. When using laminated shingles, high nailing may miss the overlap of laminated shingles; if the overlap is missed, the nail pull-through resistance is reduced (see Figure 5-46). High nailing may also influence integrity of the self-seal adhesive bond by allowing excessive deformation (ballooning) in the vicinity of the adhesive.

Shingles manufactured with a wide nailing zone, such as those installed on the house shown in Figure 5-35, provide roofing mechanics with much greater opportunity to apply the fasteners in the appropriate locations.

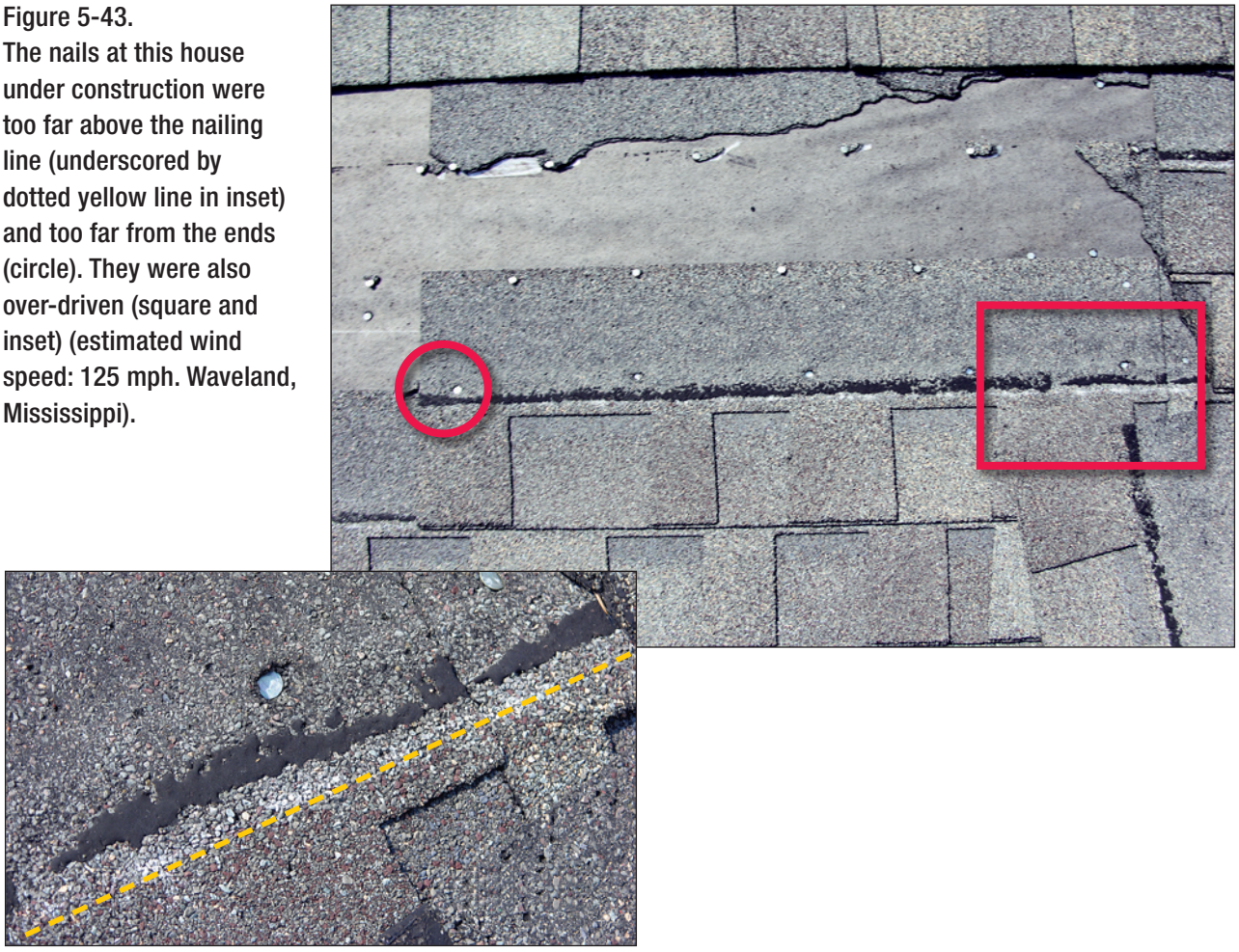


Figure 5-43.
The nails at this house under construction were too far above the nailing line (underscored by dotted yellow line in inset) and too far from the ends (circle). They were also over-driven (square and inset) (estimated wind speed: 125 mph. Waveland, Mississippi).



Figure 5-44.
The nails at this house under construction were placed quite close to the nailing line. However, some of the end nails were too far inward (the nail in the oval was several inches from the end). Distribution along the nail line was also a problem (the nails in the circles were much too far apart) (estimated wind speed: 115 mph. Slidell, Louisiana).

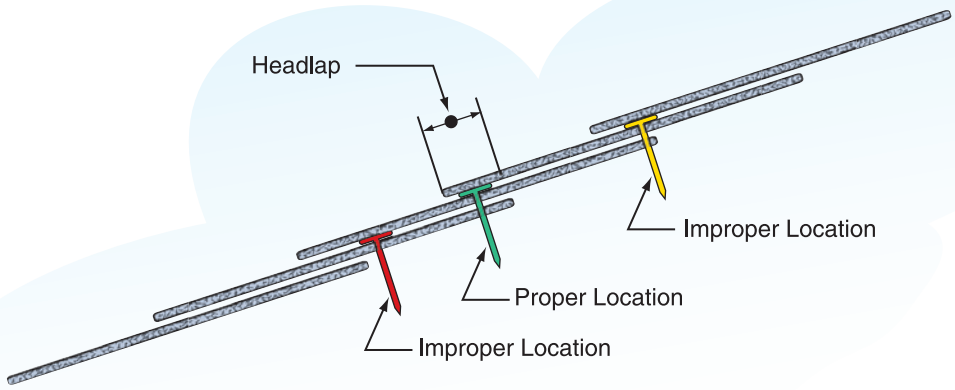


Figure 5-45.
When properly located, the nail engages the underlying shingle in the headlap area (green nail). When too high, the nail misses the underlying shingle (red arrow) or is too close the to edge of the underlying shingle (yellow nail).

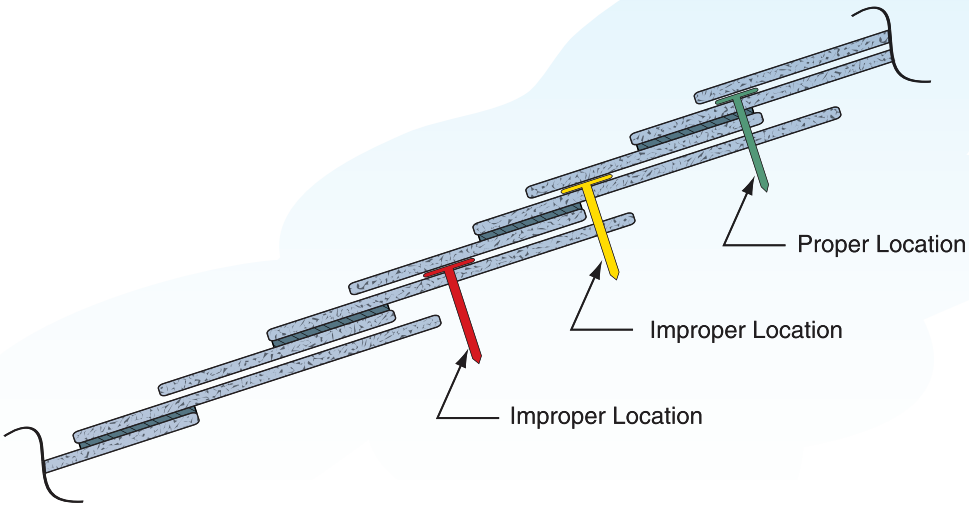


Figure 5-46.
With laminated shingles, properly located nails engage the underlying laminated portion of the shingle, as well as the headlap of the shingle below (green nail). When too high, the nail can miss the underlying laminated portion of shingle but engage the headlap of the underlying shingle (yellow arrow), or the nail can miss both the underlying laminated portion of the shingle and the headlap of the underlying shingle (red nail).

The number of nails (i.e., four versus six) and their location likely plays little role in wind performance, as long at the shingles remain bonded. However, if they are unbonded prior to a storm, or debonded during a storm, the number and location of nails and the shingles' nail pull-through resistance likely play an important role in the magnitude of progressive damage, as illustrated by Figure 5-47.[2]

[2] If the wind speed is extremely high, extensive progressive damage is likely, regardless of the number and location of fasteners and pull-through resistance.



Figure 5-47.
The starter course was incorrectly installed at this recently completed roof. The starter course and eave course lifted. A progressive peeling occurred because there was inadequate nailing attachment to resist the peel forces (estimated wind speed: 105 mph. Pascagoula, Mississippi).

5.4.1.5 Raking

Several of the damaged roofs were installed with the raking installation method. With this method, shingles are installed from eave to ridge in bands about 6-feet wide (see Figure 5-48). Where the bands join one another, at every other course, a shingle from the previous row needs to be lifted up to install the end nail of the new band shingle. Sometimes installers do not install the end nail; in these applications, the shingles are vulnerable to unzipping at the band lines, as shown in Figure 5-49. At a nursing home in Gulfport, Mississippi, a limited amount of spot checking found three shingles that were missing the right end nail (see Figure 5-50). Blown-off shingles broke some of the windows in the nursing home (see Figure 5-51), and were the likely cause of glazing damage at a building across the street.

The National Roofing Contractors Association (NRCA) recommends that the raking method not be used and that shingles should be laid one course at a time from rake to rake starting at the eave.



Figure 5-48.
This house was being re-roofed after the hurricane using the raking method. The starter course was incorrectly installed (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 5-49.
The vertical lines of missing tabs are indicative of installation by the raking method. When raked, end nails are frequently not installed. Some shingles and underlayment were also blown from the eave and rake (estimated wind speed: 125 mph. Waveland, Mississippi).



Figure 5-50.
Many shingles were blown from a nursing home. Limited checking found three shingles that were missing the right end nail (see inset for one of these). The nails that were installed were placed very high (red arrows); many missed or just nicked the underlying headlap (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 5-51. Windborne asphalt shingle debris broke several windows in this nursing home. A piece of shingle debris is embedded in the frame (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.4.1.6 Laminated Tabs

On a few roofs with architectural shingles, instances of blow-off of laminated tabs were observed (see Figure 5-52). This type of failure was due to an inadequate amount and/or strength of adhesive used in the manufacturing of the shingles.



Figure 5-52. Two laminated tabs were lifted (circles) at a house under construction (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

5.4.1.7 Recovering

On some residences that had been recovered (i.e., new shingles had been installed on top of old shingles), large numbers of the recovered shingles were blown away and the underlying older shingles remained in place. When recovering versus tearing off the old shingles down to the sheathing, more substrate irregularity occurs, which can interfere with bonding of the self-seal

adhesive of the new shingles. Most of the recover blow-offs were likely due to bonding problems associated with substrate irregularities. Some of these blow-offs may have been due to use of nails that were too short, although this failure mode is atypical.

5.4.1.8 Ridge Vents

A few instances of ridge vent blow-off were observed, but detailed investigations were not made. (Ridge vents were investigated by the Hurricane Ivan MAT. For discussion and analysis of those investigations, see FEMA 489, *Mitigation Assessment Team Report, Hurricane Ivan in Alabama and Florida*.) The performance of ridge vents with respect to prevention of wind-driven rain infiltration during the hurricane was not evaluated.

5.4.1.9 Roof-to-Wall Flashing

In a few instances, continuous metal flashing rather than step flashing was observed at roof-to-wall intersections (see Figure 5-53). Although continuous flashing is cheaper to install, this application method is susceptible to leakage and subsequent dry rot of the deck sheathing (this type of failure was observed by the Hurricane Ivan MAT). The ARMA *Residential Asphalt Roofing Manual* recommends the use of step flashings at roof-to-wall intersections. Technical Fact Sheet No. 24 in FEMA 499 provides recommendations for enhancing the roof-to-wall flashing in high-wind areas.



Figure 5-53. Continuous metal flashing at the roof-to-wall intersection of a house under construction. This detail is susceptible to leakage and subsequent dry rot of the deck sheathing (estimated wind speed: 115 mph. Slidell, Louisiana).

5.4.1.10 Underlayment

In some instances where shingles were blown off, the underlayment was not damaged and, therefore, provided some degree of protection from water infiltration. But in many other instances, the underlayment was also blown off (see Figure 5-54). Rain was then able to enter the building at the sheathing joints. In general, wind performance of exposed underlayment observed by the

Hurricane Charley and Ivan MATs in Florida and Alabama, respectively, was significantly better than the performance of underlayment in Louisiana and Mississippi in Hurricane Katrina, and was primarily due to enhanced nailing of the underlayment.

Technical Fact Sheet No. 19 in FEMA 499 provides recommended practices for underlayments on roofs in high-wind areas.



Figure 5-54. Widespread loss of underlayment. With loss of underlayment, water is free to leak into the building and cause extensive interior damage (estimated wind speed: 115 mph. Slidell, Louisiana).

5.4.2 Fiber-Cement, Slate, and Tile

Fiber-cement and slate roof coverings have very limited market shares in the southeastern United States and there is limited information in the literature on the wind performance of these products. The MAT observed one roof with fiber-cement that simulated slate and one slate roof. Figure 5-55 shows the fiber-cement roof. It experienced damage in several areas, including many of the hip lines. The simulated slates were attached with two nails. The manufacturer's literature states the nails are to be placed between 1/2 and 1-1/2 inches above the exposure so that the nail penetrates the underlying simulated slate in the headlap area. However, the nails were typically placed a few inches above the exposure and they missed the headlap. Some of the nails pulled out of the deck, but many remained in place. In several instances, the simulated slates broke at the nail line.

In 2004, the manufacturer issued high-wind attachment recommendations, which consisted of placing 1-1/2x3/8 inch beads of adhesive over the nail heads. Adhesive was not used on the roof shown in Figure 5-55; however, that roof may have been installed prior to distribution of the 2004 recommendations.

Figure 5-56 shows a slate roof. It too experienced damage in several areas, including many of the hip lines. The slates were 9-1/2 inches wide by 15-3/4 inches long, with a 7-inch exposure. They were attached with two 2-inch-long copper slating nails, located about 1-3/4 inches in from the edges and about 2-3/4 inches from the upper end. *The NRCA Roofing and Waterproofing Manual*

recommends the nails be 1-1/4 to 2 inches from the edges; therefore, the application complied with that recommendation. However, the NRCA manual recommends the nails be 1/4 to 1/3 the length of the slate from the end.[3] With a 15-3/4-inch-long slate, the nails should have been about 4 to 5-1/4 inches from the end, rather than the 2-3/4 inches. The NRCA manual also recommends use of four nails per slate in high-wind areas; therefore, the application did not comply with that recommendation. In addition, the NRCA manual recommends dabs of asphalt roof cement or polyurethane sealant at the eave in high-wind areas. It was unclear whether or not the eave slates had the recommended adhesive enhancement.



Figure 5-55.
Fiber-cement simulating slate. Note the loss of underlayment and the simulated slates broken at the nail line (circle). This house was located in Exposure C (estimated wind speed: 105 mph. Pascagoula, Mississippi).



Figure 5-56.
Damaged slate roof. The nails typically pulled out of the deck. However, as shown in the square/inset, some of the slates broke and small portions remained nailed to the deck. This house was located in Exposure C (estimated wind speed: 130 mph. Gulfport, Mississippi).

[3] The NRCA manual has a typographical error. The manual states the holes should be 1/4 inch to 1/3 inch the length of the slate from the upper end. The word "inch" should not have been included (i.e., the holes should be 1/4 to 1/3 the length of the slate).

Few tile roofs were seen in the areas in Louisiana and Mississippi that were struck by Hurricane Katrina. The tile roofs that were observed were typically damaged (see Figures 5-57 and 5-58). (Many tile roofs were investigated by the Hurricane Charley and Ivan MATs. For discussion and analysis of those investigations, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida* and FEMA 489, *Mitigation Assessment Team Report, Hurricane Ivan in Alabama and Florida*. Both of those documents include a Hurricane Recovery Advisory on tile, and that Advisory became Technical Fact Sheet No. 21 in FEMA 499.)

Note: The tile Advisory and Technical Fact Sheet No. 21 references the third edition of the *Concrete and Clay Roof Tile Installation Manual*. The fourth edition of that manual was published in August 2005 in response to the 2004 hurricanes. FEMA's tile Advisory and Technical Fact Sheet No. 21 are still applicable, but the fourth edition of the manual should be used.



Figure 5-57. Damaged tiles at roof perimeter (estimated wind speed: 120 mph. VA Hospital Chapel, Biloxi, Mississippi)



Figure 5-58. Wind turbulence behind parapet resulted in uplift of ridge tiles. Tile was also damaged along the eave (estimated wind speed: 120 mph. VA Hospital Patient Building, Biloxi, Mississippi).

5.4.3 Metal Panels and Shingles

A variety of exposed fastener and standing seam panel systems was observed, as well as metal shingles. The performance of metal roofing varied greatly.

5.4.3.1 Exposed Fastener Panels

Exposed fastener panels generally performed well, as illustrated by Figure 5-59, although in several instances, hip and/or ridge flashings were blown away. Most of the exposed fastener panels were of the R-panel design, although a few 5V-Crimp roofs were observed. (A substantial number of 5V-Crimp roofs were observed by the Hurricane Charley MAT. For discussion and analysis of those investigations, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida.*)

Success or failure of exposed fastener panels was likely dependent upon fastener spacing (see Figure 5-60) and type, and whether or not the substrate lifted, as discussed later. Panel gauge may have also had some influence. Screws provided greater pull-out resistance than ring-shank nails, and were more resistant to dynamic loading. Another key element of good performance is the spacing of fasteners along the eave and at hip and ridge flashings. Close spacing at the flashings and eave is important to keep the flashings and panel ends from billowing during high winds.



Figure 5-59. This R-panel roof was not damaged. This house was located in an area that received some of the highest winds (estimated at 125 mph). The damage at the first and second floors was caused by storm surge. The surge pushed the first floor to the right. This "leaner" is considered to be a "survivor" (estimated wind speed: 125 mph. Bay St. Louis, Mississippi).



Figure 5-60.
The R-panel roof on this house located in Exposure C was very well attached. The screws were closely spaced horizontally and vertically, and at the panel side laps. The flashing fasteners were too far apart (12 inches on center), but the attachment was sufficient for these winds (estimated wind speed: 115 mph. Slidell, Louisiana).

Several of the R-panel failures were caused by failure of the substrate to which the panels were attached. The panels on the house shown in Figure 5-61 were likely a reroofing application. The panels were installed over underlayment over plywood. On the backside of the house, one or more plywood panels were blown off from along two locations at the eave. The decking blow-off resulted in a progressive lifting and peeling failure of the panels. At the house shown in Figure 5-62, 2x4 nailers had been attached to the plywood decking and then the R-panels were attached to the nailers. The right half of the third nailer from the eave was blown away. Inadequate nailer attachment was the likely cause of this failure. Nailer failure also caused R-panels to be blown away on a few residences where nailers had been installed over existing asphalt shingles. The panels were screwed to the nailers at 12 inches on center, but the nailers were nailed to the sheathing at spacings that exceeded 12 inches. Therefore, the nailer attachment was the weak link in the load path.



Figure 5-61.
Blow-off of decking caused these panels to progressively fail (estimated wind speed: 105 mph. Pascagoula, Mississippi).



Figure 5-62.
Blow-off of one of the nailers (dotted line) caused these panels to progressively fail. Note the cantilevered condenser platform (arrow), a good practice, and the broken window (circle). The house was located in Exposure C (estimated wind speed: 130 mph. St. Bernard Parish, Louisiana).

Figure 5-63 shows an apartment complex that did not incorporate roof decking. The trusses had 2x4 nailers installed directly over them. Several of the nailers were blown away, which resulted in a progressive failure of the R-panels. Since there was no roof decking, it was not possible to install underlayment. Thus with loss of the metal panels, the living units were exposed to massive rainwater infiltration.

An advantage of exposed fastener panels (versus panels with concealed clips) is that, after installation, it is easy to verify that the correct number of panel fasteners were installed. However, if the panels are attached to nailers or decking that is inadequately attached, such deficiency will not be apparent after panel application.



Figure 5-63.
Blow-off of nailers caused these panels to progressively fail. The nailers were installed directly over the trusses and, with loss of the panels, rainwater was free to enter the building (estimated wind speed: 105 mph. Pascagoula, Mississippi).

5.4.3.2 Standing Seam Panels

A variety of architectural and structural standing seam panels was also observed. As with the exposed fastener panels, some of the roofs were undamaged, others lost hip or ridge flashings, and others lost a large number of panels (see Figure 5-64). Performance of standing seam panels is a function of the strength of the panels and their interlock with the clips, clip spacing and attachment, and strength of the flashing attachments. Some of the failed hip and ridge flashings were attached with cleats rather than exposed fasteners. Cleat attachment is not as reliable as exposed fasteners.



Figure 5-64.
Loss of architectural standing seam panels. The panels were installed over 2x4 nailers over underlayment and wood sheathing panels. Much of the exposed underlayment was blown away, thereby allowing rainwater infiltration (estimated wind speed: 130 mph. Buras, Louisiana).

Two unusual installation practices were observed. At the school shown in Figure 5-65, the standing seams were not continuously seamed together. Rather, they were crimped at an erratic spacing (in one area, it was about 4 feet between 6-inch-long crimps). Lack of continuous seaming reduces uplift resistance of the panels and makes them susceptible to leakage. Some of the copings were blown off, and several suspended ceiling boards collapsed after becoming saturated from roof leakage.

The other unusual installation practice occurred on a police station that was reroofed. The concealed clips were installed with a single screw, rather than two screws, as intended for the clips that were used. With only a single screw, the clip was eccentrically loaded (see Figure 5-66), thus making the panels susceptible to failure. However, with this building, the greater problem pertained to inadequacies of the support structure, as shown in Figure 3-54.



Figure 5-65.
The architectural standing seam panels on this school were not continuously seamed. Note the coping damage. This portion of the school was completed in 1988 (estimated wind speed: 125 mph. Waveland, Mississippi).

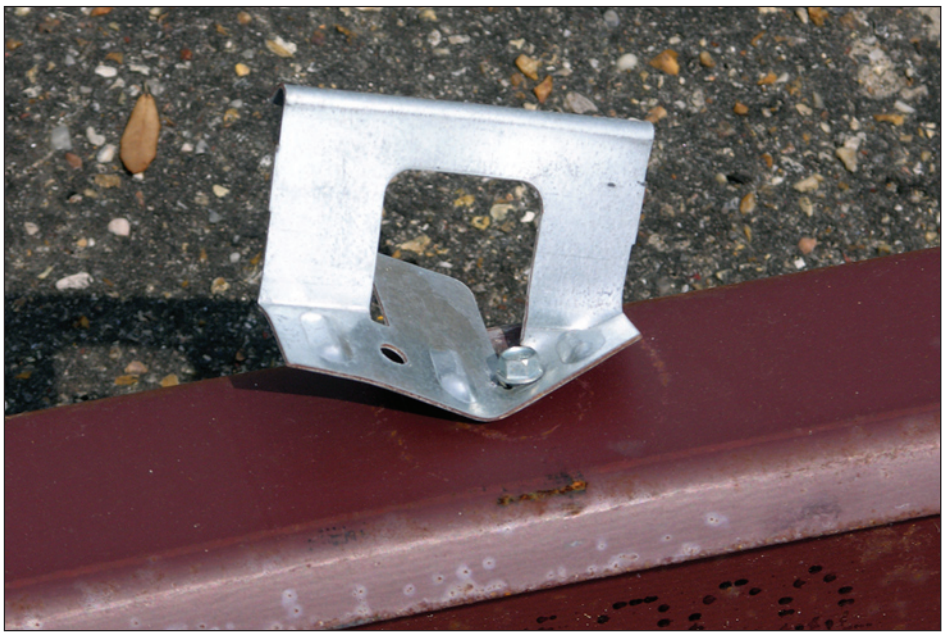


Figure 5-66.
The clips for this structural standing seam panel were intended to be attached with two screws. With only one screw, the clips were eccentrically loaded (estimated wind speed: 130 mph. Long Beach, Mississippi).

When metal panels or hip/ridge flashings blow off (see Figure 5-67), they can become high-energy windborne debris that can damage buildings and other property and cause injury. These types of windborne debris can travel a considerable distance.



Figure 5-67.
The steep-slope roof coverings on this high-rise building appear to be tile; however, they actually were metal panels that simulated tile. Several panels were blown off (estimated wind speed: 120 mph. Biloxi, Mississippi).

5.4.3.3 Metal Shingles

A limited number of metal shingles were observed. Figure 5-68 shows an aluminum shingle that has been used on many fast-food restaurants throughout the United States. These shingles are attached with two stainless steel clips per shingle. Because these shingles are quite flexible, they deformed and lost engagement with the clip. Poor performance with this type of shingle has been observed in several previous hurricanes, dating back to Hurricane Hugo in 1989. Another aluminum shingle of somewhat similar design to that shown in Figure 5-64 also deformed and lost engagement with its clips. Some batten-attached metal shingles were also observed, but detailed investigations were not performed to determine the failure mode.



Figure 5-68.
These aluminum shingles disengaged from their clips (estimated wind speed: 115 mph. Slidell, Louisiana).

5.4.4 Low-Slope Membrane Systems

The MAT observed several types of low-slope roof systems that included built-up roofs (BURs), modified bitumen, and single-ply. Membrane damage was typically caused by membrane lifting and peeling after lifting of the gutter, edge flashing, or coping, and by puncturing and tearing by windborne debris. Deck failure also caused membranes to lift and peel, and aggregate blow-off caused substantial glazing damage. In addition to these failure modes, which are discussed below, walkway pads were blown away. Walkway pads have sufficient mass to be very damaging windborne debris.

Roof membranes can successfully resist very high-wind loads but, to do so, attention needs to be given to system and component selection, detailing, and application. This is illustrated by the 670-foot tall building in New Orleans (see Figure 5-25). The penthouse roof was reroofed around 1997. It was a modified bitumen membrane over perlite insulation set in hot asphalt. This membrane blew off during Hurricane Katrina and was attributed to inadequate uplift resistance of the perlite insulation. The main roof was reroofed around 2000. The modified bitumen membrane was reportedly installed over glass mat gypsum roof board set in hot asphalt over polyisocyanurate insulation set in hot asphalt over the concrete deck. This membrane was punctured by stone veneer panels that detached from the penthouse walls; however, neither the edge flashing or membrane lifted.

5.4.4.1 Edge Failure

Lifting of metal edge flashings typically results in progressive lifting and peeling of the roof membrane. Lifting of copings can also result in progressive failure of the membrane, and blown-off copings become windborne debris that can puncture roof membranes and cause other damage. Metal edge flashing and coping lifting can be caused by inadequate attachment of the flashing or coping, inadequate attachment of nailers, or lifting of gutters. The vital importance of edge flashing and coping securement has been widely recognized since the early 1980s; however, code criteria were not incorporated into a model code until the 2003 edition of the IBC.

Some of the investigated roofs (including two of the EOCs discussed in Section 7.1) had uncleated metal edge flashings. Because of lack of securement of the vertical face, uncleated flashings are particularly susceptible to wind blow-off. However, as discovered during Hurricane Hugo (1989) investigations, presence of a continuous cleat does not ensure adequate performance. Gauge of the cleat and flashing/coping, length of cleat hem (the amount of interlock between the cleat and flashing/coping), and number, type, and location of cleat fasteners influence wind performance.

At the Federal courthouse shown in Figure 5-69, the coping had a 6-1/2-inch vertical face, but the hem on the continuous cleat was only 7/16 inch long.[4] High-wind loads caused deformation of the coping and cleat. Because of the limited engagement with the cleat, the outer face of the coping unlatched from the cleat. At several areas, the unlatched coping lifted, but remained attached to the parapet; however, some of the sections of coping were blown from the parapet. The courthouse was completed in 2003.

[4] The 2001 edition of *The NRCA Roofing and Waterproofing Manual* recommends a ¾-inch long hem.



Figure 5-69.
This coping unlatched from the cleat because the cleat hem was too short. Two sections of detached coping are resting on the roof (red arrows) (estimated wind speed: 130 mph. Gulfport, Mississippi).

At the school gym roof shown in Figure 5-70, the modified bitumen membrane was set in hot asphalt over 4x4-foot perlite set in hot asphalt over mechanically attached polyisocyanurate insulation and glass mat gypsum roof board over metal deck. The membrane peeling was caused by failure of the edge flashing nailers. Rather than stacking continuous 2x nailers, a 2x nailer about 12 inches long was attached to the deck, followed by another 2x nailer of the same length on top of it. The upper nailer was attached with two power-driven fasteners. These discontinuous stacks were spaced at 4 feet 7 inches on center. A continuous top nailer was then attached to the stacks. The continuous top nailer lifted with the metal edge flashing and caused the membrane to lift and peel. This school was completed in 1998.



Figure 5-70.
The modified bitumen membrane failure at this school was caused by lifting of the edge nailer (estimated wind speed: 130 mph. Pass Christian, Mississippi).

5.4.4.2 Puncture

Membranes were also commonly punctured and torn by windborne debris (see Figure 5-71). A substantial amount of water can leak into a building at small punctures and tears unless there is a secondary membrane (as discussed in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*) or a monolithic concrete deck. Membrane puncture is a routine occurrence in hurricanes. When a large number of buildings are damaged, emergency repairs are often not made for many weeks. In these cases, relatively minor membrane damage can cause wetting of large areas of roof insulation, resulting in damage to interior finishes and equipment.

During prolonged wind loading, as is often the case with hurricanes, membrane tears can propagate and lead to detachment of the membrane from its substrate, which can lead to blow-off of a large portion of the membrane.



Figure 5-71. This modified bitumen membrane was punctured in several locations by windborne debris. This building was located in Exposure C (estimated wind speed: 120 mph. Biloxi, Mississippi).

5.4.4.3 Deck Failure

Failure of the roof deck or the roof deck support structure sometimes occurs, particularly with buildings designed when the building code did not account for increased uplift loads at the roof perimeter and corners. Deck failure can be caused by inadequate attachment of the deck to the deck support structure, as shown in Figures 3-48 and 5-72. Deck failure can also be caused by corrosion or dry rot, as shown in Figure 5-73.



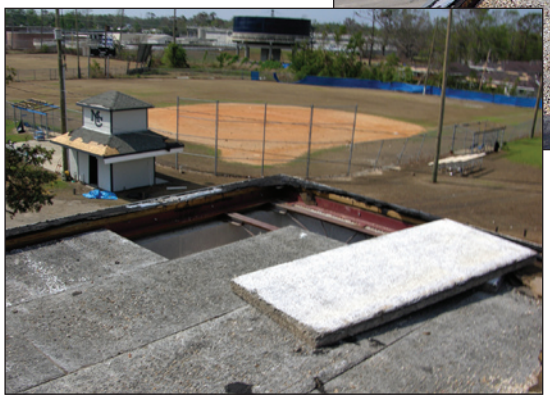


Figure 5-72.
The BUR on this school was blown off after one of the cementitious wood-fiber deck panels detached from the joists. Older cementitious wood-fiber deck attachments typically offered limited uplift resistance (estimated wind speed: 120 mph. Biloxi, Mississippi).





Figure 5-73.
The BUR on this school was blown off after a few of the rotted wood planks detached from the joists (estimated wind speed: 120 mph. Biloxi, Mississippi).

When buildings in hurricane-prone regions are reroofed, it is prudent to tear off the existing roof system down to the deck, so that the entire deck surface can be checked for attachment and deterioration. If inadequately attached or deteriorated decking is discovered, remedial action should then be taken as part of the reroofing project. By doing so, future wind damage associated with deck deficiencies can be avoided.

Figure 5-74 illustrates another type of deck and deck support failure. This school originally had a low-slope BUR. As part of a reroofing project, a steep-slope conversion was made, wherein sloped wood framing was installed over the BUR, followed by plywood decking and a modified bitumen membrane. The wood framing blew away due to inadequate attachment. This illustrates the importance of load path and connections when steep-slope conversions are made.



Figure 5-74.
The wood superstructure that was installed on this school as part of a steep-slope conversion blew away because of inadequate attachment (estimated wind speed: 125 mph. Port Sulphur, Louisiana).

5.4.4.4 Aggregate Blow-off

Many windows (including windows of critical and essential facilities) were broken by aggregate blown from roofs, as shown in Figures 3-29, 3-47, and 3-59 and discussed in Section 5.5.1. The glazing damage in downtown New Orleans was extensive and very costly. Most of the aggregate was from built-up roofs, but some of the aggregate was from ballasted single-plies.

In addition to causing damage to unprotected glazing, wind-blown aggregate can injure people who are outside during a hurricane. Although few people are normally outside during a hurricane, common exceptions are people who arrive late to shelters and those seeking care at hospitals. It is therefore prudent to avoid aggregate surfacings on critical and essential facilities.

A new section in the 2006 edition of the IBC now prohibits the use of aggregate surfaced roofs in hurricane-prone regions.

5.5 Windows, Shutters, and Skylights

Exterior windows are very susceptible to windborne debris breakage unless they are impact resistant (via use of laminated glass or shutters). The probability that any one window will be struck by windborne debris is typically small; however, when it does occur, the consequences can be significant. The probability of impact depends upon local wind characteristics and the amount of natural and manmade windborne debris in the vicinity. The greater the wind speed, the greater the amount of windborne debris that is likely to become airborne. Windows can also be broken by over-pressurization, but this damage is not as common as debris-induced damage. This section addresses debris damage to unprotected glazing, performance of protected glazing, problems caused by over-pressurization, window installation issues, and skylights.

If glazing is cracked by debris, but remains in the frame as shown in Figure 7-8, the ramifications of damage are limited to the cost of replacing the glazing and perhaps some water infiltration. However, if glass is blown from the frame, the shards become debris that can cause injury or damage, the internal pressure within the building can be substantially increased or decreased and thus lead to structural failure as discussed in Section 4.2, building envelope damage, interior partitions and ceilings can be damaged, and a substantial amount of wind-driven rain can enter the building. Figure 5-75 illustrates consequences of breached glazing at a hotel. In addition to the cost of the damage to the glazing and interior finishes and furnishings, business interruption costs can be substantial.



Figure 5-75. Interior view of the hotel shown in Figures 3-47 and 5-82. After the exterior glazing broke, wind knocked down the partitions between the guest rooms and water entered the building (estimated wind speed: 105 mph. New Orleans, Louisiana).

In addition to the performance problems discussed in this section, leakage problems were also reported, but this failure mode was not investigated by the MAT. Leakage can occur between window frames and the exterior wall, and between glazing and glazing gaskets due to sealant and/or flashing failures or gasket deterioration. However, leakage more commonly occurs around the frames of operable window units. Leakage around operable units can be caused

by deterioration of weatherstripping or installation of window units that have inadequate resistance to wind-driven rain. The maximum test pressure that is used in the current ASTM test standard for evaluation of resistance of window units to wind-driven rain is well below design wind pressures. A change is being considered to increase the maximum test pressure for water resistance from 12 psf to 15 psf. Test duration time may also be an issue, but a change has not been proposed.

5.5.1 Unprotected Glazing

5.5.1.1 New Orleans Area and Mississippi

When the MAT observed broken glazing, often only one or a few of a building's windows were broken. This type of isolated damage occurred when there was a limited amount of natural or manmade debris (such as tree limbs or building components) flying in the vicinity of the building. For example, it appeared that a cosmetic shutter was blown from the window shown in Figure 5-76 and broke the glazing. In other instances, when the MAT observed broken glazing, a large number of a building's windows were broken. In these instances, the building was pummeled with vinyl siding, asphalt shingles, or aggregate from roofs. Glazing damage associated with siding and shingles is shown in Figures 5-26, 5-27, and 5-51. Although siding and shingle debris can damage many windows, the greatest threat is aggregate from roofs. Unprotected glazing that is downwind of an aggregate surfaced roof is very susceptible to breakage due to aggregate blow-off. According to ASCE 7, during hurricanes aggregate can travel up to 1,500 feet with sufficient momentum to break unprotected glazing. The remainder of this section discusses some of the buildings the MAT observed that experienced glazing damage that was attributed to roof aggregate.



Figure 5-76.
This window was broken by a fragment from a shutter (estimated wind speed: 105 mph. New Orleans, Louisiana).

At the hospital shown in Figure 3-59, approximately 400 windows and spandrel panels were broken by aggregate blown from the hospital's own roofs. This hospital complex had several different roof areas, some of which had aggregate-ballasted single-ply membranes and some had aggregate surfaced BURs. The aggregate that caused the glazing damage shown in Figure 3-59 was from an aggregate-ballasted single-ply roof. At another roof area (see Figure 5-77), aggregate from a ballasted single-ply also broke several windows. ANSI/SPRI RP-4 *Wind Design Standard for Ballasted Single-ply Roofing Systems* (which is referenced in the IBC) prescribes aggregate requirements. Several of the aggregates shown in Figure 5-77 equal or exceed the 1-1/2 inch-nominal dimension for #4 aggregate; however, the number of aggregates that were 3/4 inches or smaller exceed that allowed by RP-4. However, more importantly, RP-4 does not permit aggregate ballast (even #2 ballast, which is 2-1/2-inches nominal) on this building, considering its design wind speed, low parapet height, and importance factor.

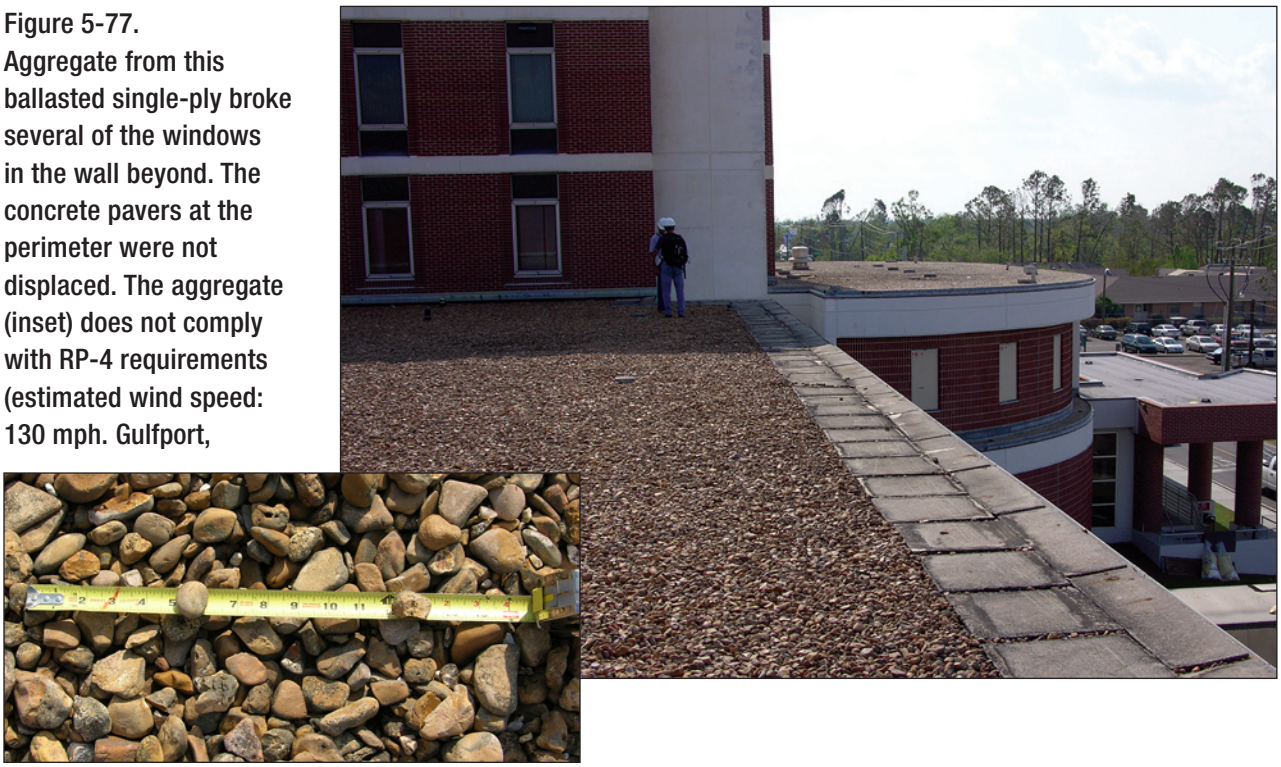


Figure 5-77. Aggregate from this ballasted single-ply broke several of the windows in the wall beyond. The concrete pavers at the perimeter were not displaced. The aggregate (inset) does not comply with RP-4 requirements (estimated wind speed: 130 mph. Gulfport,

The majority of the windows in the mid-rise building shown in Figures 5-78 and 5-79 were broken by aggregate from BURs. Most of the damage to the lower level windows was likely caused by aggregate from the podium roof adjacent to the tower (roof "A" in Figure 5-78). The south edge of the podium roof (the edge near the arrowhead in Figure 5-78) had a metal edge flashing. The roof sloped toward the tower; therefore, a parapet occurred along the east-west walls. The maximum height of the parapet was about 6 inches. Most of the aggregate that had been embedded in the flood coat was still embedded, but most of the loose aggregate had been blown away.

Wind in this area blew from two primary directions, from the southwest and east/southeast. Therefore, aggregate from the roofs on building "B" in Figure 5-78 likely impacted the tower

glazing. Several of the second-story windows in building "B" were also broken by roof aggregate. Aggregate from the roof of building "C" also likely impacted the tower. Portions of the BUR membrane and some of the wood plank decking on the five-story portion of building "C" also blew off, but there was no indication that membrane or deck debris struck the tower. Aggregate from building "D" may have also impacted the tower. Around the main roof of this seven-story building, there was a parapet in the range of 3 to 4 feet high. Aggregate on this roof was scoured, but because of lack of roof access it was not determined if aggregate was blown from the main roof. However, the parapet on the penthouse roof was about 18 inches high; therefore, aggregate was likely blown from this roof.



Figure 5-78.
The south façade of the 15-story building had a large number of windows broken by aggregate from BURs. Damage was caused by aggregate from roof A, and likely from roofs B and C. Damaging aggregate may have also been blown from roof D (estimated wind speed: 130 mph. Gulfport, Mississippi).

The tower windows were double glazed. Tempered glass was used for the outer pane. At some windows, only the outer panes were broken (the windows in Figure 5-79 that appear black and those that appear white [due to window blinds] are where the outer panes broke and the inner panes are still in place). However, at most of the broken windows, both the outer and inner panes were broken (at these windows, the openings were covered with OSB after the storm). With loss of both panes of glass, wind and water were able to enter the building. Ceiling boards were blown from their support grid and there was significant water damage to interior finishes and furnishings.

At the 15th (top floor), the outer pane at the west end broke, and the inner and outer panes broke at seven other windows as shown at Figure 5-79. As discussed in the ASCE 7 Commentary, during its flight, aggregate blown from roofs can be lifted 30 feet above the roof from which it blew. The 15th floor windows are well above the penthouse roof on the seven-story building "D"; therefore, it is unlikely that the 15th floor windows were broken by aggregate from roofs "A" - "D." The main roof on the tower was also aggregate surfaced. The parapet around this roof was 30 inches high; therefore, aggregate was likely blown from this roof.

Aggregate blown from a roof can be blown back toward the leeward side of the building and cause glazing damage. However, it did not appear that sufficiently strong winds blew from the north to cause glazing damage on the south facade. Some of the 15th floor windows may have been weakened by scratches and failed when over-stressed by wind pressure, which would have been greatest at the top floor.



Figure 5-79.
Another view of the tower shown in Figure 5-78. Roof "A" is shown by the arrow. At the black and white (circled) window areas, the outer pane broke. Temporary OSB enclosures were installed where the inner and outer panes broke (see inset) (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.5.1.2 Downtown New Orleans

Several buildings in downtown New Orleans had isolated window breakage such as that shown in Figure 5-21. These windows may have been broken by windborne debris or they may have been weakened by scratches and failed when over-stressed by wind pressure. However, nine buildings along or near Poydras Street had extensive glazing damage (see Figure 5-80) that was indicative of damage caused by windborne roof aggregate. Except for two of these buildings, virtually all of the glazing damage occurred on the windward facades. These buildings are discussed below.

Cluster A: The buildings in circle A in Figure 5-80 are shown in Figure 5-81. Wind in this area blew from two primary directions, from the north and west. Buildings T1 - T4 and S4 experienced extensive glazing damage. Buildings T1, T2, and S4 are office buildings; T3 is a hotel;

and T4 is a large skylight. These buildings are shown in Figure 5-82, and T2 and T3 are shown in Figure 3-48. Figure 3-29 is a ground-based view of T1, T3, and S4. The white areas at T1 and T3 are where plastic sheeting was installed at broken windows and spandrel panels. The brown areas at T1, T2, and S4 are where plywood was installed after the storm. Figure 5-83 is a close-up view of T1, Figure 5-84 is a close-up view of S4, Figure 5-85 is a closeup view of T2, and Figure 5-86 is a view of T4.

Building S1: This was an aggregate ballasted membrane. The aggregate appeared to be #4 (1-1/2 inch nominal). A stone-protection mat occurred between the aggregate and membrane. Because of lack of roof access, the membrane type could not be definitively determined; however, it appeared to be a modified bitumen membrane. Two rows of concrete pavers occurred around the roof perimeter; they appeared to be about 18 x 18 inches. A band of concrete about 3 feet wide was adjacent to the pavers. The concrete was cast over insulation. At the windward (north) corner, several of the concrete pavers were lifted and broken (see Figure 5-87 inset). It was unclear whether or not pavers or paver fragments were blown off the roof. A substantial amount of aggregate was scoured. Aggregate was ramped against a portion of the parapet (which appeared to be around 12 inches high) adjacent to Poydras Street, but there was no significant windrowing (i.e., piling up) of aggregate. It was therefore apparent that a substantial amount of aggregate was blown from the roof. A few of the metal panels from the equipment screen were blown away and a gooseneck was blown from its curb, but it remained on the roof (see Figure 5-87).

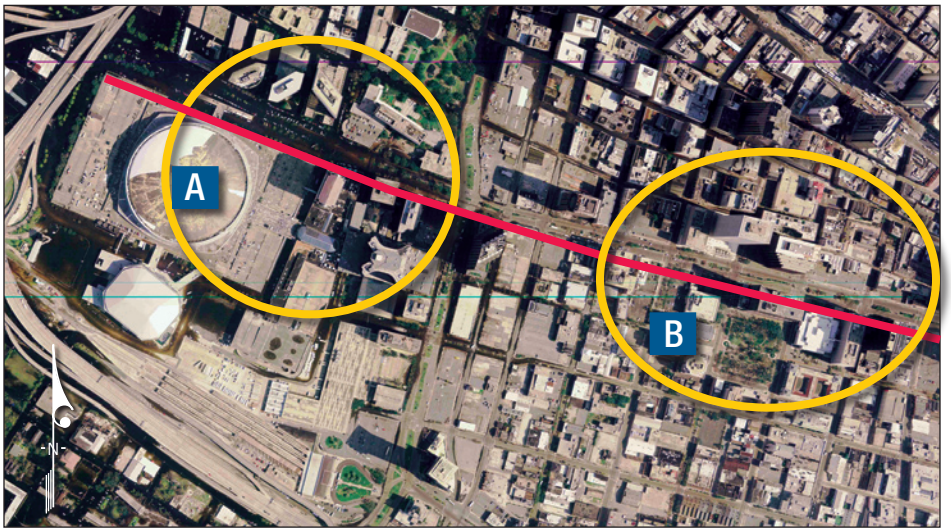


Figure 5-80. General locations of buildings (highlighted by yellow circles) along Poydras Street (highlighted in red) with extensive glazing damage. The Superdome is at the left of the figure. (estimated wind speed: 105 mph. New Orleans, Louisiana.)

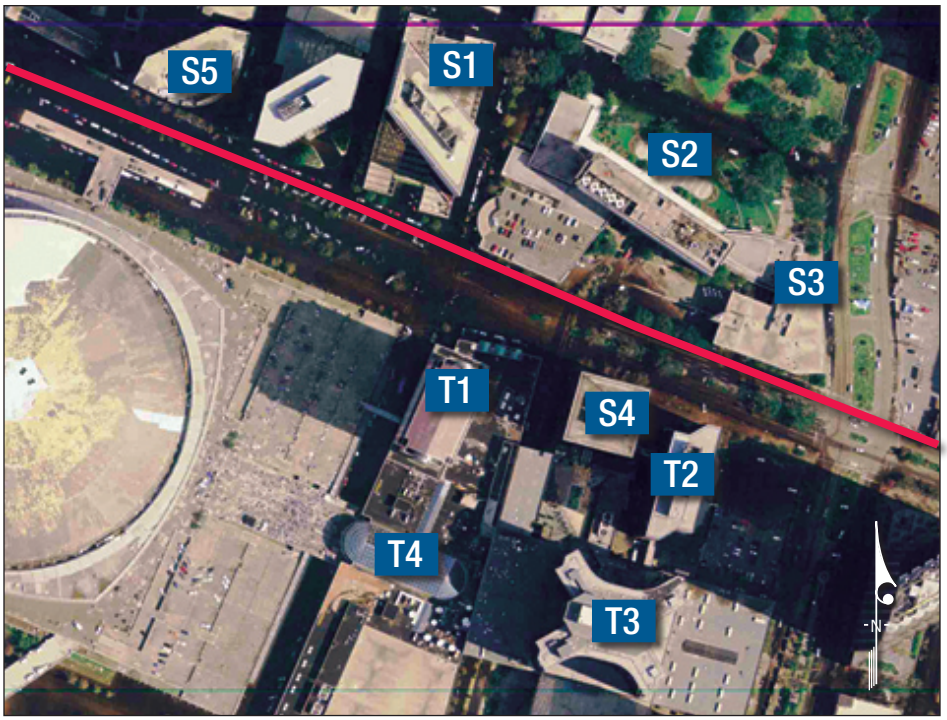


Figure 5-81.
Closeup of Cluster A (estimated wind speed: 105 mph. New Orleans, Louisiana).

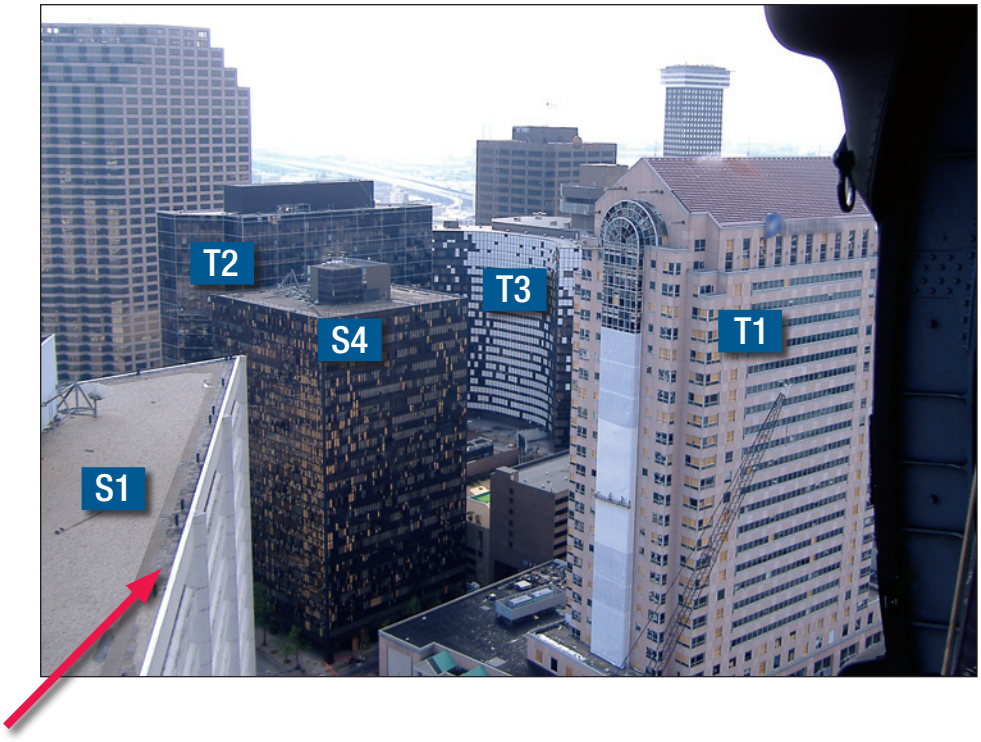


Figure 5-82.
View of glazing damage at T1 - T3 and S4. Building S1 had an aggregate ballasted roof membrane; aggregate from this roof was one of the likely sources of debris (estimated wind speed: 105 mph. New Orleans, Louisiana).



Figure 5-83.
Closeup view of T1 (estimated wind speed: 105 mph. New Orleans, Louisiana).

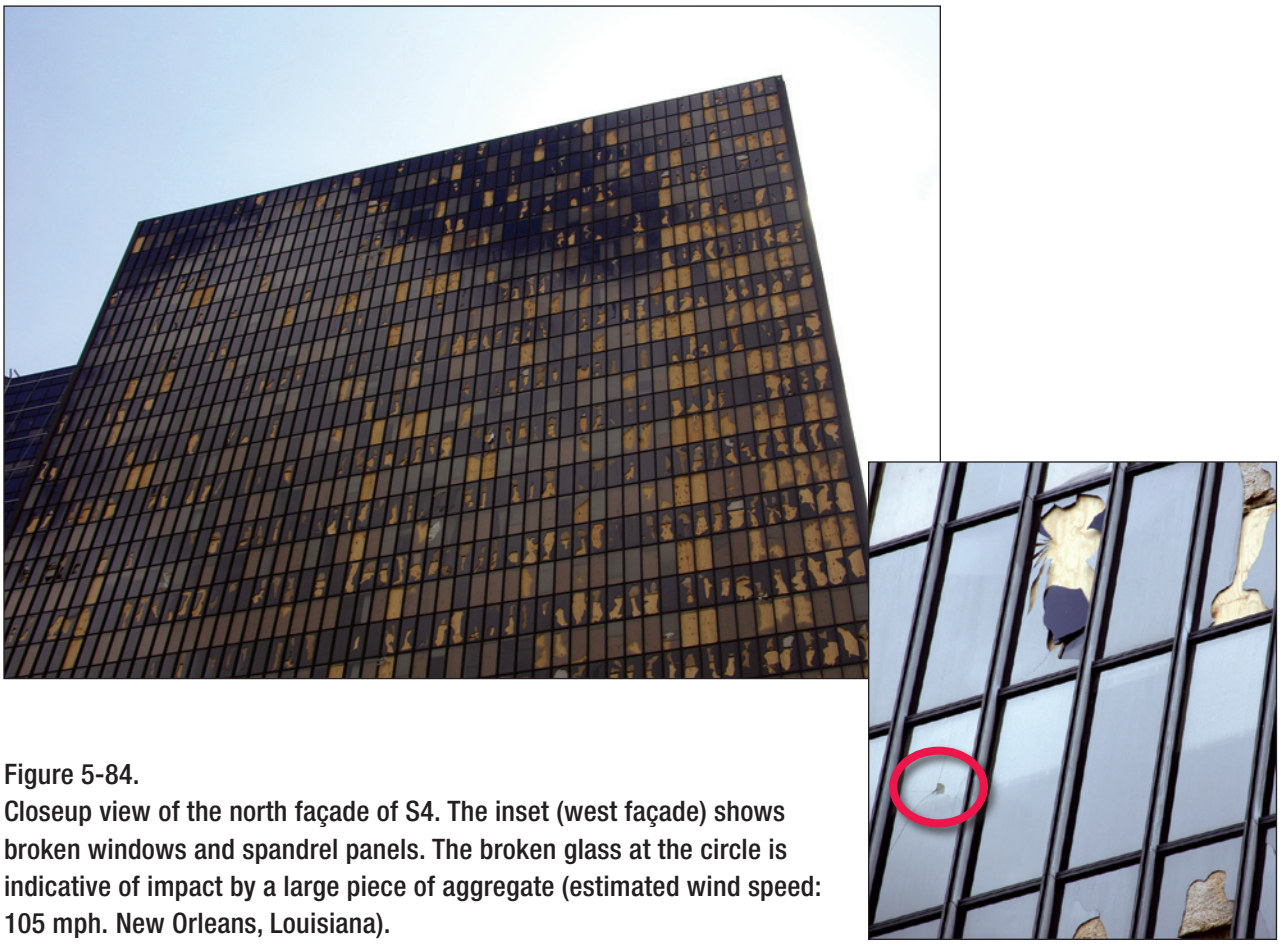


Figure 5-84.
Closeup view of the north façade of S4. The inset (west façade) shows broken windows and spandrel panels. The broken glass at the circle is indicative of impact by a large piece of aggregate (estimated wind speed: 105 mph. New Orleans, Louisiana).

Figure 5-85.
Closeup view of the north and west façades of T2. S4 is to the right. Workers on scaffolds were in the process of removing the broken glass (estimated wind speed: 105 mph. New Orleans, Louisiana).



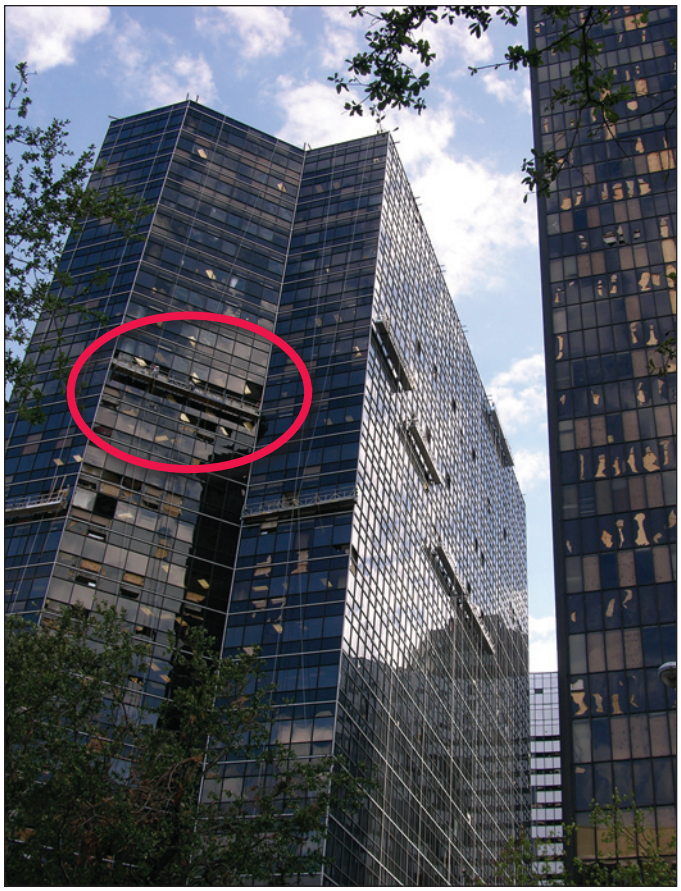


Figure 5-86.
View of skylight T4. The inset is a view from the direction of the red arrow. Large roof aggregate was found in the vicinity of the yellow arrow (estimated wind speed: 105 mph. New Orleans, Louisiana).

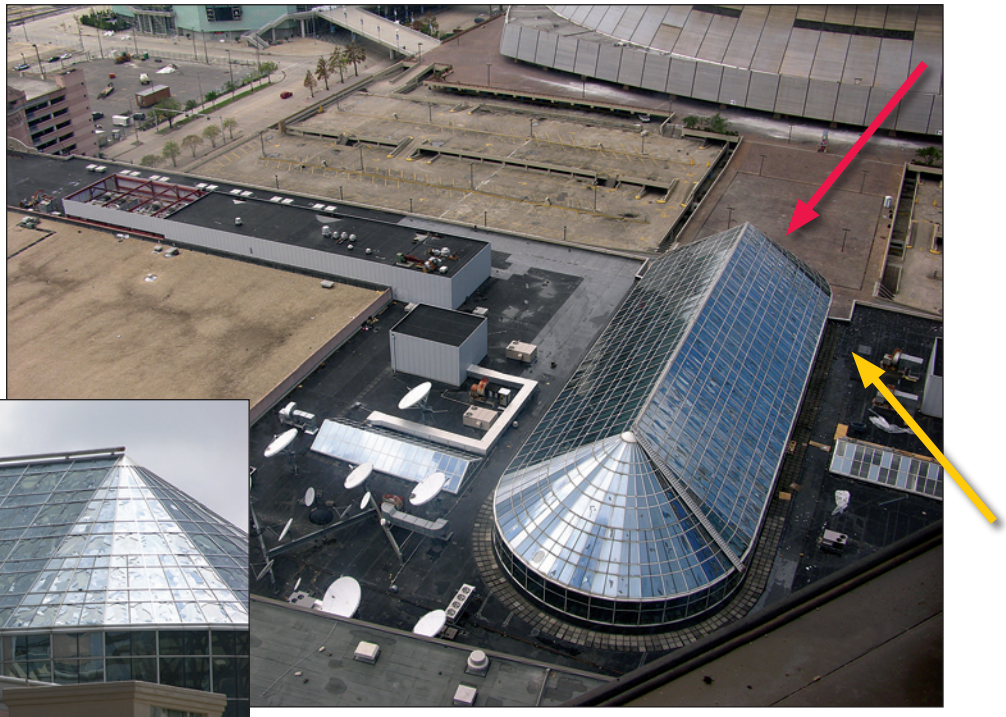






Figure 5-87. Scoured aggregate at Building T1 is shown by the blue arrows. Aggregate was ramped behind the parapet (yellow arrow). A gooseneck lifted from its curb but did not blow away (red arrow). The inset shows displaced pavers and concrete walkway at the windward corner (out of view at the bottom right of the figure) (estimated wind speed: 105 mph. New Orleans, Louisiana).

Potential Number of Aggregate Missiles

The potential number of aggregate missiles per square foot (psf) of roof area is as follows:

BUR: Aggregate surfaced BURs normally have a minimum of 4 pounds of aggregate per square foot. About 2 pounds of the aggregate per square foot is typically embedded in the flood coat; therefore, about 2 per square feet of loose aggregate are susceptible to blow-off. The standard for BUR aggregate (ASTM D 1863) includes three aggregate sizes. Depending upon the size of aggregate and gradation, the number of loose aggregates is likely in the range of 225 to 450 per square foot.

Ballasted systems using #4 aggregate: ANSI/SPRI RP-4 specifies a minimum of 10 pounds per square foot. Depending upon gradation, as a lower bound the number of loose aggregates is likely in the range of 80 per square foot.

ANSI/SPRI RP-4 provides aggregate ballast design tables for building heights up to 150 feet. Above that height, RP-4 states that "the roof design shall be based on an expert's design method and approved by the authority having jurisdiction." This building has 27 stories; therefore, it is well above the 150-foot height addressed in RP-4.

S1 is about 315 feet from T1, about 590 feet from T2, about 760 feet from T3, and about 400 feet from T4. S1 was a likely source of aggregate debris that impacted T1, T4, and S4 and aggregate from S1 may have impacted T2 and/or T3.

Building S2: This was an aggregate surfaced BUR with a parapet that appeared to be about 12 to 18 inches high. Aggregate from this roof was a likely source of debris that impacted T2 and S4, and aggregate from S2 may have impacted T3. S2 has 10 stories; therefore, it is unlikely that aggregate from this building struck above the upper half of T2, T3, and S4.

Building S3: This four-story building had an aggregate surfaced BUR with a parapet that appeared to be about 12 inches high. The roof was scoured and it appeared that a substantial amount of aggregate blew off. Because of the wind directions, some aggregate may have hit T2, but it is unlikely that other buildings in Cluster A were impacted.

Building S4: This was an aggregate surfaced BUR with a parapet that appeared to be about 18 to 24 inches high. This building is about the same height as the 27-story hotel (T3). Virtually all of the main roof was scoured and it appeared that a substantial amount of aggregate blew off. Aggregate was ramped along the south parapet (see Figure 5-88). The roof on the penthouse (red arrow in Figure 5-88) did not have a parapet. It appeared that all of the loose aggregate was blown from the penthouse roof. Equipment screen wall panels were blown toward the south (yellow arrow in Figure 5-88) and east. The north and east support structure for the screen walls collapsed. Two exhaust fan cowlings were also blown away.

T1 is at the top of Figure 5-88, T3 is to the left, and T2 is at the bottom (both T2 and T3 are out of view). Aggregate from S4 was a likely source of debris that impacted T2 and T3. Aggregate from S4 also likely impacted the east wall of this building.

Building S5: This was an aggregate surfaced BUR (see Figure 5-89). There was a parapet (which appeared to be about 2 feet high at the low point) around the main roof, but there was no parapet around the penthouse. This building is approximately the same height as S1. S5 is about 670 feet from T1 and about 840 feet from T4. Aggregate from S5 was a possible source of aggregate debris that impacted T1 and T4, and aggregate from S5 may have impacted some of the other buildings.

Buildings T1, T2, and T3: These buildings did not have aggregate roof surfacings.

Cluster B: The buildings in circle B in Figure 5-80 are shown in Figure 5-90. (Note: The buildings in cluster A are relatively close together, whereas the cluster B buildings are spread out over a few blocks.) Although not as extensively damaged as the cluster A buildings, office buildings T5 - T8 experienced notable glazing damage.



Figure 5-88.
View of the roof of S4. Note the glazing damage on the east side of S4 (bottom of figure). Equipment screen wall panels landed on a lower roof (yellow arrow). The penthouse roof (red arrow) did not have a parapet (estimated wind speed: 105 mph. New Orleans, Louisiana).



Figure 5-89.
Aggregate was scoured on the main roof of Building S5 and blown from the penthouse (red arrow). The building to the left of S5 did not have an aggregate surfaced roof, nor did the lower roofs of the Superdome (estimated wind speed: 105 mph. New Orleans, Louisiana).

Building T5: Several windows on the west façade of this 11-story building were broken (see Figure 5-91). A few isolated breaks occurred on the north and east façades. BURs occurred in the vicinity, but a likely source of aggregate debris was not definitively determined.

Building T6: Several windows were broken on the north façade (see Figure 5-92). The likely sources of debris were the aggregate surfaced roofs on S6, which is directly across the street from T6 (see Figure 5-93). The narrow stair-stepped roofs (see Figure 5-94) appeared to be aggregate ballasted single-ply membranes. Metal roof panels were also blown from S6 and may have caused some of

the glazing damage. At least 20 windows on the west façade of T6 were also broken (in most cases, only the outer pane broke). The debris source for the west façade was not determined.

Building T7: This high-rise building is shown in Figure 5-93. It had sloped glazing that was sloped to the east (see Figure 5-95). Several of the outer panes of the sloped glazing were broken. Inner panes may have also been broken where plywood was installed after the hurricane. Several of the vertical windows adjacent to the sloped glazing were broken as well as a few windows on the east façade of the tower. A few windows were also broken on the north and south façades. The main roof and one of the stair-stepped roofs had ballasted single-ply membranes. A stone-protection mat occurred between the aggregate and membrane. Some aggregate was ramped against a portion of the west parapet. A substantial amount of aggregate was scoured and blown from the main roof (see Figure 5-96). The parapet appeared to be about 3 feet high. Aggregate from the main roof was the likely source of debris that broke the sloped glazing and nearby windows.

Building T8: Several windows were broken on the north façade (see Figure 5-97). The debris source was not determined. One window was broken on the west façade and a few were broken on the east façade. The roof of this building was not aggregate surfaced.

The cost associated with the damaged glazing was enormous. In addition to the cost of repairing the damaged glazing and the wetted and wind-swept building interiors, the cost of business interruption was significant. Also, the potential for falling glass presented a significant life-safety threat to workers removing the broken glass. Pedestrians were also at risk.

This was the most significant glazing damage in an urban area since Hurricane Alicia struck Houston in 1983. Several high-rise buildings experienced extensive glazing damage during that

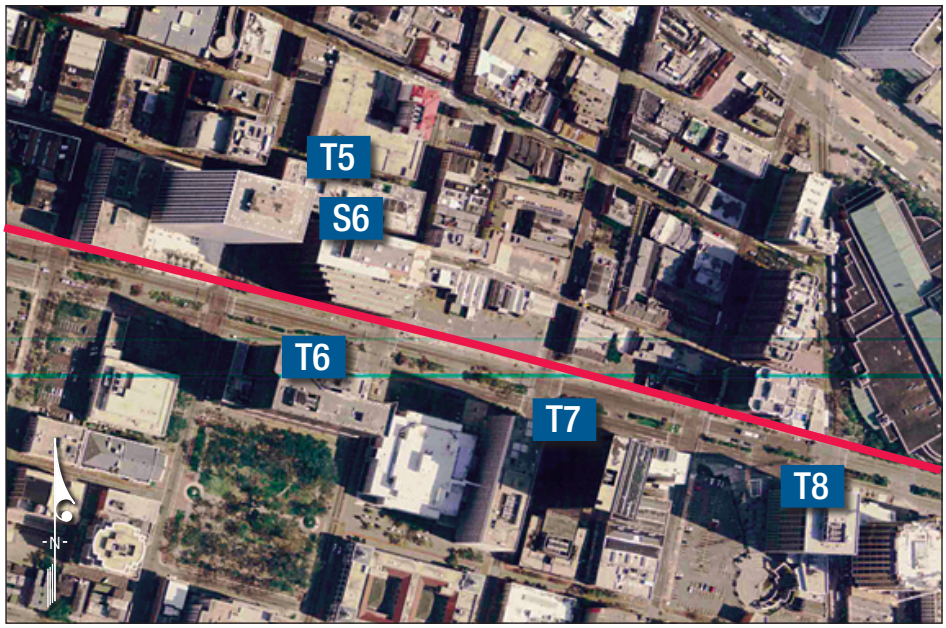


Figure 5-90. Closeup of Cluster B (estimated wind speed: 105 mph. New Orleans, Louisiana).



Figure 5-91.
View of the west façade of T5. The tallest building in New Orleans is at the right (estimated wind speed: 105 mph. New Orleans, Louisiana).

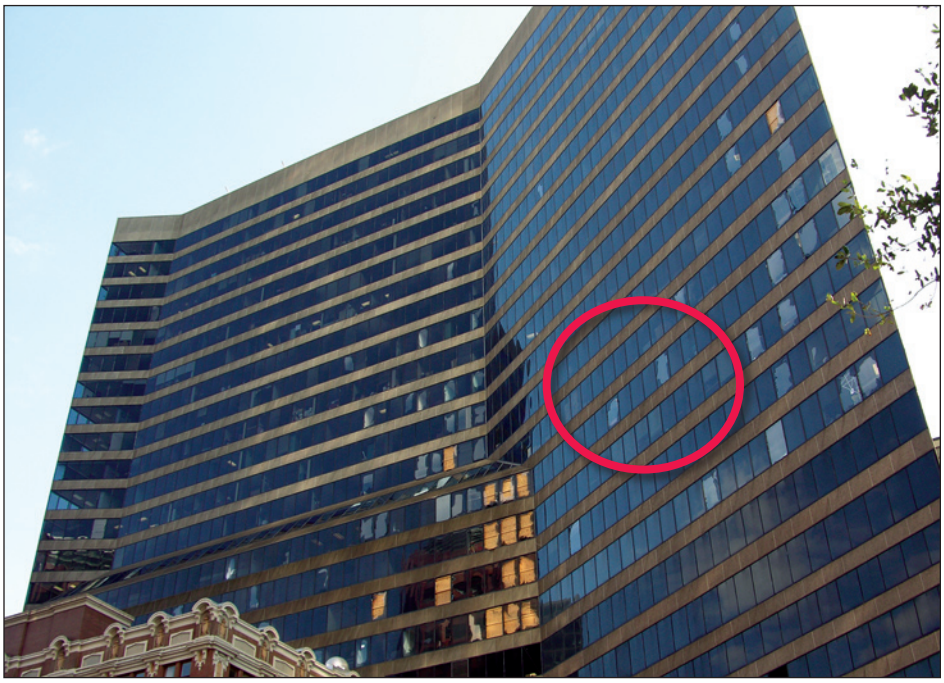


Figure 5-92.
General view of T6. Plywood had been placed where the inner and outer panes had been broken. At most of the broken windows, only the outer pane broke (red circle). The building at the lower left did not have an aggregate roof surface (estimated wind speed: 105 mph. New Orleans, Louisiana).

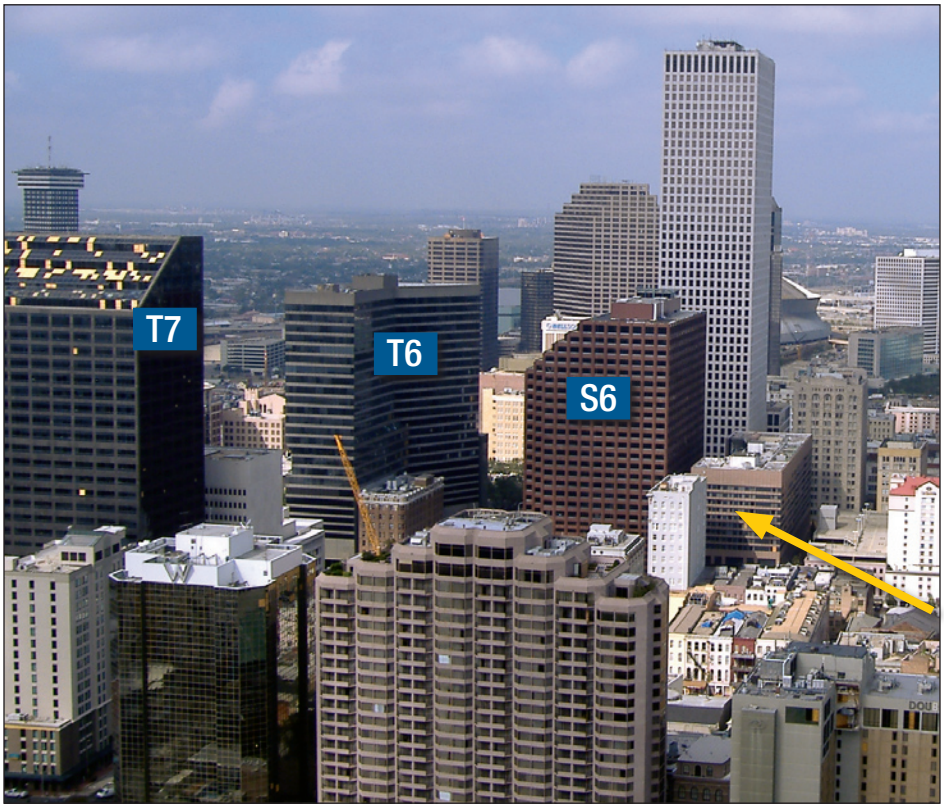


Figure 5-93.
General view of S6, T6, and T7. The east façade of T5 is shown by the arrow (estimated wind speed: 105 mph. New Orleans, Louisiana).

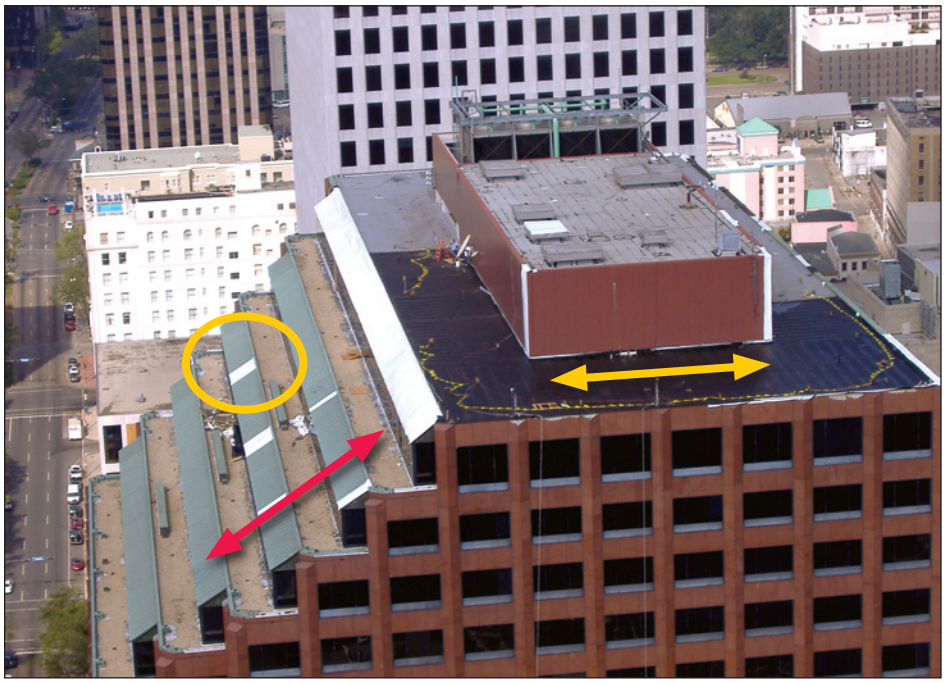


Figure 5-94.
The stair-stepped roofs of S6 (red arrow) were aggregate surfaced. Some of the metal roof panels had also blown away (yellow circle). The black area (yellow arrow) is a roof membrane installed after the hurricane (estimated wind speed: 105 mph. New Orleans, Louisiana).

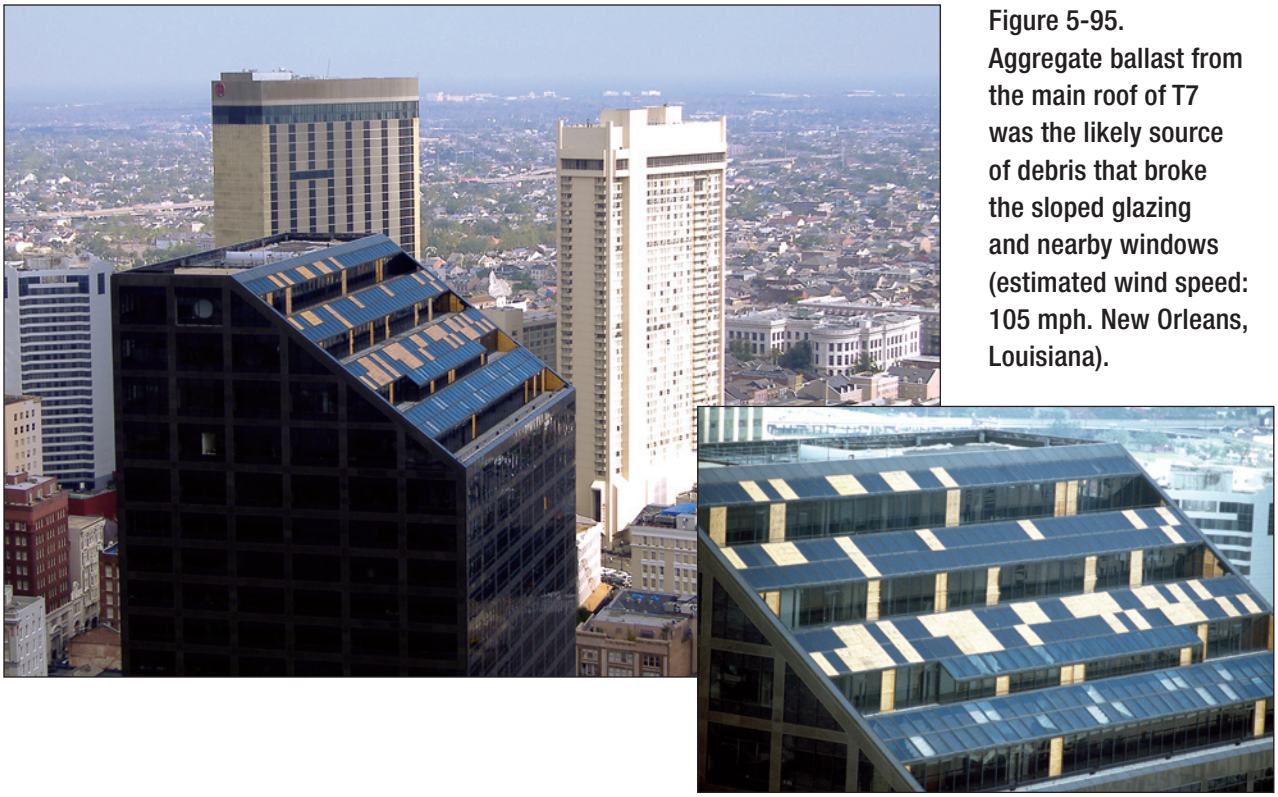


Figure 5-95.
Aggregate ballast from the main roof of T7 was the likely source of debris that broke the sloped glazing and nearby windows (estimated wind speed: 105 mph. New Orleans, Louisiana).



Figure 5-96.
Aggregate ballast was scoured and blown from a large portion of the T7 roof. Aggregate also occurred at one, but not all of the stair-stepped roofs (yellow arrow) (estimated wind speed: 105 mph. New Orleans, Louisiana).

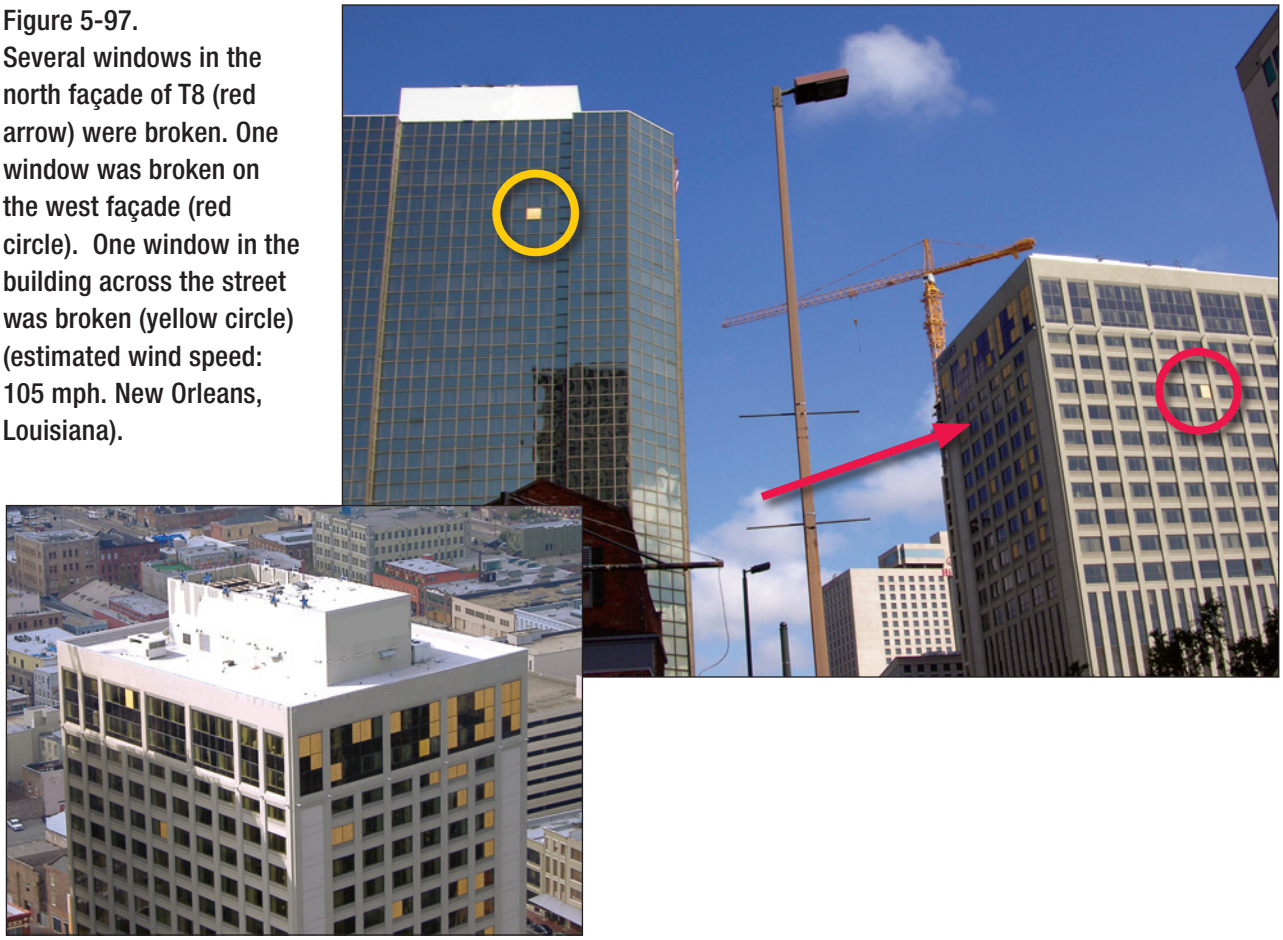


Figure 5-97. Several windows in the north façade of T8 (red arrow) were broken. One window was broken on the west façade (red circle). One window in the building across the street was broken (yellow circle) (estimated wind speed: 105 mph. New Orleans, Louisiana).

hurricane. *Hurricane Alicia, Galveston and Houston, Texas, August 17 – 18, 1983* (published in 1984 by the Committee on Natural Disasters, National Research Council) attributed the majority of the damage to windborne aggregate from BURs and subsequent cascading.[5] The phenomenon of glass breakage caused by windborne roof aggregate has been documented at least as far back as 1970 when Hurricane Celia struck the Corpus Christi area. For further information on this issue, Minor, Joseph E., "Lessons Learned from Failures of the Building Envelope in Windstorms," *Journal of Architectural Engineering*, March 2005, pp. 10 – 13.

5.5.2 Protected Glazing

The MAT observed shutters on a few residential, commercial, and critical and essential buildings. However, shuttering was not as prevalent as in the areas impacted by Hurricanes Charley, Frances, and Ivan in 2004. The greater use of shutters in Florida versus Alabama, Louisiana, and Mississippi was likely due to Florida's building code requirement for protected glazing and greater public awareness of the benefits provided by shutters.

[5] If debris breaks a window, as pieces of the broken glass fall they in turn can become windborne debris. This glass debris may then strike other windows and generate additional debris. Some of the Hurricane Katrina glazing damage was also likely due to cascading.

A variety of shutters were observed. They were made of wood sheathing, metal panels, polycarbonate, or plastic panels of various designs. Figure 5-98 shows the use of inexpensive pre-cut OSB shutters to protect storefront glazing. Because wood sheathing shutters are not pre-engineered, it is important that they be adequately anchored to avoid blow-off. Prescriptive anchoring requirements are provided in the IBC. Other examples of shutters are shown in Chapter 9.



Figure 5-98. Pre-cut OSB shutters (estimated wind speed: 115 mph. Slidell, Louisiana)

A few shutter problems were observed. At the house shown in Figure 5-99, several of the roll-up shutter slats disengaged from their tracks. Because the shutter was not labeled, it was not possible to determine if the shutter had been tested in accordance with the standard referenced in ASCE 7. At the house shown in Figure 5-100, the shutter did not completely cover the glazing. One of the windows the shutter was protecting was broken. This illustrates the importance of completely protecting the glazing. Other potential problems are illustrated at the new house shown in Figure 5-101. Although the main entry doors and some of the lower-level windows were shuttered, not all of the glazing was protected. In addition, the swinging shutters were very susceptible to being blown open due to use of very weak latches.

The MAT observed a few cases where shutters were impacted by debris and were effective in preventing glass breakage (see Figure 9-19).

5.5.2.1 Laminated Glass

The MAT observed some laminated glass that had been impacted by debris. Except for the window shown in Figure 5-102, this glazing occurred in skylights as discussed in Section 5.5.5. When laminated glass breaks, the glass remains bonded to the plastic film between the panes, and the glazing remains in the frame. Although the glass will need to be replaced, costly interior water and wind damage is avoided.



Figure 5-99.
Shutter slats detached from their tracks (estimated wind speed: 110 mph. Meraux, Louisiana)



Figure 5-100.
This plastic shutter did not completely cover the window. The lower window was broken (estimated wind speed: 105 mph. Pascagoula, Mississippi).



Figure 5-101.
Metal shutters were over the main doors, and swinging wood shutters were over the larger first floor windows. However, several windows were unprotected (yellow arrows). The shutter latch (inset) was susceptible to unlatching. Note the wood sheathing debris (yellow circle) (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 5-102.
The laminated glass broke, but remained in the frame and continued to provide wind and water protection (estimated wind speed: 105 mph. New Orleans, Louisiana).

5.5.2.2 Tempered Glass

Tempered glass is somewhat more resistant to windborne debris than common glazing. However, tempered glass does not meet the debris testing requirements in ASCE 7. Tempered glass is not considered to be windborne debris-resistant because it can easily be broken by small debris such as aggregate from built-up roofs (Figure 5-78). When tempered glass breaks, it shatters into small pieces and falls out of the frame. Wind-driven rain could then be driven into the

building and substantially increase the internal pressure. The MAT observed broken tempered glass at several buildings.

5.5.3 Over-Pressurization

Glazing damage is normally caused by windborne debris impact; however, windows can also be broken by over-pressurization via either high negative or positive wind loads. Glazing in older doors and windows is more susceptible to wind load damage because older glazing is often weakened by scratches. In addition, many older windows and glazed doors were installed when little attention was given to wind resistance. Surprisingly, at new residences under construction in Louisiana and Mississippi, the MAT found very few windows with wind pressure rating labels (see Figure 5-103). The windows typically only had labels pertaining to energy performance. This contrasts sharply to the Hurricane Charley and Ivan MAT observations, wherein all of the windows in houses under construction had pressure rating labels. Unless window and glazed doors assemblies are tested and labeled, the units' resistance to wind pressure is unknown.

At an older wing of a hospital in Gulfport, several window frames failed due to wind pressure (see Figure 5-104). Some of the glazing on the floors below were broken by pressure or debris. As discussed in Section 5.5.1, approximately 400 windows and spandrel panels were broken at this facility. This building was also damaged during Hurricane Camille.

Frame failure due to wind pressure caused the loss of several windows in the office building shown in Figure 5-105.

An unusual glazing failure is shown in Figure 5-106. This older brick building had been re-skinned with a curtain wall system. As part of the re-skinning, wood nailers had been attached

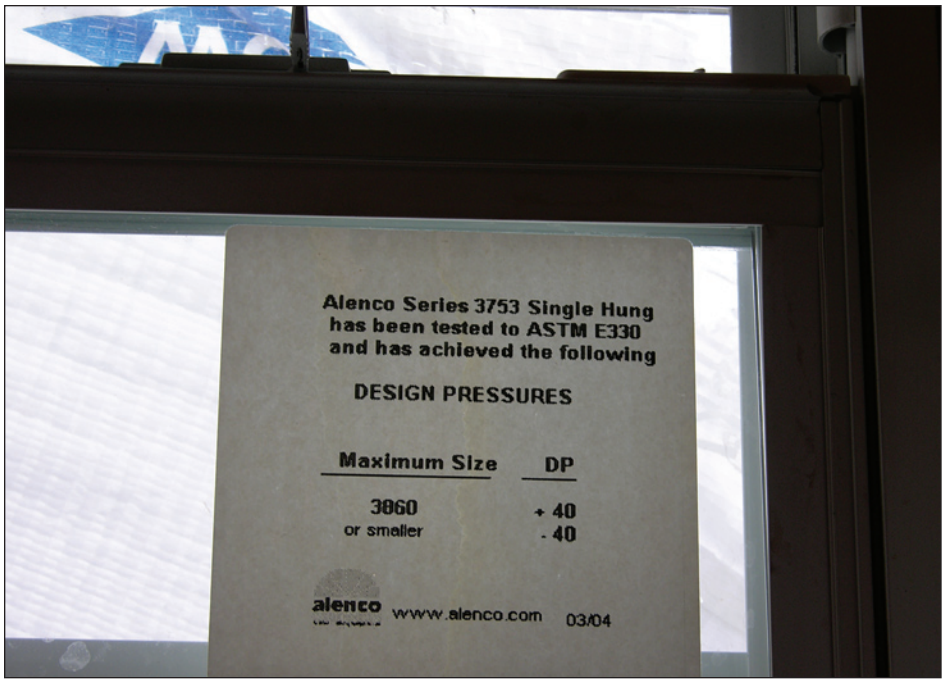


Figure 5-103. View of a wind pressure rating label at a house under construction. The windows on most of the houses observed did not have pressure labels (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

to the brick to provide anchorage for the curtain wall. A large number of spandrel panels were blown away. Several of the nailers had detached from the brick at the areas shown by the yellow circle and arrow. At the other missing spandrels, the panels had detached from the nailers.

At a relatively new school in Gulfport, Mississippi, a large window unit was blown into the corridor (Figure 3-58). The window failed because the head frame was not anchored to the structure.



Figure 5-104. The window frames on the upper floor failed (red arrow). Some of the windows on the lower level were broken by pressure or debris (estimated wind speed: 130 mph. Gulfport, Mississippi).

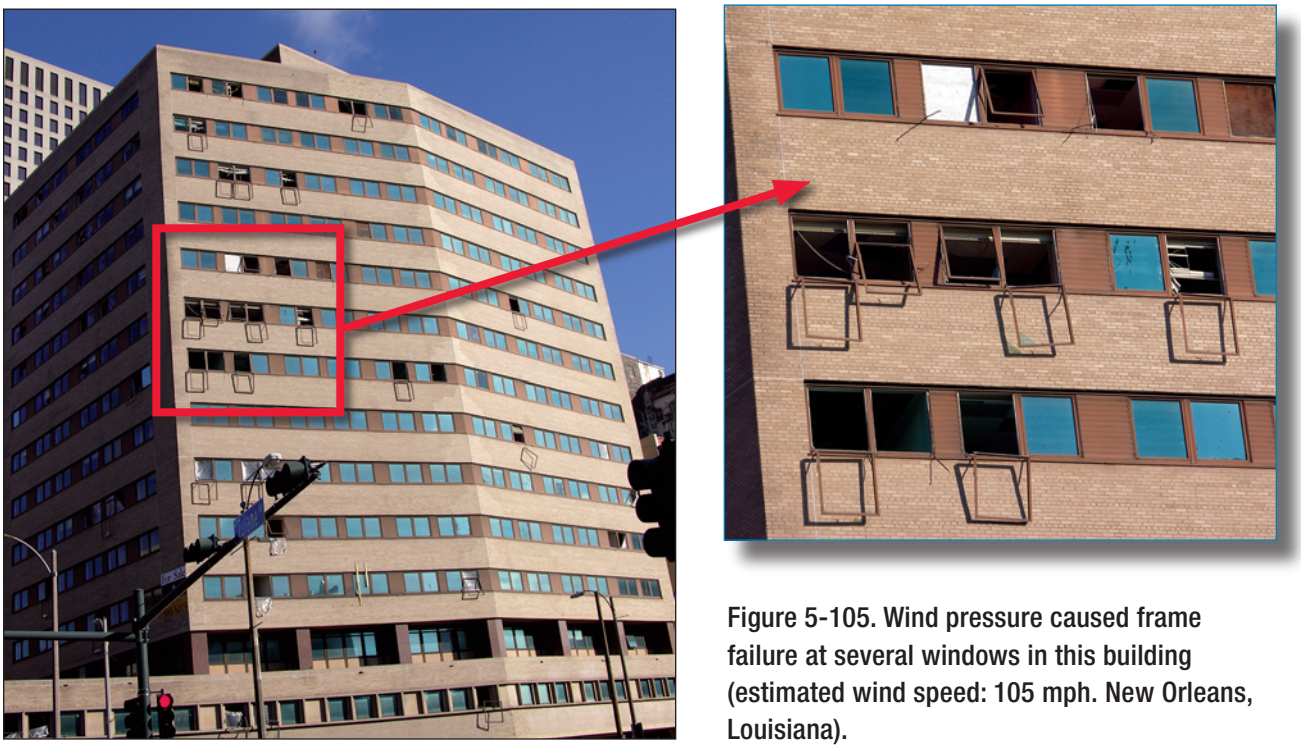


Figure 5-105. Wind pressure caused frame failure at several windows in this building (estimated wind speed: 105 mph. New Orleans, Louisiana).

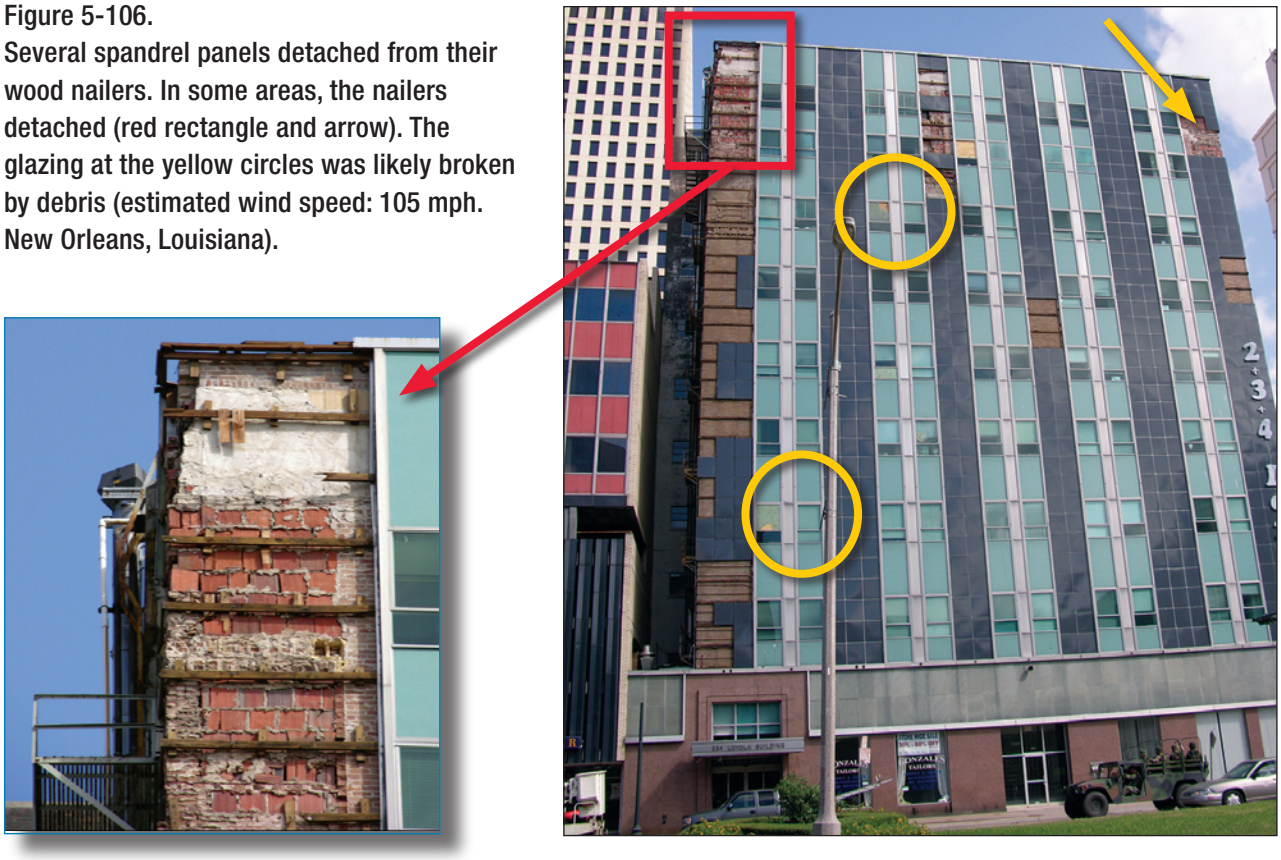


Figure 5-106.
Several spandrel panels detached from their wood nailers. In some areas, the nailers detached (red rectangle and arrow). The glazing at the yellow circles was likely broken by debris (estimated wind speed: 105 mph. New Orleans, Louisiana).

Although the jambs were anchored, those attachments were insufficient to resist the loads. A similar window unit at another corridor nearly collapsed. Its head was pushed inward about an inch. This failure was due to lack of attention to design and construction.

5.5.4 Installation

The MAT commonly observed window installation problems at houses under construction. The problems pertained to attachment and flashing. For example, at the house that had the windows with the pressure rating labels (see Figure 5-103), the manufacturer recommended attaching the nailing flange at 12 inches on center maximum. For one of the windows that was investigated, this would have required five nails at the head and sill, and six nails at each jamb. However, only two nails were installed at the head (siding prevented observation of the sill nailing) and only five were installed at the jambs. At another house, nails were spaced 21-1/2 inches apart at one area (a 12-inch spacing was likely the recommended maximum). At still another house, staples were used to attach the nailing flange even though the manufacturer recommends nails.

The window nailing flanges were not properly flashed to the housewrap at most of the observed windows. In several instances, self-adhering modified bitumen flashing tape was not installed. In other cases, the tape had been installed but improperly lapped. Flashing deficiencies do not directly affect wind performance, but they can have significant indirect influence. If water leaks past the window frame/housewrap interface, the studs and/or wood sheathing can be rotted. The window can be blown away during a storm if the framing is rotted.

5.5.5 Skylights

A few skylights with glass panes were observed, including the large skylight shown in Figure 5-86. These skylights were double-glazed. The outer panes were normal glass and the inner panes were laminated glass. Laminated glass is used for the inner panes in skylights to avoid occupant injury in the event the glazing breaks. Figure 5-107 shows a skylight in the vicinity of the skylight shown in Figure 5-86. At least six of the laminated panes were broken. Three other windows were broken, but these breaks appeared to be in the outer panes.

As discussed in Section 5.5.2, although the inner and outer panes were broken, the laminated glass avoided costly interior water and wind damage. However, unless the outer panes are also laminated, if the outer panes are broken, the shards become windblown debris (see Figure 5-108).

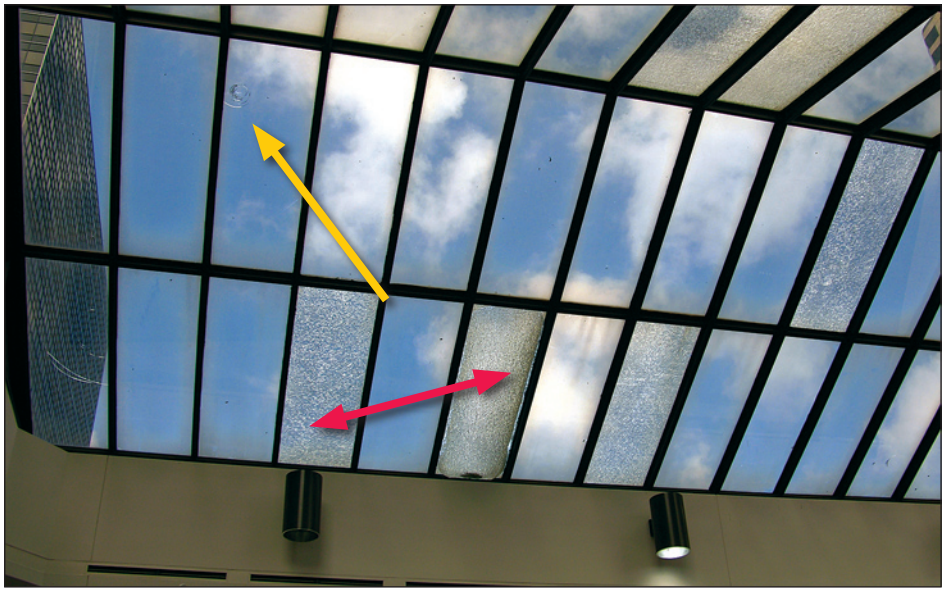


Figure 5-107. Six of the inner laminated panes were broken (two of them are shown by the red arrow). Three other breaks appeared to be at the outer panes (one of these is shown by the yellow arrow) (estimated wind speed: 105 mph. New Orleans, Louisiana).



Figure 5-108. Skylight on a new eight-story Federal courthouse. Two of the outer panes were broken. Windborne shards can cause injury and damage buildings and vehicles (estimated wind speed: 130 mph. Gulfport, Mississippi).

Performance problems were also observed with plastic-domed skylights. In some instances, the plastic dome was broken by windborne debris and in other instances skylight frames were blown from their curbs. Unlike the laminated skylights, the plastic dome skylight failures resulted in significant rainwater entry.

5.6 Exterior-Mounted Mechanical, Electrical, and Communications Equipment

The MAT observed many damages to mechanical and electrical devices mounted on the exterior of buildings. The following factors are essential to good high-wind performance of exterior mechanical and electrical equipment: determining design wind loads on equipment and designing suitable attachments to resist the loads; special anchoring of fan cowlings and access panels; and special design of lightning protection systems (LPS) anchorage. Guidance for these design factors is provided in the Hurricane Katrina Recovery Advisories on rooftop equipment and lightning protection systems in Appendix E.

Commercial and critical and essential facilities typically have a wide variety of mechanical and electrical equipment attached to their rooftops and elsewhere. Residences also frequently have rooftop equipment. In addition, condensers are also frequently mounted at grade or on elevated platforms in floodprone areas. Equipment lost as a result of Hurricane Katrina included condensers, combustion air louvers (Figure 3-60) relief air hoods, ducts, fan units and HVAC units, electrical and communications equipment, and LPS. Several effects occur due to loss of this equipment: in many instances, the displaced equipment left large openings through the roof and/or punctured the roof membrane; equipment loss often affected the operational functions of the facilities; and blown-off equipment became high momentum windborne debris in some cases. The equipment observed on critical and essential facilities was typically not anchored more effectively than the equipment on common commercial buildings.

5.6.1 Mechanical Equipment

5.6.1.1 Condensers

Condensers should be elevated in floodprone areas. Condensers at many residences observed by the MAT were supported on cantilevered platforms as shown in Figures 9-18 and 5-109. As discussed in Section 9.5.1, cantilevered platforms are preferable over knee-braced or pile-supported platforms. Several condensers were blown from their platforms because they were not anchored or had insufficient anchorage. Cantilevered platforms are preferred because they are less susceptible to damage from floodborne debris impacts than are pile or knee-braced supported platforms.

Outside of flood-prone areas, condensers are normally mounted at grade or on rooftops. Both grade- and roof-mounted condensers were typically not anchored or were insufficiently anchored as shown in Figures 5-110 and 5-111. Figure 5-112 shows one of the few buildings

observed by the MAT where special attention had been given to condenser attachment. These condensers remained attached to the structural steel equipment support stands, thereby avoiding damage to the condensers and the roof membrane.



Figure 5-109.
One of the condensers was blown off this cantilevered platform (estimated wind speed: 120 mph. Shell Beach, Louisiana).



Figure 5-110.
Inadequately attached condenser at the police station shown in Figure 3-54 (estimated wind speed: 130 mph. Long Beach, Mississippi).



Figure 5-111.
These displaced condensers had been placed on wood sleepers that rested on the roof membrane. Sleepers do not provide resistance to uplift or lateral wind loads (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 5-112.
The condensers on this new medical office building were anchored to structural steel equipment support stands (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.6.1.2 Fan Units and HVAC Units

As frequently observed following previous hurricanes, many fan and HVAC units were damaged. In several cases, the units were blown off the curbs because too few fasteners were used to attach the units to the curbs. The blown-off exhaust fan on the school in Figure 5-113 had been attached with only two screws. Had the fan been attached in accordance with the guidance in the Hurricane Katrina Recovery Advisory, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix E), there would have been five screws per side. Although the opening through the roof was small, a substantial quantity of rainwater was able to enter the school. Because of Katrina's widespread damage, this opening remained unprotected for more than a month after the storm.

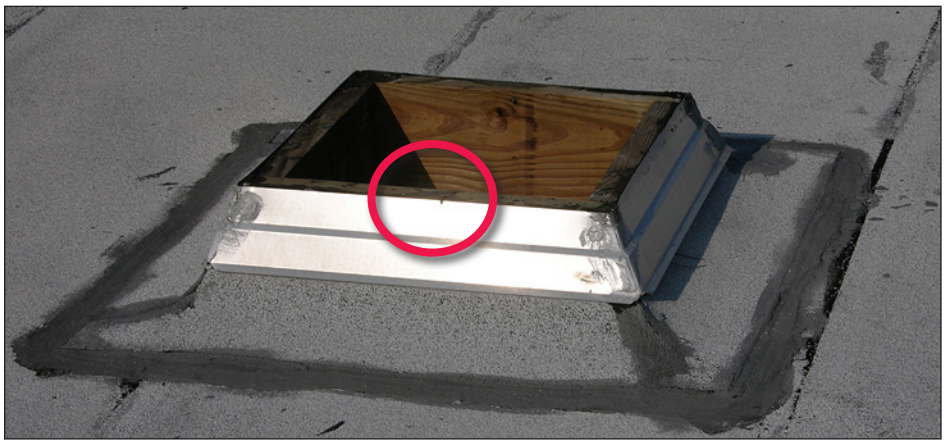


Figure 5-113.
The missing exhaust fan was attached with only two screws, one of which just grazed the top of the nailer (red circle). The screw that engaged the nailer was sheared off (estimated wind speed: 125 mph. Waveland, Mississippi).

In many other cases, the fans remained attached to their curbs, but the cowlings were blown away (see Figure 5-114). The Hurricane Katrina Recovery Advisory, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix E), provides guidance for jobsite strengthening of cowlings. Another fan near the one shown in Figure 5-114 was struck and damaged by windborne debris (see Figure 7-18). At least for critical and essential facilities, this illustrates the benefits of placing rooftop mechanical equipment in penthouses so that the equipment is protected from debris and remains operational.

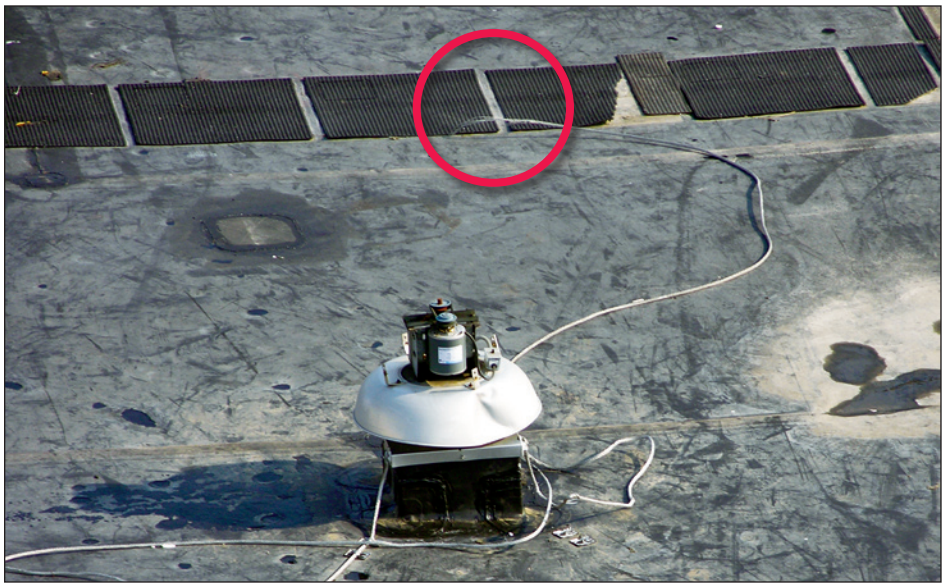


Figure 5-114.
At this hospital, the cowling was blown off the exhaust fan. Note also the loose LPS conductors (red circle, Figure 5-123) and missing walkway pads (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.6.1.3 Ductwork

Rooftop-mounted ductwork was observed on a few buildings. At the building shown in Figure 5-79, portions of the ductwork were blown away as shown in Figure 5-115. The ducts rested on top of steel support channels. At the time of the MAT's observation, the openings through the roof had been unprotected for nearly a month after the storm.

At the recently constructed 13-story building shown in Figure 3-44, the main duct runs were not damaged during this hurricane (see Figure 5-116). However, ducting on either side of a fan was blown away (see Figure 5-117). The main duct support frames were spaced at 8 feet on center. The frames were made from 1-1/2 x 1-1/2 x 1/8-inch thick angles. The frames were bolted together. The top horizontal angle was about 7/8 inch above the ducts.

Other than the guidance provided in the Hurricane Katrina Recovery Advisory, *Attachment of Rooftop Equipment in High-Wind Regions* (Appendix E), very little wind design guidance is available for rooftop-mounted ductwork.

5.6.1.4 Vibration Isolators

A particular type of vibration isolator was observed on a few new buildings. The isolator's design provided lateral resistance, but no uplift resistance. Because of the lack of uplift resistance, the equipment shown in Figure 3-61 was lifted up and blown away. Rainwater was able to enter the building at the duct openings through the roof. This same vibration isolator design was used on a lower roof of the building shown in Figure 5-116. At the equipment shown in Figure 5-118, the equipment was not blown away, but it was lifted up and three of the four springs were blown away. When equipment is mounted on vibration isolators, the isolator design needs to provide both lateral and uplift resistance, or an alternative means to accommodate lateral and uplift loads needs to be provided.

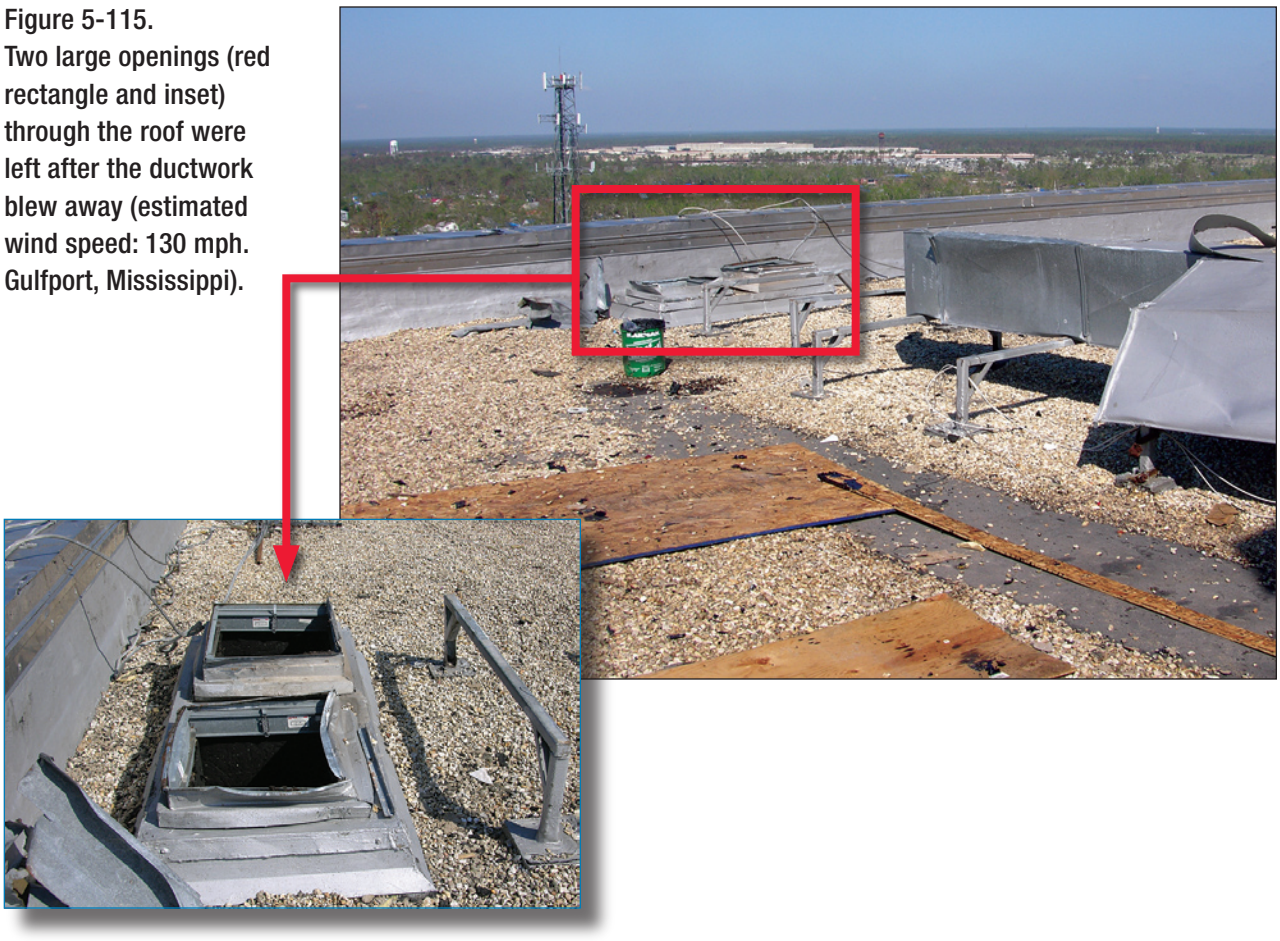


Figure 5-115. Two large openings (red rectangle and inset) through the roof were left after the ductwork blew away (estimated wind speed: 130 mph. Gulfport, Mississippi).

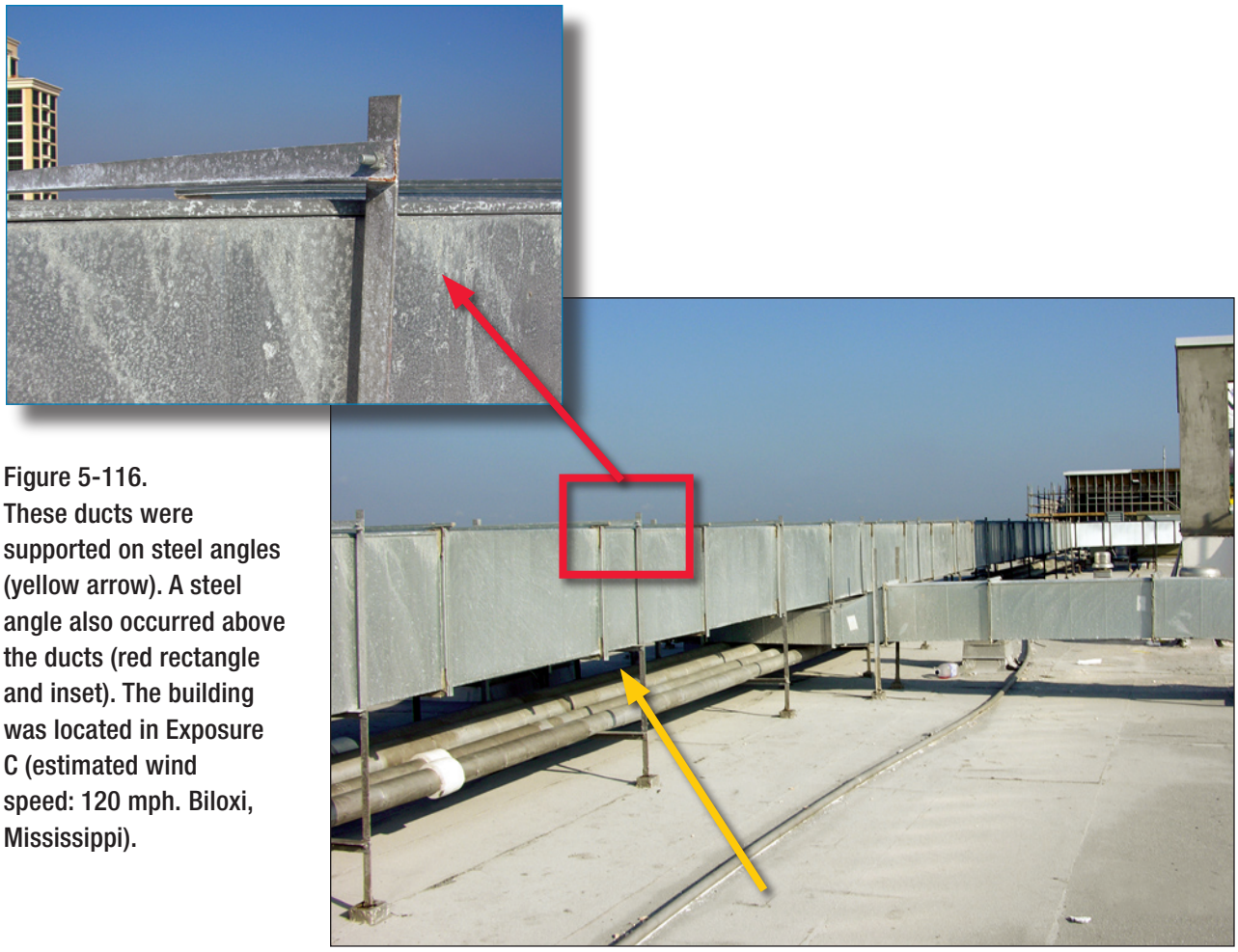


Figure 5-116.
These ducts were supported on steel angles (yellow arrow). A steel angle also occurred above the ducts (red rectangle and inset). The building was located in Exposure C (estimated wind speed: 120 mph. Biloxi, Mississippi).



Figure 5-117.
Opposite view of Figure 5-116. The ducting on either side of the fan was blown away (red arrows) (estimated wind speed: 120 mph. Biloxi, Mississippi).

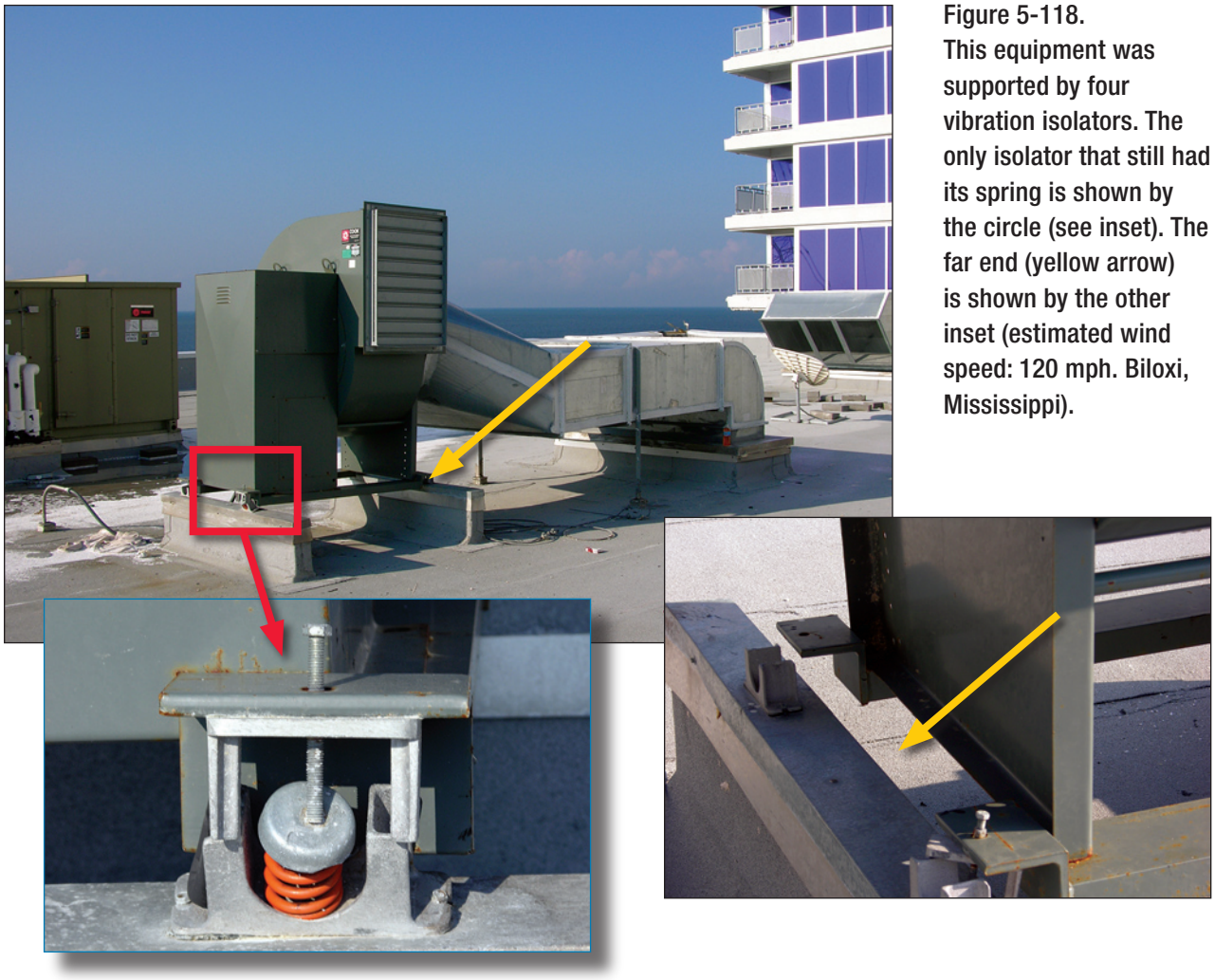


Figure 5-118. This equipment was supported by four vibration isolators. The only isolator that still had its spring is shown by the circle (see inset). The far end (yellow arrow) is shown by the other inset (estimated wind speed: 120 mph. Biloxi, Mississippi).

5.6.2 Electrical and Communications Equipment

Rooftop electrical and communications equipment was also observed to be inadequately protected and anchored. Problems included flooded generators, antenna collapse, blown over satellite dishes and displacement of LPS. Collapsed parking lot light fixtures were also observed. Consequences of the damage included loss of electrical power and communications (both of which are significant losses for critical and essential facilities), damage to roof coverings, and loss of lightning protection. The loss of lightning protection is significant, considering the frequency of lightning storms along the Gulf Coast. Damage to electrical and communications equipment may cause additional damage to a facility, as well as severe loss of function.

5.6.2.1 Emergency Generators

Several generators at critical and essential facilities were inundated by flooding. In addition, some generators were mounted outdoors as shown in Figure 7-5 and discussed in Section 7.2.2. When mounted outdoors, generators are quite susceptible to damage from windborne debris. Other generators were located in enclosures that offered limited protection from tree-fall and windblown debris (see Figure 7-10).

5.6.2.2 Antennas

Collapse of both small and large antennas was quite common at emergency operations centers, fire and police stations and hospitals. In some cases the anchorage to the building failed as shown at Figure 7-2. However, more commonly, the antenna tower buckled (see Figure 5-119).



Figure 5-119.
The antenna tower at this fire station buckled (estimated wind speed: 120 mph. Diamondhead, Mississippi).

5.6.2.3 Satellite Dishes

The MAT observed several satellite dishes that were blown over. Failed satellite dishes did not have positive connections to the roof structure. Rather, the dish support simply rested on the roof and was weighted down with concrete pavers (see Figure 5-120). Blown over satellite dishes can puncture roof membranes, and if blown from the roof can damage other buildings or vehicles.

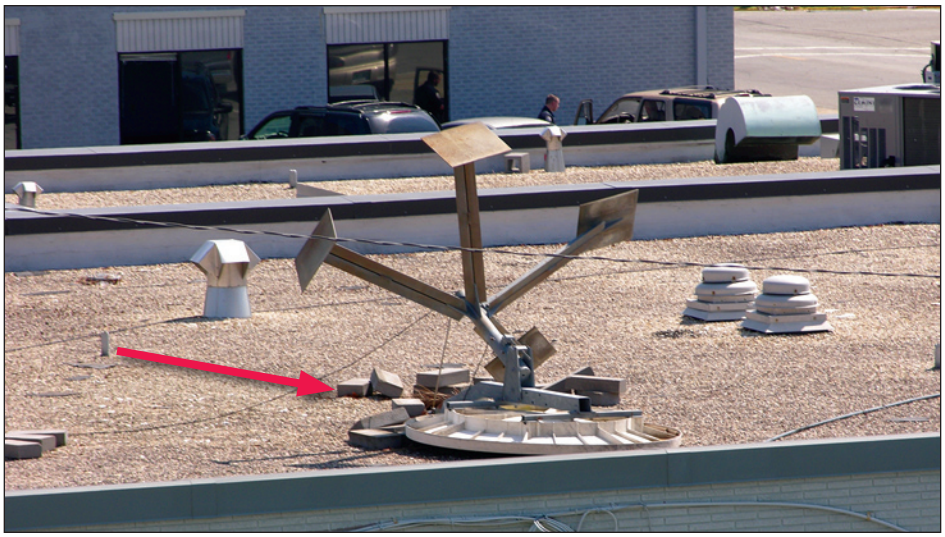


Figure 5-120.
This satellite dish was held down only with concrete pavers (estimated wind speed: 130 mph. Gulfport, Mississippi).

5.6.2.4 Lightning Protection Systems

LPS failures were typically the result of poorly anchored systems. Connectors often fail by opening up and releasing the conductor cable (see Figure 5-121) or they debond from the roof (see Figure 5-122). When conductors detach, the conductor ends can whip around and puncture and tear the roof membrane. At the hospital shown in Figures 5-122 and 5-123, several punctures had been patched after the hurricane. Some of the punctures were likely caused by loose conductors. At another hospital, a loose conductor whipped the exterior wall and punctured the EIFS in several locations (see Figure 5-124).

Two prudent practices were observed. At the hospital shown in Figure 5-122, bolted splice connectors were used (see Figure 5-125). Pronged splice connectors are approved for heights up to 75 feet. Above that height, bolted splice connectors are required. However, regardless of height, bolted connectors are prudent in hurricane-prone regions because they are less likely to pull apart if the conductor becomes detached. If detached conductors remain connected together, that minimizes the number of free ends whipping about.

The other prudent practice was the use of mechanically attached looped connectors to attach the conductor to the coping (see Figure 5-126). A looped connector does not have prongs; therefore, this is a reliable connector (provided sufficiently long screws are used).

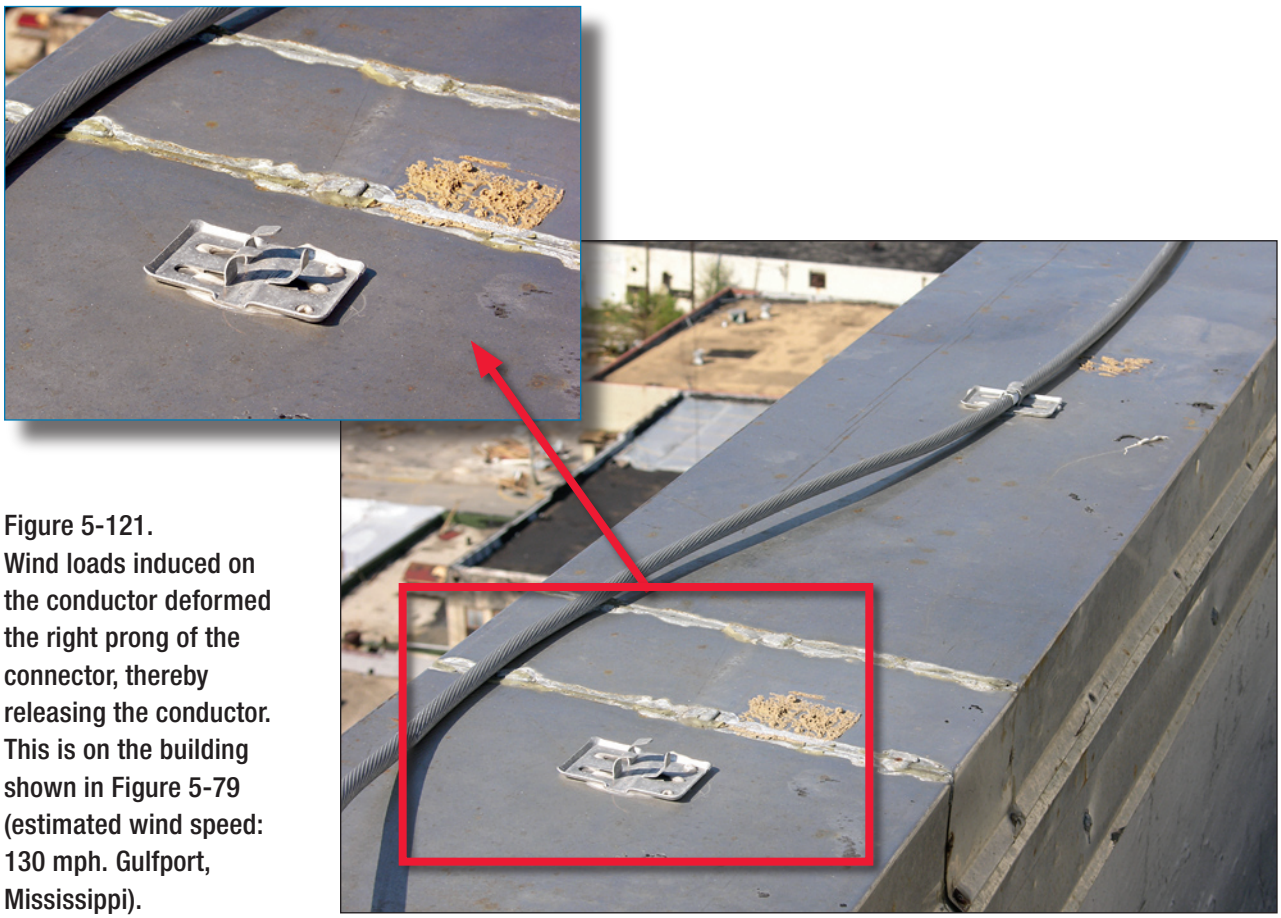


Figure 5-121. Wind loads induced on the conductor deformed the right prong of the connector, thereby releasing the conductor. This is on the building shown in Figure 5-79 (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 5-122.
At this hospital, in the area of the dashed line the conductor connectors debonded from the roof membrane. In the foreground, the connectors are attached to the roof, but the conductor pulled from the prongs (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 5-123.
View of an abraded end of a conductor that became detached at the hospital shown in Figures 5-114 and 5-122 (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 5-124.
A loose LPS conductor whipped the exterior wall and punctured the EIFS in several locations (estimated wind speed: 115 mph. Slidell, Louisiana).



Figure 5-125.
A bolted splice connector was used in lieu of a pronged splice connector (estimated wind speed: 130 mph. Gulfport, Mississippi).

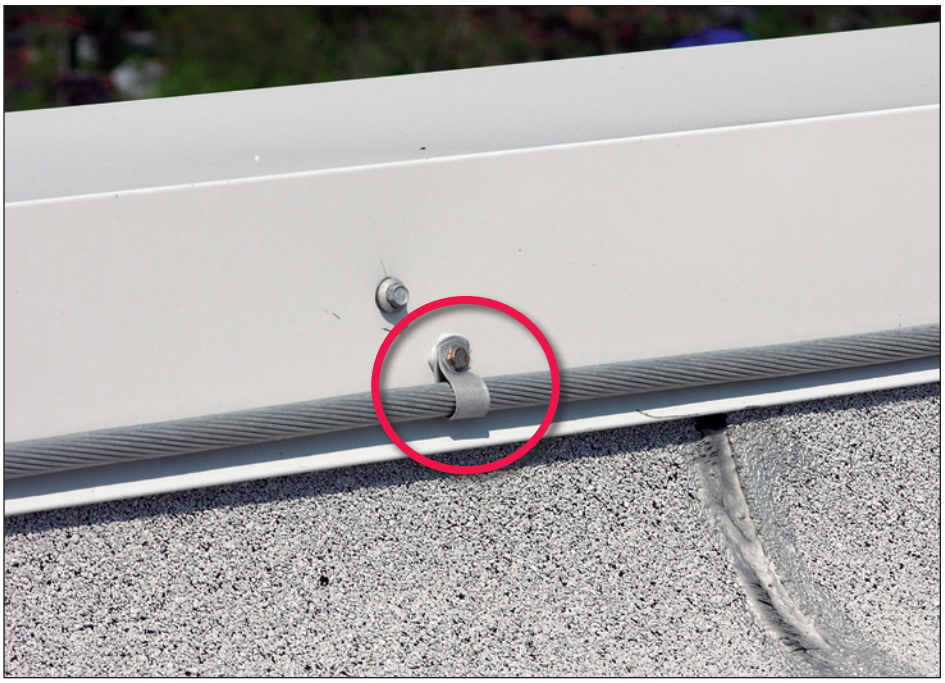


Figure 5-126. Screw-attached looped connectors were used to anchor this conductor (estimated wind speed: 130 mph. Gulfport, Mississippi).

6. Historic Buildings

Hurricane Katrina impacted a significant number of historic buildings and it is important to learn how these buildings responded. Information gathered on the behavior of these historic building systems will assist state and local officials in making sound decisions regarding their rehabilitation. Identifying best practices for rehabilitating historic building systems will also help communities nationwide as they prepare disaster plans and update historic building codes and guidelines.

Sections 6.1 and 6.2 discuss flood and wind damage to historic buildings in Mississippi and Louisiana, respectively. Appendix J contains information on pre- and post-disaster mitigation for historic buildings.

Storms claim historic properties that are exposed to coastal hazards, such as flooding and wind, and each year more efforts are undertaken to save these valuable historic assets. Although wind damage from Hurricane Katrina was observed throughout the declared disaster areas, most of the damage appeared to be flood related. In many of the towns and cities along the Mississippi Gulf Coast and in southeast Louisiana, historic properties (individual buildings and historic districts)

that escaped significant damage or complete destruction from flooding were in elevated locations or distant from the coast. The majority of the historic properties that suffered flood damage were those located in exposed locations and vulnerable to surge and wave impact, had floor elevations much lower than the severe surge elevations from Katrina, or were in low-lying areas.

6.1 Flood Damage

Flood damage to historic structures was caused by velocity flow (i.e., rapidly moving water and waves) and inundation, or rising waters. Damage from floodborne debris, associated with velocity flow, significantly contributed to the damage observed. General flooding from rising water impacted buildings differently depending on the direction of the inundation; this is discussed in more detail in Chapter 8.

Historically, many buildings were built near waterways, as they were part of the commerce transportation system. Many such buildings were designed to be intermittently flooded and included elevated floors, flood vents, or selected materials that stood up to floodwaters. These historic buildings, constructed on raised foundations to allow the water to pass underneath, or on foundations and exterior walls of substantial mass with flood vents, often fared relatively well where they were only impacted by rising water and not wave or debris impacts. One of these successes is shown in Figure 6-1.

In coastal areas, where velocity flow can have a tremendous impact on the buildings, the survivability of the buildings will be dependent on many of the design elements seen in newer construction. Regardless of these design successes, numerous historic buildings were devastated by waves and floodborne debris. On the Mississippi Gulf Coast, many historic buildings that might have otherwise survived high floodwaters were completely destroyed by waves and floodborne debris.

6.1.1 Biloxi Lighthouse (Biloxi, Mississippi)

The Biloxi lighthouse was built in 1848 just off the beach waterfront. It is constructed of brick encased by cast iron painted white. The height of the tower is 61 feet. Other than losing the door and one piece of glass, the Biloxi lighthouse suffered little damage and was one of the few successes (Figure 6-1).

Due to the location of many historic structures on the open coast, numerous buildings were damaged by floodborne casino barges (see Figures 6-2 and 6-3). It should be noted that the size of the casino barges, combined with the high storm surge that allowed the barges to reach the buildings, were unprecedented elements and unique to Katrina. The barge collisions were spectacular but not common. Beauvoir, Jefferson Davis' home (see Figures 6-4 through 6-6), represents the more common type of wave damage observed. Similar damage was observed in Mandeville, Louisiana, which is also home to many historic buildings (refer to Sections 4.1.1.3 and 9.2.2 for more information on Mandeville).

The before and after examples on the following pages illustrate the flood damage and devastation to historic properties from Hurricane Katrina.



Figure 6-1.
Other than losing the door (circled) and one piece of glass, the Biloxi lighthouse suffered little damage from Hurricane Katrina (Biloxi, Mississippi).

6.1.2 Tullis-Toledano House (Biloxi, Mississippi)

Built in 1856, the Tullis-Toledano House was an example of Greek Revival architecture with rich architectural detail. The house was furnished in a period style to interpret Biloxi's antebellum history. Badly damaged by Hurricane Camille, it was purchased by the City of Biloxi in 1975 and restored as a historic house museum and recreational area. The house was completely destroyed by a casino barge during Hurricane Katrina (see Figure 6-2). It is likely the house would have survived, although heavily damaged, had it not been struck by the barge.



Figure 6-2.
A casino barge moved by high surge completely destroyed the Tullis-Toledano House and now sits where the house was located. The inset shows the house prior to Hurricane Katrina (Biloxi, Mississippi).

6.1.3 Tivoli Hotel (Biloxi, Mississippi)

Built in 1927, the Tivoli Hotel, a 64-room luxury hotel, sat abandoned prior to Hurricane Katrina, waiting to be restored to its former glory. In 2003, the Mississippi Heritage Trust called the Tivoli Hotel one of the state's 10 most endangered historic places. With the surge from Katrina, a casino barge struck and destroyed the colonnade and four floors at the southeast corner of the hotel (see Figure 6-3).



Figure 6-3.
Tivoli Hotel after being struck by a casino barge during Hurricane Katrina. The inset shows the hotel prior to the storm (Biloxi, Mississippi).

6.1.4 Beauvoir, Jefferson Davis' Home (Biloxi, Mississippi)

Built in 1848, Beauvoir (see Figure 6-4) and the surrounding structures sustained serious flood (velocity flow) damage from Hurricane Katrina. Approximately 75 percent of the main house still stands, except for the front, side, and rear porches (see Figures 6-5 and 6-6). Many windows, doors, and columns are also gone.



Figure 6-4.
Front elevation of Beauvoir before Hurricane Katrina (Biloxi, Mississippi)



Figure 6-5.
Front elevation of Beauvoir after Hurricane Katrina (Biloxi, Mississippi)



Figure 6-6.
Rear elevation of Beauvoir after Hurricane Katrina (Biloxi, Mississippi)

The main house at Beauvoir is raised approximately 8 feet above grade with brick piers. The space between the piers was in-filled with break-away panels, allowing the surge to pass under the house, minimizing the damage to the main structure and preventing the house from collapsing. The surrounding porches and several piers were lost due to the uplift of the surge. Although not historic, the gift shop, a brick structure built slab-on-grade located approximately 200 feet east of the main house, was completely washed off its foundation (see Figure 6-7).



Figure 6-7.
Gift shop at Beauvoir completely destroyed by Hurricane Katrina (Biloxi, Mississippi)

6.1.5 Longue Vue House and Gardens (New Orleans, Louisiana)

Built in 1924, and rebuilt between 1939 and 1942 to its present state, the Longue Vue House and Gardens property borders the 17th Street Canal about 2 miles south of where the levee failed. The basement was completely flooded and water was within inches of the main level. During the MAT's visit, the water was being pumped out and staff members were working to stabilize the condition of the resident collection of museum pieces, composed of paintings, books, and other artifacts. The gardens, after a multi-year restoration, were badly damaged from immersion. Figures 6-8 and 6-9 show the front elevation and garden areas of this site, respectively.



Figure 6-8.
Front elevation of Longue Vue after Hurricane Katrina (New Orleans, Louisiana)



Figure 6-9.
Garden and fountain at Longue Vue after Hurricane Katrina (New Orleans, Louisiana)

6.1.6 Milne Boys Home (New Orleans, Louisiana)

Established in 1933, Milne Boys Home is a collection of large antebellum-style, white-columned buildings that housed orphans and wayward youths until 1986. Operated by the New Orleans Welfare Department, Milne is famous for its most notable non-resident, Louis Armstrong. Armstrong, contrary to popular lore, was never a resident at Milne. The Armstrong Manhood Development Program, however, provides assistance to wayward boys. The building experienced approximately 3 feet of flooding as shown in Figure 6-10.

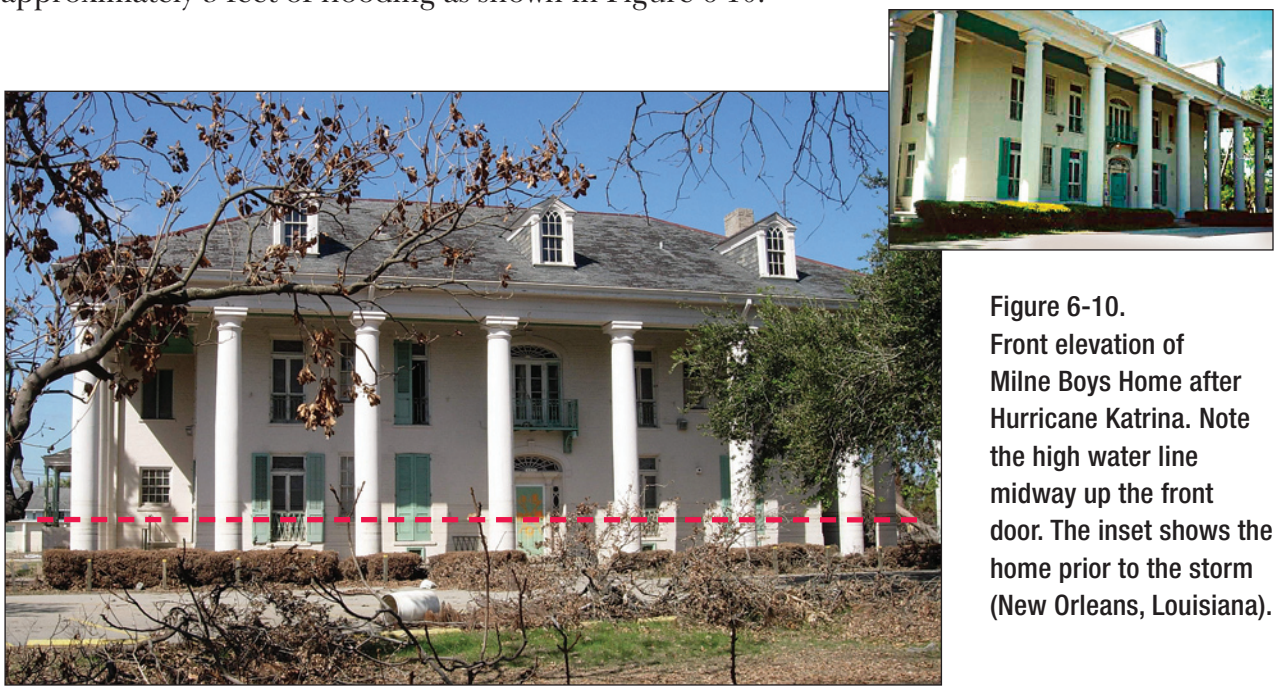


Figure 6-10.
Front elevation of Milne Boys Home after Hurricane Katrina. Note the high water line midway up the front door. The inset shows the home prior to the storm (New Orleans, Louisiana).

6.1.7 Bank Building (Bay St. Louis, Mississippi)

The "before" picture of this empty bank building (see Figure 6-11) was taken 2 weeks before Hurricane Katrina. Surge waters moved through the front windows and door, collapsing the side elevation and part of the second floor (see Figure 6-12).



Figure 6-11.
View of front elevation of bank before Hurricane Katrina (Bay St. Louis, Mississippi)



Figure 6-12.
View of front and side elevations of bank after Hurricane Katrina (Bay St. Louis, Mississippi)

6.2 Wind Damage

Katrina was not a major wind event and, with the exception of buildings within close proximity to the center of the hurricane, historic buildings sustained relatively little direct wind damage from this storm. Most of the observed damage to historic buildings was related to the effects of windborne debris or falling trees. Damage to windows allowed internal pressurization, which resulted in roof failure as shown in Figures 6-13 and 6-14.

Built in 1920, the Kress Building lost its exterior windows, allowing the wind to lift and tear off the roof. The original roof of the Kress Building was wood joist/rafters at 16 inches on center, which was lost in a fire. The replacement roof is light gauge steel framing with purlins at 4 feet on center and a standing seam metal roof covering. When the roof was replaced, the spacing of the fasteners holding down the roof covering was increased from 16 inches on center to 4 feet on center, contributing to its failure from uplift.



Figure 6-13.
Internal pressure from wind through the broken windows lifted the roof (Biloxi, Mississippi).



Figure 6-14.
Interior view of the Kress Building showing roof torn away (Biloxi, Mississippi)

Some wind damage to roof systems was observed; however, even though most historic structures do not meet today's building codes, there were many successes observed because construction techniques used in historic structures make some roofs more survivable than seen in present day framing practices. For instance, the overhangs and porches in historic structures were built with the structural framing of the porch integral with the main framing. Overhanging rafters of porches are often continuous with the main roof framing, allowing them to survive wind uplift (as seen in Figure 6-15), instead of being independently framed from the main framing, which contributes to the roof being blown away. In addition, in historic structures, roof sheathing is typically 1-x-6-inch or 1-x-8-inch board lumber, instead of plywood or oriented-strand board (OSB). Due to the frequency of fasteners and the smaller surface area per board, as compared to plywood or OSB, board lumber is less likely to act as a sail in the strong winds, compromising the integrity of the roof.

As it is in all buildings, the prevention of wind penetration into historic buildings is critical. Wind that penetrates buildings increases the interior wind pressure, contributing to additional uplift. Shutters are a common element found on many historic buildings; shutters were observed to have successfully protected windows from breakage.

Due to their age, many historic properties are surrounded by substantial tree growth. Many historic buildings, primarily residential, suffered considerable damage from trees blown over by high winds. A substantial number of trees blown over at the roots were observed by the MAT in the New Orleans area; however, the field survey was performed after Hurricane Rita, which followed Hurricane Katrina by 3 weeks, and it is believed that most of these trees were blown over during Rita as a result of the long-duration flooding and saturated ground conditions left in the wake of Hurricane Katrina.

The following series of photos illustrates some of the successes and failures observed from wind damage associated with Hurricane Katrina on the Mississippi Gulf Coast and in New Orleans.

6.2.1 Veterans Affairs Medical Center (Gulfport, Mississippi)

Built in 1917, the Gulfport Veterans Affairs Medical Center (VAMC) is a campus plan of a dozen historic structures. Although the VAMC in Gulfport lost the entire second floor porch and roof supports to velocity-flow floodwaters, the integral framing of the roof structure allowed the overhang to successfully survive the wind uplift from Hurricane Katrina (see Figure 6-15).



Figure 6-15.
Loss of the entire second floor porch and roof supports to flooding; the main roof stayed successfully intact due to integral framing of the roof structure (Gulfport, Mississippi).

6.2.2 Benachi House (New Orleans, Louisiana)

Built in 1858, the Benachi House lost two columns from the second floor front elevation from wind forces, as well as roof covering (see Figure 6-16). Its cottage house sustained structural damage from fallen trees (see Figure 6-17). The dead lawn and shrubs are an indication of long-term flooding.



Figure 6-16.
Wind damage to the second floor columns of the Benachi House. Note missing columns (circle) (New Orleans, Louisiana).



Figure 6-17.
Tree damage to the rear cottage house of the Benachi House (New Orleans, Louisiana)

6.2.3 Pitot House Museum (New Orleans, Louisiana)

Built in 1799, and located on historic Bayou St. John, the Pitot House is the only Creole colonial style house museum in New Orleans. It was home to James Pitot, the first mayor of New Orleans, who lived there from 1810-1819. The property, with its stucco-covered, brick-between-post construction and double-pitched hipped roof, was restored to its original 18th century condition in the 1960s. The house had been furnished with Louisiana and American antiques from the early 1800s, in keeping with the style and period of James Pitot.

The Pitot House Museum successfully weathered Hurricane Katrina in part due to the presence of shutters on the windows, which protected the building's glazings and prevented wind penetration into the museum (see Figures 6-18 and 6-19).



Figure 6-18.
Front elevation of Pitot House showing damage to the front wood fence. The house survived very well, with no evidence of flood damage and little wind damage (New Orleans, Louisiana).



Figure 6-19.
Although one window did sustain damage from windborne debris, the remaining windows of the Pitot House were not damaged (New Orleans, Louisiana).

6.2.4 Valence Street Baptist Church (New Orleans, Louisiana)

Built in 1886, the wood-framed Valence Street Baptist Church, registered as a historic building, sustained wind damage, which allowed water intrusion (see Figure 6-20).



Figure 6-20.
Hurricane Katrina wind damage to steeple, front door, and windows. The inset shows the church prior to Katrina (New Orleans, Louisiana).

6.2.5 Longue Vue House and Gardens (New Orleans, Louisiana)

Longue Vue House and Gardens, described in Section 6.1.5, suffered wind damage to shutters and roof covering materials during Hurricane Katrina (see Figures 6-21 and 6-22).



Figure 6-21. View of wind damage to flashing along rake of Longue Vue after Hurricane Katrina (New Orleans, Louisiana)



Figure 6-22. View of wind damage to shutters of Longue Vue after Hurricane Katrina (New Orleans, Louisiana)

7. Performance of Critical and Essential Facilities

Critical and essential facilities are important before, during, and after natural hazard events. They are needed to prepare for an event, house emergency workers during an event, and manage response and recovery operations after an event. Hurricane Katrina had a significant impact on these facilities, totally destroying many of them and devastatingly affecting others.

Many of the observed facilities were impacted by flooding, and most experienced wind damage, even though they were subjected to winds that were below current design wind speeds. Most critical and essential facilities did not perform any better than the commercial buildings, and several performed worse. The poor building performance placed additional burdens on response and recovery personnel as they endeavored to provide assistance to their communities after the event.

Critical and essential facilities are Category III and IV buildings as defined in ASCE 7 and the 2003 IBC (Section 1604, Table 1604.5). Category III and IV buildings include, but are

not limited to, hospitals and other medical facilities, fire and police stations, primary communications facilities, Emergency Operations Centers (EOCs), schools, shelters, and power stations and other facilities required in an emergency. In addition to the buildings listed in Categories III and IV, there are other buildings that can play vital roles in recovery after an event. Examples of these buildings are discussed in Section 7.4.

Most of the building damage was to envelope systems and older facilities, although a few structural and new building failures did occur. Buildings that sustained damage from flooding had not been designed to account for the level of flooding that occurred. Except for occasional shuttering of glazed openings, most of the investigated buildings did not appear to have been designed and constructed with wind-resistant enhancements to the building envelope and rooftop equipment.

Sections 7.1 through 7.4 describe the performance of some of the critical and essential facilities (EOCs, fire stations, hospitals, and airports and military bases) observed by the MAT.

Special Requirements for Critical and Essential Facilities

The 2003 edition of the IBC has only one special flood-related provision pertaining to Category III and IV buildings. That provision concerns elevation requirements that exceed the NFIP minimum requirements. IBC references ASCE/SEI 24 for the specific elevation requirements.

The 2003 edition of the IBC has only two special wind-related provisions pertaining to Category III and IV buildings:

- **Importance factor:** The importance factor for these buildings is 1.15, rather than 1.0, which is used for most other types of buildings. The effect of requiring the use of the 1.15 importance factor is that the design loads for the main wind force resisting system (MWFRS) and components and cladding (C&C) are increased by 15 percent.
- **Windborne debris loads:** For buildings located within windborne debris regions (as defined in ASCE 7) of hurricane-prone regions, exterior glazing is required to be impact-resistant. For Category III and IV buildings, the glazing is required to resist a larger energy missile load than the glazing on most other types of buildings.

7.1 Emergency Operations Centers

EOCs are key buildings in preparing for and responding to an event at both local and state levels. The MAT observed three EOCs.

7.1.1 Jackson County EOC (Pascagoula, Mississippi)

7.1.1.1 General Damage

Figure 9-15 shows a general view of the two-story building (constructed in 1977). The EOC is located on the second story of this building, which has a reinforced concrete frame, walls and roof deck, and an aggregate surfaced built-up roof (BUR). The membrane had been mopped to perlite insulation, which was mopped to the concrete deck. Polycarbonate shutters had been permanently mounted over the exterior windows and glazed door.

Floodwater rose to about an inch below the first floor, which is approximately 4-1/2 feet above grade. Wind blew off a portion of the roof membrane and blew aggregate from the roof (see Figure 7-1). The roof blow-off initiated with the metal edge flashing, which had a 5-inch vertical face that was uncleated, making it susceptible to lifting and peeling. The communications tower was also toppled (see Figure 7-2). The rooftop condensers were strapped to their curbs (Figure 7-2 inset), but the straps and their connections appeared inadequate; the condensers would have likely blown away if the winds had approached the current design wind speed.

The 2003 edition of the IBC has only one special flood-related provision pertaining to Category III and IV buildings. That provision concerns elevation requirements that exceed the NFIP minimum requirements. IBC references ASCE/SEI 24 for the specific elevation requirements.



Figure 7-1.
The roof membrane blew off at the far end and along a portion of the right side of the roof. Aggregate was also blown off. An emergency roof repair was made prior to the MAT's observation (estimated wind speed: 105 mph. Pascagoula, Mississippi).[1]

7.1.1.2 Functional Loss

The EOC was in a mapped floodplain, Zone A10. A map in the EOC indicated that it was located in an area that would be isolated by flooding during a Category 1 hurricane and inundated during a Category 3 event.[2] However, it was decided to not evacuate the building prior to the storm because it was believed that, because this area did not flood during Hurricane Camille, it would not flood during Hurricane Katrina. As floodwaters rose, there were safety concerns for the approximately 20 occupants; therefore it was decided to evacuate most of the occupants across the street to a building that was a few stories taller. Staff members waded through a few feet of water during the storm to reach the other building. Because of favorable wind direction,

[1] Estimated speeds given in this chapter are based on Figure 1-13. These are for a 3-second gust at 10 meters elevation for Exposure C. Unless otherwise noted, the buildings for which estimated speeds are given are located in Exposure B. See Table 1-4 for the estimated speed conversion for buildings located in Exposure B. For example, the 105-mph Exposure C speed given for Figure 7-1 is equivalent to 90 mph in Exposure B.

[2] See Section 2.1.1 for a description of flood zones.

aggregate that was being blown from the roof did not land in the evacuation path or injure the evacuees. Movement of staff to the other building reportedly did not have a significant impact on the EOC operations.

About 30 emergency vehicles brought to the EOC parking lot prior to the storm were flooded, and were not immediately available after the hurricane moved inland. After the water around the facility receded (which took several hours), the vehicles had to be serviced (which took several days) before they were operational. The lack of immediate availability of the vehicles hampered response efforts.

The roof membrane blow-off did not result in interior rainwater leakage because the reinforced concrete roof deck was capable of resisting water infiltration. With critical and essential facilities, incorporation of a secondary membrane (as described in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*) is a prudent practice. Such redundancy reduces the potential for water infiltration if the primary roof covering is blown away or punctured. When sealed at penetrations and parapets, cast-in-place concrete decks can also perform as a secondary membrane, as in the case of this building. However, installation of a secondary membrane over the concrete is a more conservative practice.



Figure 7-2.
The communications tower toppled due to failure of its connection to the roof deck. The condenser units were superficially strapped to their curbs (estimated wind speed: 105 mph. Pascagoula, Mississippi).

Three other prudent practices were observed at this building: the robust construction of the roof deck and walls (i.e., the concrete provided excellent protection from windborne debris, and substantial and reliable wind resistance), the retrofitting of the glazing with shutters for protection from windborne debris, and sufficient elevation of the emergency generator to keep it from being inundated by floodwater.

7.1.2 Harrison County EOC (Gulfport, Mississippi)

7.1.2.1 General Damage

The EOC occupies a small portion of a large two-story courthouse building constructed in 1977 (see Figure 7-3). The building has a reinforced concrete frame, pre-cast twin-tee exterior wall panels and some brick veneer, concrete floor and roof decks, and an aggregate surfaced BUR. Roll-down metal shutters (Figure 9-12) had been installed in 2003 at the exterior windows and glazed doors. (This work was funded via the FEMA Hazard Mitigation Grant Program; see Section 9.3.1.)



Figure 7-3.
The EOC is located near the center of the first floor of the First Judicial District Courthouse. A portion of one of the communications towers was damaged by wind (estimated wind speed: 130 mph. Gulfport, Mississippi).

Even though there was a parapet, aggregate was blown from the roof and broke the windows of a large number of vehicles in the parking lot. The parapet height varied; at the roof highpoint, the parapet was 14 inches high. A few sections of coping blew off the parapet, but a progressive roof membrane failure did not occur. A small satellite dish was blown off the roof and it appeared to have been mounted on wood sleepers. Rather than anchoring the sleepers to the deck, small blocks of concrete had been placed over the sleepers. A portion of the communications tower was damaged by wind. Some rainwater leakage occurred along a portion of the east wall, but

observations were not made to determine if it was related to sealant joints at the pre-cast wall panels or the windows.

7.1.2.2 Functional Loss

The EOC lost normal communications during the storm. However, ham radio operators were in the EOC during the storm and their communications equipment remained operational. The emergency generator shut down when a control relay within the unit failed, but was repaired within about an hour.

Three prudent practices were observed at this building: the robust construction of the roof deck and walls, the retrofitting of the glazing with shutters, and pre-positioning the ham radio operators and their equipment so that a backup was readily available when the primary communications failed.

7.1.3 Hancock County EOC (Bay St. Louis, Mississippi)

7.1.3.1 General Damage

Figure 7-4 shows general views of the one-story building that was built around 1960. The EOC occupies a small portion of a courthouse (the floor elevation of the EOC is about 2 feet lower than the floor elsewhere in the building). The portion of the building housing the EOC has a steel frame, with metal wall panels and a cementitious wood-fiber deck over steel joists, and an aggregate surfaced BUR. The roof membrane was attached to the deck with self-locking fasteners. The walls at the other portion of the building were CMU. The emergency generator was mounted outside (see Figure 7-5).



Figure 7-4.
The EOC lost a portion of its roof covering, and was flooded and totally isolated by floodwater. The EOC was located in the rear portion of the building (red oval) (estimated wind speed: 125 mph. Bay St. Louis, Mississippi).



Figure 7-5.
The EOC's emergency generator was exposed and inundated by floodwater (Bay St. Louis, Mississippi).

Floodwater rose to about 2 feet above the EOC floor. Wind blew off most of the roof membrane over the EOC and also blew aggregate from the roof (see Figure 7-6). The roof blow-off initiated with the metal edge flashing. It had a 5-1/4-inch vertical face that was uncleated; therefore, it was susceptible to lifting and peeling. Hardware on the exterior door to the EOC failed and the door blew inward. A communications tower buckled and a satellite dish was blown off its support post. The satellite dish was mounted to a wooden sleeper assembly that rested on the roof surface, with small blocks of concrete over the sleepers.

Note: Had the winds been stronger, it is likely that some of the cementitious wood-fiber deck panels would have been blown from the steel joists. (At the time this building was constructed, the typical attachment for this type of decking offered limited uplift resistance.) Some of the wall panels may have also been blown away.



Figure 7-6.
The blue tarp was used as an emergency repair where the roof membrane blew off the EOC. Although the membrane's base sheet fasteners were too far apart, the failure initiated with lifting and peeling of the metal edge flashing (estimated wind speed: 125 mph. Bay St. Louis, Mississippi).

7.1.3.2 Functional Loss

Based on direct communication with EOC personnel, thirty-five emergency workers were in the EOC at the time of the hurricane. As floodwater began to rise in the community, many residents who had not previously evacuated their homes tried to evacuate during the storm. The water was deep enough to float their vehicles. Emergency workers rescued several people and took them to the EOC (eventually about 30 people arrived at the EOC, bringing the total occupancy to about 65). The occupants reported that, during the height of the storm, they believed they would not survive and wrote their identities on their arms to aid in the identification of their corpses.

With inundation of the emergency generator, the EOC was without electrical power. Placing the generator in an exposed area was a poor practice. When exposed, a generator is susceptible to windborne debris damage. The generator was also susceptible to flooding, because it was mounted only a few inches above grade.

Blow-off of the roof membrane allowed a substantial amount of water to leak into the EOC. Aggregate from the roof broke windows of several vehicles in the parking lot, but no injuries from flying aggregate were reported. At the time of the MAT observations, there was significant mold bloom in the EOC.

A food distribution center (which included a walk-in freezer) was located within the EOC and it too was flooded.

Because the community remained flooded, including the area around the EOC, after the storm moved inland it was about a day before the EOC could be evacuated. The EOC operations were transferred to the alternate EOC *during the storm.*

The EOC was not in a mapped floodplain (it was in Zone C). However, the EOC was about 600 feet from Zone AE. A 2000 map posted in the building indicated the hurricane evacuation zones for Bay St. Louis. The area where the EOC was located was designated as an evacuation zone for Category 1 hurricanes.

An engineering evaluation completed in 2002 recommended that this facility not be used as an EOC, and that it not be used during events where flooding or isolation from floodwaters was anticipated. The evaluation report also made the following recommendations:

- Improve the connections between the roof deck and framing and between the roof framing and bearing walls, and augment the roof deck for improved windborne debris protection.
- Reinforce the walls to resist wind and windborne debris.
- Install shutters over exterior glazing.
- Perform a structural analysis on the communications tower and develop mitigation actions required to allow it to withstand a design wind event.

7.2 Fire Stations

If fire stations cannot remain operational during an event, the community loses a valuable and important part of its emergency response capability. Several fire stations in Louisiana and Mississippi were damaged from flooding and/or high winds during the hurricane. The MAT observed over 20 fire stations, several of which experienced enough damage to take them off-line for the event and for weeks or months following the event.

Many of the observed buildings were relatively inexpensive and quite old; therefore, they did not possess sufficient wind-resistance. The most common wind-induced damages were to the sectional doors at the apparatus bays, roof coverings, and collapsed communications towers. Notable and representative examples of the observed fire stations are presented in Sections 7.2.1 through 7.2.11.

7.2.1 Back Bay Fire Co. #4 (Biloxi, Mississippi)

7.2.1.1 General Damage

This is a relatively new one-story building with CMU and brick veneer walls and a standing seam metal roof with 16-inch rib spacing (see Figure 7-7). Floodwater rose to about 5-1/2 feet above the floor. The apparatus bay doors were bowed in (this was likely caused by floodwater, rather than wind pressure).



Figure 7-7. General view of Back Bay Fire Co. #4. Floodwater was about 5-1/2 feet deep inside the station (Biloxi, Mississippi).

7.2.1.2 Functional Loss

The building was occupied at the time of the hurricane. As floodwater began to rise in the community, several residents went to this station. With the influx of residents, there were a total of 19 people in the building. The occupants crowded onto the top of the fire engines to avoid the floodwater; however, there was insufficient room for everyone. One firefighter put on a self-contained breathing apparatus and stood in the water; the water rose to the middle of his forehead. Although there was extensive interior water damage, at the time of the MAT observation, the fire station was operational.

The fire station was in a mapped floodplain, Zone B/C. It was about 200 feet from Zone A9.

7.2.2 Gulfport Fire Station #1 (Gulfport, Mississippi)

7.2.2.1 General Damage

This two-story building was constructed in 1977 (see Figure 7-8). It has glue-laminated beams and wood columns, a cementitious wood-fiber deck, and an aggregate surfaced BUR.

The three windward (east-facing) sectional doors were damaged by wind (see Section 5.2.3). The door damage occurred before winds peaked. In response, fire engines were moved against the damaged doors to brace them, and the three westward doors were opened. Opening the doors likely prevented them from being damaged.[3] With the doors at each end of the apparatus bay open or partially open, uplift load on the roof assembly was likely reduced. Had the westward doors not been opened, there likely would have been sufficient wind load to cause uplifting of the cementitious wood-fiber decking. (At the time this building was constructed, the typical attachment for this type of decking offered limited uplift resistance.) One of the deck panels at an overhang had a major crack across its entire width; however, the panel may have been cracked before the storm.

Three of the 12 upper windows on the south side of the building were broken by aggregate blown from a BUR across the street (Figure 7-8 inset). One of the lower windows was also broken.

Aggregate was blown from the fire station's roof (the roof did not have a parapet).

Floodwaters rose to within inches of the base of the station's emergency generator, but the unit was not inundated during the event. The generator was located outdoors, similar to the one shown in Figure 7-5.

7.2.2.2 Functional Loss

The window and door damages caused minor disruptions.

The fire station was not in a mapped floodplain; it was in Zone X, about 1,000 feet from Zone AE.

[3] Generally it is best to keep doors in the closed position, as opening them can create high internal pressures. But in this case, where the building had already lost windward doors, opening leeward doors was beneficial because it reduced internal pressures.

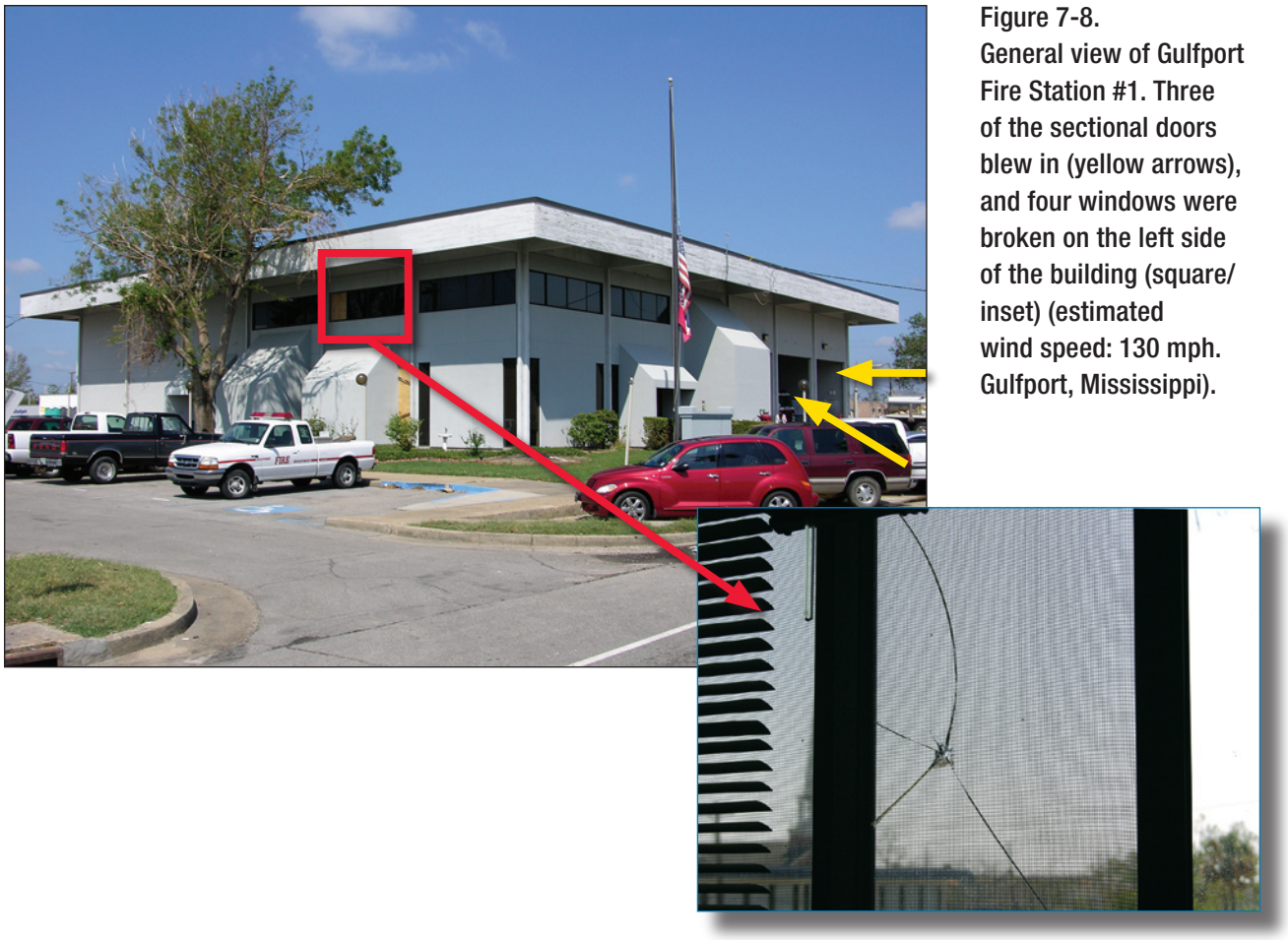


Figure 7-8. General view of Gulfport Fire Station #1. Three of the sectional doors blew in (yellow arrows), and four windows were broken on the left side of the building (square/inset) (estimated wind speed: 130 mph. Gulfport, Mississippi).

7.2.3 Gulfport Fire Station #5 (Gulfport, Mississippi)

7.2.3.1 General Damage

Figure 7-9 shows a general view of the building. It has CMU and brick veneer walls, wood roof framing, plywood decking, and an asphalt shingle roof. A tree fell on the lower roof and caused modest damage to the shingles, decking, fascia, and soffit. Some of the shingle tabs were also blown off.

7.2.3.2 Functional Loss

The tree-fall caused minor disruptions. (Note: Many of the observed fire stations were located near very large trees. Falling trees can cause significant damage to buildings, particularly wood-framed and pre-engineered metal buildings (PEMBs), and injury to occupants.)

7.2.4 Gulfport Fire Station #7 (Gulfport, Mississippi)

7.2.4.1 General Damage

This PEMB was severely damaged by storm surge (see Figure 3-22).

7.2.4.2 Functional Loss

Evacuation of the station before the storm avoided injuries and fatalities. Storm surge pushed some of the apparatus out of the building, thereby making the equipment unavailable for response. Fire hoses and other equipment were also destroyed. The station was not functional after the hurricane.

The fire station was not in a mapped floodplain (it was in Zone X), nor was it adjacent to a floodplain.



Figure 7-9. General view of Gulfport Fire Station #5. A tree fell on the left side of the building (the tree had been removed prior to the MAT's observations) (estimated wind speed: 130 mph. Gulfport, Mississippi).

7.2.5 Pass Christian Fire Department (Pass Christian, Mississippi)

7.2.5.1 General Damage

The Pass Christian Fire Department is a PEMB with metal wall panels and a structural standing-seam trapezoidal metal panel roof (see Figure 7-10). The emergency generator is housed in a free-standing PEMB. Although the walls and roof of the generator building could be penetrated by windborne debris, placing a generator in a marginal enclosure such as this is better than having it exposed as shown in Figure 7-5. Roll-down metal shutters had been installed around 1999 at the exterior windows. (This work was funded via the FEMA Hazard Mitigation Grant Program.) However, the glazing in the personnel doors was not protected from windborne debris. Some new steel columns were also located on the backside of the building; they were anchored to the structural frame to provide additional wind resistance to meet current wind loads.

In an effort to keep the doors from blowing inward, fire engines had been positioned so that they were in contact with the rolling doors. However, the slats from at least one of the rolling doors were blown out of the door track. Placing apparatus against bay doors does not increase the resistance of the doors to outward failure, nor does this practice necessarily keep doors from blowing inward on the apparatus. In lieu of using apparatus to buttress doors, doors that possess inadequate wind resistance should be replaced with doors that have sufficient strength to resist design wind loads.

7.2.5.2 Functional Loss

The door damage caused minor disruptions. The facility was in use at the time of the MAT observations.

Providing the structural upgrades and installing the shutters at the windows was perhaps prudent, but it appeared that a comprehensive building evaluation had not been performed before executing the upgrades. Had a comprehensive evaluation been made, it is likely that the rolling doors would have been upgraded (because this is typically one of the most vulnerable elements of fire stations), and the door glazing should have been protected. The roof covering, roof vents, gutters, and downspouts also looked like they had inadequate wind resistance.



Figure 7-10. General view of the Pass Christian Fire Department. The building in the foreground houses the emergency generator (estimated wind speed: 130 mph. Pass Christian, Mississippi).

7.2.6 Cuevas Volunteer Fire Department (Pass Christian, Mississippi)

7.2.6.1 General Damage

This is a PEMB with an exposed fastener metal panel roof (see Figure 7-11). It appeared that floodwater rose to about 1 foot above the floor line; however, it was reported that the water rose to a depth of 2 to 3 feet. The slats from at least one of the rolling doors at the apparatus bay dislodged from the door track (this was likely caused by wind, but may have been initiated by floodwater). The communications tower was also toppled.

7.2.6.2 Functional Loss

The building was occupied at the time of the hurricane. The door damage caused minor disruptions. The facility was in use at the time of the MAT observations.

There was a large stand of tall trees near three sides of the building, including the side from which the primary winds were coming. The trees substantially reduced the wind loads during this event. However, the fourth side of the building had a long, open, flat fetch. A future strong storm with primary winds coming over the open fetch would likely cause significant building envelope damage.

The fire station was not in a mapped floodplain (it was in Zone C). It was about 100 feet from Zone A and about 2,500 feet from Zone A9.



Figure 7-11. General view of the Cuevas Volunteer Fire Department. Note the damaged apparatus bay door (estimated wind speed: 130 mph. Pass Christian, Mississippi).

7.2.7 Northshore Volunteer Fire Department (Slidell, Louisiana)

7.2.7.1 General Damage

This is a PEMB with unreinforced CMU walls and metal wall panels. The building was severely damaged by storm surge and waves from nearby Lake Pontchartrain (see Figure 7-12).

7.2.7.2 Functional Loss

This station was not occupied during the storm (it was typically not manned). The station was not functional after the hurricane, and has since been demolished.

The fire station was in a mapped floodplain, Zone A10.



Figure 7-12. General view of the Northshore Volunteer Fire Department. Exposure C (estimated wind speed: 115 mph. Slidell, Louisiana).

7.2.8 A. J. Champagne Fire Station (Slidell, Louisiana)

7.2.8.1 General Damage

This two-story building was constructed in 1952 and remodeled in 1989 (see Figure 7-13). It has a wood-frame structure, EIFS over unreinforced CMU and brick veneer, a cementitious wood-fiber deck, and asphalt shingles. Floodwater rose to several feet above the floor line. There was flood/flotation damage to pad-mounted mechanical equipment located outside the building. Several of the shingles were blown away, some rooftop exhaust fans were damaged, and the communications tower collapsed.

7.2.8.2 Functional Loss

The building was occupied during the hurricane; the second floor provided safe refuge for the occupants. Although there was substantial interior water damage, the building remained operational. The floodwater subsided in a little over a day. Communications were interrupted due to the tower failure.

The fire station was in a mapped floodplain, Zone AE.



Figure 7-13. General view of the A. J. Champagne Fire Station (estimated wind speed: 115 mph. Slidell, Louisiana)

7.2.9 Third District Fire Headquarters (New Orleans, Louisiana)

7.2.9.1 General Damage

This is a one-story, steel-framed building with brick veneer walls, metal fascia panels, steel roof deck, rigid plastic foam roof insulation, and metal roof panels (see Figure 3-55). The metal panels had standing seams with snap-on batten covers.

A large portion of the metal roof covering was blown off the apparatus bay. In some areas the panels were still in place, but the batten covers had blown away. In other areas the batten covers

were still attached, but they had lifted and it appeared that fatigue cracks occurred along the standing seams (see Figure 7-14).

7.2.9.2 Functional Loss

This station was occupied at the time of the storm. Some equipment was destroyed. The station was not functional after the hurricane. For some time after the storm, operations were conducted from a modular unit furnished by FEMA.

The fire station was not in a mapped floodplain; it was in Zone B, about 50 feet from Zone A9.

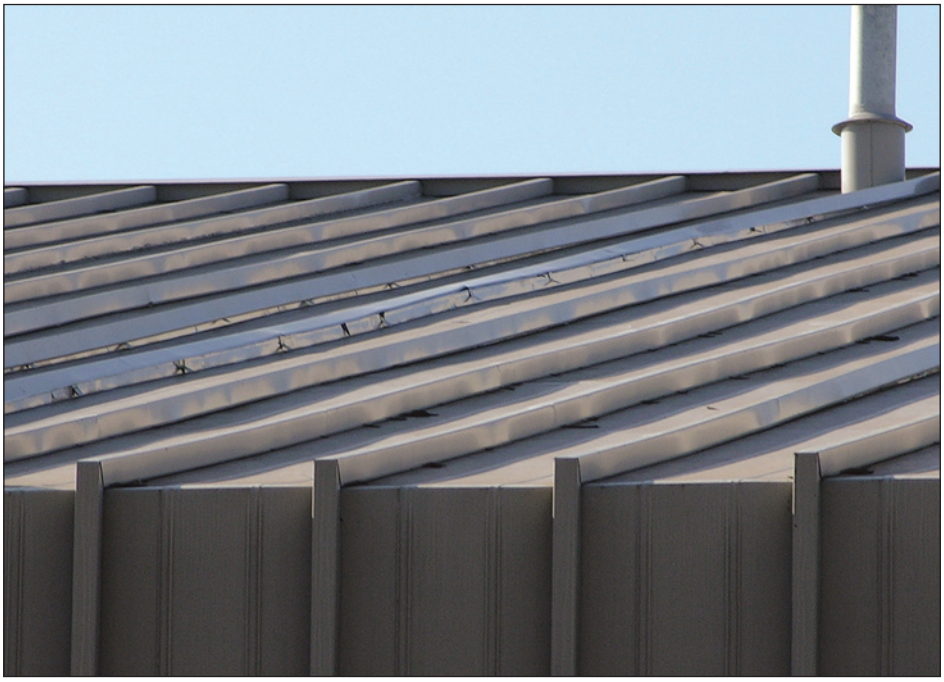


Figure 7-14. This portion of the roof was not blown off, but some of the batten covers lifted. It appeared that fatigue cracks occurred along the standing seams (estimated wind speed: 105 mph. New Orleans, Louisiana).

7.2.10 Port Sulphur Volunteer Fire Department (Port Sulphur, Louisiana)

7.2.10.1 General Damage

This is a PEMB with metal wall panels and a structural standing-seam trapezoidal metal panel roof (see Figure 7-15). Storm surge severely damaged the rolling doors and walls. Wind blew off a portion of the roof panels.

7.2.10.2 Functional Loss

The station was not functional after the hurricane.

The fire station was in a mapped Zone A99.



Figure 7-15.
General view of the Port Sulphur Volunteer Fire Department showing damage caused by storm surge and wind. Note the inundated apparatus in the foreground (estimated wind speed: 125 mph. Port Sulphur, Louisiana).

7.2.11 Buras Volunteer Fire Department (Buras, Louisiana)

7.2.11.1 General Damage

Storm surge severely damaged the rolling doors and walls (see Figure 7-16).

7.2.11.2 Functional Loss

The station was not functional after the hurricane.

The fire station was in a mapped Zone A99.



Figure 7-16.
General view of the Buras Volunteer Fire Department (estimated wind speed: 130 mph. Buras, Louisiana)

7.3 Hospitals

When a hurricane strikes, hospitals, EOCs, and shelters are the most important buildings in a community. In addition to providing continuity of care for patients in hospitals before a storm, hospitals also receive large numbers of people seeking medical treatment after strong hurricanes. Blunt-force trauma injuries caused by windborne debris, falling trees, collapsed ceilings, partial building collapse, and flood-related injuries occur during hurricanes; however, most of the hurricane-related injuries typically occur in the days afterward. These injuries are typically due to chainsaw accidents, stepping on nails, lacerations incurred while removing debris, vehicle accidents at intersections that no longer have functional traffic lights, people falling off roofs as they attempt to make emergency repairs, and carbon monoxide poisoning or electrical shock from improper use of emergency generators. Therefore, at a time when many hospitals in an area may be functionally impaired or no longer capable of providing service due to building damage, hospital staffs are faced with a higher than normal number of people seeking treatment. Before arrival of a hurricane, hospitals also often receive an influx of women in their third trimester of pregnancy so that they will already be at the hospital in case they go into labor during the storm or shortly thereafter, when getting to the hospital could be hazardous or impossible.

Thirteen medical hospitals and one psychiatric hospital were observed by the MAT. Most of the observed hospitals experienced building envelope damage and a few were flooded. The flood and/or wind damage placed significant burden on several of the hospitals, and three of the observed hospitals were completely taken out of service. The hospital discussed in Section 7.3.1 is one of the newer facilities that was observed. (Note: see Section 7.4.2 for the Keesler Air Force Base Medical Center.)

7.3.1 Garden Park Medical Center (Gulfport, Mississippi)

7.3.1.1 General Damage

This 130-bed hospital was opened in 2000 (see Figure 7-17). The building has EIFS over metal studs, and ethylene propylene diene monomer (EPDM) membrane roof coverings (some were ballasted and some were fully adhered).

The nearby Flat Branch Creek (Figure 7-17 inset) rose above its banks and reached a depth of about 6 inches inside the hospital. The EIFS blew off the hospital in a few areas (detachment of the gypsum board from the studs was the primary failure mode). With loss of the EIFS, water was able to enter the wall cavities. A penthouse door was blown off its hinges (see Figure 5-5). The roof membrane lifted and peeled back in some areas, and in other areas it ballooned. Rubber walkway pads were blown away and the roof membrane was punctured in several areas (some of the punctures were likely caused by the lightning protection conductors and/or air terminals that became detached; see Figures 5-122 and 5-123). Some of the vents for the lightweight insulating concrete (LWIC) and an exhaust fan were damaged by windborne debris (see Figure 7-18). (Note: unless in a penthouse or protected by screen walls, rooftop equipment is vulnerable to debris damage.) Some fan cowlings were blown off (see Figure 5-114) and several of the storm caps over exhaust ducts were blown away (Figure 7-18 inset).



Figure 7-17.
General view of Garden Park Medical Center. EIFS repairs were underway at the time the photo was taken. The inset shows one of the hospital's lower roofs and Flat Branch Creek beyond (arrow) (estimated wind speed: 130 mph. Gulfport, Mississippi).

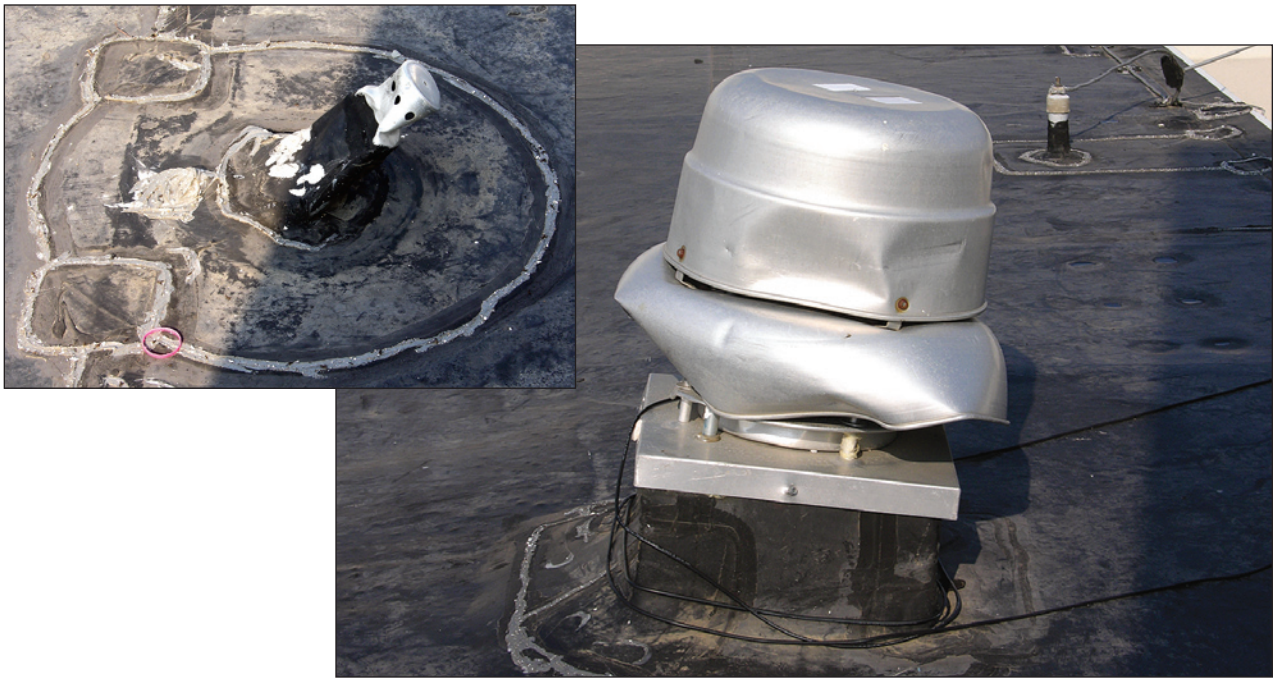


Figure 7-18.
This exhaust fan was struck by windborne debris. The inset shows a LWIC vent that was also hit by debris. Water could enter the roof where the vent cap was knocked off (estimated wind speed: 130 mph. Gulfport, Mississippi).

Although no exhaust fans were blown from their curbs, they were only marginally attached. At one fan that was on a 28 x 28-inch curb, the fan was only attached with one screw per side. Had the fan been attached in accordance with the guidance in the Hurricane Katrina Recovery Advisory section on attachment of rooftop equipment (Appendix E), there would have been six screws per side.

The municipal water supply was out of service for several days; therefore, the cooling towers were inoperable due to loss of water service, and the hospital was without air conditioning. The emergency power was also interrupted because the roof mounted air intake louvers blew off (see Figure 3-60). One of the communications towers was also damaged.

7.3.1.2 Functional Loss

Because of the flooding, the surgical suite was taken out of service for about 2 weeks. The entire fourth floor roof was temporarily reroofed after the storm. However, a substantial amount of water leaked into this floor (a nursing floor), and it was still being repaired nearly a month after the storm. Loss of air conditioning resulted in interior condensation and the warm/humid interior conditions interfered with the functioning of some of the electronic medical equipment.

A FEMA Disaster Medical Assistance Team (DMAT) was on site within 48 hours after the storm to assist with medical treatment.

The hospital was not in a mapped floodplain (Zone X).

7.4 Airports and Military Bases

Airports and military bases can provide valuable services in the aftermath of hurricanes. In the case of the Louis Armstrong New Orleans International Airport, after Hurricane Katrina the airport served to evacuate a large number of citizens from the New Orleans area. ASCE 7 does classify some airport and military facilities as Category IV buildings; however, as discussed in Sections 7.4.1 and 7.4.2, ASCE 7 does not classify all airport or military facilities as Category III or IV buildings. Therefore, for those buildings that will play vital roles in response and recovery, it is prudent to voluntarily design them as critical and essential buildings even though it is not required to do so.

7.4.1 Gulfport-Biloxi International Airport

Airports are vital to hurricane response and recovery. After a hurricane strikes an area, the primary initial function of nearby airports is to receive supplies and emergency response personnel being airlifted into the impacted area. A functional airport within an impacted area also facilitates arrival of insurance adjustors, volunteers, and contractors. Damage to airport facilities often prohibits the use of airports within impacted areas for a few or several weeks. When this occurs, airports farther away from the impacted areas have to be used. A fully functional airport is also needed to support normal commerce as surrounding communities begin their recovery.

The only airport facilities that ASCE 7 designates as critical and essential are aviation control towers, air traffic control centers, and emergency aircraft hangars. However, passenger terminals are also vital to airport operations. Cargo buildings may also be vital; if their loss would hamper receipt of emergency supplies, they too should be voluntarily designed as critical and essential buildings.

The MAT observed the Gulfport-Biloxi International Airport. All buildings on the airport complex were significantly damaged by wind and water from Hurricane Katrina.

7.4.1.1 General Damage

Damage to the airport control tower is shown in Figure 7-19. Wind pressure and windborne debris broke about 30 percent of the tower wall glazing and damaged the metal wall cladding.

The commercial air terminal had four operational airline gates and two new gates under construction. The hurricane damaged two operational gates, leaving only two gates available for flights. Damage to the terminal included loss of some of its EIFS wall cladding (see Figure 7-20), damage to the built-up roof, and loss of two large window curtain walls (see Figure 7-21), by wind pressures.

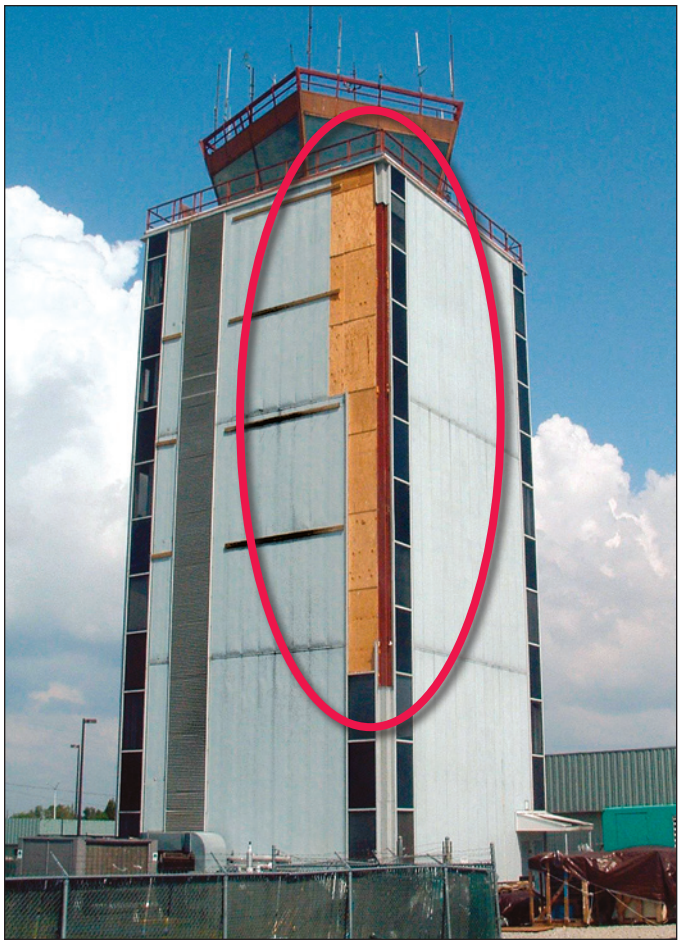


Figure 7-19.
Airport control tower. Note damaged glazing and cladding (circle) (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 7-20. Damaged terminal gate at the Gulfport-Biloxi International Airport. Note the damaged roof coping (arrow) and the wind damaged EIFS (circle) (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 7-21. Glazed curtain wall pushed inward by wind pressure. Note the location of damaged curtain walls with temporary weather seal (arrows) (estimated wind speed: 130 mph. Gulfport, Mississippi).

Figures 7-22 and 7-23 portray the wind damage to the airport cargo building. The building was constructed with a pre-engineered metal building frame with metal siding. Damage to the building resulted when positive wind forces pushed in the two large rolling doors. The building became internally pressurized, causing the loss of most of the wall panels on the west side of the building and some of the roof panels.



Figure 7-22.
Wind damage to the southwest corner of the airport cargo building. Note the pressure damaged rolling door (circle) and the west wall panels removed by combined internal and external pressures (arrow) (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 7-23.
Roof and wall panel damage at the airport cargo building. Note the damaged rolling door at the southeast corner (circle) and roof and wall damage (arrows) (estimated wind speed: 130 mph. Gulfport, Mississippi).

The airport Fixed Based Operator (FBO) building servicing general aviation experienced roof decking and roofing removal when one of its large sliding hangar doors was blown into the building. This failure allowed the building to become internally pressurized. Figure 7-24, an aerial view, portrays the extent of the roof damage. Figure 7-25 shows the hangar door on the ground.

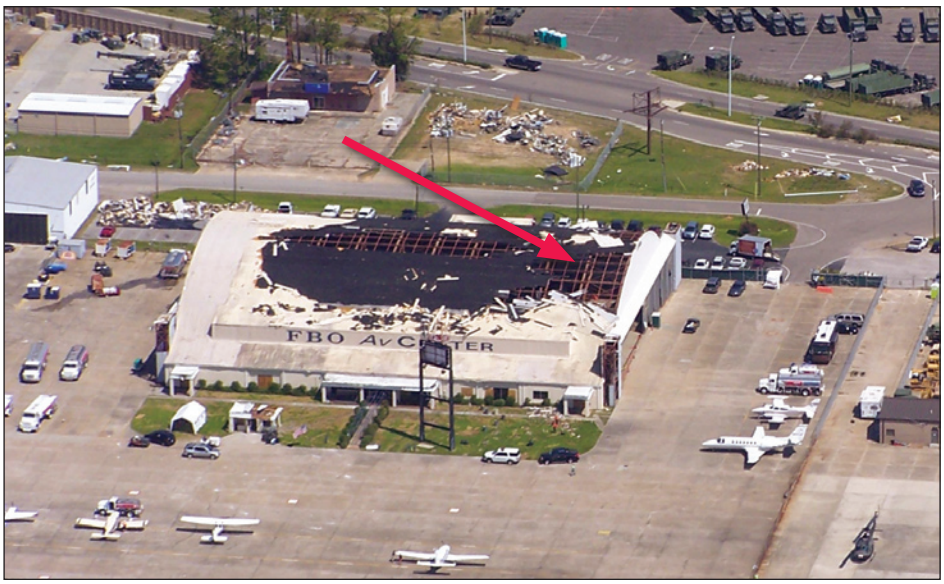


Figure 7-24.
Airport FBO building. Note the decking and roofing materials removed by wind pressure (arrow) (estimated wind speed: 130 mph. Gulfport, Mississippi).



Figure 7-25.
Sliding door blown into hangar (estimated wind speed: 130 mph. Gulfport, Mississippi)

7.4.1.2 Functional Loss

Prior to Hurricane Katrina, the Gulfport-Biloxi Airport handled 25 flights per day; after the storm, that number was reduced to 12 flights per day. The very high frequency (VHF) visual omnidirectional range (VOR) navigation system building was destroyed by the storm winds, thereby affecting direct navigation to the air field. The visual approach lighting system was damaged by floodwater at the ends of the runway, restricting the airport to daylight operation only.

The wind damage to the terminal building caused the loss of two functioning departure gates, and the winds damaged and slowed the construction completion of the two new gates. Wind

damage to the cargo building left the airport without any large-scale cargo storage capabilities. Maintenance of general aviation aircraft was limited due to the FBO building damage.

7.4.2 Keesler Air Force Base

In addition to their national defense mission, military bases in hurricane-prone regions often provide needed response and recovery services. If key buildings on a base in an area impacted by a hurricane are damaged, the response can be impaired.

ASCE 7 states that buildings having critical national defense functions shall be designated as critical and essential facilities. Thus at any given military base, in addition to buildings normally classified as critical and essential (such as hospitals and fire stations), only those buildings that have critical defense functions need to designated as Category IV buildings. However, other buildings on a base in a hurricane-prone region that could also be vital to providing emergency response to surrounding communities should be identified and voluntarily designed as critical and essential facilities.

The MAT observed Keesler Air Force Base (AFB) in Biloxi. It is a primary military electronics and communications training center and medical training center. Home to over 8,000 military personnel, the base encompasses over 1,500 acres fronting Biloxi Bay on the north, and is located two city blocks from the Gulf of Mexico to the south (see Figure 7-26).



Figure 7-26.
Aerial of Keesler Air Force Base (estimated wind speed: 120 mph. Biloxi, Mississippi)

7.4.2.1 General Damage

Wind and water damage to the base buildings was extensive, with most buildings exhibiting some form of damage. Repair and reconstruction costs for Keesler AFB were estimated at $915 million. The types of buildings surveyed by the team included heavy engineered buildings,

lightweight pre-engineered buildings, and residential buildings. The engineered buildings performed well structurally, but experienced loss of roof and wall coverings, resulting in water intrusion. The majority of the on-base housing was affected. Damage included loss of roof coverings, glazing damage, and water inundation. Flood levels varied from 2 feet to nearly 8 feet. (The majority of on-base housing is located in Zone C.)

The 81st Civil Engineering Squadron is responsible for carrying out design and construction responsibilities on Keesler Air Force Base. Programming personnel within the engineering flight typically develop programming documents that define the scope of work and estimate the cost for a given project. These documents are then sent to a review office, the Air Education and Training Command (AETC) in this case, and the Pentagon for purposes of project prioritization among other base projects in the given command and the Air Force, for funding.

The Keesler Civil Engineering Squadron uses the latest effective ASCE 7 criteria and model building codes for project design and bid documentation. Federal facilities, such as military bases, are self-insured. The Department of Defense (DoD) requests funding from Congress to repair or replace facilities damaged or destroyed by storms.

Military bases are not typically mapped or reviewed by FEMA for NFIP compliance because the Pentagon has this responsibility. Keesler AFB is mapped by the NFIP, but is not subject to local ordinance. As a Federal agency, the Pentagon is responsible for carrying out all the requirements noted above. This includes:

1. Executive Order 11988, Floodplain Management
2. Executive Order 11990, Protection of Wetlands

Both of these Executive Orders originated with the President of the United States and are codified and defined in:

1. The Code of Federal Regulations, Title 44
    a. Part 9, Floodplain Management and Protection of Wetlands
    b. Part 59, General Provisions
    c. Part 60, Criteria for Land Management and Use

7.4.2.2 Functional Loss

Most personnel were evacuated from the base prior to Hurricane Katrina. However, about 350 essential personnel remained and took shelter in Allee and Wolfe Halls (see Figure 7-27). During the storm, large portions of the roof covering blew off, resulting in major water leaks inside the building, and great anxiety for the building occupants.

The Keesler Medical Center (see Figure 7-28), which is used annually by 56,000 military retirees and active duty personnel, was flooded during the storm, with surge spilling into the basement

of the building and inundating the emergency generators. The medical center was not expected (at the time of this report) to be fully operational until later in 2006. The hospital was not in a mapped floodplain (Zone C).



Figure 7-27.
Allee Hall, place of refuge for base essential personnel during the storm (estimated wind speed: 120 mph. Biloxi, Mississippi)



Figure 7-28.
Keesler AFB Medical Center (estimated wind speed: 120 mph. Biloxi, Mississippi)

8. Overview of Hurricane Katrina in the New Orleans Area

FEMA was particularly interested in the long-duration impacts of flooding on buildings in New Orleans as well as the floodplain management issues surrounding the levee breaches. The New Orleans Flood Team conducted ground inspections throughout the New Orleans area, including the City of New Orleans and Orleans Parish, as well as the nearby communities of Chalmette in St. Bernard Parish and Metairie in Jefferson Parish.

The Flood Team visited a total of 23 residential buildings and critical and essential facilities in the New Orleans area from October 4 to 8, 2005 (see Figure 8-1). The focus of the site inspections was to assess flood damage to residential buildings and critical and essential facilities, and evaluate opportunities for flood restoration. The Flood Team's investigation showed that

structural damage to buildings was localized to certain areas, and that the most significant damage was from long-duration flooding of non-structural building components related to saturation of porous building materials with contaminated water.



Figure 8-1. Residential buildings and critical and essential facilities visited by the New Orleans Flood Team. (Due to the map scale, some sites are not included on this map.)

Section 8.1 discusses flooding in the New Orleans area. Floodplain management issues related to levees and floodwalls in the New Orleans area, including the history of the New Orleans levee system, and floodplain mapping and building construction within the New Orleans

levee-protected area, are presented in Section 8.2. Section 8.3 contains a general characterization of structural and non-structural flood damage. Long-duration flood impacts on buildings, including deterioration of building materials and contamination, are discussed in Section 8.4.

8.1 Flooding in the New Orleans Area

Flooding in most places within the levee/floodwall protected area in and around New Orleans was due to breaches in levees and canals. Pump systems that would normally have removed floodwaters were non-operational due to inundation or from a loss of primary and backup power. In Metairie, flooding was caused by high water from Lake Pontchartrain surcharging the drainage system with pumps off. Local officials decided to evacuate pump operators on August 28 before the storm hit, according to *The Times-Picayune* and first-hand accounts given to the New Orleans Flood Team.

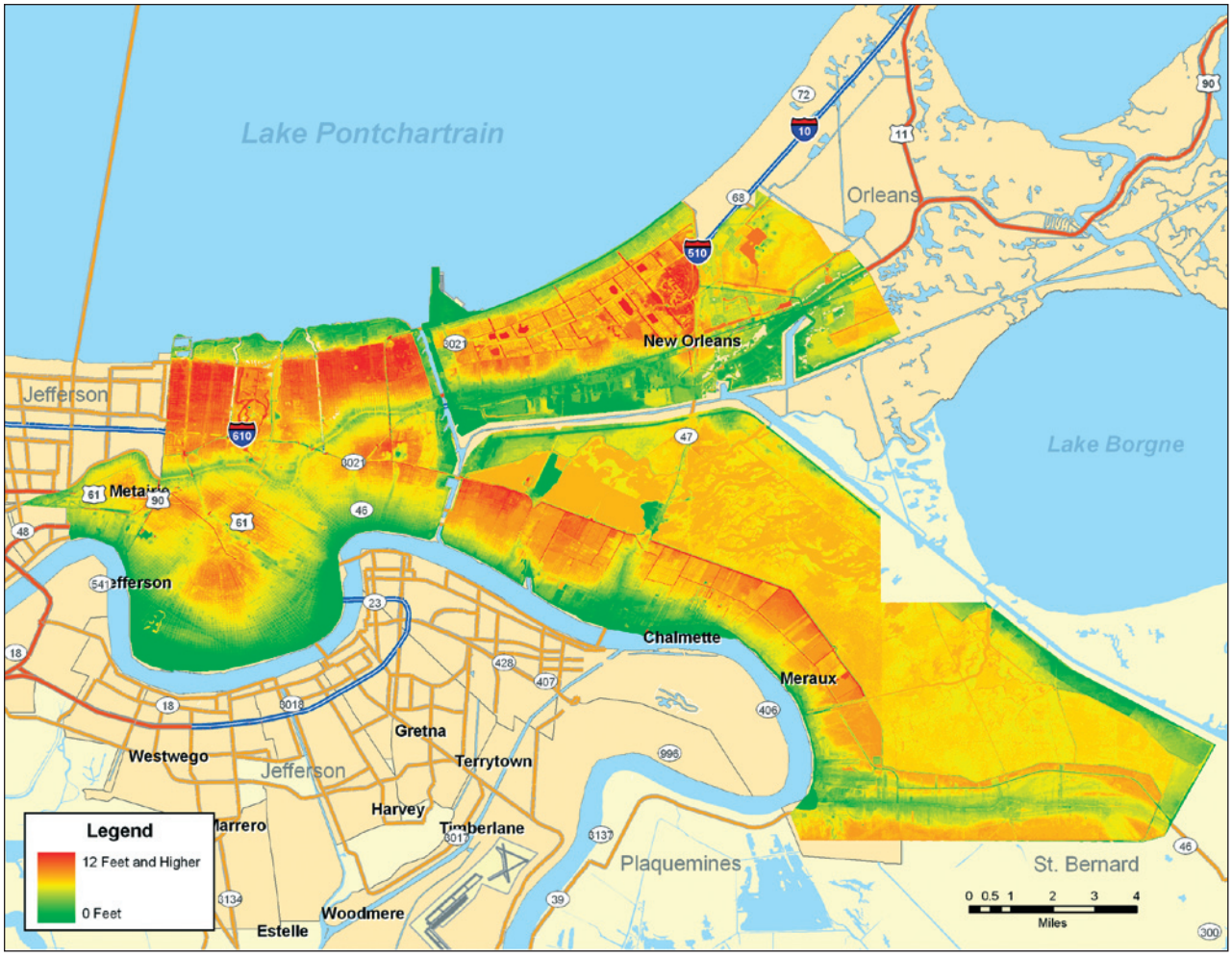


Figure 8-2. Map of estimated flood depths in New Orleans

SOURCE: FEMA

As a result of the levee/floodwall breaches, widespread flood damage to residential neighborhoods occurred throughout the New Orleans area. The depth of flooding within the Greater New Orleans area varied greatly, as did damage to structures. West of the 17th Street Canal, areas of Metairie in Jefferson Parish had shallow flooding, typically less than 1 foot in depth. East of the 17th Street Canal, flood depths in excess of 8 feet were observed in Lakeview on the north side of New Orleans near Lake Pontchartrain, the Lower Ninth Ward, and Chalmette (see Figure 8-2). Floodwaters remained in most New Orleans neighborhoods for approximately 2 to 3 weeks after the levee/floodwall breaches. Areas by the Mississippi River and the high ground along Lake Pontchartrain between the 17th Street Canal and the Industrial Canal were essentially free of flooding. These relatively elevated land areas form parts of the rim of the New Orleans "bowl."

In all areas affected by flooding resulting from Hurricane Katrina, property elevation was the key difference in the magnitude of damage. The higher the property grade elevation, the lower the flood damage. In areas of New Orleans at the same grade elevation, buildings elevated on crawlspaces generally sustained less flood damage than slab-on-grade buildings. In addition, flooding was exacerbated by the long-term subsidence of the New Orleans area, which has resulted in some areas being below sea level. Scientists estimate that the rate of subsidence of Southern Louisiana is as much as 3 feet every 100 years, or a little less than a 1/2 inch per year (*National Geographic News*, "New Orleans — A Man Made Disaster?", October 13, 2005, National Geographic Society, Washington, DC).

8.2 Floodplain Management Issues Related to Levees/Floodwalls in the New Orleans Area

Floodplain mapping in the New Orleans area has historically been based on an assumption that the area was protected by the USACE-certified levee system, which was developed over several decades beginning in the 1920s. This assumption led to floodplain regulations that allowed building construction to occur at or below sea level with no accommodations made for the possibility of riverine or coastal flooding. A detailed discussion of the New Orleans levee system and the floodplain management issues related to the levees/floodwalls is provided in Sections 8.2.1 and 8.2.2, respectively.

8.2.1 History of the New Orleans Levee System

Based on information provided by the New Orleans District of the USACE, the New Orleans levee/floodwall system was constructed in two parts. The first part, the Mississippi River Levee System (MR&T), was designed to protect the city from a flood flow of 3 million cubic feet per second from the Mississippi River, and was constructed under the authority of the Flood Control Act of 1928 and subsequent amendments. The MR&T system in the New Orleans District extends along the west bank of the Mississippi River from the vicinity of Black Hawk, Louisiana, generally southward to the vicinity of Venice, Louisiana, and on the east bank from Baton Rouge, Louisiana, to Bohemia, Louisiana.

The second part of the levee system, the Lake Pontchartrain and Vicinity Hurricane Protection Project (LP&V-HPP), was designed to protect residents between Lake Pontchartrain and the Mississippi River levee from surges in Lake Pontchartrain and Lake Borgne by storms up to a fast-moving Category 3 hurricane. The LP&V-HPP was authorized by the Flood Control Act of 1965, the Water Resources Development Act of 1974, and subsequent amendments. The LP&V-HPP is located in St. Bernard, Orleans, Jefferson, and St. Charles Parishes, generally in the vicinity of the City of New Orleans, and between the Mississippi River and Lake Pontchartrain. The LP&V-HPP system also protects residents from surges in the canals, which extend from Lake Pontchartrain to the south. These canals have been in existence since the late 1800s and were originally designed to provide navigation and drainage of the lowest parts of the City of New Orleans. The LP&V-HPP system is composed of numerous levees and flood walls, including the 17th Street Canal and London Avenue Canal levees/floodwalls.

8.2.2 Floodplain Mapping and Building Construction within the New Orleans Levee-Protected Area

The two-part New Orleans levee/floodwall system was certified by the USACE as providing at least 100-year flood protection, in accordance with the NFIP requirements. Due to this certification, the FIRMs for the area, which are the basis for the flood insurance and floodplain management, did not reflect flooding from the Gulf of Mexico, Lake Pontchartrain, or the Mississippi River. Although the FIRMs did reflect some flooding in the areas protected by the levee/floodwall system, the source of this flooding was not from a levee/floodwall breach, but from rainfall within the protected 'interior' area, generating runoff and producing localized flooding. This interior flooding was to be removed by a network of pumps supported by backup power in the case of major power outages. As a result, the FIRMs showed some of the interior areas either as having no floodplain or with a floodplain reflective of local runoff or ponding and awaiting removal outside the levee/floodwall system by the pumping network.

The 100-year flood elevations, or BFEs, in the interior areas protected by the levee/floodwall system were low compared to the actual flood elevations experienced as a result of Hurricane Katrina. A review of the FIRMs for neighborhoods observed by the New Orleans Flood Team indicated that most of the BFEs were at approximately sea level elevation, with some actually below sea level. This meant that, in areas of New Orleans that were protected by the certified levee/floodwall system, building development could occur below sea level while still being at or above the BFE and compliant with the NFIP.

Examples of the disparity between the BFE as compared to the elevation of the levee/floodwall and the flood elevations observed due to Hurricane Katrina were found in many neighborhoods of the city. Many buildings were newer construction and were fully compliant with the NFIP and the local building code. In many instances, homeowners had added freeboard to elevate their homes higher than the BFE by 1 or 2 feet as added protection from the flood source. They understood they were vulnerable to interior flooding. Yet many of these residential buildings still experienced 3 to 5 feet of flooding above their first floor elevation as a result of the levee/floodwall breach (see Figure 8-3). Homeowners interviewed in these neighborhoods stated that they did not realize that a breach of the levee/floodwall system could allow such major flooding to occur.

Aggravating this issue was the change in building construction techniques in the New Orleans area since the construction of the levee/floodwall system. Historically, New Orleans residential construction often incorporated elevation where the first finished floor was elevated several feet above grade (see Figure 8-4, upper left). The area below the first finished floor was unfinished and was used as a crawlspace or, if high enough, a garage area. When floods occurred, the first finished floor remained dry, the lower unfinished area was easily cleaned after the flood, and flood damages were minimal. More recent New Orleans residential construction has consisted almost exclusively of either slab-on-grade foundations or slight elevations above grade with a minimal crawlspace, both reflecting BFEs based only on local drainage flooding in the protected areas shown on the FIRM (see Figure 8-4, lower right). This recent change in construction techniques, combined with ongoing land subsidence, contributed to the magnitude of flood damage observed in New Orleans.



Figure 8-3. Residential building constructed approximately 1 foot above the BFE in accordance with current codes. Note flood depths were even with the top of the garage door, or about 3-5 feet above the first floor (red line).

8.3 General Characterization of Flood Damage

As discussed previously, most of the damage observed in the New Orleans area was nonstructural and related to long-duration flood issues; only limited structural damage was observed. Damages to various building types were similar, with no significant difference in impacts observed between residential buildings and critical and essential facilities. Most observed buildings, including residential as well as critical and essential facilities, were constructed on vented crawlspaces or slab-on-grade foundations with wood-framed walls covered by brick veneer.

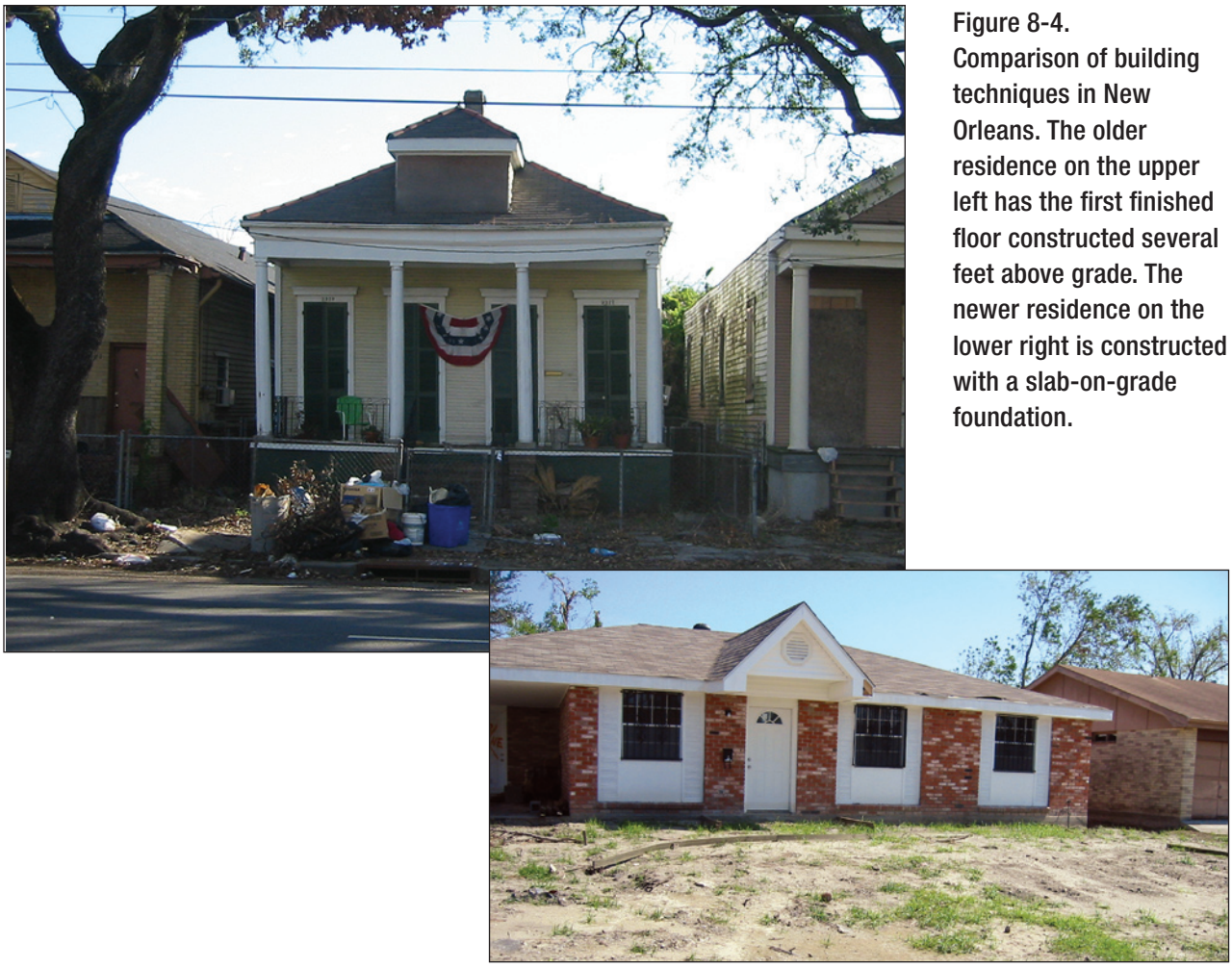


Figure 8-4. Comparison of building techniques in New Orleans. The older residence on the upper left has the first finished floor constructed several feet above grade. The newer residence on the lower right is constructed with a slab-on-grade foundation.

8.3.1 Structural Damage

Only minimal structural damage was observed in the majority of buildings in New Orleans as a result of flooding from Hurricane Katrina. There are two primary reasons for this observation. First, the flooding in New Orleans was caused by slow-moving floodwaters, which greatly reduced or eliminated the damaging effects of hydrodynamic forces and floodborne debris impacts on buildings. Second, the crawlspaces, foundation vents, garage bay doors, and other openings allowed hydrostatic pressures on walls and floors from floodwaters to equalize as floodwaters gradually rose and receded, which greatly reduced the net hydrostatic force on load-bearing walls, floors, and other structural elements.

Although flood-related structural damage was typically minor, there were several significant exceptions:

- First, the failure of the Industrial Canal (see Figure 8-5) and coastal levees produced intense flooding in eastern New Orleans and St. Bernard Parish, resulting in severe structural damage in the Lower Ninth Ward of New Orleans and Chalmette in St. Bernard Parish. Observations by the New Orleans Flood team indicated widespread destruction of

residential buildings in the Lower Ninth Ward from high velocity floodwaters and strong winds, waves, and high floodwaters that knocked buildings off their foundations, collapsed load-bearing walls, and caused other structural failures.

- Second, residential buildings sited immediately behind failed sections of levees or other flood control structures such as the 17th Street Canal levee breach suffered significant structural damage, failure of load-bearing walls, and excessive scour around slab foundations from large hydrodynamic forces generated by the levee breach (see Figure 8-6). However, these forces and impacts were quickly dissipated within a few blocks of the breach.
- Third, buildings sited on poor foundation soils suffered significant structural damage and cracking of load-bearing walls and sagging floors due to subsidence or differential settlement of saturated soils that support one or more foundation walls and/or piers (see Figure 8-7). While most of the observed structural damages triggered by soil settlement or subsidence did not constitute an imminent danger of collapse, such damages (and the underlying soil problems behind them) typically require analysis by a foundation engineer and can be expensive to isolate and repair.



Figure 8-5. The Industrial Canal levee breach in New Orleans

SOURCE: LSU HURRICANE CENTER



Figure 8-6.
Structural damage to residential buildings (circle) in New Orleans located immediately behind the site of 17th Street Canal levee breach (arrow)



Figure 8-7.
Settlement cracks in upper floor wall of New Orleans residence due to subsidence/differential settlement of underlying foundation soils during long-duration flooding

Visual observations of interior walls of both older (more than 50 years old) and newer (less than 5 years old) residential buildings showed little to no evidence of deterioration of the exposed portions of the structural wall studs due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards (see Figures 8-8 and 8-9). However, moisture readings taken inside various residential buildings indicated that excess moisture remained trapped in the walls and floors following the flood. Continued entrapment of moisture within the wall and floor systems due to a lack of drying could induce rotting of the structural framing in the long term.



Figure 8-8.
Exposed wall studs and sheathing boards in 74-year-old New Orleans residential building, showing no significant deterioration from long-duration flooding



Figure 8-9.
Exposed wall studs and sheathing boards in 2-year-old New Orleans residential building, showing no significant deterioration from long-duration flooding.

8.3.2 Non-Structural Damage

Widespread non-structural damage occurred to areas in and around New Orleans that were impacted by long-duration flooding. Unlike other hurricane-impacted areas, where residents could access their buildings relatively quickly after the flood event, the residents of New Orleans who were protected by the levee/floodwall system were unable to access buildings for several weeks because of prolonged flood inundation. As a result, the extent of interior damage was larger than damages observed in previous hurricane events.

Typical flood damages to buildings included damaged or destroyed interior drywall, plaster, fiber insulation, metal studs, flooring, wall finishes, carpets, and furniture (see Figure 8-10). Mold growth observed in flooded residences varied from light to extensive, depending on the depth of flooding, the type of interior wall finishes, and the amount of drying that occurred after the floodwaters receded (see Figures 8-10 and 8-11). Additionally, floodwaters carried bacterial and chemical pollutants into buildings, thereby contaminating porous building materials (refer to Section 8.4.2).

Several fire stations in New Orleans suffered flood damage to garage bay doors (see Figure 8-12). The fire stations in New Orleans observed by the MAT did not contain fire trucks or other heavy equipment; these appear to have been relocated prior to the flood. Many New Orleans hospitals suffered interior damage such as collapsed drop ceilings due to a loss of emergency power generators, which shut down HVAC systems used to control temperature and humidity. In some hospitals, the loss of emergency generators resulted from flooding of the generator controls or the fuel storage tanks (see Figure 8-13). However, in most hospitals, the loss of emergency generators occurred as a result of mechanical breakdown from extended use following Hurricanes Katrina or Rita.



Figure 8-10.
Typical interior flood damage to residential building in New Orleans, showing extensive mold growth (circle)



Figure 8-11.
Typical interior flood damage to residential building in New Orleans, showing light mold growth (compare to Figure 8-10)



Figure 8-12.
Damage to garage bay doors at fire station in New Orleans. The door on the right was pushed in by flooding; the door on the left appears to have been pulled open from the outside by looters.



Figure 8-13. Flooded emergency generator at hospital in New Orleans (note flood line in red)

8.4 Long-Duration Flood Impacts on Buildings

Damage from long-duration exposure to floodwaters often lies concealed within the building envelope and within wall cavities. The level of the water intrusion, the concentration of floodborne contaminants, and the length of time until floodwaters recede are important factors influencing the potential salvagability of building materials and personal property. In general, the long-duration flood damages observed in the New Orleans area were primarily to porous building materials, including wall sheathing, ceilings, and floor coverings. These materials experienced deterioration from being saturated and were impregnated with contaminated floodwater.

In order to examine the effects of long-duration flooding on porous building materials, members of the New Orleans Flood Team conducted field readings and took building material samples for laboratory testing from seven residential buildings and two fire stations in the New Orleans area from October 6 to 8, 2005. The buildings sampled were selected from among the 23 residential buildings and critical and essential facilities visited in the New Orleans area from October 4 to 8, 2005 (Figure 8-1) to reflect a variety of observed flood depths, building types, and potential contamination levels. The sampling undertaken was for informational purposes only and was not intended as a statistical representation of conditions throughout the City. Table 8-1 summarizes the buildings sampled for field readings and laboratory testing. Specific information on the field readings and laboratory tests is provided in Sections 8.4.1.2 and 8.4.2.1.

Table 8-1. Summary of Buildings Sampled and Tests Conducted

Building Sampled	Interior Flood Depth (feet)	Summary of Readings and Tests Conducted			
		Specific Humidity (Section 8.4.1.2)	Material Moisture Contents (Section 8.4.1.2)	Biological Contaminants (Sections 8.4.2.1 and 8.4.2.2)	Chemical Contaminants (Sections 8.4.2.3 – 8.4.2.6)
Residence at Elysian Fields	6.0 - 8.0	✔	✔	✔	✔
Residence at General Diaz Street	6.0 - 7.0	✔	✔	✔	✔
Residence at Memphis Street	6.0	✔	✔	✔	✔
Residence at Savoie Court	0.83 - 1.0	✔	✔	✔	✔
Residence at Munster Boulevard	7.5		✔	✔	✔
Residence at Cleary Avenue	0.83 - 1.0	✔	✔	✔	✔
Residence at Octavia Street	5.5		✔	✔	✔
Fire station at Louisiana Avenue	3.0		✔	✔	✔
Fire station at South Carrollton Avenue	2.0 - 3.0		✔	✔	✔

8.4.1 Deterioration of Building Materials from Long-Duration Flooding

8.4.1.1 Mechanics of Deterioration

In general, differing types of long-duration flood damage occur above and below the high water mark. Above the high water mark, moisture damage occurs as the result of capillary action, water vapor migration, and condensation. Below the high water mark, damage occurs from solvent action, corrosion, waterborne solids, contaminants, and bacterial degradation.

- **Capillary action:** Visual observations of interior walls and other building materials in various residential buildings and critical and essential facilities in the New Orleans area showed evidence of capillary action above the water line. A summary of specific humidity readings taken by the New Orleans Flood Team inside and outside the selected residential buildings is provided in Table 8-2. The specific humidity readings confirmed field observations that the interiors of the homes were consistently wetter than the outdoors and that opening exterior doors and windows would facilitate drying of building materials within homes. Material moisture content readings taken in various residential buildings and critical and essential facilities also showed elevated moisture contents in the drywall and/or plaster in the first floors of the buildings when compared to the upper floors.

- **Water vapor migration:** Visual observations of building materials in various residential buildings and critical and essential facilities in the New Orleans area showed evidence of water vapor migration above the water line. Interior doors and cabinet doors and drawers constructed of laminated wood products and other porous building materials were swollen shut and difficult to open as a result of water vapor migration (see Figure 8-14).
- **Solvent action:** Visual observations of interior walls of both older (more than 50 years old) and newer (less than 5 years old) residential buildings and various critical and essential facilities in the New Orleans area showed little to no evidence of deterioration by solvent action above or below the water line.
- **Corrosion:** Visual observations of metal connectors and electrical components in both older (more than 50 years old) and newer (less than 5 years old) residential buildings and various critical and essential facilities in the New Orleans area showed little to no evidence of deterioration by corrosion above or below the water line. This may be explained by the generally low salinity of the floodwaters that impacted the New Orleans area following Hurricane Katrina.

Capillary action. Capillary action, commonly referred to as "wicking," is the process by which water molecules adhere to surfaces and climb upward through materials against gravity.

Water vapor migration. Water vapor migration through the interior of a building is invisible and often overlooked. Water vapor affects materials such as wood and paper, which increase or decrease in size (i.e., swell or shrink) based on their moisture content.

Solvent action. Water is a powerful and effective solvent and can dissolve some paper products such as drywall (gypsum board) paper.

Corrosion. Metals of differing composition in contact with one another in the presence of water or water vapor are vulnerable to corrosion. Corrosion is predictable. For example, when copper electrical wire contacts a steel screw, the more chemically active metal corrodes. Corrosion increases as the salinity of the water increases.

Table 8-2. Summary of Specific Humidity Readings (grains per pound)

Property	Outside	Crawlspace	Inside (1st Floor)	Inside (2nd Floor)	Inside (3rd Floor)
Residence at Elysian Fields	102.2	119.0	115.5	-	-
Residence at General Diaz Street	127.6	133.0	145.2	-	-
Residence at Memphis Street	112.2	-	132.0	138.6	153.3
Residence at Savoie Court	80.6	-	85.8	-	-
Residence at Cleary Avenue	91.2	-	100.8	-	-



Figure 8-14. Kitchen cabinet doors above the flood level were damaged from the excessive moisture in the house from long-duration flooding.

8.4.1.2 Damage Observations and Flood Resistance of Building Materials in the New Orleans Area

Floodwater damage to specific building materials depends on a variety of factors, including the depth, velocity, and composition of the floodwater, and the type, design, age, and construction methods of the building materials. For vulnerable building materials, flood damage is typically a progressive condition (the longer materials remain wet, the greater the damage that occurs). Some floodprone materials reach a point-of-no-return when exposed to floodwaters, after which salvage attempts are futile. Examples of such floodprone materials include laminated wood products used for interior doors and cabinets, which will swell and deteriorate, and hardwood flooring, which will warp. A summary of typical building materials observed in New Orleans and their basic flood resistance is described in the bullets that follow.

- **Exterior walls.** Many of the exterior walls in residential buildings observed in New Orleans were constructed of brick veneer or stone, which are durable porous materials that are resistant to flooding damage and can frequently be cleaned with minimal difficulty. Other observed exterior wall materials that can frequently be washed and cleaned included other durable porous surfaces, such as engineered stone and stucco, and nonporous surfaces, such as vinyl and aluminum siding.

- **Wood framing.** Of the available wood products, solid dimensional lumber is typically the most resistant to water, while materials made from chips or oriented strands of wood are most vulnerable due to additional points for moisture intrusion. Laminated plied materials, such as exterior-grade plywood with waterproof adhesives, are reasonably water-resistant. Other materials, such as OSB, are less water-resistant. Some wood products are pressure-treated with chemical agents that resist microbial attack and can improve flood resistance.

  When moisture content in various wood products was measured and compared in one New Orleans residence, the moisture content in the OSB was twice as high as in the pressure-treated plywood even though the plywood was the lowest course of sheathing and the OSB

sheathing course was located above it. The Flood Team observations indicate that:

1. If not permitted to adequately dry, OSB retains moisture longer, and can be more vulnerable to microbial attack, than plywood.
2. OSB requires either extended drying periods when drying naturally or higher capacity drying equipment when structural drying is performed mechanically.

Visual observations of interior walls and floors of various residential buildings and critical and essential facilities showed little to no evidence of deterioration of the exposed portions of the wood framing due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards in residential buildings. Visible fungal growth was noticeable when inspecting the wood in the crawlspaces under several residential buildings; however, some of the growth appears to have existed prior to the flood.

- **Insulating materials.** Typical insulating materials are fibrous and need to be replaced after being impacted by floodwaters. A variety of insulating materials were found within residential buildings in New Orleans. While older dwellings had no insulation or mineral wool insulation, the predominant insulating material found in one- and two-family dwellings was paper-faced fiberglass insulation. After the floodwaters receded, flooded fiberglass insulation retained water, and the moisture "wicked" farther up into the paper due to capillary action.
- **Interior wall materials.** The most common interior wall material observed in newer New Orleans residences was drywall. Drywall (gypsum board) consists of gypsum sandwiched between paper layers. In residential buildings that were more than 50 years old, drywall and/or thin coats of plaster were layered over the original lath and plaster walls. When flooded, drywall is typically subject to deterioration by softening due to

Specific Humidity and Drying Flooded Buildings

After hurricanes, residents are generally urged to open their buildings to dry out building materials as soon as possible. Relative humidity (which changes according to air temperature) has been used in the past to measure progress and make decisions regarding post-flood building drying. However, relative humidity is an inaccurate measurement and should be abandoned in favor of using specific (or absolute) humidity (which is a measure of the actual moisture content, regardless of temperature). When determining the extent of drying in a building following a flood, temperature and relative humidity readings should be taken inside and outside of the building in order to determine the specific humidity readings inside and outside the building. These readings can be obtained by using tables or charts that convert temperature and relative humidity to specific humidity, or by means of special equipment such as a commercially-available moisture meter.

When the specific humidity inside the building is greater than the specific humidity outside, natural processes such as opening the windows and doors can be used to facilitate drying inside the building. By contrast, when the specific humidity inside the building is less than the specific humidity outside, artificial means such as fans or drying equipment should be used to facilitate drying inside the building. It is important to note that the comparative specific humidity readings outside and inside the building should be taken at about the same time, and that the comparative readings and the moisture reduction methods employed in a given building are subject to change during the course of the drying process.

"wicking" and increased vulnerability to impact damage. Another common interior wall material observed in New Orleans was plaster. Plaster begins as a mixture of dry components that crystallize through chemical reaction when water is added. Plaster is applied in layers to a substrate of wood, metal, or rock lathe. Although plaster typically absorbs less water than drywall, plaster is a dense material, which is slow to dry after wetting.

Observations by the New Orleans Flood Team did not indicate evidence of drywall deterioration from softening due to solvent action. However, both the drywall and the plaster in buildings impacted by floodwaters experienced "wicking," which led to extensive fungal growth and entrapment of floodborne contaminants within the drywall materials (refer to Section 8.4.2 for details).

- **Wall coverings and coatings.** Depending on the source(s) of moisture, wall coverings and coatings can either protect surfaces from moisture intrusion or exacerbate damage by trapping moisture within the materials. Observations of flooded buildings in New Orleans indicated most surfaces covered by common household paints were not resistant to floodwater damage. In addition, wallpaper paste found in some residences was dissolved by floodwaters from solvent action and facilitated widespread fungal growth (refer to Section 8.4.2.2 for details).
- **Interior doors and cabinets.** The majority of interior doors and cabinets observed in New Orleans buildings were constructed of laminated wood products. The water vapor migration that occurred throughout many building interiors caused countless laminated wood passage doors, and cabinet doors and drawers to swell shut (see Figure 8-14).
- **Floors and floor coverings.** Floors and floor coverings observed in New Orleans included bare concrete, hardwood, laminate, carpeting, vinyl tiles, and linoleum. Bare concrete floors found in fire station apparatus bays were typically most resistant to flood damage. By contrast, the long-duration flooding in New Orleans led to warping and buckling of hardwood and laminate flooring from moisture absorption. Vinyl and linoleum floor coverings observed in most buildings did not experience significant damage, except for some tiles in older buildings that were found to be loose or had curled edges; however, the coverings can entrap moisture that could damage the underlying wood sub-floor. Also, many older (pre-1970s) vinyl and linoleum flooring products, such as 9-inch square tiles and adhesives, often contain asbestos.
- **Framing connections.** Metal framing connectors and fasteners observed in the New Orleans buildings did not experience significant long-duration flood damage as a result of corrosion.
- **Utility systems.** As with connections, most plumbing and plastic-encased electrical lines observed in the New Orleans buildings did not experience significant long-duration flood damage as a result of corrosion. However, other flooded utility lines and associated small equipment, such as HVAC ductwork and electrical receptacles, experienced greater flood damage. The New Orleans Flood Team observed furnaces and air conditioning units located in attic spaces, as well as multi-story dwellings where condensing coils were externally elevated and water heaters, furnaces, air conditioners, and laundry rooms were located on upper levels. These measures resulted in a reduction or elimination of damage to the utility equipment and appliances.

8.4.2 Long-Duration Flood Impacts from Contamination

The extent and duration of the flooding that impacted New Orleans following Hurricane Katrina gave rise to numerous questions and concerns regarding hazardous materials that might have been present in the floodwaters. In an effort to address these questions and concerns, the U.S. Environmental Protection Agency (USEPA), in cooperation with the Louisiana and Mississippi Departments of Environmental Quality, the USGS, and NOAA, mobilized a coordinated effort to sample standing floodwater remaining in the impacted area as well as sediments and air.

According to the USEPA website (http://www.epa.gov/katrina/testresults/katrina_env_assessment_summary.htm), the USEPA collected the following samples and obtained the following results:

- **Floodwater samples.** Floodwaters in the east bank of the Greater New Orleans area were extensively tested. Nearly 400 water samples were collected by the Louisiana Department of Environmental Quality (LDEQ) and USEPA to represent the flooded areas and floodwaters from these areas that were pumped to Lake Pontchartrain when the areas were dewatered. Each of these samples was analyzed for nearly 200 chemicals and fecal coliform bacteria. The results indicated average concentrations of chemicals were below levels of concern for short-term (i.e., 90 days) dermal contact and incidental ingestion. However, numerous floodwater samples revealed elevated bacteria levels from floodwaters that had mixed with sewage collection system waters. According to the USEPA, the remaining floodwaters were removed from the New Orleans area on October 11, 2005, and thus no longer served as a source of exposure to residents returning to impacted areas.

- **Sediment samples.** From September 10 through October 14, 2005, USEPA collected sediment samples at 430 sites in the streets and public areas of Jefferson, Orleans, Plaquemines, and St. Bernard Parishes. The USEPA's sampling procedures specified that efforts were to be made to bias the samples toward areas that were more likely to contain elevated levels of contamination such as areas that contained oily sediments. Each sample was tested for fecal coliform bacteria and about 200 different chemicals, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), metals, pesticides, herbicides, polychlorinated biphenyls (PCBs), and hydrocarbons. The results indicated that a variety of chemicals were detected in the sediments. The most frequently detected chemicals included some metals, hydrocarbons, and, to a lesser extent, pesticides. These levels are consistent with the results that would be expected in a densely populated urban area and are similar to the historical levels found in these parishes before Katrina, and to other urban areas throughout the nation. The majority of chemicals detected were below levels of health concern. However, there were some localized areas with levels of arsenic and petroleum hydrocarbons that exceeded both LDEQ's Risk Evaluation/Corrective Action Program (RECAP) and USEPA's risk criteria (e.g., range of 1 in 1,000,000 to 1 in 10,000 risk of an individual developing cancer over a lifetime), based on long-term (30 years) residential exposure assumptions. The levels of fecal coliform bacteria and petroleum hydrocarbons in the sediments also exceeded health screening values; however, these levels are expected to naturally decrease over time. Subsequent data from samples collected in November 2005 indicate that the highest arsenic concentrations were found in samples taken from golf courses and are associated with herbicides. Composite samples collected in February 2006 indicate that the elevated arsenic detections not on golf courses were isolated and not indicative of larger areas of contamination that might pose a chronic health risk.

- **Air samples.** LDEQ and USEPA conducted extensive air sampling in the areas impacted by Hurricane Katrina. All of the results collected to date for ambient air quality samples appear to be typical for this region of the state, and are below any levels of health concern.

In an effort to determine if contaminants were present in structures after the floodwaters receded, seven residential structures and two critical and essential facilities (fire stations) were visually inspected and samples were collected. The focus of the site inspections for the New Orleans Flood Team was to assess and evaluate opportunities for flood restoration; the sampling was not intended to be statistically representative of contamination in the impacted area. Sample collection was limited to public buildings or structures where permission had been granted by the owners. Wherever possible, a sample of flood residue in the form of wet sludge or dried sediment was collected from inside the structure (see Figure 8-15). Additional samples, primarily of wall materials, were also collected. An effort was made to collect samples of materials from below the water line and comparison samples from above the water line (see Figure 8-16). See Appendix I for a detailed description of sampling and analytical methods.



Figure 8-15.
Flood residue and buckled floor observed on General Diaz Street. A sample of the flood residue was collected for analysis.



Figure 8-16.
Samples were collected from wall materials both above and below the waterline as shown on this wall of a house on Memphis Street. Where practical, samples were collected from surfaces that were already substantially damaged or scheduled for tear-out.

Analytical parameters were chosen following a review of the USEPA floodwater and sediment contaminant data from the New Orleans area. Unless the sample volume was insufficient to support multiple analyses, each sample was subjected to the following analyses:

Biological Contaminants

- **Bacteria.** Overall quantification and breakdown by Gram Negative and Gram Positive types. Refer to Section 8.4.2.1 for details.
- **Fungal.** Identification of fungal (mold) materials. Refer to Section 8.4.2.2 for details.

Chemical Contaminants

- **Heavy metals.** Thirteen EPA and Occupational Safety and Health Administration (OSHA) priority element pollutants as described in the Clean Water Act. Refer to Section 8.4.2.3 for details.
- Diesel range organics (DROs) that were likely to be left after the floodwaters had receded and evaporation had taken place. Refer to Section 8.4.2.4 for details.
- **Pesticides.** Organochlorine compounds that were less likely to be diluted than the water soluble organophosphates that are used today. Refer to Section 8.4.2.5 for details.
- **PCBs.** Polychlorinated biphenyls are persistent chemicals that were often used in transformer oils and in other industrial processes. Refer to Section 8.4.2.6 for details.

A total of 9 water/sludge samples and 38 wall material samples were collected for analysis. Table 8-3 presents an overall review of the samples that were collected, as well as significant highlights of the test results related to each building. A review of the sample results indicated the biological and chemical contaminant levels were consistent with the USEPA's floodwater and sediment sample results. Refer to the USEPA website for details (http://www.epa.gov/katrina/testresults/katrina_env_assessment_summary.htm). Details on each of the biological and chemical parameters tested are provided in Sections 8.4.2.1 through 8.4.2.6. The detailed sample results, including an interpretive summary chart with critical information related to each type of analytical data, laboratory quality control information, and notes regarding any limitations on the sample information, are also presented in Appendix I.

Table 8-3. Highlights of the Biological and Chemical Contaminant Sampling Results

Building Sampled	Number of Samples	Highlights
Residence at Elysian Fields	Eight samples were collected from inside and outside the house. There was sufficient sample volume for all of the samples to be analyzed for all six contaminant types noted on the previous page. However, one sludge sample was too wet for mold analysis.	1. Extremely high levels of bacterial contamination in most water-impacted areas. 2. Significant mold contamination on wall materials above the water line. *Chaetomium* is the dominant fungal type in samples both above and below the water line. *Chaetomium* also recovered from unimpacted second floor. 3. Above average levels of arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc in interior and exterior samples. 4. Average levels of DROs in the flood damaged areas, with above average levels in the exterior dry sludge. 5. Above average levels of DDT and heptachlor. 6. No detectable levels of PCBs.
Residence at General Diaz Street	Four samples were collected from inside the structure. One wall sample was not large enough for the mercury, DROs, pesticides, or PCBs analyses to be completed. Also, the sludge sample was too wet for mold analysis.	1. Extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination on wall materials above the water line. Limited mold growth from samples below the water line. *Aspergillus/ Penicillium* and *Chaetomium* flourishing above the water line. 3. Above average levels of arsenic and nickel in interior wet sludge sample, and above average level of beryllium in wall sample above water line. 4. Above average levels of DROs. 5. Above average levels of chlordane, DDT, dieldrin, and heptachlor. 6. No detectable levels of PCBs.
Residence at Memphis Street	Four samples were collected from inside the structure. Two wall samples were not large enough for the DROs, pesticides, or PCBs analyses to be completed.	1. Moderate to extremely high levels of bacterial contamination in all water-impacted areas. 2. Mold contamination present in dry sludge and wall samples above and below the water line. *Aspergillus / Penicillium* and *Chaetomium* dominate samples above the water line, but also the wood stud samples below the water line. *Stachybotrys* present in the sludge. 3. Above average levels of arsenic, beryllium, cadmium, chromium, copper, lead, selenium, silver, and zinc in interior dry sludge sample. 4. Below average levels of DROs. 5. No detectable levels of pesticides. 6. No detectable levels of PCBs.

Table 8-3. Highlights of the Biological and Chemical Contaminant Sampling Results (continued)

Building Sampled	Number of Samples	Highlights
Residence at Savoie Court	Nine samples were collected from inside the structure. Four wall samples were not large enough for heavy metals, DROs, pesticides, or PCBs analyses to be completed.	1. Extremely high levels of bacterial contamination in the majority of samples. 2. Significant mold contamination on all samples. *Aspergillus/Penicillium* and *Chaetomium* dominate samples from both above and below the water line. 3. Average to below average levels of most heavy metals. 4. Below average levels of DROs. 5. Generally average levels of pesticides, except for an above average level of dieldrin in a wall sample above the water line. 6. No detectable levels of PCBs.
Residence at Munster Boulevard	Three samples were collected from inside and outside the structure. The sludge sample was too wet for mold analysis.	1. Extensive to extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination on the wall below the water line and the exterior sludge. *Stachybotrys* in both sludge and wall material, below the water line. 3. Above average levels of beryllium in the exterior dry sludge sample. 4. Average to below average levels of DROs. 5. Below average levels of pesticides in the interior and exterior samples. 6. No detectable levels of PCBs.
Residence at Cleary Avenue	Nine samples were collected from inside the structure. Three samples were not large enough for the DROs, pesticides, or PCBs analyses to be completed, and one sample was not large enough for heavy metals analysis.	1. Extensive to extremely high levels of bacterial contamination in most samples. 2. Significant mold contamination in wall samples above and below the water line. Substantial mold with *Stachybotrys* on both sides of the drywall and studs above the water line. 3. Average levels of most heavy metals. 4. Below average levels of DROs. 5. Below average levels of pesticides. 6. No detectable levels of PCBs.
Residence at Octavia Street	Four samples were collected from inside the structure.	1. Extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination. *Aspergillus/ Penicillium* and *Chaetomium* dominates three of the four interior wall material samples. 3. Above average levels of mercury in wall material above the water line. 4. Average levels of DROs. 5. Above average levels of chlordane and DDT in the drywall. 6. No detectable levels of PCBs.

Table 8-3. Highlights of the Biological and Chemical Contaminant Sampling Results (continued)

Building Sampled	Number of Samples	Highlights
Fire station at Louisiana Avenue	Three samples were collected from inside the structure. One wall sample was not large enough for DROs, pesticides, or PCBs analyses to be completed.	1. Extensive to extremely high levels of bacterial contamination in all water-impacted areas. 2. Significant mold contamination. *Chaetomium* in samples both above and below the water line. 3. Above average levels of arsenic, cadmium, chromium, copper, lead, silver, and zinc in dry sludge sample. Generally below average levels of heavy metals detected in the drywall samples. 4. Average levels of DROs. 5. Above average levels of chlordane in the drywall. 6. No detectable levels of PCBs.
Fire station at South Carrollton Avenue	Three samples were collected from inside the structure. One sample was not large enough for the DROs, pesticides, or PCBs analyses to be completed.	1. Extensive to extremely high levels of bacteria contamination in all water-impacted areas. 2. Significant mold contamination. *Stachybotrys* found in sludge and wall materials below the water line. 3. Above average levels of antimony, arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc. 4. Below average levels of DROs. 5. Below average levels of chlordane. 6. No detectable levels of PCBs.

8.4.2.1 Bacterial Contamination

Floodwaters carry biological contamination in the form of bacteria, viruses, and parasites. Bacteria are one-celled microorganisms that are invisible to the naked eye. Following flooding, they are the first microorganisms to multiply. Bacteria pose a significant post-flood health threat. Some bacteria produce poisonous toxins that can cause diseases such as lockjaw and food poisoning in humans. Other bacteria produce enzymes that dissolve or destroy living cells, thereby damaging commercial goods and fouling surfaces. Also, bacterial growth on food and food handling equipment is a major source of disease.

A total of 47 material samples and 1 floodwater sample taken from nine buildings were analyzed for bacterial growth. Bacteria levels ranged from undetectable to "overloaded," which is reported as 456,000 colony forming units per square centimeter (cfu/cm^2). The majority of bacteria identified in the samples were *Gram Negative Bacilli*. Samples dominated by this bacteria type generally indicate contact with sewage or animal feces. The results are summarized in Table 8-4.

Table 8-4. Total Bacteria Contamination Levels (cfu/cm²) by Materials and Moisture Level

Building	Range of Values	Wet Sludge	Dry Sludge	Wall Materials Below Water Line	Wall Materials Above Water Line
Residence at Elysian Fields	Maximum	40,600	1,200	41,346	456,000
	Minimum	40,600	1,200	7,460	BMDL
	Average	40,600	1,200	22,420	234,334
Residence at General Diaz Street	Maximum	64,900	No Sample	183,000	41,500
	Minimum	64,900		20,200	41,500
	Average	64,900		101,600	41,500
Residence at Memphis Street	Maximum	No Sample	590	381,000	544
	Minimum		590	381,000	544
	Average		590	381,000	544
Residence at Savoie Court	Maximum	No Sample	No Sample	233,000	242,000
	Minimum			BMDL	27,000
	Average			90,000	134,500
Residence at Munster Boulevard	Maximum	7,020	4,860	456,000	No Sample
	Minimum	7,020	4,860	456,000	
	Average	7,020	4,860	456,000	
Residence at Cleary Avenue	Maximum	No Sample	8,280	404,000	350,000
	Minimum		8,280	BMDL	BMDL
	Average		8,280	138,500	98,483
Residence at Octavia Street	Maximum	No Sample	No Sample	251,000	456,000
	Minimum			251,000	168,000
	Average			251,000	312,667
Fire station at Louisiana Avenue	Maximum	No Sample	3,690	327,000	156,000
	Minimum		3,690	327,000	156,000
	Average		3,690	327,000	156,000
Fire station at South Carrollton Avenue	Maximum	No Sample	2,460	23,600	6,130
	Minimum		2,460	23,600	6,130
	Average		2,460	23,600	6,130

For cultural bacterial swab sample results:

- Below the method detection limit (BMDL) is less than 18 cfu/cm².
- Moderate is between 18 cfu/cm² and 1,000 cfu/cm².
- Extensive is between 1,001 cfu/cm² and 20,000 cfu/cm².
- Extremely high is greater than 20,000 cfu/cm².

A number of patterns were observed in the bacterial sampling data. The strongest correlation was seen between wet materials and bacterial growth. Since most bacteria need a warm, moist environment to proliferate, the connection between elevated moisture levels and higher bacteria levels was expected. Table 8-4 shows that, for the two facilities where both wet and dry flood residues were sampled, bacteria levels were higher in the wet sludge as compared to dry sludge. Similarly, with one exception (Elysian Fields residence), bacteria levels from the same wall were significantly higher in the samples of drywall collected from below the waterline as compared to samples collected from a level above the floodwater line.

As might be expected, only low levels of bacteria were identified in samples collected from relatively dry materials. Negligible levels were detected in samples collected from the unimpacted second floor at the Elysian Fields residence and in the drier materials in the Cleary Avenue and Memphis Street residences.

Bacteria levels were relatively high on the outer surface of exposed wooden studs. The sample results on the studs were consistent with those from the drywall with *Gram Negative Bacilli* dominating the results (samples 6379-16, 6379-21, and 6379-37).

Bacterial growth appeared to be inhibited by fungal growth in numerous areas. Rampant fungal growth on the damp carpet and wallpaper in the living room of the Savoie Court residence may well account for the fact that bacteria were not detected in those areas (see Table 8-4). Bacterial levels were also very low in the samples of visible fungal growth that were scraped from the carpet and a dresser leg in the Savoie Court residence (samples 6379-18, 6379-19, 6379-24, and 6379-25) (see Figure 8-17).

Figure 8-17.
Bacteria levels were frequently found to be significantly lower in areas with rampant fungal growth. This pattern held true at the residence on Savoie Court, where fungal levels were extensive on the dresser and carpet near the door frame while the bacteria levels were negligible at these same locations.



8.4.2.2 Fungal Contamination (Mold)

Fungi feed on either living or dead organisms by absorbing nutrients from the environment around them. Fungi accomplish this by growing through and within a host substrate. Fungal growth and contamination is a secondary health risk following flooding; the floodwater acts as a source of moisture, "wicking" into materials by capillary action, and stimulating fungal growth. The presence of fungi can cause allergic reactions, athlete's foot, ringworm, and infections of the skin and nails.

A total of 44 material samples taken from 9 facilities were analyzed for fungal contamination. In most cases, the fungal types were dominated by *Aspergillus/Penicillium* or *Chaetomium*. These mold types are frequently found as initial and secondary colonizers of water-impacted building materials. Various strains of *Aspergillus/Penicillium* and *Chaetomium* are linked to significant health problems. In addition to *Chaetomium*, a number of other mold types that are indicative of substantial water damage were detected. These included *Stachybotrys* and *Memnoniella*, which are also associated with serious health symptoms. Results are shown in Table 8-5.

Table 8-5. Summary of Fungal Sampling Data

Building Site	Sample Location	Indicator Organisms	Common Organisms	Target Organisms	Hyphae
Residence at Elysian Fields	Dry Sludge	No (1/1)	Yes (2/1)	No (1/1)	Yes (1/1)
	Wall Materials Below Water Line	No (3/3)	Yes (2/3)	Yes (1/3)	Yes (2/3)
	Wall Materials Above Water Line	Yes (1/3)	Yes (4/3)	Yes (3/3)	Yes (2/3)
Residence at General Diaz Street	Dry Sludge	No Sample			
	Wall Materials Below Water Line	No (2/2)	Yes (2/2)	No (2/2)	No (2/2)
	Wall Materials Above Water Line	Yes (1/1)	Yes (4/1)	Yes (1/1)	Yes (1/1)
Residence at Memphis Street	Dry Sludge	Yes (1/1)	Yes (1/1)	Yes (2/1)	Yes (1/1)
	Wall Materials Below Water Line	Yes (1/2)	Yes (1/2)	Yes (1/2)	Yes (1/2)
	Wall Materials Above Water Line	Yes (1/1)	No (1/1)	No (1/1)	No (1/1)
Residence at Savoie Court	Dry Sludge	No Sample			
	Wall Materials Below Water Line	Yes (3/3)	Yes (1/3)	Yes (3/3)	Yes (3/3)
	Wall Materials Above Water Line	Yes (2/2)	Yes (1/2)	Yes (1/2)	Yes (1/2)
Residence at Munster Boulevard	Dry Sludge	Yes (1/1)	Yes (5/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Below Water Line	No (1/1)	No (1/1)	Yes (2/1)	Yes (1/1)
	Wall Materials Above Water Line	No Sample			

Table 8-5. Summary of Fungal Sampling Data (continued)

Building Site	Sample Location	Indicator Organisms	Common Organisms	Target Organisms	Hyphae
Residence at Cleary Avenue	Dry Sludge	No (1/1)	Yes (4/1)	No (1/1)	No (1/1)
	Wall Materials Below Water Line	Yes (3/3)	Yes (1/3)	Yes (1/3)	Yes (3/3)
	Wall Materials Above Water Line	Yes (4/4)	Yes (7/4)	Yes (2/4)	Yes (3/4)
Residence at Octavia Street	Dry Sludge	No Sample			
	Wall Materials Below Water Line	No (1/1)	No (1/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Above Water Line	Yes (3/3)	Yes (5/3)	Yes (2/3)	Yes (1/3)
Fire station at Louisiana Avenue	Dry Sludge	No (1/1)	Yes (3/1)	No (1/1)	Yes (1/1)
	Wall Materials Below Water Line	Yes (1/1)	Yes (1/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Above Water Line	Yes (1/1)	No (1/1)	Yes (2/1)	Yes (1/1)
Fire station at South Carrollton Avenue	Dry Sludge	No (1/1)	Yes (1/1)	Yes (2/1)	Yes (1/1)
	Wall Materials Below Water Line	No (1/1)	Yes (1/1)	Yes (1/1)	Yes (1/1)
	Wall Materials Above Water Line	No (1/1)	No (1/1)	No (1/1)	No (1/1)
Totals	Dry Sludge	Yes (2/6)	Yes (16/6)	Yes (5/6)	Yes (5/6)
	Wall Materials Below Water Line	Yes (8/17)	Yes (9/17)	Yes (11/17)	Yes (13/17)
	Wall Materials Above Water Line	Yes (13/16)	Yes (21/16)	Yes (11/16)	Yes (9/17)

For fungal bulk sample results:

No (#/#)	No Organisms Detected (# of # samples)
Yes (#/#)	Indicator Organisms associated with potentially significant health problems detected = *Aspergillus/ Penicillum* (# of indicator organisms detected in # of total samples)
Yes (#/#)	Common Organisms associated with minor health problems/ allergies, including *Ascospore, Basidiospore, Cladosporium, Culvaria, Epicoccum, Fusarium, Myxomycete, Nigospora, Periconia* and *Smut* (# of different common organisms detected in # of total samples)
Yes (#/#)	Target Organisms associated with potentially serious health problems detected; which include *Chaetomium, Fusarium, Memnomiella, Stachybotrys* and *Trichoderma* (# of different target organisms detected in # of total samples)
Yes (#/#)	Hyphae: growth structures in addition to spores detected (# of hyphae detected in # of total samples)
Yes (#/#)	Spores

Substantial fungal contamination was observed in all of the inspected facilities. In the majority of inspected structures, fungal growth was observed to be more vigorous on porous contents



Figure 8-18.
Prolific mold growth was seen on porous contents in most inspected buildings.



Figure 8-19.
The mold growth on the walls was generally much more vigorous above the floodwater level than below it. Sediments, heavy metal contamination, and oil film residue, as well as material moisture content and lack of exposure to air during flooding, may contribute to minimizing the fungal growth on the saturated wall materials.

(see Figures 8-18 and 8-19) and porous wall finishes above the water line as compared to wall materials below the water line. In several houses, the fungal growth was rampant on surfaces high enough above the water line to suggest that the growth was supported by high humidity levels and/or condensation as compared to water "wicking" (see Figure 8-20). This was especially evident in the residence on Savoie Court, where the water level only reached approximately 18 inches above the floor. Even so, mold growth in this structure was extensive in many rooms extending all the way to the ceiling (see Figure 8-21). In addition, minor visible mold growth was observed on the concealed side of the drywall on the majority of the wall samples taken, even



Figure 8-20.
In many buildings, the mold growth above the waterline appears to have been fueled by condensation of moisture in addition to water "wicking." The upper cabinets and kitchen ceiling in the building on General Diaz Street were well above the floodwater line, yet showed extensive fungal growth.



Figure 8-21.
On Savoie Court, fungal growth was observed up to the ceiling on some walls, despite the fact that floodwaters only reached up 18-24 inches. This wall showed thick mold growth both above and below the high water mark.

for samples where the exposed surface was covered with mold. However, sample results of materials inside the wall cavities confirmed the presence of fungal contamination inside the wall as well as on the exposed surfaces.

Fungal contamination was typically observed above the high water mark and was generally absent or significantly less vigorous below it. There is evidence in the technical literature that the dirt and sediment, which is present in the building materials after being saturated by floodwater, discourages fungal growth. Fungal growth may also have been discouraged below the high water mark by some of the residual contaminants in the wall materials, including pesticides and heavy metals, which are documented to have antifungal properties.

8.4.2.3 Heavy Metals

Heavy metals such as lead and mercury are natural components of the Earth's crust that cannot be degraded or destroyed. Heavy metals can be introduced into the water supply through industrial and consumer waste, or from acid rain breaking down soils and releasing heavy metals into lakes, rivers, and groundwater. These heavy metals can then be carried by floodwaters and spread over a wide area.

Thirty-six material and eight sludge samples collected from nine buildings were analyzed for the following 13 heavy metals: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Because mercury is subject to a different analytical technique than the other metals, there was only enough sample volume in 40 of the samples to provide a reading for mercury. A summary of the maximum levels of heavy metals evaluated during the analysis of the samples collected from the New Orleans area is shown in Table 8-6.

The results of Table 8-6 indicate the following:

- Levels of arsenic exceeded the 250 percent of the mean (average) values in a majority of the buildings sampled.
- Levels of beryllium, cadmium, chromium, copper, lead, nickel, silver, and zinc exceeded the 250 percent of the average values in three or more of the buildings sampled.
- Levels of antimony, selenium, silver, and thallium were below the method detection limit (BMDL) in a majority of the buildings sampled.

The highest concentrations of heavy metals were typically encountered in the wet and dry sludge samples than in the wall materials. However, it is important to note that the number of available sludge sample results was relatively low compared to the number of available wall sample results. In addition, concentrations of heavy metals appeared to be higher in buildings located closer to Lake Pontchartrain and lower in buildings located farther away from the Lake Pontchartrain. These results suggest that the some of the heavy metal contaminants came from Lake Pontchartrain floodwater.

Heavy metals typically enter the human body via ingestion and inhalation. As trace elements, some heavy metals (e.g., copper, selenium, and zinc) are essential to maintain the metabolism

of the human body. However, at higher concentrations, they can lead to poisoning. Heavy metals are particularly dangerous as they tend to bioaccumulate. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. Cadmium, lead, and mercury are considered toxic heavy metals. Exposure to high levels of heavy metals identified in Table 8-6 can have the following adverse health effects:

- **Antimony:** Exposure to high levels of antimony for short periods of time causes nausea, vomiting, and diarrhea. There is little information on the effects of long-term antimony exposure.
- **Arsenic:** Acute (short-term) arsenic poisoning may cause nausea, vomiting, diarrhea, weakness, loss of appetite, shaking, cough, and headache. Chronic (long-term) exposure may lead to a variety of symptoms, including skin pigmentation, numbness, cardiovascular disease, diabetes, and vascular disease. Arsenic is also known to cause a variety of cancers, including skin cancer (non-melanoma type), kidney, bladder, lung, prostate, and liver cancer.
- **Cadmium:** Long-term exposure to cadmium is associated with renal dysfunction. High exposure may lead to obstructive lung disease and has been linked to lung cancer, although data concerning the latter are difficult to interpret due to compounding factors. Cadmium may also produce bone defects (osteomalacia, osteoporosis) in humans and animals.
- **Chromium:** Low-level exposure to chromium can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage circulatory and nerve tissue.
- **Copper:** Although copper is an essential substance to human life, in high doses it can cause anemia, liver, and kidney damage, and stomach and intestinal irritation. People with certain illnesses such as Wilson's disease are at greater risk for health effects from overexposure to copper.
- **Lead:** Exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Various effects occur over a broad range of doses, with infants and children being more sensitive than adults. High levels of lead exposure may result in toxic biochemical effects in humans, which, in turn, cause problems in the synthesis of hemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system.
- **Mercury:** Mercury is a toxic substance that has no known function in human biochemistry or physiology and does not occur naturally in living organisms. Inorganic mercury poisoning is associated with tremors, gingivitis, and/or minor psychological changes. Natural biological processes can cause methylated forms of mercury to form and bioaccumulate over a million-fold and concentrate in living organisms, especially fish. These forms of mercury are highly toxic, causing neurotoxicological disorders. The main pathway for mercury to humans is through ingestion and not inhalation.
- **Zinc:** Ingestion of high doses of zinc in a short period of time can lead to adverse health effects, such as stomach cramps, nausea, and vomiting. Long-term health impacts of

ingesting large amounts of zinc can include anemia, nervous system disorders, damage to the pancreas, and lowered levels of "good" cholesterol.

8.4.2.4 Hydrocarbon Contamination

Petroleum products such as motor fuels and lubricants enter floodwaters when storage tanks and vehicles overturn or are covered by floodwaters. Petroleum products dispersed by rapidly moving floodwaters dissolve into the water column and, due to the density of the petroleum fractions, float on the water surface and, as floodwaters recede, insoluble petroleum products floating on the water's surface frequently leave a film on building materials. These petroleum products are sticky and can attract particulates.

According to the Centers for Disease Control and Prevention (CDC), prolonged dermal contact with petroleum hydrocarbons can cause skin erythema (reddening), edema, and burning. The skin effects can be exacerbated by subsequent exposure to sunlight from the phototoxicity of trace contaminants in the oil. Human epidemiological studies have shown that high-dose, chronic, and occupational exposure to mineral oils may cause skin cancer.

Material samples were analyzed for DROs. These hydrocarbon compounds are the less volatile fractions of petroleum and, therefore, are less likely to have evaporated during the course of the 4 weeks that passed between the time of the initial flooding and the field investigation by the New Orleans Flood Team.

Of the 47 samples, 35 had enough collected material for an appropriate analysis. Over 95 percent of the analyzed sludge and wall material samples had quantities of DROs that exceeded the method detection limit of 18,000 µg/kg of hydrocarbons. As shown in Table 8-7, the sample levels ranged from 18,000 to 3,100,000 µg/kg. The highest concentrations were found in wallpaper and wall material samples above the water line.

Table 8-6. Summary of Maximum Levels Sampled for Heavy Metal Contamination (µg/kg)

Building	Element	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
	Mean (Average) Value**	12,337	6,787	226	3,491	9,362	31,263	62,690	1,190	14,340	1,109	157	169	1,373,191
Residence at Elysian Fields	Wet Sludge	650	17,000	850	42,000	25,000	81,000	130,000	260	130,000	14,000	BMDL	350	4,800,000
	Dry Sludge	BMDL	9,700	1,200	2,400	33,000	64,000	170,000	63	26,000	BMDL	1,200	BMDL	750,000
	Wall Materials Below Water Line	650	17,000	850	42,000	25,000	81,000	130,000	260	14,000	1,800	350	BMDL	4,800,000
	Wall Materials Above Water Line	BMDL	1,900	120	160	4,400	4,800	390	89	26,000	1,800	BMDL	BMDL	11,000
Residence at General Diaz Street	Wet Sludge	BMDL	23,000	430	5,700	14,000	62,000	120,000	BMDL	130,000	BMDL	320	BMDL	2,300,000
	Dry Sludge	No Sample												
	Wall Materials Below Water Line	BMDL	560	BMDL	BMDL	1,400	610	2,500	ISFA	8,100	BMDL	BMDL	BMDL	23,000
	Wall Materials Above Water Line	300	1,100	1,400	BMDL	1,400	540	750	BMDL	8,200	BMDL	BMDL	BMDL	4,000
Residence at Memphis Street	Wet Sludge	No Sample												
	Dry Sludge	2,300	60,000	760	10,000	36,000	220,000	240,000	140	18,000	3,100	870	340	32,000,000
	Wall Materials Below Water Line	370	520	BMDL	76	3,300	820	780	120	7,200	1,300	BMDL	BMDL	28,000
	Wall Materials Above Water Line	BMDL	1,200	150	220	4,800	1,400	780	180	13,000	3,300	BMDL	BMDL	19,000
Residence at Savoie Court	Wet Sludge	No Sample												
	Dry Sludge	No Sample												
	Wall Materials Below Water Line	BMDL	2,500	150	BMDL	3,800	3,200	1,000	70	13,000	BMDL	160	BMDL	26,000
	Wall Materials Above Water Line	BMDL	3,000	110	700	12,000	6,800	4,000	BMDL	6,200	BMDL	BMDL	BMDL	300,000
Residence at Munster Boulevard	Wet Sludge	BMDL	3,200	320	400	5,600	10,000	12,000	BMDL	8,700	590	BMDL	BMDL	62,000
	Dry Sludge	BMDL	8,200	1,100	840	16,000	30,000	35,000	BMDL	26,000	1,800	330	BMDL	170,000
	Wall Materials Below Water Line	BMDL	1,500	BMDL	BMDL	910	590	1,300	120	5,800	BMDL	BMDL	BMDL	18,000
	Wall Materials Above Water Line	No Sample												
Residence at Cleary Avenue	Wet Sludge	No Sample												
	Dry Sludge	Analysis voided due to insufficient sample quantity												
	Wall Materials Below Water Line	BMDL	1,200	270	140	13,000	10,000	47,000	83	8,400	2,000	100	BMDL	31,000
	Wall Materials Above Water Line	BMDL	2,400	BMDL	150	1,800	12,000	2,000	160	8,700	2,100	110	BMDL	12,000

Table 8-6. Summary of Maximum Levels Sampled for Heavy Metal Contamination (µg/kg) (continued)

Building	Element	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
	Mean (Average) Value**	12,337	6,787	226	3,491	9,362	31,263	62,690	1,190	14,340	1,109	157	169	1,373,191
Residence at Octavia Street	Wet Sludge	No Sample												
	Dry Sludge	No Sample												
	Wall Materials Below Water Line	BMDL	290	BMDL	54	5,600	1,300	25,000	10,000	BMDL	BMDL	BMDL	BMDL	74,000
	Wall Materials Above Water Line	BMDL	1,400	180	670	16,000	8,800	34,000	32,000	7,300	BMDL	100	BMDL	210,000
Fire station at Louisiana Avenue	Wet Sludge	No Sample												
	Dry Sludge	11,000	45,000	110	22,000	24,000	200,000	1,300,000	470	13,000	1,000	890	330	5,400,000
	Wall Materials Below Water Line	470	2,700	BMDL	200	2,600	4,200	7,400	BMDL	8,300	BMDL	BMDL	BMDL	180,000
	Wall Materials Above Water Line	BMDL	2,100	110	53	1,900	1,300	2,300	BMDL	7,700	800	BMDL	430	9,800
Fire station at South Carrollton Avenue	Wet Sludge	No Sample												
	Dry Sludge	330,000	81,000	310	24,000	100,000	490,000	390,000	1,600	44,000	BMDL	740	BMDL	8,500,000
	Wall Materials Below Water Line	BMDL	730	140	60	3,300	1,600	2,400	93	7,300	BMDL	BMDL	BMDL	9,800
	Wall Materials Above Water Line	BMDL	1,000	BMDL	BMDL	2,500	930	3,600	65	8,400	BMDL	BMDL	BMDL	6,000

* BMDL = Below minimum detectable limit

Heavy Metal	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
Below Method Detection Limit is less than (µg/kg)	300	100	100	50	300	300	200	60	300	500	100	300	300

** The Mean (Average) Value was the statistical average value computed for the 44 heavy metal sample results. When computing the average value, samples with BMDL values were assumed to have a value equal to 1/2 the BMDL detection limit in accordance with USEPA standard practice.

Values are BMDL or less than 10% of the mean value.
Values are greater than minimal but less tha 50% of themean value.
Values are greaten than 50% but less than 250% of the mean value.
Values are greater than 250% of the mean value.

Table 8-7. Hydrocarbon Contamination - Diesel Range Organics (µg/kg)

Building	Range of Values	Wet Sludge	Dry Sludge	Wall Materials Below Water Line	Wall Materials Above Water Line	Mean (Average) Value**
Residence at Elysian Fields	Maximum	85,000	760,000	150,000	650,000	454,143
	Minimum	85,000	760,000	18,000	77,000	
	Average	85,000	760,000	69,333	270,333	
Residence at General Diaz Street	Maximum	130,000	No Sample	110,000	1,200,000	454,143
	Minimum	130,000		110,000	1,200,000	
	Average	130,000		110,000	1,200,000	
Residence at Memphis Street	Maximum	No Sample	ISFA*	230,000	210,000	454,143
	Minimum			ISFA	210,000	
	Average			230,000	210,000	
Residence at Savoie Court	Maximum	No Sample	ISFA	270,000	360,000	454,143
	Minimum			82,000	360,000	
	Average			184,000	360,000	
Residence at Munster Boulevard	Maximum	69,000	520,000	170,000	No Sample	454,143
	Minimum	69,000	520,000	170,000		
	Average	69,000	520,000	170,000		
Residence at Cleary Avenue	Maximum	No Sample	ISFA	450,000	200,000	454,143
	Minimum			190,000	120,000	
	Average			320,000	150,000	
Residence at Octavia Street	Maximum	No Sample	ISFA	990,000	3,100,000	454,143
	Minimum			990,000	980,000	
	Average			990,000	1,860,000	
Fire station at Louisiana Avenue	Maximum	No Sample	No Sample	580,000	220,000	454,143
	Minimum			580,000	220,000	
	Average			580,000	220,000	
Fire station at South Carrollton Avenue	Maximum	No Sample	ISFA	130,000	190,000	454,143
	Minimum			130,000	190,000	
	Average			130,000	190,000	

* ISFA = Insufficient sample for analysis

** The Mean (Average) Value was the statistical average value computed for the 35 DRO sample results

Values are BMDL or less than 10% of the mean value.

Values are greater than minimal but less than 50% of the mean value.

Values are greater than 50% but less than 250% of the mean value.

Values are greater than 250% of the mean value.

Statistical Sample Values	
BMDL	18,000
10% Mean	45,414
50% Mean	227,071
Mean	454,143
250% Mean	1,135,357
Maximum	3,100,000

8.4.2.5 Pesticide Contamination

Historically, the New Orleans area has suffered damages to many of its buildings from termites. In the past, termite treatment involved applying a barrier of organochlorine pesticides (e.g., chlordane, dichloro-diphenyl-trichloroethane (DDT), dieldrin, and heptachlor) into the soil surrounding the building and to the wooden sills of houses. After drilling holes, the insecticide was diluted with water to form a solution and applied to the soil. Depending on the size of the property, it was not unusual to apply 100 gallons or more of the insecticide solution.

Floodwaters transport both water-soluble and non-water-soluble chemicals. In the case of pesticides, many of the organophosphates that are used today are water soluble, which means that any residue in the soil impacted by the flooding would tend to be diluted by the floodwaters. By contrast, older pesticides, such as DDT and chlordane, were generally organochlorine compounds that are not as water soluble as the newer materials, because they were diluted by oils rather than water. This chemical composition allowed the now banned pesticides to have a longer impact in protecting buildings from termites and other insects, with many such compounds residing in soil for over 20 years without significant loss in concentration. However, this residual effect also allowed the chemicals to build up in the environment, which was a significant rationale for eliminating their use in the United States approximately 18 years ago.

Pesticide residues, such as those found in the building materials of older structures, can cause skin rashes from dermal contact. Inhalation of such residue in demolition dust can lead to a host of problems as many of the substances are neurotoxins. Another significant risk of exposure can occur when individuals involved in the gutting and decontamination fail to wash their hands before eating, since hand to mouth activities have been demonstrated as the source of ingested pesticides. When ingested or absorbed through the skin, organochlorine pesticides affect the nervous system, the digestive system, and the liver in people and animals.

The USEPA floodwater sampling data from New Orleans confirmed the supposition that the newer organophosphate pesticides were diluted by the large volumes of floodwater while the organocholorine pesticides were not. These findings, along with the documented heavy historic use of organocholorine pesticides to control termites in the New Orleans area, led to the concern by the New Orleans Flood Team that these contaminants may have been disturbed during the flooding and carried into buildings. Therefore, 5 of the sludge and 30 of the building material samples collected were screened for organochlorine type pesticides (these samples had enough remaining volume to be analyzed after the other tests had been completed). A summary of the highest levels of pesticides evaluated during the analysis of the samples collected from the New Orleans area is shown in Table 8-8.

Table 8-8. Summary of Maximum Levels Sampled for Pesticides (µg/kg)

		Pesticide	Chlordane	alpha-Chlordane	gamma-Chlordane	DDT	Dieldrin	Heptachlor
Building	Age of Building	Mean (Average) Value**	890	104	146	14.2	14.4	5.5
Residence at Elysian Fields	1940s	Wet Sludge	280	19	11	7	BMDL	13
		Dry Sludge	410	30	14	9	BMDL	16
		Wall Materials Below Water Line	280	19	16	6	BMDL	16
		Wall Materials Above Water Line	810	73	87	78	14	41
Residence at General Diaz Street	1930s	Wet Sludge	190	18	39	40	19	4
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	160	13	10	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	2,100	130	350	35	150	45
Residence at Memphis Street	1990s	Wet Sludge	No Sample					
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Residence at Savoie Court	1960s	Wet Sludge	No Sample					
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	130	18	20	BMDL	10	BMDL
		Wall Materials Above Water Line	1,400	170	220	BMDL	260	BMDL
Residence at Munster Boulevard	1940s	Wet Sludge	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
		Dry Sludge	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
		Wall Materials Below Water Line	130	21	24	6	BMDL	BMDL
		Wall Materials Above Water Line	No Sample					
Residence at Cleary Avenue	1990s	Wet Sludge	No Sample					
		Dry Sludge	Analysis voided due to insufficient sample quantity					
		Wall Materials Below Water Line	37	5.0	5.5	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	26	BMDL	BMDL	BMDL	BMDL	BMDL

Table 8-8. Summary of Maximum Levels Sampled for Pesticides (µg/kg) (continued)

		Pesticide	Chlordane	alpha-Chlordane	gamma-Chlordane	DDT	Dieldrin	Heptachlor
Building	Age of Building	Mean (Average) Value**	890	104	146	14.2	14.4	5.5
Residence at Octavia Street	Older	Wet Sludge	No Sample					
		Dry Sludge	No Sample					
		Wall Materials Below Water Line	2,200	220	380	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	1,600	200	240	250	BMDL	BMDL
Fire station at Louisiana Avenue	Older	Wet Sludge	No Sample					
		Dry Sludge	Analysis voided due to insufficient sample quantity					
		Wall Materials Below Water Line	17,000	2,100	2,900	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	1,400	180	260	BMDL	BMDL	BMDL
Fire station at South Carrollton Avenue	1954	Wet Sludge	No Sample					
		Dry Sludge	Analysis voided due to insufficient sample quantity					
		Wall Materials Below Water Line	100	15	18	BMDL	BMDL	BMDL
		Wall Materials Above Water Line	130	13	11	BMDL	BMDL	BMDL

* BMDL = Below minimum detectable limit. For pesticide sample results, BMDL values are summarized below:

Pesticide	Chlordane	alpha-Chlordane	gamma-Chlordane	DDT	Dieldrin	Heptachlor
Below Method Detection Limit is less than (µg/kg)	17	3.3	3.3	3.3	3.3	3.3

** The Mean (Average) Value was the statistical average value computed for the 35 pesticide samples results. When computing the average value, samples with BMDL values were assumed to have a value equal to 1/2 the BMDL detection limit in accordance with USEPA standard practice.

Values are BMDL or less than 10% of the mean value.

Values are greater than minimal but less than 50% of themean value.

Values are greater than 50% but less than 250% of the mean value.

Values are greater than 250% of the mean value.

The pesticide results provided in Table 8-8 indicate that six organochlorine pesticides were found in significant quantities: chlordane, alpha-chlordane, gamma-chlordane, DDT, dieldrin, and heptachlor. Other pesticides detected in much smaller quantities and not listed in Table 8-8 include beta-benzene hexachloride (BHC), gamma-BHC, dichloro-diphenyl-dichloroethane (DDD), dichloro-diphenyl-dichloroethylene (DDE), endosulfan II, endosulfan sulfate, endrin ketone, and methoxychlorindicate. Table 8-8 indicates that the highest concentrations of organochlorine pesticides were typically found in wall materials rather than sludge materials. For example, the highest level of chlordane identified in the sludge samples was 410 µg/kg, while the highest level of chlordane identified in the wall material samples was 17,000 µg/kg. In fact, two of the five sludge samples analyzed for organochlorine pesticides were below the method detection limit.

The pesticide contamination results were compared to the estimated age of each building (estimated based on its appearance, construction materials, architectural components, and other details). As shown in Table 8-8, older buildings, which were more likely to have been protected with chlordane and other organocholorine pesticides, had higher levels than newer buildings (post-chlordane). Presumably, the floodwaters released some of the pesticide residues from soils near the buildings. Once the pesticide was in suspension, it would be diluted by the water and transported onto flooded materials.

8.4.2.6 PCB Contamination

Although PCB contamination was anticipated based on the number of transformers and other electrical devices that were submerged or knocked down during the hurricane, no PCBs were detected in the 35 samples that were analyzed for the substance.

No PCBs were detected in any of the 35 samples analyzed for the substance. These findings were not unusual since the use of PCBs was banned by the USEPA in 1979. Also, the findings were consistent with the results of sampling conducted by the USEPA in the New Orleans area following Hurricanes Katrina and Rita.

9. Mitigation Successes and Best Practices

In addition to the wide range of damage observed, the MAT also found a series of mitigation projects and activities implemented prior to Hurricane Katrina that showcased the successes of mitigation in the affected area.

This chapter highlights certain noteworthy examples of successful mitigation projects and best practices, organized under the general categories of acquisition projects (Section 9.1), elevation projects (Section 9.2), wind retrofit projects (Section 9.3), higher regulatory standards implemented by local jurisdictions (Section 9.4), and other best practices (Section 9.5). Figure 9-1 provides an overview of site locations.

9.1 Acquisition Projects

9.1.1 Brickyard Bayou Acquisition Project (Gulfport, Mississippi)

This acquisition project was begun following Hurricane Georges in 1998 and completed in 2002 as a result of coastal flooding repetitive losses from the adjacent Brickyard Bayou. The at-risk

properties included in this acquisition project consisted of approximately 230 buildings located along both sides of Brickyard Bayou on Jeffrey Circle, Johnson Drive, 30th Street, Katz Avenue, Boyd Avenue, Brookwood Avenue, Audubon Drive, Pineland Drive, Hunter Avenue, and Altbach Avenue in Gulfport, Mississippi.

The community's goal in administering this project was to acquire as many properties as possible along these streets to avoid a "checkerboard" approach to mitigation, by uniformly removing all at-risk buildings from the target area. A number of the buildings acquired were repetitive loss properties (at least 17 of these had 4 or more insured losses since 1978 according to NFIP data). Several were also on State of Mississippi and Federal target repetitive loss lists. Based on MAT observations in the area (post-Katrina), the initial indication was that the majority of the acquired homes would have been flooded by up to 6 feet of water had they not been removed. As further evidence of this, houses just outside the project area appeared to have sustained significant damage from flooding.



Figure 9-1.
Locations of some of the mitigation successes and best practices observed by the MAT

Figure 9-2 shows a typical building within the project area prior to its acquisition and subsequent demolition. Figure 9-3 shows a small representative portion of the cleared area after the acquisition and demolition of the houses.



Figure 9-2.
Pre-acquisition/pre-demolition photo of representative building included in project (photo ca. 1999/2000) (Gulfport, Mississippi)



Figure 9-3.
This photo, taken post-Katrina, shows a few of the vacant lots after the acquisition project removed approximately 230 residential buildings from the flood hazard area. The primary source of flooding (Brickyard Bayou) is located just beyond and running perpendicular to the south end of this street (arrow) (Gulfport, Mississippi).

Approximately $19 million in Hazard Mitigation Grant Program (HMGP), Flood Mitigation Assistance (FMA) program, and supplemental funding was used. (This total may include some additional buildings in Gulfport that have been approved, but not yet mitigated.) This project has essentially paid for itself with losses avoided in this one event.

9.1.2 Acquisition Project (Pascagoula, Mississippi)

The City of Pascagoula used a combination of HMGP and supplemental funding (approved in 2001) to acquire and demolish approximately 10 at-risk buildings on Parsley Avenue, Chickasaw Avenue, Edgewood Avenue, Canty Street, Sherwood Street, Tupelo Avenue, 11th Street, and 14th Street (see Figure 9-4). Over half of the buildings included in this project were repetitive loss properties. Structures within the area that were not part of this project sustained damages from up to 6 feet of water.



Figure 9-4.
An example of a vacant lot resulting from the acquisition/demolition project (right arrow) next to a property that did not participate in the program and that was damaged by Hurricane Katrina (left arrow) (Pascagoula, Mississippi).

9.2 Elevation Projects

9.2.1 Lacombe, Louisiana

The residential property shown in Figure 9-5, located in Lacombe, Louisiana (in St. Tammany Parish southwest of Slidell), was elevated using HMGP funding to a height well above the flood depth associated with Hurricane Katrina. No flood damage was observed to the lowest finished floor. Some wind damage was noted to the roof, as evidenced by the blue roof covering.

The house shown in Figure 9-6 was also elevated (using HMGP funding) above the flood depths associated with Katrina.



Figure 9-5.
Post-Katrina photo of an HMGP-elevated house. Note the estimated water line associated with Hurricane Katrina (red line) (Lacombe, Louisiana).



Figure 9-6.
Another post-Katrina photo of an HMGP-elevated house. Note the estimated water line associated with Hurricane Katrina (red line) (Lacombe, Louisiana).

9.2.2 Elevations Along Lakeshore Drive in Mandeville, Louisiana

Much of central Mandeville has a shorefront road along Lake Pontchartrain (Lakeshore Drive) with houses only on the north side. The houses range in elevation from those close to ground level to higher elevations designed to accommodate under-house parking. The elevated houses represent a mix of mitigation projects, owner-elevated houses (no Federal funding used), local building inspector recommendations, and historic buildings that were elevated by the owner/builder long before any official flood maps would have been created for the community. In all observed instances, the low-elevation houses were heavily damaged, while the elevated houses survived the event in good condition. Figures 9-7 through Figure 9-11 illustrate the range of elevations observed and the level of damage to each.



Figure 9-7.
This building, elevated only a few feet above ground level, was heavily damaged by storm surge and flooding during Hurricane Katrina. Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).



Figure 9-8.
This building is the oldest house in Mandeville (built in 1836) and is on the National Register of Historic Places. The house is elevated 3 feet on piers and suffered wave damage to 18 inches above the floor. Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).



Figure 9-9.
In contrast to the preceding examples, this 100-year-old building, also on the National Register of Historic Places and located next door to the house in Figure 9-7, received minimal damage. Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).



Figure 9-10.
Another example of an elevated house that sustained only minor damage. Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).



Figure 9-11.
This building was relocated from New Orleans for use as a restaurant. The local building inspector recommended the elevation seen here, which protected this building from flood damage. Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).

According to local officials, recent flood retrofit successes were apparent to other homeowners, many of whom have since expressed interest in considering Increased Cost of Compliance or mitigation grant program funding for elevation retrofits, if available.

9.3 Wind Retrofit Projects

9.3.1 Harrison County Courthouse (Gulfport, Mississippi)

In 1999/2000 (following Hurricane Georges in 1998, which heavily impacted the Mississippi Gulf Coast), officials from Harrison County, Mississippi Emergency Management Agency, and FEMA's Building Sciences division met to evaluate the Harrison County Courthouse, which also currently houses the Harrison County EOC, as an opportunity for a potential hurricane wind retrofit project. Among other observations, the team noted rows of unprotected windows around the building, under which were stored valuable records and documents (some dating back to 1841), computers, and other electrical equipment. Roll-down metal shutters were installed using HMGP funding (see Figure 9-12).

During Hurricane Katrina, windows of vehicles located in the building's parking lot were broken by windborne aggregate blown from the roof of the building. At least some of this aggregate, along with branches from nearby trees, is likely to have struck the shutters and may have broken the glass had the windows not been protected. The estimated wind speed for this location is 130 mph. (See Section 7.1.2 for additional information on this building.)



Figure 9-12. Closeup of the roll-down metal shutters on the Harrison County Courthouse building. Note the partially lowered shutters on the middle windows (circle) (estimated wind speed: 130 mph. Gulfport, Mississippi).

9.3.2 Ocean Springs Middle School (Ocean Springs, Mississippi)

In September 1998, Ocean Springs Middle School was awarded $49,477 in HMGP funding for the installation of roll-down shutters to protect all exterior classroom windows from windborne debris (see Figure 9-13). Without glazing protection, occupants would be susceptible to injury from glass shards, and the building interior would be susceptible to damage from wind and wind-driven rain. The school was used as a shelter during Hurricane Katrina for as many as 400 people. Homeowners, urban search and rescue, police and fire personnel, and the National Guard used the facility as a shelter for up to a week. Following Hurricane Katrina, the MAT observed only minimal damage to the facility. In addition to the use of the shutters, other windows on the building were observed to have polycarbonate glazing.

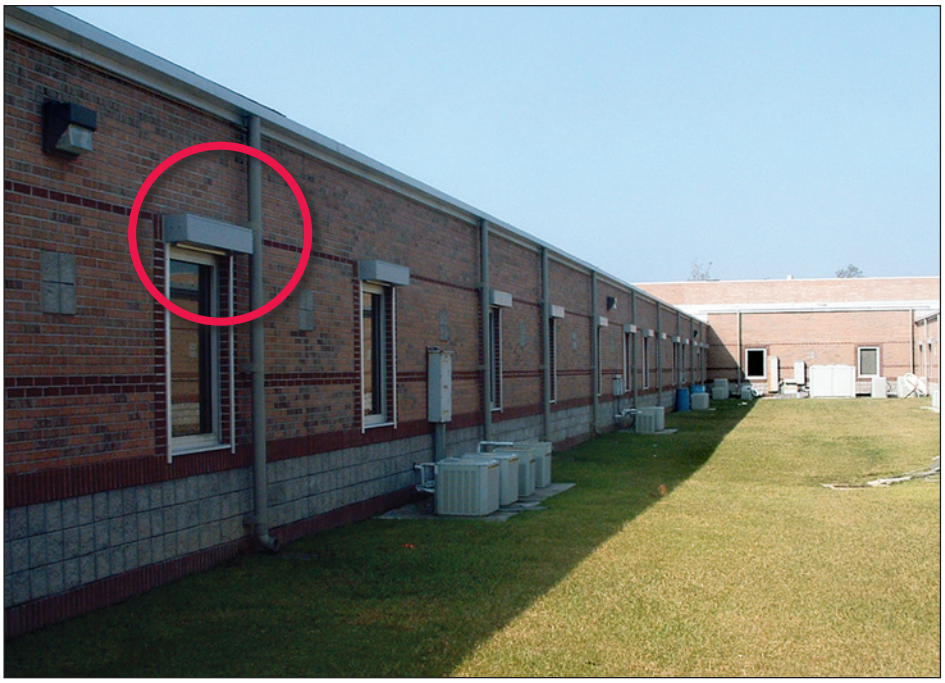


Figure 9-13. View of the Ocean Springs Middle School. Note the roll-down shutters over the windows (one example circled) (estimated wind speed: 120 mph. Ocean Springs, Mississippi).

9.3.3 Hancock County Senior Citizens Center (Bay St. Louis, Mississippi)

The Hancock County Senior Citizens Center received HMGP funding for the installation of shutters in 1999/2000 to protect windows and glazed doors from windborne debris (see Figure 9-14). The facility was identified in the local Hazard Identification and Risk Assessment Plan as a critical and essential facility, and was designated for use as a local shelter.

Hancock County Civil Defense ordered an evacuation of the facility as Hurricane Katrina approached. Water did not enter the building from the ground (e.g., stillwater flooding or storm surge), but water did enter the building via the roof, although structurally the roof remained intact.

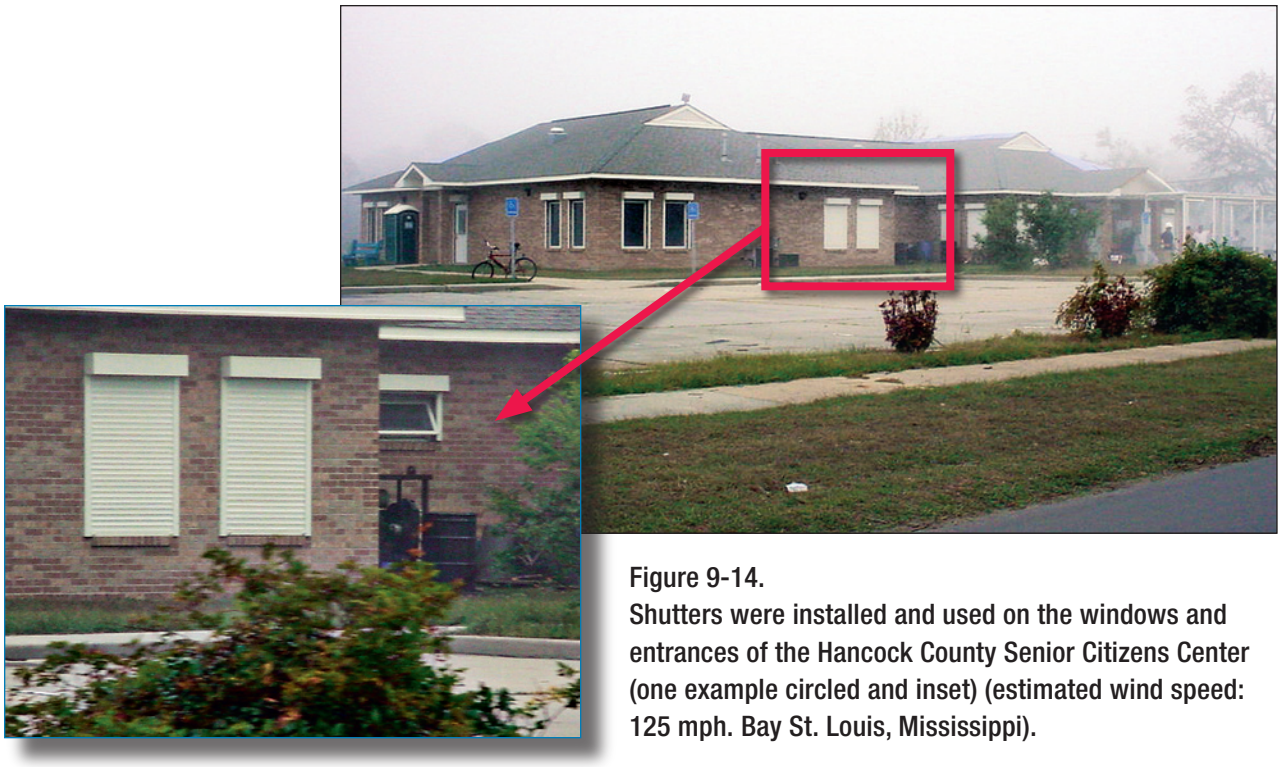


Figure 9-14.
Shutters were installed and used on the windows and entrances of the Hancock County Senior Citizens Center (one example circled and inset) (estimated wind speed: 125 mph. Bay St. Louis, Mississippi).

9.3.4 Jackson County EOC (Pascagoula, Mississippi)

The Jackson County EOC facility was observed by the MAT to have several prudent retrofit/wind-hardening features that helped the building survive Katrina. Polycarbonate shutters had been permanently mounted over the exterior windows and glazed door at this facility (see Figure 9-15). The roof deck and walls were constructed of concrete, which provided substantial wind resistance and excellent protection from windborne debris. In addition, the emergency generator had been sufficiently elevated to keep it from being inundated by Katrina's floodwaters. (See Section 7.1.1 for more detailed information.)



Figure 9-15.
Exterior view of the Jackson County EOC. Note the polycarbonate shutters over the windows (estimated wind speed: 105 mph. Pascagoula, Mississippi).

9.4 Higher Regulatory Standards – Citywide Elevation Standard (Pascagoula, Mississippi)

Following Hurricane Georges in 1998, the City of Pascagoula established an elevation standard of 13.1 feet msl for new construction, a standard higher than the BFEs stated on the community's FIRMs. In some cases, this represented up to a 5-foot increase above mapped BFEs. As a result, buildings impacted by Hurricane Katrina that were built to this standard suffered less flood damage than older housing built to lower elevation requirements (see Figures 9-16 and 9-17). The example shown in Figure 9-16 was the first elevation project in the State of Mississippi to use Increased Cost of Compliance funding. The estimated flood depth at this location from Hurricane Katrina was approximately 1 foot above the first finished floor and reportedly caused only minor damage to the house. According to the effective FIRM at the time of Hurricane Katrina, the building is located in Zone AE with a BFE of 11 feet.



Figure 9-16.
This photo was taken pre-Katrina ca. 1999/2000. Note the "Build Safe! 13.1' MSL Pascagoula Elevation Standard" sign in front yard (circle) (Pascagoula, Mississippi).



Figure 9-17.
This photo was taken post-Katrina, illustrating the successful survival of this elevated building. The house was elevated to the citywide standard of 13.1' msl using Increased Cost of Compliance funding (Pascagoula, Mississippi).

9.5 Other Best Practices

9.5.1 Cantilevered Condenser Platforms

Condensers placed at ground level or elevated but not secured typically fail from hurricane wind and flood forces. Cantilevered platforms are preferable over knee-brace platforms and platforms that use piles at the outward corners, because knee-braces can be broken by flood-borne debris and piles for condenser platforms are usually smaller in diameter than the piles used for the building itself, and are more easily broken. Figure 9-18 shows a cantilevered condenser platform that performed successfully during Hurricane Katrina.



Figure 9-18. This condenser was strapped to a cantilevered platform to enhance blow-off resistance (estimated wind speed: 125 mph. Plaquemines Parish, Louisiana).

9.5.2 Shutters over Windows (Non-Retrofit)

Shutters protected vulnerable glazing in the home shown in Figure 9-19. The home is located in St. Bernard Parish near Hurricane Katrina's path. The wind speeds in the area were sufficient to create damaging windborne debris; however, the shutters successfully protected the vulnerable glazing from breakage.



Figure 9-19.
The black area at the left window and the two black areas at the middle window (circles) are pieces of asphalt shingle debris. Had the windows not been protected by shutters, they would have likely been broken by windborne debris (estimated wind speed: 125 mph. Shell Beach, Louisiana).



10. Conclusions

The conclusions presented in this report are based on the MAT's observations in the areas studied; evaluations of relevant codes, standards, and regulations; and meetings with state and local officials, business and trade associations, contractors, and other interested parties. These conclusions are intended to assist the States of Alabama, Louisiana, and Mississippi; communities; businesses; and individuals in the reconstruction process; and to help reduce future damage and impacts from flood and design level wind events similar to Hurricane Katrina. The report and recommendations will also help FEMA assess the adequacy of its flood hazard mapping and floodplain management requirements, and determine whether changes are needed or additional guidance required.

Section 10.1 discusses impacts of flood hazards caused by Hurricane Katrina, including damaged lowest floor elevations, foundations and structures; and long-duration impacts. Wind hazard impacts, including those caused by the lack of an adopted building code, and performance of structural systems are presented in Section 10.2. Sections 10.3 and 10.4 discuss performance of critical and essential facilities (including shelters), and historic buildings, respectively.

10.1 Flood Hazards

Flood levels from Hurricane Katrina throughout parts of the Alabama, Louisiana, and Mississippi coasts were often much higher than the FEMA-mapped BFEs. Flood and wave effects extended well beyond the SFHAs in most communities investigated. As a result, a significant number of buildings inside and outside of the SFHA were destroyed or heavily damaged.

Two circumstances account for the fact that the high flood levels exceeded the BFEs:

1. The region's storm history, which served as the basis for the effective BFEs, was prepared in the early 1980s. Since that time, numerous storms in addition to Katrina have impacted the area. Consideration of the more recent storms can be expected to significantly increase the BFEs.
2. BFEs in the levee-protected areas of New Orleans were based on the assumption that the levees and floodwalls would protect the surrounded buildings. When developing BFEs, current NFIP standards require that a levee be certified that it has been adequately designed and constructed to provide protection against the base flood. Since the levees protecting New Orleans are USACE-certified, the BFEs for the levee-protected areas of the City (which are currently mapped with BFEs as low as -4.5 feet NGVD) only reflect flooding from precipitation that falls on and accumulates inside these areas; the BFEs do not include flooding effects from waterbodies on the non-protected side of the levee, such as Lake Pontchartrain. When levees and flood walls were overtopped or failed in Katrina's storm surge, deep water flooding was widespread behind the levees (see Figure 10-1).

Additional damage was attributed to erosion and floodborne debris, and on Dauphin Island, Alabama, erosion and scour were severe. The erosion undermined shallow foundations and piles with shallow embedment. Many areas had been weakened by prior coastal storms, which made the areas susceptible to Hurricane Katrina. The methodology used to develop the FIRMs takes into account the erosion that would likely occur during a single 100-year event. Long-term erosion and the effects of multiple storms that alter the shoreline position or dunes are not considered in the flood maps.

Along the developed shorelines of Louisiana and Mississippi, erosion and scour were occasionally a localized problem but, considering the severity of the storm surge and wave heights, were relatively mild. In those areas, the height and rapid rise of the storm surge and the relatively flat slope of the land appeared to be the factors that likely moderated the erosion.



Figure 10-1.
Levee failures resulted in widespread flooding throughout the New Orleans area.

Floodborne debris and wave damage characteristic of V Zone damage was widespread in A and X Zones in Mississippi. The unprecedented debris and resultant debris field of Hurricane Katrina included shipping containers, lumber, and bulk paper, as well as casino barges that broke from their moorings and severely impacted several buildings. Most of the floating debris field was produced as the storm surge and waves moved inland and progressively destroyed buildings, increasing the speed and severity of damage. However, the debris field eventually reached sufficient proportions in the most heavily damaged areas to function as a floating breakwater, damping the wave heights farther inland, and served to protect the landward areas from even more severe wave damage.

10.1.1 Lowest Floor Elevations

Many of the damaged buildings were pre-FIRM construction and built on slab foundations that do not satisfy current NFIP requirements. Structures next to each other in impacted neighborhoods had varied elevations and buildings that were constructed to the BFE or below (for the pre-FIRM buildings) experienced greater impacts from flood levels, damaging waves, and floodborne debris than those structures situated well above the BFE (see Figure 10-2).

10.1.2 Foundations and Structures

Structural failure was caused by severe high surge elevations, and wave and debris impacts. In areas subjected to coastal erosion and scour, shallow foundation damage was extensive and the structural failures were dramatic. Overall, since erosion and scour were not a major factor in most areas of Louisiana and Mississippi, newer stem-wall and pile foundations performed well; however, once the flood levels and wave heights exceeded the lowest floor, severe building damage resulted.

The only buildings that survived the event were those with high first floor elevations that were constructed with a well-embedded deep pile foundation structurally connected to the building frame or with deep piles that extended from the ground to the roof, or fully-engineered mid- and high-rise buildings elevated on pile, column, or shear wall foundations.

Current NFIP regulations require elevation of V Zone buildings on pilings and columns (i.e., foundations). However, the NFIP has allowed some V Zone buildings, particularly mid- and high-rise buildings, to be constructed using some solid foundation walls beneath the BFE. These walls, called shear walls, are necessary to transfer large lateral loads (e.g., wind and seismic loads) from the upper stories into the ground. Use of properly constructed, shore-perpendicular shear walls in these large V Zone buildings has not been observed by the MAT to lead to building damage or failure during coastal flood events. Some one- and two-family residential buildings require elevation above the ground in excess of one story. For these residential buildings, the technical, policy, and financial implications of using shore-perpendicular foundation walls, such as the shear walls used by mid- and high-rise buildings, should be considered. The use of any solid foundation walls beneath a V Zone building will complicate the flood insurance rating process and may lead to substantially higher flood insurance premiums than those for a building supported entirely on piles or columns (see Figure 10-3).



Figure 10-2. Elevation of the lowest floor well above the BFE as indicated by the slab in the foreground (Pass Christian, Mississippi)



Figure 10-3. Home constructed on solid, shore-perpendicular foundation walls. The walls are supported by reinforced concrete beams placed on driven piles (Dauphin Island, Alabama).

10.1.3 Long-Duration Flood Impacts in the New Orleans Area

The failure of the levee/floodwalls protecting the City of New Orleans led to deep floodwaters and long-duration flooding throughout the levee-protected areas. Directly behind the point of levee failure, some buildings experienced structural failure and were knocked off their foundations when impacted by floodwaters. The majority of the buildings observed in New Orleans, however, did not sustain significant structural damage from high velocity floodwaters. The only major exceptions observed by the New Orleans Flood Team were in the Lower Ninth Ward of eastern New Orleans and Chalmette in St. Bernard Parish. There were a couple of reasons that account for the severe structural damage observed in the Lower Ninth Ward and Chalmette:

- Some of the buildings may not have been in good condition before the storm. Thus, the winds, high floodwaters, and saturated soil conditions made them more vulnerable to structural failure.
- Some of the areas in eastern New Orleans had just been dewatered of Hurricane Katrina flooding when Hurricane Rita passed through with additional flooding from a breach of the canal repair. Strong winds and high velocity floodwaters could be the reason why the Lower Ninth Ward area was so severely damaged, while areas immediately adjacent, but in a different levee/floodwall system, were not.

The long duration of flooding had a tremendous impact on the building damage experienced in New Orleans. Since virtually all essential city services (e.g., electricity, water, sewer) were inoperable and, because the land was flooded and many roads impassable, residents were kept from their homes for up to 3 weeks. Most of the impacted buildings had extensive damage to the interior contents and building materials. The saturated conditions within the homes and buildings, combined with the warm and humid climate, led to extensive mold and mildew growth in many flooded buildings. The long-duration flooding also led to moisture entrapment within the walls and floors of flooded buildings, which could impact the structural integrity of building materials over time. Finally, the long-duration flooding also caused inundated homes and businesses to become contaminated with floodborne biological and chemical contaminants (refer to Section 10.1.3.2).

10.1.3.1 Long-Duration Flood Damage and Salvageability of Building Materials

As building owners begin to reconstruct and rebuild, building materials impacted by floodwaters will need to be either cleaned or replaced. Porous finish materials such as drywall, plaster, and insulation can be dried under some circumstances, particularly when professional drying equipment is used shortly after the flooding has occurred. However, the buildings in the New Orleans area were flooded for an extended period of time and some materials experienced permanent deterioration or contamination (refer to Section 10.1.3.2).

Exterior walls: Most exterior wall materials observed in New Orleans can be cleaned with minimal difficulty.

Wood framing: Visual observations of interior walls and floors of various residential buildings and critical and essential facilities showed little to no evidence of deterioration of the exposed portions of the wood framing due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards in residential buildings. Based on these observations, it appears that the majority of wood framing does not need to be replaced, provided that it is properly cleaned to remove contaminants (as described in Section 10.1.3.2) and dried to remove excess moisture.

Insulating materials: After the floodwaters receded, flooded fiberglass insulation retained water, and the moisture "wicked" farther up into the paper due to capillary action. For this reason, paper-faced insulation impacted by flooding will need to be removed and replaced.

Interior wall materials: Both drywall (gypsum board) and the plaster in buildings impacted by floodwaters experienced significant "wicking" and entrapment of floodborne contaminants and are unlikely to be salvageable.

Wall coverings and coatings: Because most interior walls covered by common household paints and wallpaper were not resistant to floodwater damage, wall coverings and coatings will need to be removed and replaced as well.

Interior doors and cabinets: Interior doors and cabinetry constructed of laminated wood products subjected to long-duration exposure to floodwaters were severely damaged due to water vapor migration and are not considered salvageable.

Floors and floor coverings: Carpet and padding saturated by floodwaters should be replaced. Additionally, flooded vinyl tile and linoleum over wood sub-floors should be removed to allow the wood sub-floor to dry.

Framing connections: Most flooded connectors and fasteners can be salvaged once they are inspected and cleaned to remove floodborne contaminants.

Utility systems: Many of the flooded plumbing and electrical lines can be salvaged once they are inspected and cleaned to remove floodborne contaminants. However, other flooded utility lines and associated small equipment, such as HVAC ductwork and electrical receptacles, will need to be removed and either thoroughly cleaned or replaced.

10.1.3.2 Long-Duration Flood Impacts from Contamination

Buildings in the New Orleans area were subjected to intense flooding for an extended period of time, with waters that carried a number of biological and chemical contaminants. Based on test results of wall material and sludge samples, buildings that were subjected to long-duration flooding are likely to have levels of contaminants that may cause ill health effects to reconstruction workers who do not take appropriate safety precautions (as described in Section 11.1.3.) It is likely that other porous materials, such as drywall, fiberglass insulation, particle-board backs on cabinetry, carpet, and carpet padding may be contaminated. Similarly, appliances that were impacted by floodwaters are likely to have contamination in insulated cavities.

Contaminated building materials may be nearly impossible to clean, and the residual contamination may have adverse health consequences for building occupants. Those contaminated materials that cannot be cleaned must be removed from the buildings.

Biological Contaminants

Bacterial contamination: Environments where building materials have been wet for more than 7 days, or where the floodwater was impacted by sewage, pose the most risk for potential bacterial contamination. Bacterial contamination was found in most of the structures and typically ranged from high to extreme (high: 1,000 – 20,000 cfu/cm^2; extreme: 20,000+ cfu/cm^2). As noted in Section 8.4.2.1, *Gram Negative Bacilli* dominated the sample results. These bacteria often cause stomach problems, dehydration, internal and skin infections, and respiratory difficulties in exposed individuals. Standard flood response activities, such as pumping, mopping, and agitating the air can put the restoration workers and occupants at significant risk, while simultaneously contaminating areas of the building that were previously not affected.

The presence of the bacteria types and levels identified by the MAT means that workers involved in the tear-out and cleanup of flooded structures are at risk of disease if not properly protected. Full face respirators would shield the eyes and respiratory tract. Any wounds, even small scratches, that result from such work should be disinfected promptly and covered to prevent infection.

Fungal contamination: Substantial fungal contamination was observed in all of the inspected facilities. As noted in Section 8.4.2.2, most of the fungal types detected in the samples were dominated by *Aspergillus/Penicillium* or *Chaetomium*. Various strains of these fungal types are linked to health problems, primarily skin irritation and respiratory distress. Health effects from fungi can range from mild allergic reactions to severe illnesses in individuals whose immune systems have been compromised.

The variety of fungal types and extensive levels of visible contamination in all of the examined structures provide support for the use of extensive personal protective equipment during demolition and cleanup. The rampant fungal growth also reinforces the recommendations made in the FEMA Hurricane Katrina Recovery Advisories (Appendix E) to remove and replace porous materials impacted by floodwaters.

Chemical Contaminants

Heavy metal contamination: Thirty-six material samples and eight sludge samples were analyzed for 13 priority element pollutants designated in the Clean Water Act. The 13 elements (heavy metals) are antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. A wide variety of heavy metal contamination was observed in the samples collected. In some of the samples, concentrations of arsenic, beryllium, cadmium, chromium, copper, lead, nickel, silver, and zinc exceeded 250 percent of the average values in three or more of the nine buildings sampled. However, the sample results for heavy metals were consistent with the USEPA's floodwater and sediment sample results, indicating the chemicals detected were below levels of health concern.

High concentrations of heavy metals detected in the sludge and building products saturated by the floodwaters could pose a health hazard to individuals exposed to the contaminants during demolition, cleanup, or restoration. The negative health effects of lead, zinc, and other heavy metals in adults and children are well defined in the literature from the USEPA and the CDC. The presence of heavy metal contaminants further highlights the need for restoration workers to use appropriate protective equipment.

Diesel range organics: All 35 samples analyzed for DROs had measurable quantities of DROs, with concentrations ranging from 18,000 to 3,100,000 µg/kg of hydrocarbons. Some of these samples exceeded 250 percent of the average value for the buildings sampled. However, the results were consistent with the USEPA's floodwater and sediment sample results, indicating the values were below the levels of health concern. The highest concentrations were found in wallpaper and sludge samples. From a health standpoint, DROs in building materials can impact individuals in two ways. First, skin irritation commonly occurs with frequent contact. Second, and more importantly, the organics in DROs may liberate pesticides trapped in other building materials.

Pesticide contamination: Measurable levels of organochlorine pesticides were found in 74 percent of the 35 samples analyzed for that contaminant, despite the fact that organochlorine pesticides were banned in the United States approximately 18 years ago. Chlordane was the most consistent contaminant in the samples analyzed, with levels as high as 17,000 µg/kg (2,100 µg/kg of alpha-chlordane and 2,900 µg/kg of gamma chlordane was detected in the same sample). Chlordane levels in the hundreds and thousands of µg/kg were common; some of these levels exceeded 250 percent of the average value for the buildings sampled. However, the results were consistent with the USEPA's floodwater and sediment sample results, indicating the values were below the levels of health concern.

Results indicate a relationship between the age of the house and chlordane levels. Older houses, which are more likely to be originally protected with chlordane, showed higher levels of chlordane, while newer houses generally had much lower levels.

Because the major route of entry for chlordane is absorption through the skin, there is potential for exposure to people working to demolish or renovate flooded structures without proper protection. Chlordane and similar pesticides affect the nervous system, the digestive system, and the liver in humans and animals. Chlordane is not classified as a carcinogen,

although low levels of chlordane have resulted in liver cancer in mice. People exposed to high levels of chlordane experience headaches, irritability, confusion, vision problems, vomiting, diarrhea, and jaundice.

Polychlorinated biphenyls: PCBs are long-lasting chemicals often used in transformer oils and in other industrial processes. Because they are carcinogens, exposure to PCBs has been documented to cause long-term health problems. However, no PCBs were detected in any of the 35 samples collected and analyzed.

10.2 Wind Hazards

The wind speeds during Hurricane Katrina were below current design wind speeds in most areas, but the wind pressures still exceeded some of the older building code-level wind pressures. The wind conditions from the storm resulted in limited structural damage to buildings, but widespread damage to building envelopes. Poor envelope performance led to extensive damage to the interiors of residences, businesses, and critical and essential facilities. The wind-related building damage was generally a result of inadequate design, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement.

The following are discussed in this section:

- Building codes
- Performance of structural systems
- Performance of building envelope, and mechanical and electrical equipment
- Design and construction guidance
- Mitigation for existing buildings

This report's conclusions and recommendations relate only to what was observed by the MAT in the areas affected by Hurricane Katrina. In regard to hurricane wind hazards, the reader is encouraged to obtain a copy of the Hurricane Charley and Ivan MAT reports (FEMA 488 and 489) and the summary report for all four hurricanes that impacted Florida in 2004 (FEMA 490, Summary Report on Building Performance 2004 Hurricane Season, March 2005). These reports are available on line at http://www.fema.gov/rebuild/mat/mat_reprts.shtm.

Residential Construction in Florida Compared with That in Louisiana and Mississippi:

The MAT noted a stark contrast in newly constructed residences observed after Hurricane Katrina in Louisiana and Mississippi versus newly constructed residences observed after Hurricanes Charley and Ivan in Florida. In Florida, there was much more attention to nailing of shear walls and diaphragms, greater use of metal framing connectors, greater use of pressure-rated doors and windows, and, in windborne debris regions, much greater use of protected glazing. The increased attention to wind-resistant construction in Florida greatly improved the wind performance. This increased attention is attributed to Florida's response to the damage caused by Hurricane Andrew (1992). In the aftermath of Andrew, Florida adopted a statewide building code that is periodically updated. Jurisdictions in Florida also endeavor to enforce the code. These building code related measures are augmented by contractor licensing regulations and increased awareness of wind-resistant design and construction issues by designers and contractors.

10.2.1 Building Codes

Two major causes for the amount and magnitude of building damage observed in many of the areas impacted by Hurricane Katrina were the lack of an adopted building code and, where a code had been adopted, the lack of code enforcement. In some communities, a building code had been adopted, but newer editions had never been adopted, resulting in the use of an out-of-date code. For buildings constructed in accordance with the 1982 and later editions of the SBC and IBC/IRC, investigation of the damage suggested that non-compliance with building codes was a major cause of that damage.

Buildings designed and constructed to resist wind loads prescribed in the 2000 IBC, 2003 IBC, and ASCE 7 performed well structurally and showed how improvements to the building codes can produce successful results. Based on the amount of wind damage observed by the MAT for buildings constructed in accordance with the 1979 and earlier editions of the SBC, it is evident that under-prediction of the design wind loads by past building codes for critical building areas, such as roof and wall corners, led to significant building envelope and structural damage. In addition, some building elements constructed under older codes were vulnerable to damage because of the lack of specific provisions for those elements. Building envelope components such as roof coverings have much more stringent requirements in the current codes. Rooftop equipment and protection of glazing, for example, were largely ignored in older codes, but now have more stringent code requirements. Although current building codes are substantially better than those of a few years ago, some improvements are still needed (see Chapter 11).

10.2.2 Performance of Structural Systems (Residential and Commercial Construction)

Most structural failures observed by the MAT appeared to be the result of inadequate design and construction methods commonly used before 2000 IBC and 2000 IRC were adopted and enforced. Only a relatively small number of structures that were observed in the areas affected by Hurricane Katrina were constructed in accordance with current model building codes; most that were observed were constructed in accordance with older codes such as the SBC or were not constructed to any building code standards. Buildings designed and constructed to resist wind loads prescribed in the 2000 IBC, 2003 IBC, and ASCE 7 performed well and showed how improvements to the building codes can produce successful results. However, adoption of the IBC in several of the impacted communities in Alabama and Mississippi is so recent that few buildings have been constructed under those provisions.

Although a number of structural failures from wind were observed, the percentage of buildings that experienced structural failure was quite small. Structural failures predominately occurred in older buildings. In addition to wind-induced failures, some structural failures were the result of tree-fall.

Throughout the Hurricane Katrina damage zone, the limited structural damage caused by wind was most commonly observed in residential wood roof framing and occurred below current code wind pressures design levels. Inadequate nailing of roof sheathing panels, gable

end wall failures, and lack of properly installed metal framing connectors were the major factors in these structural failures.

Most heavy engineered commercial buildings (e.g., casino hotels, banks, hospitals) performed well structurally, which is attributed to engineering attention paid to details and to the safety factors normally included in the performance of the engineering analysis conducted for the structures' designs. In contrast to heavily engineered structures, older pre-engineered structures, generally constructed before the mid-1980s, performed poorly. These structures are often designed to minimum standards to reduce cost. Lack of building codes and older codes often resulted in structures being constructed to minimum design requirements.

Structural damage was caused in some buildings when the building envelope was breached and significant changes of the internal pressures occurred. Failures of windows and doors on the windward face of a building have been correlated with subsequent failures of partition walls, windows, and doors on side and leeward walls, attic access panels, roof sheathing, and even whole roof structures. Numerous failures occurred at and below the design wind speed as the result of inadequate design and construction of the connections as well as contribution from internal pressurization.

Soffit failures in residential buildings often led to internal pressurization of attics and loss of inadequately attached roof decking (see Figures 10-4 and 10-5).



Figure 10-4.
Classic soffit failure resulting in attic pressurization and roof decking failure. The stairwell soffit (circled) was blown away during the storm (Long Beach, Mississippi).



Figure 10-5.
The failure of this apartment building was the result of inadequate connections and interior pressurization caused by broken windows and failure of the porch ceiling. Note the broken glazing (circle) and the failed porch ceilings (arrows) (Ocean Springs, Mississippi)

10.2.3 Performance of Building Envelope, and Mechanical and Electrical Equipment

Building envelope damage and damage to rooftop equipment was observed to residential, commercial, and critical and essential buildings throughout all areas visited by the MAT. Poor performance of building envelopes was a function of both inadequate wind resistance and damage from windborne debris impact. Inadequate resistance to high-wind pressures on building envelopes and rooftop equipment was responsible for much of the wind damage caused by Hurricane Katrina. Envelope and equipment damage was more widespread and significant on older buildings. The most commonly damaged elements were roof coverings, vinyl siding, soffits, EIFS, glazing, and rooftop equipment.

In addition, windborne debris caused significant envelope damage, and virtually all of the glazing damage that the MAT observed. In several instances, blown-off envelope elements became windborne debris that caused additional damage.

In part, the building envelope failure problem is due to lack of high-wind design guides for envelope assemblies and various types of rooftop equipment. Ramifications of poor performance include the following:

- **Property damage:** Property damage was extensive, requiring repair and/or replacement of the damaged envelope itself and rooftop equipment components. Even when damage to the building envelope or equipment was limited, such as blow-off of a portion of the roof covering or broken glazing, substantial rainwater damage frequently resulted because of the heavy rains accompanying the hurricane and rains occurring in the following days and weeks. Rainwater entered the buildings through the breaches in the building envelope. Rainwater and/or wind damage in the building interior resulted in the need for replacing equipment and furniture. In many cases, mold remediation was also required.
- **Loss of function:** Depending upon the magnitude of the wind and rainwater damage, repairs can take days or months. As a result, residents may not be able to return home, businesses

may not be able to reopen, and critical and essential facilities may be incapable of providing their vital services. In addition to the costs associated with repairing the damage and/or replacing the damaged property, other financial ramifications related to interrupted use of the building can include rental costs of temporary facilities or lost revenue due to business interruption. These additional costs can be quite substantial.

10.2.3.1 Roof Coverings, Wall Coverings, and Soffits

Roof coverings of many types failed during Hurricane Katrina. Some of these failures were due to the age of the coverings. Age-related failures were associated with weather-induced change in material properties and with testing limitations and design standards that were available years ago. Other failures were due to design and construction related issues or debris impact. The MAT's main observations and conclusions are as follows:

- Asphalt roof shingle performance, including newly installed shingles, was generally extremely poor. Installation deficiencies pertaining to fastener location and starter strips were commonly observed at damaged roofs. Enhanced attachment of hip, ridge, rake, and eave shingles was not observed.

- Edge flashing, coping, and gutter/downspouts failure was common. Failure of these roofing components often initiated lifting and peeling of roof membranes. Failure was in part due to inadequate design and construction attention, and, in the case of gutters, due to lack of testing and design standards.

- During Hurricane Katrina, as with many previous hurricanes, aggregate roof surfacing was commonly blown off roofs and caused glazing damage. Use of aggregate surfacing in hurricane-prone regions is problematic.

- Vinyl siding performance was generally extremely poor. Use of vinyl siding manufactured for high-wind areas was not observed.

- In general, EIFS performed poorly. For many buildings, the poor performance resulted in significant rainwater infiltration damage. Installation deficiencies were commonly observed at the investigated EIFS failures.

- Widespread loss of soffits was observed in residential construction. In numerous buildings, rain was driven into attic spaces because of soffit failures.

10.2.3.2 Windows, Doors, and Shutters

Glazing damage was observed throughout the area visited by the MAT. Use of protected glazing (either laminated glass or shutters) was not nearly as commonly observed in Louisiana or Mississippi as it was during the MAT's 2004 observations in Florida. Damage to the contents of many homes and businesses would have been prevented if glazing had been protected. Additionally, in newly constructed houses, doors and windows with wind pressure labels were only rarely observed.

10.2.3.3 Attached Equipment (Rooftop and Ground Level)

Displacement or damage to rooftop equipment was observed throughout the areas visited by the MAT. This not only resulted in the loss of function associated with the damaged units, but in many cases led to the loss of function of the occupied space due to rainwater infiltration at the displaced equipment. Rooftop and ground level equipment need additional design, installation, and code attention to adequately protect equipment from wind events. ASCE 7 provides basic information to calculate wind loads on these elements, but additional design guidance is needed.

10.2.4 The Need for High-Wind Design and Construction Guidance

Failure to adequately maintain a proper load path was observed in many instances of failed building elements. For instance, fasteners were commonly spaced too far apart, were too small, or had weak connections. There were numerous examples of failures to follow well-established basic construction practices, such as minimum edge distances for fasteners.

Hurricanes can have devastating effects on building envelopes and equipment. Unless wind resistance issues are understood by designers and contractors, envelope and equipment failures will continue to occur. Designers, contractors, and building officials need additional education and resources regarding these modes of failure. In part, the envelope and equipment problem is due to lack of high-wind design guides for various envelope assemblies and various types of rooftop equipment.

10.2.5 Wind Mitigation for Existing Buildings

Based on damage that the MAT observed, many buildings (residential, commercial, critical and essential) constructed before the mid-1990s have building envelopes with significant wind vulnerabilities, and many buildings constructed before the mid-1980s have significant structural vulnerabilities. Even many recently constructed buildings in Louisiana and Mississippi are vulnerable to wind damage.

Buildings with vulnerabilities have three likely scenarios: the buildings will be damaged in future hurricanes, they will be phased out (i.e., torn down and replaced), or they will be mitigated to avoid future damage. Mitigation is preferable to the damage and then repair scenario.

10.3 Performance of Critical and Essential Facilities (Including Shelters)

In general, buildings functioning as critical and essential facilities did not perform better than the commercial buildings. The same construction issues observed in residential and commercial buildings were observed in critical and essential facilities. Some buildings designed to critical and essential facility requirements experienced damage and partial failures during the hurricane due to lack of protection from windborne debris.

The flood- and wind-related building damage to critical and essential facilities experienced during Hurricane Katrina led to a significant, and avoidable, loss of function. Specific conclusions for critical and essential facilities based on these observations are as follows:

- Facilities that sustained damage from flooding had not been designed to withstand the level of flooding that occurred.
- Unless wind mitigation measures have been taken, older buildings used as critical and essential facilities will likely have wind damage to the roof coverings, wall coverings, window and door systems, and rooftop equipment (including communications towers and antennas). This type of damage can lead to significant loss of function at the facilities.
- Some critical and essential facilities experienced damage and partial failures during the hurricane due to lack of protection from windborne debris. Lack of protection of windows was common at hospitals, nursing homes, and schools (including schools used as shelters) and led to window failures and significant damage to building contents.
- Building components blew off of several critical and essential facilities during Katrina. Windborne debris can injure or kill first responders at EOCs, late arrivers at shelters, or those seeking medical attention at hospitals. Although people are not usually outdoors during hurricanes, buildings used as essential and critical facilities can be the exception. It is common for people to arrive at these facilities during a hurricane and additional efforts should be made to reduce the potential for windborne debris at these sites.

10.4 Historic Buildings

Historic buildings, many of which had been around for more than 100 years, were totally destroyed by Hurricane Katrina. These buildings had survived numerous previous storms, including Hurricanes Betsy and Camille, but they had not experienced the surge levels unleashed by Katrina. Many of the historic buildings sat on higher ground along Highway 90 in Mississippi and never experienced the storm surge, and wave and debris impacts produced by Hurricane Katrina. The buildings that survived the storm surge generally performed well from a wind standpoint. Most of the wind damage to historic buildings was a result of debris impacts or falling trees. In a few cases, windborne debris did cause glazing damage that led to internal pressurization, which resulted in roof failure.



11. Recommendations

The recommendations in this report are based solely on the observations and conclusions of the MAT. They are intended to assist the States of Alabama, Louisiana, and Mississippi; communities; businesses; and individuals in the reconstruction process; and to help reduce future damage and impacts from flood and design level wind events similar to Hurricane Katrina. The recommendations will also help FEMA assess the adequacy of building performance standards as they relate to flood hazard mapping and floodplain management requirements and determine whether changes are needed or additional guidance required.

The general recommendations presented in Sections 11.1 (for flood) and 11.2 (for wind) relate to measures that are needed to ensure that designers, contractors, building officials, and coastal populations understand what is necessary for disaster-resistant construction in hurricane-prone regions.

11.1 Flood Related Recommendations

A few of the main recommendations are outlined in the following sections; details and additional recommendations are provided in Tables 11-1 through 11-4.

11.1.1 Codes and Standards

Adoption of modern building codes, such as the IBC, IRC, or NFPA 5000 are recommended. These codes include up-to-date design and construction provisions that are consistent with the NFIP. The 2006 editions of the IBC and NFPA 5000 incorporate flood load (ASCE 7-05) and flood-resistant construction (ASCE 24-05) standards (see Table 11-1). The IRC currently does not explicitly reference ASCE 7 and ASCE 24 for flood loads and flood-resistant construction. Thus, it is recommended that communities containing land within the estimated 100-year floodplain shown on the Katrina Flood Recovery Maps use ASCE 7-05 for flood load calculations and ASCE 24-05 for flood-resistant one- and two-family residential construction purposes. Adoption of any model code or standard should keep intact the minimum criteria established by the parent or expert document such as ASCE 7 or ASCE 24.

In the case of new and replacement manufactured home installations, adoption of the 2005 edition of NFPA 225 (*Model Manufactured Home Installation Standard*) is recommended. This edition of NFPA 225 contains the latest flood- and wind-resistant guidance for installation in hurricane- and flood-prone areas.

Table 11-1. Flood Hazard - Design and Construction Recommendations

Flood Hazard		
Building Component	**Recommendation***	
Design, Foundations, and Structures		
Code	1.	Adopt the 2006 IBC, IRC, or NFPA 5000 building codes for all jurisdictions in Alabama, Louisiana, and Mississippi.
Code	2.	Adopt the ASCE 24-05 for all jurisdictions in Alabama, Louisiana, and Mississippi.

* All recommendations are detailed in this report unless otherwise noted,

11.1.2 General Hazard Identification

Hurricane Katrina was a significant event that destroyed buildings well beyond the effective SFHA; in order to assess the adequacy of current flood mapping and hazard identification, a few of the key recommendations are provided below (additional recommendations are provided in Table 11-2):

- Evaluate existing storm surge modeling: Review the storm surge data and modeling procedures that served as the basis for the effective FIRMs. Conduct a revised tide frequency analysis,

update storm climatology for the area, and use modern storm surge models to estimate the BFEs throughout the Katrina impact area.

- Katrina Flood Recovery Maps: As an interim approach (pending completion of coastal flood restudies), adopt the ABFEs and flood hazard areas shown on the Katrina Flood Recovery Maps. This approach is preferable to adding freeboard within the SFHA on the pre-Katrina effective FIRM, because the latter approach does not address known flood hazards outside the mapped SFHA.
- Re-evaluate the hazard identification/mapping approaches in coastal flood hazard zones. Re-evaluate and revise the methodology used to determine flood zones and flood elevations in coastal areas.
- Revise flood hazard mapping procedures and maps for areas behind levees: Refer to Section 11.1.3 for recommendations.

11.1.3 Long-Duration Flooding Impact

In order to adequately portray the risk to buildings within levee-protected areas, the guidance and procedures for hazard mapping in areas protected by levees need to be re-evaluated. Recommendations are provided in Table 11-3 and a few of the key recommendations are described below:

Flood hazard mapping procedures and maps for areas behind leveesshould be revised. As guidance in carrying out the requirements of 44 CFR 65.10, FEMA issued an August 22, 2005, memo titled "Procedure Memorandum 34 – Interim Guidance for Studies Including Levees" (FEMA, David I. Maurstad, August 22, 2005) for immediate implementation. This memo provides guidance and standards in properly identifying flood hazards in areas possibly protected by levees. The procedure includes working with local entities responsible for levees to determine the accreditation of the levee providing flood protection. If a levee is not accredited, the area behind the levee will be identified as SFHA and will reflect the actual BFE. A copy of the memo is included in Appendix G.

The long-duration flooding of buildings in the New Orleans area resulted in deterioration of certain building materials, as well as contamination of building materials from biological vectors or agents and chemical contaminants.

The presence and concentration of the bacteria types and levels identified by the New Orleans Flood Team means that workers involved in the tear-out and cleanup of flooded structures are at risk of disease if not properly protected. Safety precautions (including the use of personal protective equipment) will need to be taken by building owners and restoration workers during repair and reconstruction work to minimize the health risks from biological and chemical contaminants (see the OSHA website <http://www.osha.gov>). Full face respirators would shield the eyes and respiratory tract. Any wounds, even small scratches, that result from such work should be disinfected promptly and covered to prevent infection. Similarly, the variety of fungal types and extensive levels of visible contamination in all of the examined structures support the use of extensive personal protective equipment during demolition and cleanup. The rampant fungal growth also reinforces the recommendation to remove and replace porous materials impacted by floodwaters.

Table 11-2. Flood Hazard - Hazard Identification and Regulations Recommendations for Government Agencies

Flood Hazard		
Parameter		Recommendation*
Hazard Identification and Regulation		
Storm Surge	1.	Review the storm surge data and modeling procedures that served as the basis for the effective FIRMs. Conduct a revised tide frequency analysis, update storm climatology for the area, and use modern storm surge model to estimate the BFEs throughout the Katrina impact area.
Katrina Flood Recovery Maps	2.	Adopt the Katrina Flood Recovery Maps as an interim approach (pending completion of coastal flood restudies). This approach is preferable to adding freeboard within the SFHA on the pre-Katrina effective FIRM, since the latter approach does not address known flood hazards outside the mapped SFHA. Post-event flood recovery maps should delineate the 100-year and 500-year flood limits and hazard zones, including the landward limits of anticipated V Zone, Coastal A Zone, and A Zone conditions. For future Recovery Maps, develop 500-year Advisory Flood Elevations.
Mapping	3.	Include 500-year elevation determinations for future ABFEs performed; this information is vital to reconstruction of critical and essential facilities.
Mapping Flood Hazards in Coastal Areas	4.	Re-evaluate the methodology to determine flood zones and flood elevations in coastal areas. Post-hurricane investigation revealed damage to A Zone-type structures exposed to less than 3-foot waves. Consider adoption of the 1.5-foot breaking wave height as the basis for mapping Coastal A Zones and requiring V Zone type building standards (the distinction currently is based on a 3-foot breaking wave height). Following a major coastal flood event that causes severe erosion and/or significant topographic changes to upland areas, evaluate whether updating the FIRMs is required and, if so, revise the FIRMs.
Future Conditions Mapping	5.	The effects of long-term erosion, wetland loss, sea level rise, and subsidence should be incorporated into flood hazard identification and mapping. Even if shown as optional data layers, the information will be available to communities, designers, lenders, and owners.
Flood Insurance Premiums	6.	Flood insurance provisions and premiums should reflect the actual risk during base flood conditions. For example, actual risk refers to those flood conditions that would potentially exist if the levees provided minimum, or no, protection.
Flood Insurance Premiums	7.	Flood insurance provisions and premiums should reward best practices for siting, design, and construction.
"What If" Mapping	8.	Maps should be developed that illustrate the effects of various disaster scenarios, such as floods that exceed design levels. These maps, to be developed by state and local agencies, can help educate local officials and the public, and can be used as a planning and decision-making tool. Coordination of "what if" mapping with local mitigation strategies and evacuation planning will be required.

* All recommendations are detailed in this report unless otherwise noted.

The presence of the chemical contaminants detected in flood-impacted building materials indicates the use of proper personal protective equipment during all restoration activities, including respirators with HEPA filters or masks rated N-95 or higher. Furthermore, based on the presence of contaminants such as DROs, heavy metals, and pesticides in porous building materials, it is recommended that all flood-impacted porous materials be removed from buildings during restoration.

For additional details on safety precautions and flood restoration techniques, refer to the FEMA Hurricane Recovery Advisories, *The ABCs of Returning to Flooded Buildings,* and *Initial Restoration for Flooded Buildings.* FEMA Recovery Advisories can be found at http://www.fema.gov/rebuild/mat/mat_katrina.shtm.

11.1.4 Design and Construction

Recommendations related to design and construction of buildings are presented in Table 11-4. Some of the main recommendations include:

It is highly recommended that buildings be constructed to survive flood levels that exceed the base flood design conditions. Flood conditions can exceed those shown on the FIRM for a variety of reasons, but the most common include: storms more severe than the 1 percent annual chance flood; and outdated flood maps, either because of changed site conditions, the availability of better topographic data, or improved modeling procedures. For these reasons, design for flood conditions more severe than the base flood is recommended.

Constructing buildings to survive flood levels can be done by elevating the lowest floor above the BFE (preferably to the ABFE), choosing a foundation that is more resistant to flood forces and erosion, and using flood damage-resistant materials above the BFE. Using these measures will make a building more "storm-resilient," reduce future flood damages, provide for easier repairs, and reduce flood insurance premiums.

- Although not mandated by the IRC, use the 2005 edition of ASCE 24 for flood-resistant design of one- and two-family structures in coastal areas, as well as for floodways. Moreover, use the 2005 edition of ASCE-24 and update, from the 1998 edition, referenced by the 2003 IBC and IRC.
- Use the *Home Builder's Guide to Coastal Construction Technical Fact Sheets* (FEMA 499) found at http://www.fema.gov/rebuild/mat/mat_fema499.shtm and the *Coastal Construction Manual* (FEMA 55) for additional guidance related to flood- and wind-resistant design and construction.
- Refer to the National Institute of Building Sciences (NIBS) *Whole Building Design Guide* for more flood recommendations for commercial and public buildings (http://www.wbdg.org/design/env_flood.php).

Table 11-3. Flood Hazard - Long-Duration Flooding Impact Recommendations

Flood Hazard			
Category		Recommendation*	Action Required By**
Flooding within Levee-Protected Areas	1.	Implement FEMA Procedure Memorandum - Interim Guidance for Studies Including Levees (FEMA, David I. Maurstad, August 22, 2005). This memo provides guidance and standards in properly identifying flood hazards in areas possibly protected by levees. The procedure includes working with local entities responsible for levees to determine the accreditation of the levee providing flood protection. If a levee is not accredited, the area behind the levee will be identified as a SFHA and will reflect the actual BFE.	G
	2.	Revise hazard identification and mapping procedures to consider predicted rates of sea level rise and subsidence.	G
	3.	Building owners should consider the savings in repair costs from damages that may occur in future events versus the initial cost in constructing the building to a higher elevation.	C, O
	4.	Develop "what if" maps for levee-protected areas to illustrate the effects of various disaster scenarios, such as floods that exceed design levels and levee failures. The maps, to be developed by state and local agencies, can help educate local officials and the public, and can be used as a planning and decision-making tool.	G
Biological and Chemical Contamination of Building Materials	5.	For details on safety precautions and flood restoration techniques, refer to the FEMA Hurricane Recovery Advisories: *The ABC's of Returning to Flooded Buildings* and *Initial Restoration for Flooded Buildings.* Recovery Advisories can be found at: www.fema.gov/rebuild/mat/mat_katrina.shtm	C, O
	6.	To facilitate restoration of flooded buildings, building owners should: ■ Open windows and doors to maximize air flow ■ Remove contents for restoration or disposal ■ Remove porous wall materials, fibrous wall insulation, carpeting, vinyl flooring, and electrical components that were impacted by floodwaters ■ Thoroughly clean and sanitize interior surfaces ■ Allow sufficient time for drying prior to initiating reconstruction activities	C, O
	7.	Take appropriate safety precautions (including the use of personal protective equipment) during repair and reconstruction work to minimize the health risks from biological and chemical contaminants.	C, O
	8.	Conduct a feasibility study to develop screening standards and action levels for building materials exposed to chemical contaminants.	G

* All recommendations are detailed in this report unless otherwise noted.

** Action required by: Contractor (C), Government Official (G), Building Owner (O).

Table 11-4. Flood Hazard - Design and Construction Recommendations

Flood Hazard			
Building Component		Recommendation*	Action Required By**
Design, Foundations, and Structures			
Design Guidance	1.	Use ASCE 7-05, Chapter 5 for the calculation of flood loads during the base flood, including floodborne debris loads.	D, C, G
Design Guidance	2.	Use ASCE 24-05 for the flood-resistant design of all structures in flood hazard areas, including one- and two-family structures.	D, C, G
Design Guidance	3.	Use the *Home Builder's Guide to Coastal Construction Technical Fact Sheets* (FEMA 499) and the *Coastal Construction Manual* (FEMA 55) for additional guidance related to flood and wind resistant design and construction.	D, C, G
Design Guidance	4.	Use the guide: *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550).	D, C, G
Installation Guidance, Manufactured Homes	5.	Where manufacturers' installation manuals don't prohibit placing homes in the floodplain, use NFPA 225 for installation of new and replacement manufactured homes in flood hazard areas.	D, C, G
Installation Guidance, Historic Buildings	6.	Refer to the recommendations in this section for those elements that apply and coordinate with the State Historic Preservation Officer. For the vacant buildings, it is necessary to take earlier precautionary measures to stabilize the building to prevent deterioration, which may be further exacerbated by a major storm.	D, C, G
Coastal A Zones	7.	Require V Zone standards for new construction, per ASCE 24-05, in Coastal A Zones subject to erosion, scour, velocity flow, and/or subject to wave heights greater than 1.5 feet.	D, C, G
Foundation Type	8.	Select the type of foundation based on the flood hazards depicted on the Katrina Flood Recovery Maps, not based on the flood hazard zones shown on the pre-Katrina FIRMs.	D, C, G

* All recommendations are detailed in this report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Government Official (G).

Table 11-4. Flood Hazard - Design and Construction Recommendations (continued)

Flood Hazard			
Building Component		Recommendation*	Action Required By**
Design, Foundations, and Structures			
Use of Fill	9.	In some V Zone areas shown on the Katrina Flood Recovery Maps, ABFEs are many feet above grade. This can result in lowest floor elevations of new and reconstructed buildings more than one story above grade. Design professionals, communities, and owners may wish to consider the feasibility of adding non-structural fill under and around new or reconstructed buildings. The use of fill may facilitate building access, improve the aesthetics of highly elevated buildings, and reduce local flood depths near buildings. An engineering evaluation can assess the stability and impact of non-structural fill, both from a damage-prevention standpoint and a damage inducing standpoint (i.e., potential wave runup and flood flow deflection). ASCE 24-05 provides some guidance on the technical evaluation of such fill. Other issues (e.g., economic and environmental) may also require evaluation.	D, C, G
Shear Wall Foundation	10.	Investigate the technical, policy and financial implications of allowing shore-perpendicular foundation walls beneath one- and two-family residential buildings in V Zones where the required lowest floor elevation above the ground is in excess of one story.	G
Lowest Floor Elevation	11.	Elevate all new construction (including substantially improved structures and replacement of substantially damaged structures) in coastal flood hazard zones with the bottom of the lowest horizontal supporting member above the BFE (preferably to the ABFE). Freeboard for all buildings in all special flood hazard zones is desirable; the amount will vary with building importance, but ASCE 24-05 can provide guidance.	D, C, G
Ground Level Slabs, Fully-Engineered, Multi-Story Construction (governed by the IBC)	12.	The ground level floor of a multi-story building (typically used for parking or building access) should either: 1) use a lowest floor slab or floor system that will not collapse and can support all anticipated design loads and conditions, including undermining, or 2) use a slab or floor system that will collapse into small pieces.	D, C, G
Ground Level Slabs, Buildings (governed by the IRC)	13.	Within the V Zone, the grade-level slab should collapse and break into small pieces if undermined. The same performance is recommended for elevated buildings in Coastal A Zones subject to erosion, scour, velocity flow, and/or subject to wave heights greater than 1.5 feet. Slabs under elevated buildings in non-Coastal A Zones need not break up.	D, C, G

* All recommendations are detailed in this report unless otherwise noted.
** Action required by: Designer (D), Contractor (C), Government Official (G).

Table 11-4. Flood Hazard - Design and Construction Recommendations (continued)

Flood Hazard			
Building Component		Recommendation*	Action Required By**
Design, Foundations, and Structures			
Debris Impacts	14.	Buildings should be designed, and constructed, to resist loads and conditions during the design flood. At a minimum, the design flood should be the base flood, but designing for more severe floods is recommended in accordance with ASCE 24-05. Floodborne debris characteristics and loads should be determined using Section C.5 of ASCE 7-05.	D, C, G
Foundations Near Bay and Bayou Shorelines	15.	For sites near bay or bayou shorelines, foundation selection should be based on factors as described in this chapter.	D, C, G

* All recommendations are detailed in this report unless otherwise noted.
** Action required by: Designer (D), Contractor (C), Government Official (G).

11.1.5 Foundations

Recommendations related to foundations are presented in Table 11-4 and a few of the key recommendations are shown below:

- Select and design foundations based on ABFEs shown on Katrina Flood Recovery Maps, not the pre-Katrina FIRMs, until such time that revised regulatory floodmaps become available for the Gulf Coast: The pre-Katrina effective FIRMs understate the lateral extent of the special flood hazard area and the area subject to damaging waves. Therefore, prudent reconstruction should be based on flood elevations and flood hazard zones depicted on the Katrina Flood Recovery Maps (with the caveat that the maps may overstate wave heights and wave crest elevations away from the Gulf of Mexico shoreline).
- Use the *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550) when building new homes in coastal areas. FEMA 550 contains schematic designs for several foundation styles to assist local engineers, builders, and code officials in designing and constructing flood- and wind-resistant residential foundations. FEMA 550 was developed with input from the Gulf Coast Homebuilding Industry.
- New and replacement manufactured homes should be elevated with their lowest floor in accordance with the requirements of NFPA 225 (2005 ed.), Chapter 12. This chapter requires that: 1) in existing manufactured home parks, new and replacement homes must be elevated with the bottom of the main chassis frame beam no less than 3 feet above grade, unless a home previously on a site was substantially damaged by flood, in which case the new or replacement home on the site must be elevated with the bottom of the main chassis frame beam no lower than the BFE (ABFE), and 2) outside of existing man-

ufactured home parks, all new and replacement homes must be elevated with the bottom of the main chassis frame beam no lower than the BFE (ABFE). See Figure 11-1 for exact requirements in V and A Zones.

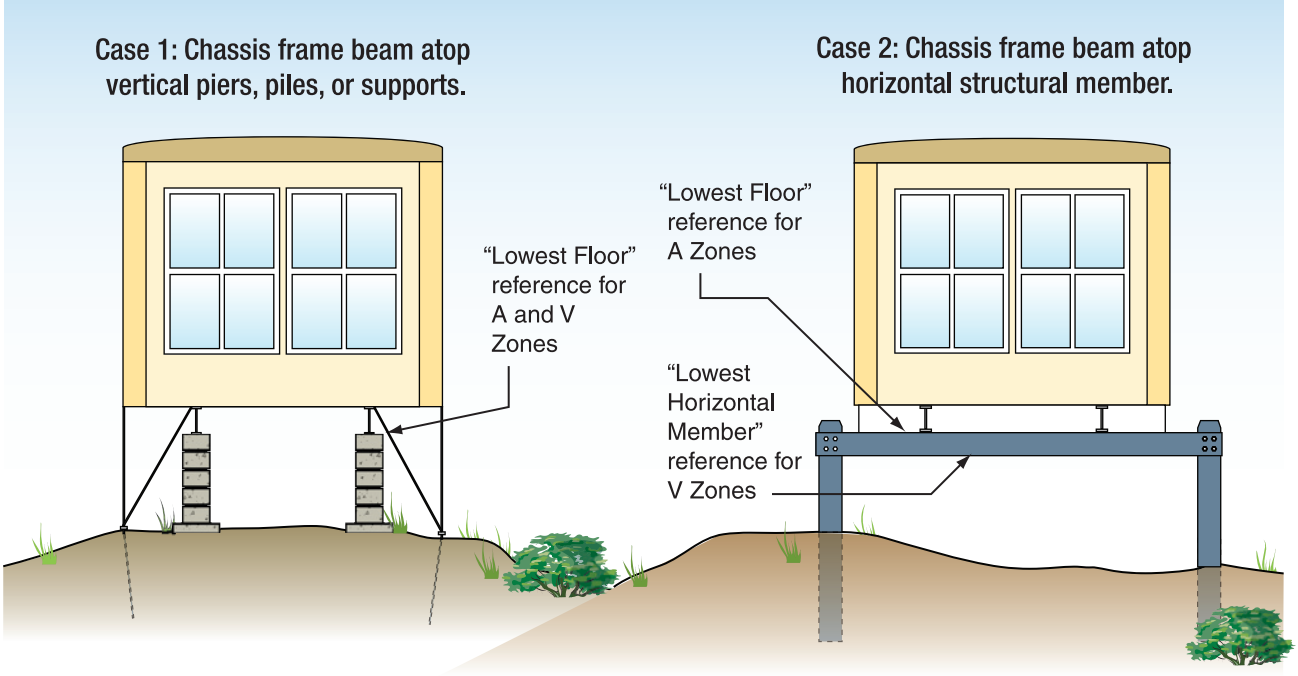


Figure 11-1.
Recommended elevation of new and replacement manufactured homes as recommended by NFPA 225. Specific anchorages shall be determined based on manufacturer's instructions.

SOURCE: NFPA 225

Note that this recommendation is consistent with current NFIP requirements with one exception, the change in A Zone lowest floor reference from the top of the floor to the bottom of the main chassis frame beam. This recommendation is not intended to eliminate the 3-foot pier exception allowed for new and replacement homes on sites in existing manufactured home parks that have not previously experienced substantial damage due to flooding. However, this report suggests that new and replacement homes in existing parks be elevated higher than the 3-foot pier exception allows, preferably with the bottom of the main chassis frame beam at the ABFE.

- Freeboard is a factor of safety typically expressed in feet above the flood level for purposes of floodplain management (see Figure 11-2). For flood insurance purposes, the freeboard is referenced from the top of the lowest floor to the BFE in A Zones and the bottom of the lowest horizontal structural member to the BFE in V Zones. Freeboard is recommended for all buildings in all special flood hazard zones. At a minimum, the freeboard specified in ASCE 24-05 should be considered (freeboard amounts in ASCE 24-05 depend on the building importance, flood hazard zone, and floor beam orientation). Consider using more freeboard than ASCE 24-05 specifies if ABFEs are not adopted by a community.

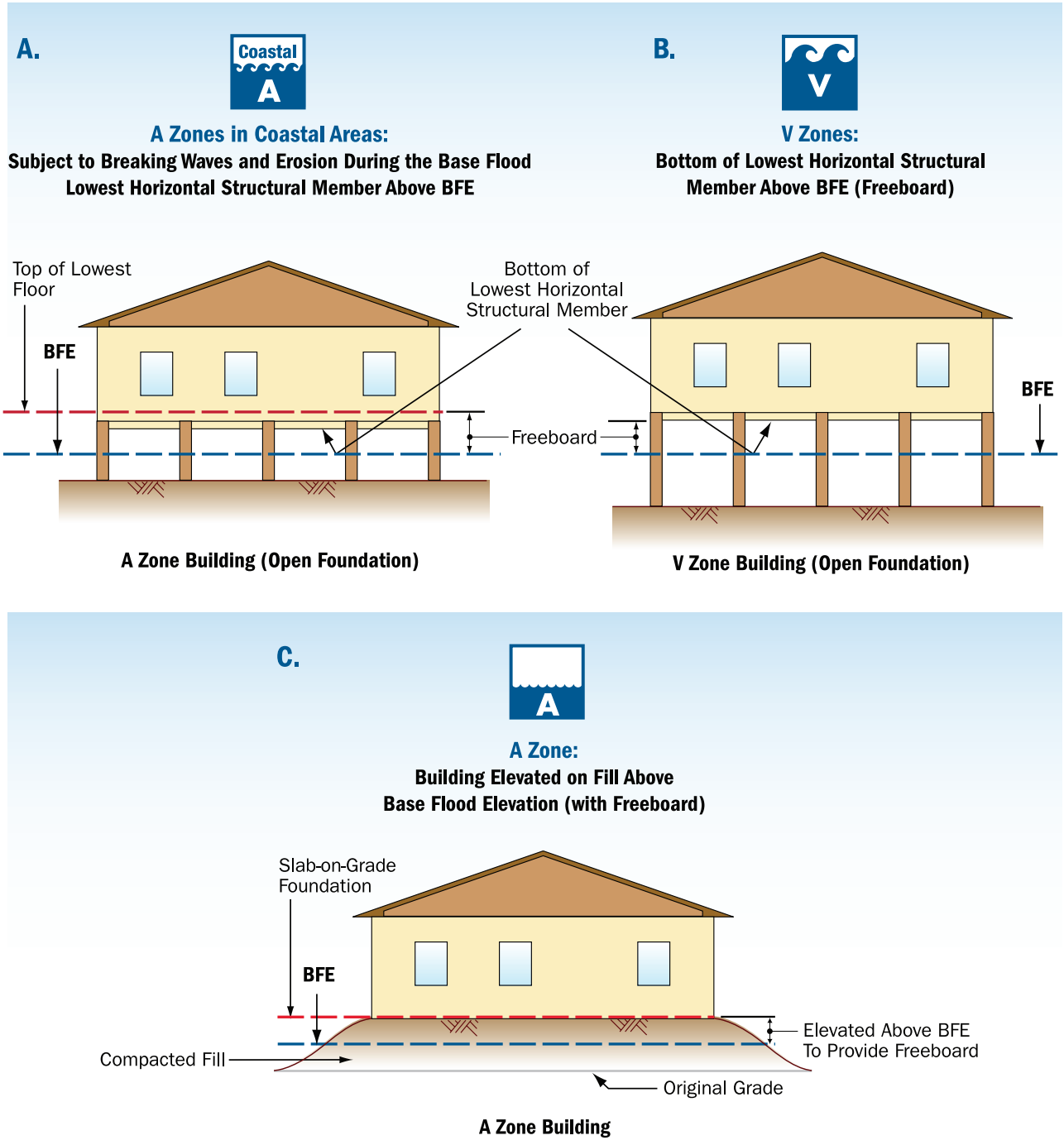


Figure 11-2.
Freeboard and open foundations are recommended for V Zones and Coastal A Zones. Illustration C shows an example of a building in an A Zone elevated on fill above the BFE with freeboard.

- Foundations along the shoreline: Pier foundation performance in coastal areas has been poor where erosion, waves, and/or debris impacts are present, especially during base flood events. Pier foundations should only be considered when these hazards are not present.
  - Use a deep pile and/or column foundation along the Gulf of Mexico shoreline if significant erosion is likely during the base flood. Use of other foundation types should be limited to those areas far from the shoreline and not subject to erosion.
  - Use a deep pile or column foundation along shorelines for bays and sounds if significant erosion is likely during a base flood event. For sites near bays or along bayous, foundation selection should be based on several factors: erodibility of the soil; exposure to "damaging" waves (greater than 1.5 feet high); potential for velocity flow; potential for floodborne debris; and required resistance to lateral flood and wind forces. Table 11-5 should be used to help select an appropriate foundation near bay/bayou shorelines.
  - Where limited erosion and scour allow the use of shallow foundations, construct footings using continuous concrete grade beams or mat foundations in lieu of discrete concrete footings.
  - Construct piers and columns with reinforced concrete in lieu of masonry and provide sufficient reinforcement to resist wind loads, flood forces, and debris impact.

Table 11-5. Recommended Foundations for Coastal Areas near Bay or Bayou Shorelines (but not mapped as a V Zone)

Foundation Type	Base Flood Condition Present			
	Erodible Soils, Base Flood Inundation Possible	Wave Heights between 1.5 and 3 Feet[1]	Velocity Flow	Large Debris[3]
Fill	no	no	no	no
Slab-on-Grade	no	no	no	no
Crawlspace, Shallow Footing	no	no	no	no
Foundation Walls, Shallow Footing	no	no	no	no
Stemwall, Shallow Footing	no	yes	no	yes
Stemwall, Deep Footing[2]	yes	yes	yes	yes

[1] Wave heights greater than 3 feet mapped as V Zone: fill, slab, crawlspace, wall foundations not permitted.

[2] Deep means sufficiently deep to withstand erosion and scour (including that induced by the presence of the foundation itself), and withstand all lateral flood loads and resist sliding.

[3] Building materials, dock pilings, vegetation.

Table 11-5. Recommended Foundations for Coastal Areas near Bay or Bayou Shorelines (but not mapped as a V Zone)

Foundation Type	Base Flood Condition Present			
	Erodible Soils, Base Flood Inundation Possible	Wave Heights between 1.5 and 3 Feet[1]	Velocity Flow	Large Debris[3]
Pier, Shallow Footing	no	no	no	no
Pier, Deep Footing[2]	yes	yes	yes	no
Post, Shallow Embedment	no	no	no	no
Pile/Column, Deep Embedment[2]	yes	yes	yes	yes

[1] Wave heights greater than 3 feet mapped as V Zone: fill, slab, crawlspace, wall foundations not permitted.

[2] Deep means sufficiently deep to withstand erosion and scour (including that induced by the presence of the foundation itself), and withstand all lateral flood loads and resist sliding.

[3] Building materials, dock pilings, vegetation.

Absent a detailed study for a site, exposure to damaging waves greater than 1.5 feet can be estimated based on three factors:

1. Evaluate the potential for generating waves during the base flood for bays and bayous, which will be dependent on the direction of the wind from varying directions across the water body: If the distance from one shoreline to the other is less than 1 mile, the potential for generation of damaging waves is low. If the distance is 1 mile or greater, assume damaging waves can be generated.
2. Stillwater depth at the site, after accounting for erosion: If the stillwater depth is 2 feet or greater, sufficient depth exists to allow passage of 1.5-foot waves. If the stillwater depth is less than 2 feet, waves may be present, but should be less than 1.5 feet high.
3. Obstructions between the site and the shoreline: If dense stands of trees or buildings/structures capable of withstanding the base flood forces stand between the site and the shoreline, it is reasonably safe to assume the height of any damaging waves will be reduced. If these obstructions do not exist (or if their future existence is questionable), assume the wave heights will not be reduced appreciably.

Pier foundations should be used only where soil characteristics and flood conditions permit, and where their design and construction are consistent with the details shown in Figure 11-3. Footings should consist of continuous reinforced grade beams or mats. Discrete piers should only be used where local soils data and analyses confirm that discrete pier foundations will resist all flood and debris loads without failure. Although this is a common foundation type, its performance in coastal areas has been poor where erosion, waves, and/or debris are present.

Near bay and bayou shorelines, elevating the building on piles or another deeply embedded open foundation, and leaving the area below free of obstructions or enclose it with breakaway walls is recommended. Although stemwall foundations (backfilled with a concrete slab on top) performed better than many other A Zone type foundations near bay/bayou shorelines, their use should be contingent on having footings deep enough to withstand erosion and scour.

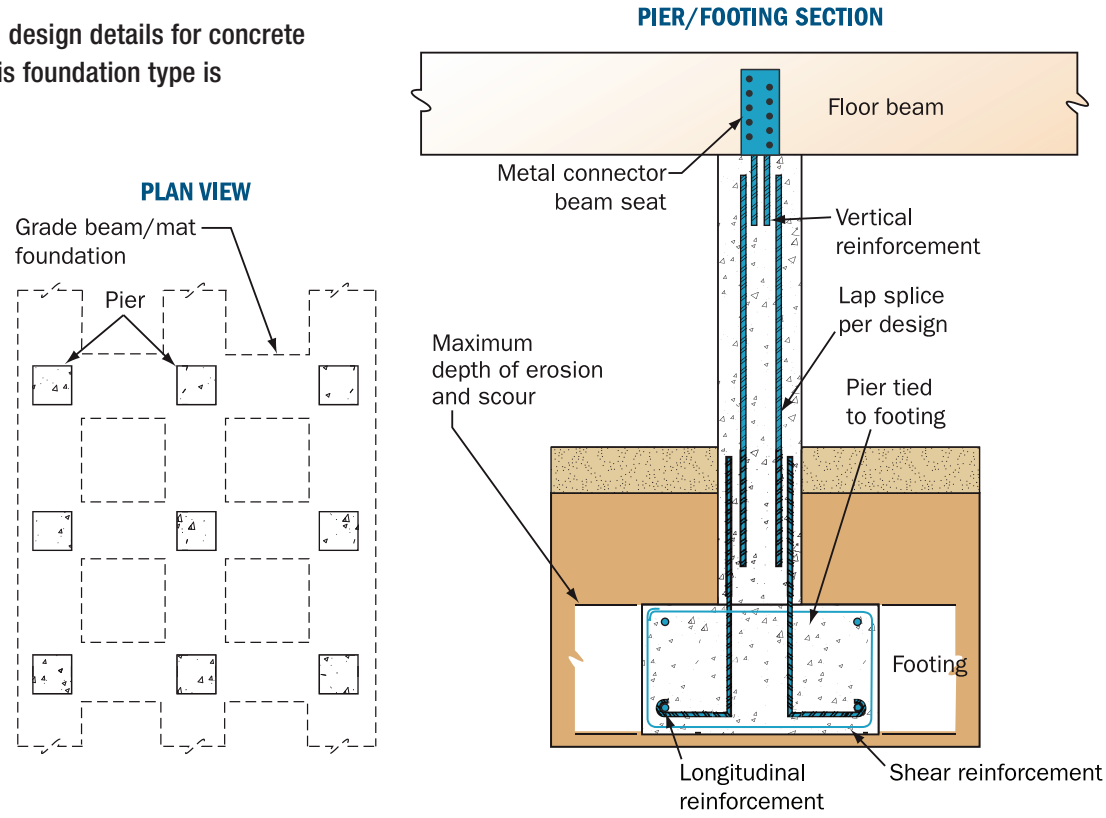


Figure 11-3.
Recommended design details for concrete piers where this foundation type is appropriate

11.1.6 Flood Insurance

Like flood hazard maps, flood insurance provisions and premiums should reflect the actual risk during base flood conditions. Flood insurance provisions and premiums should reward best practices for siting, design, and construction (such as through the use of the V Zone Risk Factor Rating Form), and should recognize those practices that result in improved flood resistance of buildings. Current NFIP provisions do not reward buildings where pilings extend to and support multiple stories above the BFE, which was observed to perform better than most structural systems. This pole-type or structural frame construction is discussed in Chapter 4.

11.2 Wind Related Recommendations

The recommendations from the MAT report are intended to assist the States of Alabama, Louisiana, and Mississippi; communities; businesses; and individuals lessen the impact of wind damage from future events. The following recommendations address building code, design and construction, and mitigating existing buildings.

11.2.1 Building Codes

Buildings that had been designed or mitigated to resist high-wind loads in accordance with modern building codes were observed to perform substantially better than buildings constructed to earlier codes. Therefore, adoption and enforcement of a current building code like the 2006 editions of the IBC, IRC, or NFPA 5000 is key to improved wind performance. When adopted, current building codes should not be amended or modified in any fashion that reduces their criteria. For example, wind speeds should not be reduced and windborne debris provisions should not be exempted.

The study of buildings and their interaction with high winds associated with hurricanes is an evolving process. Incorporating many of the recommendations in this report into the next available code cycle is key to setting the new standard in hurricane-resistant construction in all hurricane-prone regions. For example, test method improvements are recommended to assess the performance of exterior systems like EIFS, vinyl siding, and soffit panels that historically have performed poorly during hurricanes.

Recommendations related to building codes and standards are shown in Table 11-6. Some of the recommended code changes in the table will require research before they can be incorporated.

11.2.2 Design and Construction

Roof covering and wall cladding failures were widespread during Hurricane Katrina, which was less than a design wind event in most areas. To ensure that components and cladding elements are being engineered and designed per the code requirements, additional focus should be given to the design and construction of the building envelope. Specific recommendations related to roof systems, soffits, exterior cladding, windows, doors, and rooftop equipment are provided in Table 11-7. The table also provides general recommendations regarding renovation and remodeling, inspecting for moisture intrusion following hurricanes, and protection of historic buildings.

11.2.3 Wind Mitigation for Existing Buildings

To avoid future damage of buildings that have vulnerable structural systems and/or building envelopes or rooftop equipment, the MAT recommends that owners of commercial and public buildings have a vulnerability assessment performed by qualified professionals. If vulnerabilities are discovered, they should be mitigated to avoid future losses. For buildings that are located in windborne debris regions and have unprotected glazing, installation of protection (e.g., shutters) is recommended.

Residential homeowners should consider mitigation measures such as installation of metal framing connectors (e.g., straps between rafters/trusses and bearing wall, connections between the roof deck and rafter/trusses), and upgrading the attachment of the roof covering to the roof deck.

Table 11-6. Wind Hazard - Recommendations for Building Codes/Standards and Adopting Agencies

Wind Hazard		
Building Component		Recommendation*
General		
Code	1.	Adopt the 2006 IBC, IRC, or NFPA 5000, for all affected jurisdictions in Alabama, Louisiana, and Mississippi.
Code	2.	Do not reduce the wind provisions of the IBC and IRC, ASCE 7, or NFPA 5000 with local amendments. Prior to Hurricane Katrina, some jurisdictions had reduced the design wind speed and/or the windborne debris region requirements prescribed in ASCE 7. Reductions such as these reduce the effectiveness of the building code.
Code	3.	If and until the recommendations below are adopted by the model codes, applicable recommendations should be considered best practices and incorporated in all new construction and mitigation projects.
Code	4.	Ensure code compliance through increased enforcement of construction inspection requirements such as the IBC, IRC, and NFPA 5000. Ensure enforcement of Special Inspections Provisions per the IBC and NFPA 5000.
Code	5.	The 2006 IRC does not require the use of high-wind provisions at speeds below 110 mph. However, the IRC Code development Committee has approved a code change proposal for the 2007 amendments to lower the threshold to 100 mph. Therefore, it is recommended that high-wind provisions for residential construction be used in wind zones of 100 mph and greater.
Building Envelope		
Soffit	6.	Develop and adopt wind resistance and wind-load criteria for soffits. Wind-driven rain resistance of ventilated soffit panels should also be added. Testing Application Standard (TAS) 110 may be a suitable test method, although it may require modification.[a]
EIFS	7.	Revise test method ASTM E 330: Use a 60-second load duration instead of a 10-second load duration. Incorporate deflection criteria specified in test method ASTM E 1592 into ASTM E 330.
Vinyl Siding	8.	Revise test method ASTM D 5206: Use a 60-second load duration instead of a 30-second load duration. Incorporate the deflection criteria specified in test method ASTM E 1592 into ASTM D 5206.
Vinyl Siding	9.	The ASTM task group responsible for ASTM D 5206 should give consideration to dynamic testing of vinyl siding in lieu of the static testing now prescribed in ASTM D 5206.
Vinyl Siding	10.	Revise ASTM D 3679 to require a minimum safety factor of 2 versus the 1.5 factor currently specified. Revise ASTM D 4756 to require installation of a water-shedding underlayment (e.g., asphalt-saturated felt or housewrap).

* All recommendations are detailed in this report unless otherwise noted.

[a] TAS is a Florida document: http://infosolutions.com/icce/gateway.dll?f=templates$fn=default.htm$vid=icc:florida_hurricane

[b] ASTM D 7158 was published in 2006 as a replacement for UL 2390.

Table 11-6. Wind Hazard - Recommendations for Building Codes/Standards and Adopting Agencies (continued)

Wind Hazard		
Building Component		Recommendation*
Building Envelope (continued)		
Gutters and Downspouts	11.	Develop and add criteria for uplift resistance of gutters and downspouts.
Reroofing	12.	Except for minor repairs, require removal of existing roof covering down to the deck and replacement of deteriorated decking in areas where basic wind speed is 110 mph or greater. If existing decking attachment does not comply with loads derived from Chapter 16 of the IBC, require installation of additional fasteners to meet loads.
Asphalt Shingles	13.	Require compliance with ASTM D 7158.[b] Also require six nails per shingle and require use of asphalt roof cement at eaves, rakes, hips, and ridges where basic wind speed is 110 mph or greater (refer to FEMA 499, Fact Sheet 20).
Windows and Shutters		
Shutters	14.	Add requirement to label shutters (other than wood) to indicate compliance with ASTM E 1886. Without labels, building owner does not know if shutters are suitable.

* All recommendations are detailed in this report unless otherwise noted.

a TAS is a Florida document: http://infosolutions.com/icce/gateway.dll?f=templates$fn=default.htm$vid=icc:florida_hurricane

b ASTM D 7158 was published in 2006 as a replacement for UL 2390.

The Institute of Building and Home Safety (IBHS) (http://www.ibhs.org) and the Federal Alliance for Safe Homes (FLASH) (http://www.flash.org) have comprehensive guidelines and plans for retrofitting existing homes for wind resistance. The mission of both organizations is to reduce the loss of life and property damage from natural disasters by promoting construction techniques that typically exceed those of the minimum adopted building code. Their guidelines are strongly recommended and highly relevant for mitigating damage from events such as hurricanes.

Building owners should consider covering windows with impact-resistant shutters or replace them with impact-resistant windows.

Mitigation can be expensive because it often requires partial demolition and replacement of interior building finishes, and it may require displacement of occupants while mitigation is performed. However, even though mitigation measures may not be required by the building code or local ordinance, proactively implementing needed mitigation will ensure that future damages and interrupted use of buildings are lessened or avoided entirely.

Renovation work and roof covering replacement projects offer opportunities to perform mitigation retrofits to improve a building's continuous load path. For instance, installing additional fasteners to secure decking to rafters is relatively inexpensive when they are installed in conjunction with a planned reroofing project. Also, the connections between the walls and roof structure can often be made economically accessible during these projects, thus allowing the installation of metal framing connectors to help create a continuous load path. (Note that additional anchorage of the bottom of the wall may still be required to develop a complete load path.) Such mitigation measures would have avoided much of the roof decking and roof structure failures observed after Hurricane Katrina. Refer to FEMA Fact Sheet 30: "*Repairs, Remodeling, Additions and Retrofitting.*"

For buildings with aggregate surfaced roofs, mitigation is recommended to avoid aggregate blow off.

Table 11-7. Wind Hazard - Design and Construction Recommendations

Wind Hazard			
Building Component		Recommendation*	Action Required By**
General	1.	Increase inspections during construction by designers or third-party inspectors. This recommendation pertains to residential as well as non-residential construction. In addition to inspecting structural elements, it is recommended that building envelopes and rooftop equipment also be inspected to verify that various components are being properly installed and attached.	D, C, G, O
General	2.	Involve a structural design engineer, architect, or professional-licensed contractor in designing and planning renovation or remodeling of structural or building envelope improvements.	O
General	3.	Perform followup inspections after a hurricane to look for moisture or wind-related damage that may affect the structure or building envelope.	C, O
General, Historic Buildings	4.	Refer to the recommendations in this section for those elements that apply and coordinate with the State Historic Preservation Office. For vacant buildings, it is necessary to take earlier precautionary measures to stabilize the building to prevent deterioration, which may be further exacerbated by a major storm.	D, C, G
Building Envelope			
All	5.	For commercial and public buildings, refer to NIBS *Whole Building Design Guide* at http://www.wbdg.org/design/env_wind.php	
Asphalt Shingles	6.	Ensure manufacturers' installation instructions are followed (i.e., starter strips and nail locations) and use Fact Sheets 19 and 20 (FEMA 499).	D, C
Metal Panel Roof System	7.	Specify close spacing of fasteners at eaves, and hip and ridge flashings (e.g., spacings in the range of 3 to 6 inches on center, commensurate with the design wind loads.)	D
Tile Roof System	8.	Use Fact Sheet 21 (FEMA 499).	D, C
Edge Flashings and Copings	9.	Comply with American National Standards Institute (ANSI)/ SPRI ES-1 (2003). Use safety factor of 2 for Category II buildings and a safety factor of 3 for Category III and IV buildings.	D
Edge Flashings and Copings	10.	Place a bar over roof membrane near edge of flashing and coping to provide secondary protection (see FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*).	D, C
Gutters and Downspouts	11.	Develop design guide for wind-resistant gutters; include attachment of downspouts.	M, C
Brick Veneer	12.	Use Hurricane Katrina Recovery Advisory (in Appendix E): *Attachment of Brick Veneer in High-Wind Regions*.†	M, G

* All recommendations are detailed in this report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O).

† The Hurricane Katrina Recovery Advisories can be accessed on-line at: http://www.fema.gov/rebuild/mat/mat_katrina.shtm

Table 11-7. Wind Hazard - Design and Construction Recommendations (continued)

Wind Hazard			
Building Component		Recommendation*	Action Required By**
EIFS	13.	Manufacturers should re-evaluate their training programs to ensure that EIFS assemblies are installed properly by adequately-trained workers.	M
EIFS	14.	EIFS Industry Members Association (EIMA) should consider all elements of the EIFS assembly. Although EIMA members may not manufacture or supply assembly components such as metal framing, sheathing, or sheathing fasteners, these elements are also critical in achieving suitable wind performance.	M
EIFS	15.	When EIFS is installed over sheathing, designers should specify attachment requirements for all elements of the assembly, including framing and sheathing attachment.	D
EIFS	16.	Designers should specify special inspections to ensure proper application of all elements of the assembly.	D
EIFS	17.	Develop design guidance for EIFS attachment.	M, G
Vinyl Siding	18.	Develop design guidance for vinyl siding attachment.	M, G
Soffits	19.	Design guidance: Develop design guidance for attaching soffits, including design of baffles or filter media to prevent wind-driven rain from entering attics.	M, G
Doors			
Exterior Doors	20.	Specify wind-driven rain-resistant weather stripping at exterior doors (see FEMA 424).	D
Entrance Vestibules	21.	Design entrance vestibules for areas where basic wind speed exceeds 120 mph (see FEMA 424). When design conditions of 120 mph or greater are experienced, it is very difficult to avoid water infiltration around doors; therefore, vestibules are recommended.	D
Rolling and Sectional Doors	22.	Consider type, size, and spacing of door, frame, and frame fasteners to loads. If frame is attached to wood blocking, attention should also be given to the blocking attachment. Maintain adequate edge distances for frame fasteners placed in concrete or masonry.	D, C
Exterior Equipment			
General	23.	For all rooftop equipment, see Hurricane Katrina Recovery Advisory (in Appendix E): *Attachment of Rooftop Equipment in High-Wind Regions*.†	D
Lightning Protection Systems	24.	See Hurricane Katrina Recovery Advisory (in Appendix E): *Rooftop Attachment of Lightning Protection Systems in High-Wind Regions*.†	M, D, G

* All recommendations are detailed in this report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O).

† The Hurricane Katrina Recovery Advisories can be accessed on-line at: http://www.fema.gov/rebuild/mat/mat_katrina.shtm

11.3 Critical and Essential Facilities Recommendations

Based on the poor flood and wind performance experienced by many of the critical and essential facilities impacted by Hurricane Katrina as well as other previous storms, and lack of needed criteria in model building codes for these important buildings, it is clear that much greater attention is needed in the design, construction, maintenance, and operation of critical and essential facilities. FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds,* will be available in the summer of 2006. It will address new and existing facilities. Until it becomes available, please refer to the recommendations presented in Tables 11-8 and 11-9.

Table 11-8. Flood Hazard - Recommendations Specific to Critical and Essential Facilities

Flood Hazard			
Parameter		Recommendation*	Action Required By**
Critical/Essential Facilities			
Public Shelters	1.	Do not open shelters located in potential storm-surge inundation zones until after the hurricane has moved inland sufficiently to allow safe travel.	G, CFO
New Critical and Essential Facilities (reconstruction of existing facilities)	2.	At a minimum, elevate or protect new facilities in flood hazard areas to the 500-year (0.2% annual exceedance) flood level, or based on ASCE 24-05, whichever is higher. This is a current requirement per 44 CFR Section 9.11 for reconstructing existing facilities. Areas below this elevation can be used for vehicle and equipment storage, but plans should be made to relocate vehicles and equipment in the event of a severe storm. Floodproofing of vehicle and equipment storage areas may be an alternate approach for facilities located outside the V Zone and Coastal A Zone.	D, G, CFO
Existing Critical and Essential Facilities	3.	For facilities located within a SFHA, develop emergency operation plans that allow building occupants and operations to be relocated to sites outside SFHA before onset of storm. Do not occupy vulnerable facilities during an event.	G, CFO
Existing Critical and Essential Facilities	4.	Evacuate emergency supplies and equipment to the extent possible if an existing facility is to be evacuated before hurricane landfall.	G, CFO
Existing Critical and Essential Facilities	5.	Evaluate vulnerability of existing facilities in light of recent damage to similar facilities; strengthen and floodproof structures where feasible.	D, G, CFO

* All recommendations are detailed in this report unless otherwise noted.

** Action required by: Designer (D), Government Official (G), Critical Facilities Operator (CFO).

Table 11-9 . Wind Hazard - Recommendations Specific to Critical and Essential Facilities

Wind Hazard			
Building Component		Recommendation*	Action Required By**
New Construction			
General	1.	Emphasize best practices for schools and shelters described in FEMA 424 and FEMA 361, respectively, and in the latest codes and standards for wind resistance (ASCE 7).	D, CFO
General	2.	Develop additional criteria to help ensure continuity of function. See FEMA 424 and FEMA 361. Occupant needs for utilities should be provided through multiple sources.	D, CFO
General	3.	Contract drawings and specifications for new construction and remedial work on existing building envelopes and rooftop equipment should undergo rigorous peer review. During construction, perform detailed submittal reviews, field observation (inspection), and testing of building envelopes and rooftop equipment.	D, CFO, G
General	4.	Incorporate hazard mitigation peer review into the design approval process to ensure that critical and essential facilities are adequately designed to resist wind.	D, CFO
General	5.	Conduct special inspections for key structural items and connections to ensure performance of critical and essential facilities.	D, C, CFO
Design Loads	6.	Use a Directionality Factor of 1.0 for the building envelope and rooftop equipment, and 0.85 for the main wind force resisting system (MWFRS).[1]	D, CFO
Material Selection	7.	Reinforced concrete roof deck and reinforced concrete and/or reinforced and fully-grouted CMU exterior walls are recommended. FEMA 424 and FEMA 361 provide detailed guidance on material selection for structural and building envelope systems.	D, C, CFO
Detailing and Notations on the Building Plans	8.	Facility plans should delineate the facility area designed to function as a shelter or hardened area. Details of the shelter or hardened area and the envelope elements should be provided to ensure that the construction requirements are clearly understood by the builder and building official. Provide facility design criteria and maximum design pressures for the MWFRS and for components and cladding.	D, C, CFO
Roof System	9.	Design a roof system that will prevent or reduce water infiltration if roof is hit by windborne debris.	D
Gutters and Downspouts	10.	Secure gutters to resist wind uplift and to avoid membrane blow-off.	D, C, CFO

* All recommendations are detailed in this report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Government Official (G), Critical Facilities Operator (CFO).

*** See applicable items under New Construction

[1] Wind directionality factor: The ASCE 7 wind load calculation procedure incorporates a wind directionality factor (k_d). The directionality factor accounts for the reduced probability of maximum winds coming from any given direction. By applying the prescribed value of 0.85, the loads are reduced by 15 percent. Because hurricane winds can come from any direction, and because of the historically poor performance of building envelopes and rooftop equipment, a more conservative approach for critical facilities is recommended. A directionality factor of 1.0 is recommended for the building envelope and rooftop equipment (this results in a 15 percent load increase on these elements). For the MWFRS, a directionality factor of 0.85 is recommended (hence, no change for MWFRS).

Table 11-9 . Wind Hazard - Recommendations Specific to Critical and Essential Facilities (continued)

Wind Hazard			
Building Component		Recommendation*	Action Required By**
New Construction (continued)			
Rolling and Sectional Doors	11.	Install high-wind-rated, sectional, or rolling doors to protect against high wind.	D, C, CFO
Windows	12.	Implement window protection systems to protect critical facilities from windborne debris.	D
Existing Facilities***			
General	13.	American Red Cross 4496 provides a baseline for a shelter's integrity and performance, but meeting this criterion does not guarantee that the building will resist wind and windborne debris associated with hurricanes. Emphasize best practices for shelters described in FEMA 361.	D, CFO
General	14.	Implement mitigation measures or structurally retrofit critical and essential facilities to design levels other than minimum code requirements for general use buildings. Do not house critical and essential facilities in buildings that have not received thorough architectural and engineering attention.	D, CFO
General	15.	Conduct special inspections for key building envelope components to ensure performance of critical and essential facilities. Inspect rooftop equipment twice a year. Inspect windows, doors, and wall coverings at 5-year intervals. Conduct special inspections of the entire facility (both structural and building envelope systems) after major storms.	D, CFO
Vulnerability Assessment	16.	Perform vulnerability assessment to ensure continuity of operations. The assessment should evaluate the building performance and utilities that service critical and essential facilities, so that the building owner understands potential impacts to the facility during a storm, and operational impacts resulting from limited utility services.	D, C, CFO
Older Buildings	17.	Do not house critical and essential facilities in older buildings unless they are investigated by qualified engineers and architects to ensure survival in design level storms. If weaknesses are identified, the building should not be occupied during the event.	
Roof Structure	18.	Install hurricane clips or straps on inadequately connected roof beams and joists in those buildings that will be occupied during a hurricane.	D, C, CFO
Roofing	19.	Replace aggregate-surfaced roof systems with non-aggregate systems.	D, C, CFO
Edge Flashings and Copings	20.	Install exposed fasteners on the vertical face of weak metal edge flashings and copings (see FEMA 424).	D, C, CFO
Rolling and Sectional Doors	21.	Ensure sectional and rolling doors are properly installed and reinforced to prevent catastrophic door failure and building pressurization. Replace or retrofit existing doors that lack adequate resistance.	D, C, CFO

* All recommendations are detailed in the this report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Government Official (G), Critical Facilities Operator (CFO).

*** See applicable items under New Construction

Table 11-9 . Wind Hazard - Recommendations Specific to Critical and Essential Facilities (continued)

Wind Hazard			
Building Component		Recommendation*	Action Required By**
Existing Facilities*** (continued)			
Shutters	22.	In windborne-debris regions (as defined in ASCE 7), install shuttering system on all exterior glazing that is not windborne-debris-resistant. Install power-operated shutters, laminated glass, or engineered film systems, to the glazing and frame on upper-level floors.	D, C, CFO
Design Guidance	23.	Develop a comprehensive design guide to complement FEMA 424 for mitigating existing facilities.	D, G

* All recommendations are detailed in the this report unless otherwise noted.
** Action required by: Designer (D), Contractor (C), Government Official (G), Critical Facilities Operator (CFO).
*** See applicable items under New Construction

11.4 Public Outreach Recommendations

Reconstruction of the Alabama, Louisiana, and Mississippi communities affected by Hurricane Katrina will require adherence to the codes and best practices for building design and construction. Before that can occur, however, flood and wind hazards must be communicated to interested parties, reconstruction options must be determined and discussed, and the best option(s) must be identified. Public outreach and education on codes will be essential to this process, particularly with regard to identifying hazards and reconstruction options. A variety of audiences must be involved and engaged, including building owners and homeowners, designers, contractors, building officials, floodplain managers, and elected officials.

Key topics to be part of any effective outreach and education program should include:

- Mapping flood hazards: ongoing restudies and interim Katrina Flood Recovery Maps.
- Design and construction guidance as to how to resist future hurricanes, including consideration for storm impacts above design conditions.
- The costs, benefits, and consequences of employing (or not employing) best practices for design and construction.
- Provide training to local designers, contractors, and building officials on *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, publication available July 2006).
- Provide training to local designers, contractors, and building officials, on requirements of the latest adopted codes.

In addition to the adoption and enforcement of a current model building code, the other key element needed to significantly increase the wind performance of buildings is greater education for building owners and homeowners, designers, building officials, and contractors.

Educational efforts need to be multi-faceted and ongoing. Specific recommendations related to flood and wind hazards are given in Table 11-10.

Table 11-10. Flood and Wind Hazard - Public Outreach Recommendations

Education Topic		Outreach Method
Building Owners and Homeowners		
Mapping flood hazards: ongoing restudies and interim Katrina Flood Recovery Maps.	1.	✓ Conduct public meetings to educate building owners on Katrina Flood Recovery Maps and rebuilding information.
Design and construction guidance as to how to resist future hurricanes, including consideration for storm impacts above design conditions.	2.	✓ Provide outreach, via local newspapers and pamphlets, to describe advisory elevations and what they mean to building owners.
The costs, benefits, and consequences of employing (or not employing) best practices for design and construction.	3.	✓ Provide the FEMA web site address where the Katrina Flood Recovery Maps can be viewed.
Plan and budget construction projects that incorporate natural hazard mitigation measures.	4.	✓ Provide information to public and building owners regarding reconstruction guidance and best practices.
Select design and construction teams knowledgeable in effective construction methods in hurricane-prone areas.	5.	✓ Tailor informational pamphlets to homeowners and building owners.
Prepare and protect building prior to hurricane landfall.	6.	✓ Develop strategy to distribute information (e.g., standardized information sheets during sale of building).
Educate building owners on what to do after hurricane passes (inspecting for building damage, performing emergency repairs, and drying out building interiors).	7.	✓ Enlist assistance of real-estate companies and organizations such as the Building Owners and Managers Association.
Rebuild damaged structure in manner that protects against future damage.	8.	✓ Provide public service notices at start of each hurricane season.
Inspect exterior connections and fasteners for wear, corrosion, and other deterioration.	9.	✓ Develop informational materials on how wind-driven rainwater enters buildings, the resulting damage, and prevention methods.
Educate building owners on how wind-driven rainwater enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	10.	

Table 11-10. Flood and Wind Hazard - Public Outreach Recommendations (continued)

Education Topic		Outreach Method
Architects, Engineers, Consultants		
Improve the technical proficiency of building envelope design.	11.	✓ Prepare monographs for trade-wide distribution. ✓ Prepare Web-based tutorials and seminars. ✓ Encourage colleges and universities to augment existing curriculum with hurricane-resistant design instruction.
Provide adequate level of design details for connecting rooftop equipment, including mechanical, electrical, and lightning protection.	12.	
Share post-disaster building performance information to maximize the value of lessons learned. Broaden understanding of multihazard mitigation, disaster preparedness, risk analysis, and vulnerability assessment.	13.	
Provide training to local designers, contractors, and building officials on *Recommended Residential Construction for the Gulf Coast: Building Strong and Safe Foundations* (FEMA 550, publication available July 2006).	14.	
Provide training to local designers, contractors, builders, and building officials on requirements of the latest adopted codes.	15.	
Building Officials		
Share post-disaster building performance information to maximize the value of lessons learned.	16.	✓ Conduct annual seminars for building officials and plan reviewers in coastal areas to share lessons learned.
Train building officials to identify structural weaknesses that may cause structural or building component failure during a hurricane (e.g., unbraced gable end walls, missing truss bracing, truss anchorage, window/door anchorage).	17.	✓ Implement hurricane disaster building inspection training program and "train the trainer" program. ✓ Encourage building officials and inspectors to become Certified Coastal Construction and Floodplain Inspectors.
Implement effective enforcement techniques to maintain a high construction quality.	18.	
Provide training to local designers, contractors, and building officials on *Recommended Residential Construction for the Gulf Coast: Building Strong and Safe Foundations* (FEMA 550, publication available July 2006).	19.	
Provide training to local designers, contractors, builders, and building officials on requirements of the latest adopted codes.	20.	

Table 11-10. Flood and Wind Hazard - Public Outreach Recommendations (continued)

Education Topic		Outreach Method
Contractors		
Educate contractors who construct building envelopes and install rooftop equipment about hurricane-resistant fastening and anchoring systems.	21.	✓ Develop and distribute visual tools such as instructional videos or DVDs. ✓ Conduct on-the-job training to highlight failures that occur when simple anchoring techniques are not applied. ✓ Encourage trade schools in hurricane-prone areas to augment their curriculum with courses on state-of-the-art, hurricane-resistant construction.
Educate contractors on how wind-driven water enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	22.	
Provide training to local designers, contractors, and building officials on *Recommended Residential Construction for the Gulf Coast: Building Strong and Safe Foundations* (FEMA 550).	23.	
Provide training to local designers, contractors, builders, and building officials on requirements of the latest adopted codes.	24.	
Manufacturers		
Educate manufacturers of building envelope materials and rooftop equipment on the performance of their products during hurricanes.	25.	✓ Develop and distribute informational notices to manufacturers. ✓ Need to tie this with increased sales or profitability. Suggest possibility of a national testing system to replicate/replace Miami-Dade standards. This would make it easier to recommend products.
Encourage manufacturers to provide special guidance for use of their products in hurricane-prone areas.	26.	
Develop improved products and systems for hurricane-prone areas.	27.	
Manufacturers should educate designers and contractors on their products.	28.	
Associations, Institutes, and Professional Societies		
Advocate hurricane-resistant design and construction to their membership	29.	✓ Develop educational materials for distribution to their members and industry.

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C. Acronyms and Abbreviations

A

AAWA	American Association of Wind Engineers
ABFE	Advisory Base Flood Elevations
A/C	air conditioning
ACI	American Concrete Institute
AETC	Air Education and Training Command
AF&PA	American Forest and Paper Association
AFB	Air Force Base
ANSI	American National Standards Institute
AOML	Atlantic Oceanographic and Meteorological Laboratory
ARA	Applied Research Associates
ARMA	Asphalt Roofing Manufacturers Association
ASCE	American Society of Civil Engineers
ASOS	Automated Surface Observing Systems
ASTM	American Society for Testing and Materials

B

BESTT	Building Engineering Sciences and Technology Team
BFE	Base Flood Elevation
BHE	benzene hexachloride
BIA	Brick Industry Association
BMDL	below method detection limit
BUR	built-up roof

C

C&C	components and cladding
CABO	Council of American Building Officials
CCV	continuing calibration verification
CDC	Centers for Disease Control and Prevention
CDT	Central Daylight Time
CEMP	Comprehensive Emergency Management Plan
CFR	Code of Federal Regulations
cfu/cm²	colony forming units per square centimeter
C-MAN	Coastal Marine Automated Network
CMU	concrete masonry unit
COOP	Continuity of Operations
CRS	Community Rating System
CTP	Cooperating Technical Partner

D

DDD	dichloro-diphenyl-dichloroethane
DDE	dichloro-diphenyl-dichloroethylene
DDT	dichloro-diphenyl-trichloroethane
DFE	Design Flood Elevation
DHS	Department of Homeland Security

DoD	Department of Defense
DMAT	Disaster Medical Assistance Team
DRMO	Defense Reutilization and Marketing Office
DRO	diesel range organics

E

EDT	Eastern Daylight Time
EIFS	exterior insulation and finish systems
EIMA	EIFS Industry Members Association
EMPAT/EMLAP	Environmental Microbiology Proficiency Analytical Testing/Environmental Microbiology Laboratory Accreditation Program
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
EPDM	ethylene propylene diene monomer
ESDU	Engineering Sciences Data Unit

F

FBO	fixed base operator
FCMP	Florida Coastal Monitoring Program
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FLASH	Federal Alliance for Safe Homes
FLIS	FEMA Levee Inventory System
FMA	Flood Mitigation Assistance

G

GEV	Generalized Extreme Value
GNB	Gram Negative Bacilli

GPB	Gram Positive Bacilli
GPS	global positioning system

H

H&H	hydraulics and hydrology
HAZUS-MH	Hazards U.S. – Multi-Hazard
HMGP	Hazard Mitigation Grant Program
HMTAP	Hazard Mitigation Technical Assistance Program
HQ	Headquarters
HRD	Hurricane Research Division
HUD	U.S. Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
HWM	high water mark

I

IBC	International Building Code
IBHS	Institute of Building & Home Safety
ICC	International Code Council
ID/IQ	Indefinite Delivery/Indefinite Quality
IEBC	International Existing Building Code
IRC	International Residential Code
ISFA	insufficient sample for analysis
IWA	International Waterproofing Association

K

kts	knots

L

LDEQ	Louisiana Department of Environmental Quality
LIDAR	Light Detection and Ranging
LP&V-HPP	Lake Ponchartrain and Vicinity Hurricane Protection Project
lpm	liters per minute
LPS	lightning protection system
LSU	Louisiana State University
LSU AgCenter	Louisiana State University Agricultural Center
LWIC	lightweight insulating concrete

M

m	meter
MAT	Mitigation Assessment Team
mb	millibars
MCEER	Multidisciplinary Center for Earthquake Engineering Research
MEPS	molded expanded polystyrene
MHCC	Manufactured Home Construction and Safety Standard
MIP	Multi-hazard Information Platform
MO	Management Option
mph	miles per hour
MR&T	Mississippi River Levee System
MS	matrix spike
MSD	matrix spike duplicate
msl	mean sea level
MWFRS	main wind force resisting system

N

NAD	North American Datum

NAVD	North American Vertical Datum of 1988
NCDC	National Climatic Data Center
NESDIS	National Environmental Satellite Data and Information Service
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NGVD	National Geodetic Vertical Datum of 1929
NHC	National Hurricane Center
NIST	National Institute of Standards and Technology
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NRCA	National Roofing Contractors Association
NWS	National Weather Service

O

CRS	Other Federal Agency
OH Door	overhead door
OSB	oriented-strand board
OSHA	Occupational Safety and Health Administration

P

PCBs	polychlorinated biphenyls
PEMB	pre-engineered metal building
psf	pounds per square foot
PVC	polyvinyl chloride

R

RECAP	Risk Evaluation/Correction Action Program (LDEQ)
Rmax	radius of maximum winds
RPO	Regional Project Officer

S

SBC	Standard Building Code
SBCCI	Southern Building Code Congress International, Inc.
SEI	Structural Engineering Institute (of ASCE)
SFHA	Special Flood Hazard Area
SHPO	State Historic Preservation Office
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SSTD	Standard for Hurricane Resistant Residential Construction
SVOC	semi-volatile organic compound
SWEL	Stillwater Elevation

T

TAS	Testing Application Standard
TMS	The Masonry Society

U

UL	Underwriters Laboratories
USACE	U.S. Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time

V

VA	Veterans Affairs
VAMC	Veterans Affairs Medical Center
VHF	very high frequency
VOC	volatile organic compound
VOR	visual omnidirectional range

W

WHAFIS	Wave Height Analysis for Flood Insurance Studies
w/o	without



D. Glossary

100-year flood – The flood elevation that has a 1-percent chance of being equaled or exceeded each year.

ASCE 7 – National design standard issued by the American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, which gives current requirements for dead, live, soil, flood, wind, snow, rain, ice, and earthquake loads, and their combinations, suitable for inclusion in building codes and other documents.

ASCE 24-05 – National design standard issued by the American Society of Civil Engineers, *Flood Resistant Design and Construction*, which outlines the requirements for flood resistant design and construction of structures in flood hazard areas.

Base Flood Elevation (BFE) – Elevation of the 1-percent flood. This elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program.

Building envelope – The entire exterior surface of a building, including roofs, walls, windows, and doors, which encloses or envelops the space within.

Capillary action – Commonly referred to as "wicking," capillary action is the process by which water in liquid form climbs upward through materials in opposition to the force of gravity.

Critical and essential facilities – Facilities that, if damaged, would present an immediate threat to life, public health, and safety. Critical and essential facilities include, but are not limited to, hospitals, emergency operations centers, water systems, and utilities.

Design flood event – The greater of the following two flood events: (1) the base flood, affecting those areas identified as special flood hazard areas on a community's Flood Insurance Rate Map (FIRM); or (2) the flood corresponding to the area designated as a flood hazard area on a community's flood hazard map or otherwise legally designated.

Design wind event – An event where the observed wind speed equaled or exceeded the wind speed.

Design wind speed – The wind speed designated in the building code or engineering design standard.

Eave – The horizontal lower edge of a sloped roof.

Erosion – Process by which floodwaters lower the ground surface in an area by removing upper layers of soil.

Fetch – The distance along open water or land over which the wind blows.

Floodborne debris impact – Floodwater moving at a moderate or high velocity can carry floodborne debris that can impact buildings and damage walls and foundations.

Floodwall – A long, narrow concrete or masonry wall built to protect land from flooding.

Freeboard – The height added to place a structure above the base flood to reduce the potential for flooding. The increased elevation of a building above the minimum design flood level to provide additional protection for flood levels higher than the 1-percent chance flood level and to compensate for inherent inaccuracies in flood hazard mapping.

Gable end wall – The triangular end of an exterior wall above the eaves formed under a gable roof.

Girt – A horizontal structural member that is attached to sidewall or endwall columns and supports wall paneling.

Glazing – Glass or transparent or translucent plastic sheet used in windows, doors, and skylights.

Hem – The portion of the cleat (coping or edge flashing) that bends out at about a 60 degree angle at the bottom portion of the cleat/coping or edge flashing.

Hurricane – An intense tropical weather system with a well-defined counter-clockwise circulation and sustained winds of 74 mph or higher.

Insulated concrete form construction – A construction technique where the walls of the building are composed of hollow styrofoam blocks or foam panels, which serve as concrete forms that remain in place after they are reinforced and filled with concrete.

Levee – A manmade structure, usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water so as to provide protection from temporary flooding.

Pier foundation – Vertical support member of masonry or cast-in place concrete that is designed and constructed to function as an independent structural element in supporting and transmitting both building loads and environmental loads to the ground. Typical pier foundations are constructed on footings.

Pile foundation system – Vertical support member of wood, steel, or precast concrete that is driven or jetted into the ground and supported primarily by friction between the pilings and surrounding earth. Pilings often cannot act as independent support units and therefore are often braced with connections to other pilings.

Pole construction – A type of construction where the pilings extend from the ground to the roof system. It differs from platform construction where the pilings terminate at the lowest floor.

Purlin – A horizontal structural member that supports roof covering and carries loads to the primary framing members.

Rake – The inclined edge of a sloped roof over a wall (the edge above the gutter).

Reinforced concrete – Concrete with steel mesh or bars embedded in it to increase its tensile strength.

Saffir-Simpson Scale – Measures a hurricane's intensity on a 1-5 scale to give an estimate of the potential property damage and flooding expected. Wind speed is the determining factor in the scale. A Category 1 hurricane is the weakest, with winds from 74-95 mph (maximum, 1-minute sustained speeds), and a Category 5 hurricane is the strongest, with winds over 155 mph. Refer to Table 1-2.

Slab-on-grade foundation – Type of foundation in which the lowest floor of the house is formed by a concrete slab that sits directly on the ground.

Soffit – The underside of a horizontal element of a building, especially the underside of a stair or a roof overhang.

Special Flood Hazard Area – Portion of the floodplain subject to inundation by the base flood.

Steel moment frame – In steel moment frame buildings, the ends of the beams are rigidly joined to the columns so that the buildings can resist lateral wind forces without the assistance of additional braces or walls.

Stem wall foundation – A type of foundation that uses masonry block and reinforced with steel and concrete. The wall is constructed on a concrete footing, back-filled with dirt, compacted, and the slab is then poured on top.

Storm surge – The water that is pushed toward land from the high winds of a major storm (i.e., hurricane).

Tropical storm – A tropical cyclone with maximum sustained (1-minute average) winds of 39 to 73 mph.

HURRICANE *Katrina* IN THE GULF COAST

E. FEMA Hurricane Katrina Recovery Advisories

FEMA has prepared a series of Recovery Advisories that present guidance for design, construction, and restoration of buildings in areas subject to coastal flooding and high winds from Hurricane Katrina. To date, eight advisories have been prepared and are included in this appendix:

- Reconstruction Guidance Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevation Maps
- Initial Restoration for Flooded Buildings
- Design and Construction in Coastal A Zones
- The ABCs of Returning to Flooded Buildings
- Attachment of Brick Veneer in High-Wind Regions
- Attachment of Rooftop Equipment in High-Wind Regions
- Rooftop Attachment of Lightning Protection Systems in High-Wind Regions
- Designing for Flood Levels Above the BFE

These Advisories are also available online at http://www.fema.gov/rebuild/mat/mat_katrina.shtm where future Advisories will also be posted.

Reconstruction Guidance Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To discuss available flood hazard information and to recommend reconstruction practices using Advisory Base Flood Elevations (ABFEs).

Key Issues

- Following Hurricane Katrina, FEMA updated its flood frequency analyses to include more recent storm surge data (including storm surge stillwater levels measured after Katrina). The results of the analysis show that the updated 1 percent annual chance stillwater levels (also known as the 100-year stillwater levels) are 3 to 8 feet above the stillwater levels previously used to produce the pre-Katrina Flood Insurance Rate Maps (FIRMs).
- For post-Katrina recovery purposes, FEMA devised a method to approximate 1 percent annual chance wave crest elevations. The results of this effort are known as Advisory Base Flood Elevations (ABFEs, sometimes referred to as Advisory Flood Elevations [AFEs]), which are shown on a series of 228 maps for Hancock, Harrison, and Jackson Counties, Mississippi. These maps are also known as "Katrina Recovery Maps" (see Figure 1).
- The ABFEs are updated estimates of the 1 percent annual chance flood elevations, and are generally 5 to 12 feet higher than the base flood elevations (BFEs) shown on the pre-Katrina FIRMs. ABFEs also extend farther inland than the Special Flood Hazard Areas (SFHAs) shown on the pre-Katrina FIRMs.

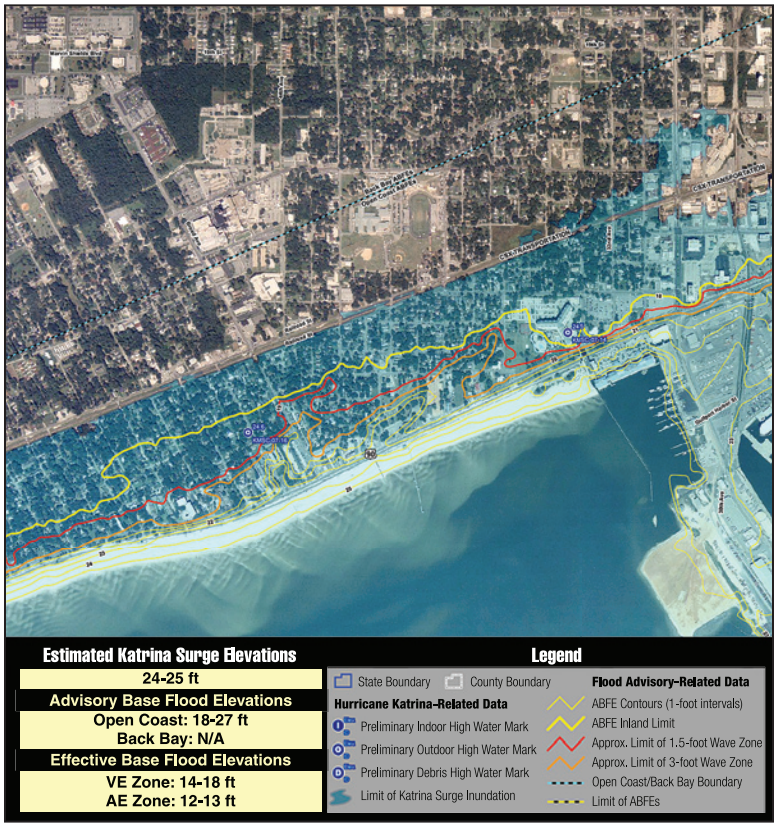


Figure 1. Sample Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations. The shaded region in blue indicates the approximate inland extent of storm surge inundation experienced during Katrina; the ABFE contours are shown in yellow and the predicted inland limit of damaging wave effects during the advisory base flood is shown by the red line. Blue points indicate surveyed Katrina high water mark elevations.

- The Katrina Recovery Maps also show the approximate inland extent of storm surge inundation experienced during Hurricane Katrina. Since Katrina exceeded the BFE in most locations (based on the updated flood frequency analysis), the inland extent of Katrina storm surge penetration generally lies inland of the ABFE limit. However, where the Katrina impact was less extreme (very near the eye where the hurricane winds are small, to the left of the eye where the peak winds blow offshore rather than onshore, and far to the right of the eye where the winds weaken), the Katrina surge penetration properly lies seaward of the ABFE limit.
- FEMA and the State of Mississippi will conduct detailed studies during 2005 and 2006 to produce revised FIRMs. The revised FIRMs will result from more detailed storm surge stillwater analyses and more detailed wave analysis methods than those used to produce the Katrina Recovery (ABFE) Maps. As a result, BFEs on the revised FIRMs may differ from the ABFEs. In the interim, the ABFEs should be treated as the best available 1 percent annual chance elevation information.

- Although the information contained on the Katrina Recovery Maps is advisory in nature, communities are encouraged to use ABFEs to regulate reconstruction and new construction until the revised FIRMs are produced by FEMA.
- Until such time as the revised FIRMs are published by FEMA and adopted by communities, those communities may use the pre-Katrina FIRMs, or Katrina Recovery Maps, or other flood elevations to regulate reconstruction and new construction (as long as the other flood elevations are not lower than those shown on the pre-Katrina FIRMs).

Advisory Base Flood Elevations (ABFEs)

The pre-Katrina FIRMs for communities in Hancock, Harrison, and Jackson Counties were published between the early 1980s and 2002; the current maps underestimate today's risk. Following Hurricane Katrina, FEMA updated the stillwater flood frequency analysis for coastal Mississippi to include tide and storm surge stillwater data for the past 25 plus years. These revised stillwater elevations formed the basis for FEMA's calculation of ABFEs.

The revised 1 percent annual chance storm surge stillwater levels were published by FEMA on October 3, 2005, for Hancock, Harrison, and Jackson Counties in Mississippi (see Table 1). The procedure which makes use of these elevations to compute ABFEs is illustrated in Figure 2 and the example below.

Table 1. Updated 1 Percent Annual Chance (100-Year) Stillwater Elevations for Use in Calculating ABFEs

County (Mississippi)	Updated 1 Percent Annual Chance Stillwater Elevations (SWEL), (ft NAVD*)	
	Gulf of Mexico Shoreline	Back Bay Shorelines
Jackson	14	12
Harrison	18	16
Hancock	20	18

*North American Vertical Datum of 1988
Storm Surge Stillwater Elevation (SWEL)

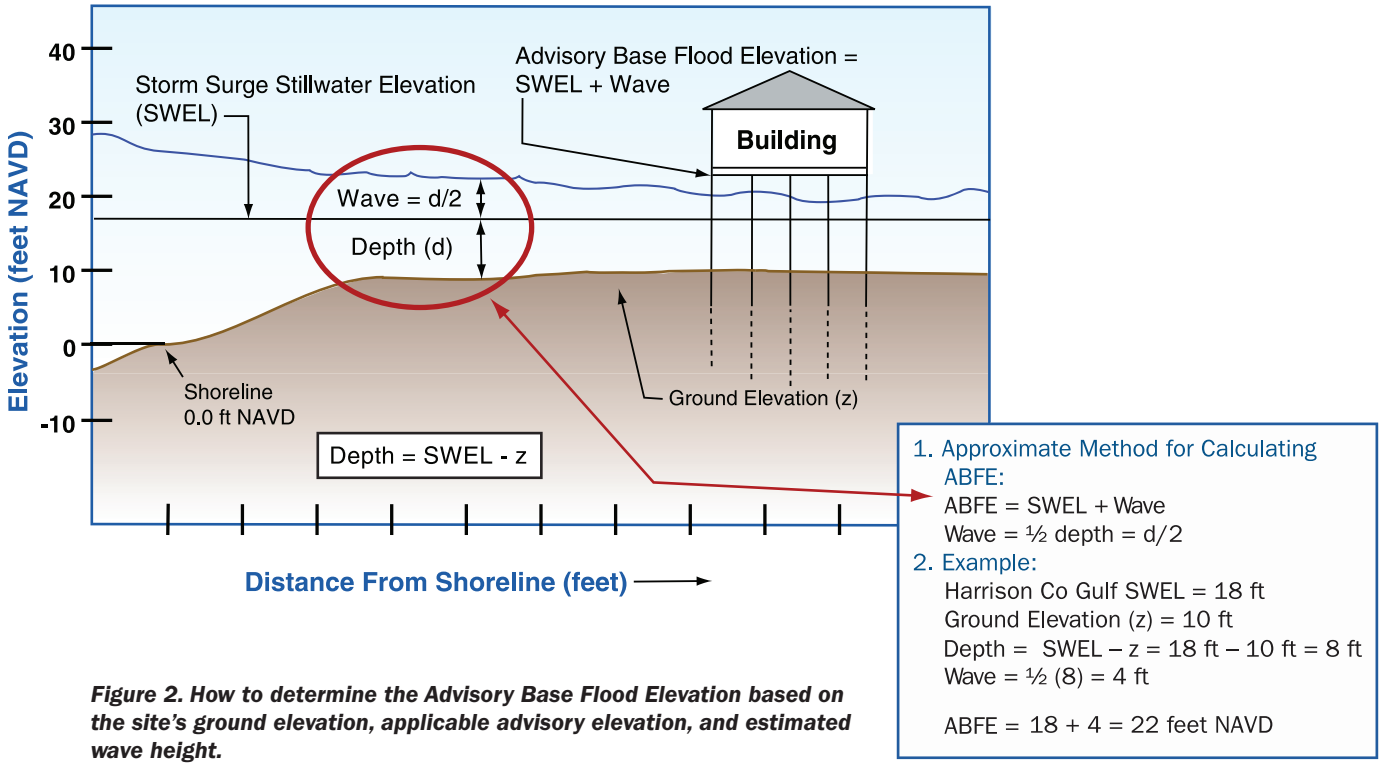


Figure 2. How to determine the Advisory Base Flood Elevation based on the site's ground elevation, applicable advisory elevation, and estimated wave height.

Communities and designers may note that the ABFE procedure is a simplified version of FEMA's Wave Height Analysis for Flood Insurance Studies (WHAFIS) program used to map base flood conditions on coastal FIRMs. The ABFE procedure does not account for wave attenuation due to dense stands of vegetation, buildings, or other obstructions. Nor does it account for wave growth and regeneration across flooded upland areas. Thus, BFEs on the revised FIRMs (anticipated in 2007) may differ from the ABFEs computed during this interim period. The ABFEs can be considered the best available data at this time.

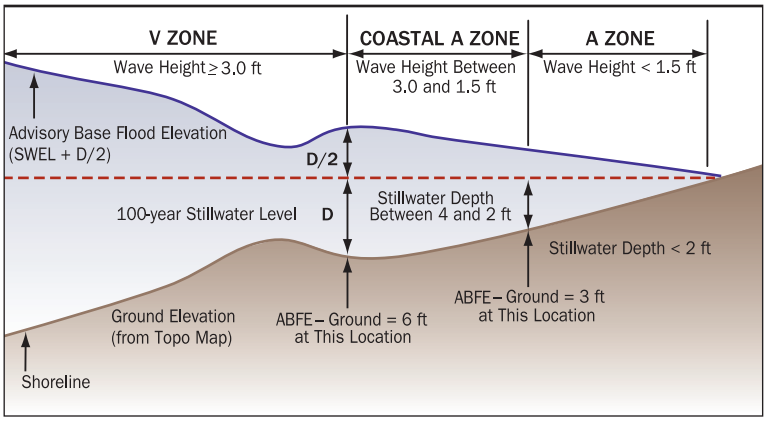


Figure 3. Cross-section showing 1 percent annual chance stillwater elevation, stillwater depth and ABFE, and inland limits of V Zone and Coastal A Zone.

Figure 3 illustrates the relationships between the stillwater flood elevation, ground elevations, associated 1 percent annual chance stillwater flood depths, ABFEs, and associated flood hazard zones.

Advisory Base Flood Elevations

The Katrina Recovery Maps (see Figure 1) include the following information:

- Pre-Katrina aerial photographs (as a base map)
- Approximate Katrina surge inundation limit (shaded area)
- ABFE contours (ft NAVD)
- Predicted inland limit of damaging wave effects during the advisory base flood (red line)
- Surveyed Katrina high water mark elevations

More background information on ABFEs and their use can be found in Flood Recovery Guidance-Frequently Asked Questions, dated October 3, 2005, and available at:

www.fema.gov/hazards/floods/recoverydata/katrina_ms_resources.shtm

Communities are encouraged to use the Katrina Recovery Maps. They may continue to enforce their adopted FIRMs and associated design and construction requirements. However, by using the ABFEs any reconstruction or new construction (following Katrina and before issuance of revised FIRMs, expected in 2007) will be at much less risk from future flood damage, and will be eligible for reduced flood insurance premiums (new and reconstructed buildings can be rated using BFEs and flood hazard zones on the effective FIRM, until revised FIRMs are adopted by the community).

Flood Protection Levels for Post-Katrina Reconstruction and New Construction

Until revised FIRMs are published by FEMA and adopted by communities, those communities are free to regulate reconstruction and new construction using several methods:

- Continue to use pre-Katrina FIRMs (understanding that this would knowingly put people and buildings at risk)
- Modify the use of pre-Katrina FIRMs (e.g., add freeboard to the pre-Katrina BFEs)
- Use the Katrina Recovery (Advisory Base Flood Elevation) Maps
- Modify the Katrina Recovery Maps (e.g., conduct a more detailed wave analysis and add to the 1 percent annual chance stillwater elevation, replacing ABFE contours shown on the maps)
- Develop other maps and methods (as long as the resulting BFEs and flood hazard zones are no less restrictive than the pre-Katrina FIRMs)

Each of these methods has advantages and disadvantages, both for implementation and for the long-term protection of buildings constructed after Hurricane Katrina. These are summarized in Table 2.

Table 2. Comparison of Various Methods for Providing Post-Katrina Flood Protection to Reconstructed Buildings and New Construction

Advantages	Disadvantages
Continue Use of Pre-Katrina FIRMs	
No change from pre-Katrina flood hazard maps	• Underestimates inland extent of flooding during base flood • Underestimates flood depths • Underestimates inland extent of the V Zone and damaging wave effects • Does not protect buildings outside the pre-Katrina SFHA against damage during the base flood • Limits eligibility for post-Katrina hazard mitigation grants and other reconstruction funds
Add Freeboard to Pre-Katrina FIRMs (where freeboard is less than that indicated by updated 1 percent annual chance flood analysis)	
• Provides increased flood protection for buildings within the pre-Katrina V Zone • Provides increased flood protection for buildings near the inland limit of the pre-Katrina A Zone • Buildings elevated to the new (freeboard) elevation will be eligible for flood insurance premium discounts (they can be rated using the pre-Katrina FIRM)	• Underestimates inland extent of flooding during base flood • Does not protect buildings outside the pre-Katrina SFHA against damage during the base flood • Does not expand the V Zone inland, and does not protect buildings in the seaward portion of the pre-Katrina A Zone against wave damage • Does not fully protect any buildings subject to the updated 1 percent annual chance flood • Limits eligibility for post-Katrina hazard mitigation grants and other reconstruction funds
Use Katrina Recovery (ABFE) Maps	
• Uses the latest 1 percent annual chance flood elevation and mapping guidance to characterize the extent, depth and severity of updated base flood hazards • ABFEs near the coast may be comparable to revised BFEs expected in 2007 • Provides flood protection consistent with the latest estimate of the updated base flood • Reduces potential floor elevation and foundation differences between buildings reconstructed/ constructed to ABFEs and those constructed after adoption of revised BFEs. • Buildings elevated to the ABFE will be eligible for flood insurance premium discounts (they can be rated using the pre-Katrina FIRM)	• Large differences between pre-Katrina building floor elevations and post-Katrina building floor elevations • ABFEs near the inland limit of flooding and in areas sheltered from wave effects may overstate wave hazards and wave crest elevations
Modify the Katrina Recovery (ABFE) Maps (via improved wave height analysis)	
• Same as ABFE entries above • Reduce wave height overestimates introduced by the ABFE approach	Large differences between pre-Katrina building floor elevations and post-Katrina building floor elevations
Other Methods	
Vary with method selected	Vary with method selected

Using the Advisory Base Flood Elevations

Communities can make use of the Advisory Base Flood Elevations by those methods summarized in Table 2. In addition, communities can take several steps that will help to protect reconstruction and new construction:

- Define the revised inland extent of the SFHA using ground contours equal to the stillwater elevations contained in Table 1.
- Define the revised inland extent of the coastal high hazard area (V Zone) based on a 4-foot stillwater depth (the depth required to support a 3-foot wave), using whatever new 1 percent stillwater elevation the community adopts. If the community adopts the stillwater elevations in Table 1, ground elevations corresponding to the new inland V Zone limit are shown in Table 3. In most cases, the first encounter with that ground elevation (starting at the shoreline and moving inland) will be the inland V Zone limit.
- Define the inland extent of a Coastal A Zone (see Hurricane Katrina Recovery Advisory, Design and Construction in Coastal A Zones) based on a 2-foot stillwater depth (the depth required to support a 1.5-foot wave), using whatever new 1 percent stillwater elevation the community adopts. If the community adopts the stillwater elevations in Table 1, ground elevations corresponding to the inland limit of the Coastal A Zone are shown in Table 3. In most cases, the first encounter with that ground elevation (starting at the shoreline and moving inland) will be the inland limit of the Coastal A Zone.
- Implement a local ABFE revision process, to allow for special circumstances where property owners can supply better topographic data or information which will result in a more accurate delineation of flood hazards. Note: such a revision process should not allow reduction of the stillwater elevations in Table 1.
- If a community has adopted the International Building Code or the International Residential Code, define the "Design Flood Elevation" as the ABFE. Define the "Flood Hazard Area" as the inland extent of flooding using the ABFE procedure.

Table 3. Ground Elevations Corresponding to Inland Limits of V Zones and Coastal A Zones (based on 1 percent annual chance stillwater elevations published by FEMA, October 3, 2005)

County, Flood Source	1 Percent Annual Chance Stillwater Elevation (ft NAVD)	Ground Elevation Corresponding to Inland Limit of V Zone (ft NAVD)	Ground Elevation Corresponding to Inland Limit of Coastal A Zone (ft NAVD*)
Jackson, Gulf of Mexico	14	10	12
Jackson, Back Bay	12	8	10
Harrison, Gulf of Mexico	18	14	16
Harrison, Back Bay	16	12	4
Hancock, Gulf of Mexico	20	16	18
Hancock, Back Bay	18	14	16

* North American Vertical Datum of 1988

Design and Construction Practices Using ABFEs

FEMA recommends that all reconstruction and new construction within the revised flood hazard area employ a "best practices" approach, incorporating those methods known to eliminate or reduce flood damage. This will mean:

- Elevating buildings higher than before Katrina, on stronger foundations, with continuous load paths and stronger connections, and with wind- and water-resistant walls, windows, doors, and roofs.
- Elevating buildings with the bottom of the lowest horizontal structural member supporting the lowest floor above the ABFE (or whatever regulatory flood elevation a community adopts). *In A Zones, do not elevate the building only such that the lowest floor walking surface is at the ABFE (or whatever regulatory flood elevation a community adopts).*
- Using flood-damage resistant building materials above the lowest floor elevation of the building (remember, floods more severe than the base flood can, and do, occur).
- Designing and constructing buildings using methods and materials described in:
    - The latest model building codes and standards
    - FEMA 55, *Coastal Construction Manual* (revised 2000)
    - FEMA 499, *Home Builder's Guide to Coastal Construction,* Technical Fact Sheet Series (2005) (http://www.fema.gov/fima/mat/fema499.shtm)

Initial Restoration for Flooded Buildings

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

NOTE: This advisory is specifically intended for buildings subject to the effects of long-term flooding and widespread mold growth following Hurricane Katrina. For additional information on more common water leakage and mold situations, refer to the FEMA website (http://www.fema.gov) and related links to the Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC) sites listed at the end of this advisory.

During the initial visit to a flood-damaged building, the situation often appears overwhelming (Figure 1). However, despite the shock that often accompanies an individual's first look at the damage, there are a number of straightforward principles can be applied to assist with the flood restoration effort. In addition to following the steps outlined below, individuals should review the Hurricane Katrina Recovery Advisory, *The ABC's of Returning to Flooded Buildings*.



Figure 1. Typical flood damage to furniture and interior walls (Hurricane Katrina).

1. Air Out

- To promote drying, open all doors and windows whenever you are present and leave as many open when you are not present as security concerns allow. Some styles of windows (double-hung) and patio doors may be able to be left partially open and secured from external opening by inserting a nail in the window frame or using a wooden dowel or stick. Upper floor windows can usually be left open all the time and will also assist in drying the whole house. Try to take advantage of cross-ventilation by opening windows on multiple levels and opposite sides of the building.
- Open interior doors, especially closets and interior rooms, to allow air movement to reach all areas of the building. Take doors off their hinges if necessary to promote air flow.
- Open kitchen cabinet and bathroom vanity doors; remove drawers and stack them to dry.
- Open the attic access, if available, to increase ventilation. Consider the benefits (improved drying) and risks (falling dust, insulation, or other debris) of adding an attic access where none exists.
- When electricity is available, use fans to push moist air outside. However, avoid use of fans if the house is contaminated with sewage as the air movement may spread bacterial contamination.

2. Move Out

- Remove salvageable contents that were not impacted by the water. If the upper floors are dry, it may be possible to move such items to those areas. When moving items from impacted areas of the building to other locations, consider using protective mats or non-slip drop cloths (e.g., fabric painter cloths) to avoid contamination of unimpacted surfaces.
- Remove saturated porous materials such as mattresses or upholstery, especially those with visible fungal growth. These items should be moved out of the building as soon as possible. Cover contaminated items with plastic drop cloths prior to moving to prevent spread of contaminants. Appropriate personal protective equipment should be utilized to avoid injury from possible exposure to mold and bacteria.

3. Tear Out

- Prior to beginning tear out, install plastic barriers between affected and unaffected areas of the premises (typically between the first and second floors). This will reduce the potential for secondary damage occurring in the unaffected areas.
- Remove wet carpet and padding. Tack strips should also be removed completely when the carpet is taken out to minimize injury during subsequent activities. Since carpet tack strips have protruding nails, wear leather gloves to protect hands from puncture wounds while removing and handling tack strips. Removing wooden baseboards prior to carpet tear out may allow for their later reinstallation.
- Remove any curled vinyl tiles or linoleum over concrete floors, and remove all vinyl tiles or linoleum over wooden sub-floors to allow the wood to dry. Respiratory protection should be worn as many older (pre-1970s) flooring products, such as 9-inch square tiles and adhesives, often contain asbestos.
- Although punching holes in walls for drainage is commonly recommended, this practice does not drain water nor does it cause the wall to dry faster. If holes are not punched in the walls, the drywall (gypsum board) may be able to be easily repaired and restored.
- If drywall or plaster has been saturated by contaminated floodwater, it should be removed. Respiratory protection should be worn when removing drywall as some older drywall joint compound contains asbestos. If the water level was less than 2½ feet, the wall material should be removed to a height of 4 feet to facilitate reinstallation of full sheets of drywall. If the water level was greater than 2½ feet, the wall material should be removed to a height of 8 feet or the ceiling junction, whichever is higher. Electrical outlet and wall switch plates and door and window moldings must be removed prior to the tear out of the wall material.
- Fibrous wall insulation (fiberglass, mineral wool, cellulose, wood fiberboard, etc.) saturated by floodwater should be removed completely. Foam plastic insulation may be left in place and allowed to dry.
- Flooded electrical receptacles should be removed completely after the appropriate circuit breakers or fuses are deactivated.
- Wall paneling should be removed if it is swollen or if saturated drywall is behind the paneling.

4. Clean Out

- Following any necessary tear out, clean up any remaining debris and muck. Squeegees, shovels, and brooms are effective for such cleaning. Personal protective equipment should be utilized. Detailed cleaning and sanitizing of the remaining materials should be conducted. A shop vacuum with dry filters in place and with a solution of clean water and disinfectant in the tank (2-inch depth) to minimize the spread of dust can be used.
- **Mold removal**. Treatment with commercial mold removers does eliminate visible evidence of mold growth on exposed surfaces and is recommended for restoring flood-damaged homes. Tests have found very little or no evidence of mold growth in the non-exposed (hidden) portions of the walls. Treating the non-exposed portions of the walls for mold control does not appear warranted in most cases. Spraying vertical surfaces using a compression (pump-up) garden sprayer with a commercial mildew remover is recommended.
- **Understand the limitations of bleach**. While this material is convenient and appropriate as a sanitizer for hard, non-porous items after they have been cleaned, it has distinct drawbacks when cleaning flood-impacted buildings. Application of bleach water can cause corrosion of electrical components and other metal parts of mechanical systems, and can compromise the effectiveness of termite treatments in the soil surrounding the building. Its effectiveness at killing bacteria and mold is significantly reduced when it comes in contact with residual dirt. Moldy surfaces should be cleaned first and then disinfected. Residual mold spores should then be removed, since killing them does not reduce their toxicity.
- Remove mud and gross contamination from floors by shoveling into suitable containers. Reduce soil and



Figure 2. Using a pressure washer to clean contaminated surfaces.

contaminant levels on surfaces by flushing off with clear water. The fastest and most efficient method to clean and decontaminate materials and surfaces is by using a residential-type pressure washer to apply a cleaner-disinfectant solution to the affected areas (Figure 2). Brushes improve decontamination of floors and some walls by scrubbing solution into affected surfaces. Avoid scrubbing drywall and plaster walls at this time because they have become softened by the flooding and moisture and may have their surface damaged by scrubbing. Following the first cleaning, floors and walls should be rinsed with water and the cleaning process redone a second time. Squeegees can be used to control or direct spent solution, and wet vacuums can be used to collect spent solution.

Warning: Failure to allow for adequate drying prior to reconstruction can trap moisture in the building, which can cause structural damage and potential health problems in the future.

5. Dry Out

- Once the clean process is completed, the building and any remaining contents need to dry. Drying is a naturally occurring process. Over time, all wetted building materials will dry. Drying of structural materials will take an extended period of time to dry to pre-flood conditions. Exterior rooms with excellent ventilation can take 2 to 4 weeks to dry, depending on the temperature and humidity outside. Interior rooms, or those with minimal ventilation, can take 4 to 6 weeks or more to dry and are candidates for the use of mechanical drying equipment. The use of fans, dehumidifiers, air conditioners, and/or auxiliary electric heaters will speed drying. Allowing materials to dry naturally will take considerably longer.
- **Wood framing**. The moisture content of wood framing must be checked professionally or with a commercially available moisture meter before refinishing or recovering so that excessive moisture does not become trapped in the materials and cause future problems (Figures 3a and 3b). Dryness of wood framing materials can be determined quantitatively using the table on the right above. Wetted materials are presumed dry when their moisture content readings are less than or equal to 15 percent when taken with an intrusive/penetrating moisture meter (Figure 3a). If an intrusive/penetrating moisture meter is not available, a non-intrusive/penetrating moisture meter (Figure 3b) may be used; however, keep in mind that the material moisture results measured from non-intrusive meters may be less accurate than intrusive meters.
- **Walls, floors, and other building materials**. The moisture content of drywall (gypsum board), plywood floors, and other building materials must also be checked professionally or with a commercially available moisture meter before refinishing or recovering so that excessive moisture does not become trapped in the materials and cause future problems (Figures 3a and 3b). Unlike wood framing, the dryness of other building materials must be confirmed qualitatively by comparing readings between like materials in affected areas of the building (at or below flood level) and unaffected areas of the building (a room or upper floor above the flood

Summary of Moisture Reading Results for Wood Framing Materials

Moisture Reading	Results
> 20%	Wet - no good
15 - 20%	Partially dry - caution
< 15%	Dry - OK



Figure 3a. An intrusive/penetrating moisture meter–recommended for final moisture readings.



Figure 3b. A non-intrusive/non-penetrating moisture meter–recommended for initial and interim moisture readings.

level, or inside a nearby building that was not flooded). Wetted materials are presumed dry when their moisture content readings are within 5 percent of those of like materials in unaffected areas of the building when taken with an intrusive/penetrating moisture meter (Figure 3a). If an intrusive/penetrating moisture meter is not available, a non-intrusive/penetrating moisture meter (Figure 3b) may be used; however, keep in mind that the material moisture results measured from non-intrusive meters may be less accurate than intrusive meters.

- Kitchen cabinets, bathroom vanities, and other "built-in" furnishings that were subjected to flood water should be removed from their location to permit drying of the material behind them. Once these "hidden" areas are dried, the furnishings can be reinstalled if they are salvageable.
- When saturated wood, drywall, and/or other structural materials vulnerable to fungal growth are naturally air dried over an extended period (weeks), the application of a disinfectant prior to drying can prevent mold growth. Materials should be closely observed and disinfectant reapplied at the first sight of mold.

General Notes for Drying Foundation Floors

- **Crawlspaces**. Access to crawlspaces is necessary for decontamination purposes. For crawlspaces that do not have an existing access opening, the simplest method to access the crawlspace is by strategically removing sections of overlying flooring to permit access. When the flooring is not salvageable, removal of the flooring provides the necessary access openings. Once access is obtained, gross (solid) contamination should be removed from the ground underneath the building for health and sanitation purposes. Next, any remaining water should be removed. If there is an existing vapor retarder on the ground, it can be left in place to collect spent water and cleaning solutions. Following remediation and any necessary final cleaning, the vapor retarder can be left in place to facilitate drying. If there is exposed ground within the crawlspace after cleaning, it should be covered with a plastic vapor retarder to minimize potential mold growth and future moisture migration into the house. Plastic vapor retarders can be made watertight by overlapping and sealing them together using either glue or heavy-duty adhesive. Suitable adhesives can be obtained from hardware stores or home improvement centers. After the vapor retarder is placed, the underlying support structure of salvageable wooden floor joists, wood sub-floors, and foundation walls should be cleaned and sanitized. Following cleaning, application of a wood preservative will provide protection against fungi and wood destroying insects.
- **Grade slabs**. Concrete grade slabs provide a dense barrier between the ground and the interior of the home. Remove mud and gross contamination from slabs by shoveling into suitable containers. Reduce soil and contaminant levels on surfaces by flushing off with clear water. The fastest and most efficient method to clean and decontaminate contaminated grade slabs and adjacent building materials and surfaces is by using a residential type of pressure washer to apply a cleaner-disinfectant solution to affected areas. Brushes improve decontamination of floors and base of walls by scrubbing solution into affected surfaces. Following the first cleaning, floors and base of walls should be rinsed with water and the cleaning process redone a second time. Squeegees can be used to control or direct spent solution, and wet vacuums can be used to collect spent solutions. Following cleaning, the slab should be visually examined for signs of heaving or cracking due to hydrostatic pressure. When in doubt, contact the local building inspector, structural engineer or other appropriate professional.

Additional Resources

- Repairing Your Flooded Home (ARC #4477/FEMA 23)
  http://www.redcross.org/services/disaster/0,1082,0_570_,00.html
- Cleaning Flood-Damaged Homes (LSU AgCenter)
  http://www.louisianafloods.org/en/family_home/hazards_and_threats/recovery_assistance/cleaning_up/structural_damage/Cleaning+FloodDamaged+Homes.htm
- Mold Fact Sheet (LSU AgCenter)
  http://www.louisianafloods.org/en/family_home/home/health_safety/indoor_air_quality_mold/Mold+Fact+Sheet.htm

For additional information on more common water leakage and mold situations:

- Environmental Protection Agency (EPA), http://www.epa.gov/mold
- Centers for Disease Control and Prevention (CDC), http://www.cdc.gov/mold

Design and Construction in Coastal A Zones

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To recommend design and construction practices in coastal areas where wave and flood conditions during the base flood will be less severe than in V Zones, but still cause significant damage to typical light-frame construction

Key Issues

- Recent post-storm investigations have shown that typical A Zone construction techniques (e.g., wood-frame, light gauge steel or masonry walls on shallow footings or slabs, etc.) are subject to damage when exposed to less than 3-foot breaking waves, which is the current threshold for V Zone conditions.
- Coastal A zone buildings that employ typical residential and light commercial walls to elevate and support habitable space above the flood level will be susceptible to flood damage (see Figure 1). Laboratory tests and recent field investigations confirm that breaking wave heights as small as 1.5 feet will cause failure of these types of walls (see Figures 2 and 3).
- Other flood hazards associated with coastal waves (e.g., floating debris, high velocity flow, erosion and scour) also damage A Zone type construction in coastal areas (see Figures 4 and 5).
- NFIP flood hazard mapping is generally divided into two categories, V Zone and A Zone. In coastal areas, the A Zone category could be subdivided into "Coastal A Zone" and "A Zone." Base flood conditions in the Coastal A Zone will be similar to, but less severe than, those in the V Zone; base flood conditions in the A Zone will be similar to those in riverine or lake floodplains.
- The Coastal A Zone is not shown on the FIRM at present; therefore, communities, designers, and owners will have to determine whether a site lies within a Coastal A Zone.
- **V Zone design and construction standards are recommended in Coastal A Zones subject to erosion, high velocity flow, and/or wave heights greater than 1.5 feet.**



Figure 1. Failure of wood-frame walls used to support a coastal building, which was subjected to shallow flooding, small waves, and floating debris (Hurricane Opal).



Figure 2. Masonry walls destroyed by 3 feet of stillwater flooding and small waves (Hurricane Dennis).

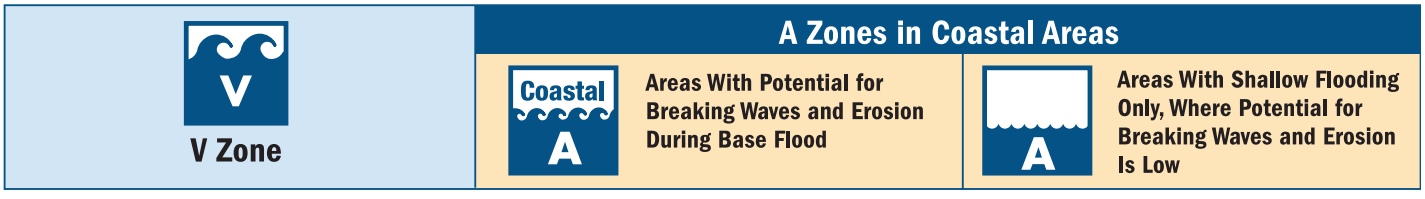




Figure 3. Failure of wood-frame wall, brick veneer, and windows as a result of 4 feet of stillwater flooding and small waves (Hurricane Katrina).



Figure 4. Failure of A Zone type foundation in coastal area, not subject to V Zone conditions (Hurricane Fran).



Figure 5. Damage to light frame walls due to floating debris and small waves. The damaged home was in the third row back from a bay shoreline (Hurricane Ivan).

Coastal A Zone, Defined

Coastal A Zone: area landward of a V Zone, or landward of an open coast without mapped V Zones. In a Coastal A Zone, the principal source of flooding will be astronomical tides, storm surges, seiches or tsunamis, not riverine flooding. During base flood conditions, the potential for breaking wave heights between 1.5 feet and 3.0 feet will exist (see Figure 6).

Coastal A Zone design and construction practices described herein are not mandated by the NFIP, but are recommended for communities that wish to adopt higher floodplain management standards. Community Rating System (CRS) credits are available for doing so. Note that some Coastal A Zone practices may be required by the International Building Code, through its reference to ASCE 24-98.

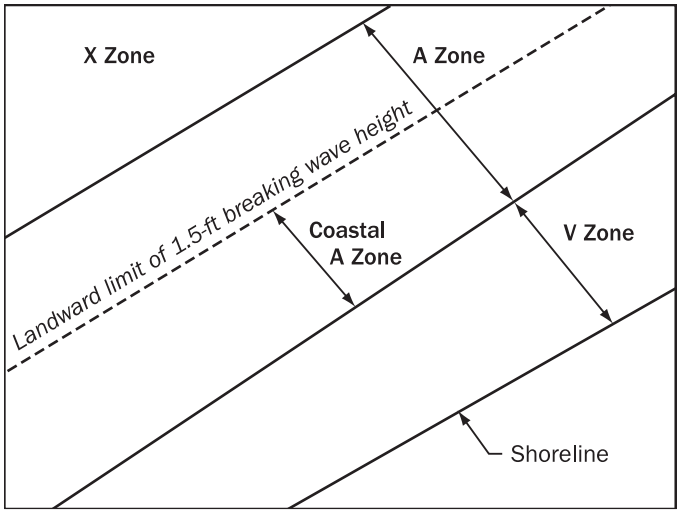


Figure 6. Plan view showing Coastal A Zone landward of V Zone (source: ASCE 24-05).

Coastal A Zone Construction Guidance

Because of the presence of damaging waves, V Zone design, construction, and certification practices are recommended for Coastal A Zones.

Coastal A Zone construction should include:

- Use of open foundations (pile or pier) designed to resist all base flood conditions (waves, high velocity flow, erosion and scour, floodborne debris). Where high velocity flow, scour, and erosion will not be experienced under base flood conditions, a traditional stem wall foundation may be acceptable – see Table 1.
- Elevation of the bottom of the lowest horizontal structural member supporting the lowest floor above the base flood wave crest elevation (see Figure 7).Since waves and debris will be impacting on the floor joists and other foundation elements during the base flood, *do not follow current NFIP minimum requirements that allow the lowest floor's walking surface to be set at the wave crest elevation in Zone A.*
- Use of flood-resistant materials above the level of the walking surface of the lowest floor (in the event that future flooding exceeds the lowest floor level).
- Specification of connections between the foundation and the elevated building that are capable of withstanding simultaneous wind and flood forces. Post-Katrina investigations found many foundation-to-building connections to be deficient (see Figure 8).
- Use of space below the lowest horizontal structural member for parking, access, or storage only. Adding sufficient freeboard to allow parking beneath the building will not only reduce future flood damages, but will also lower flood insurance premiums.
- Use of screen, lattice, or breakaway walls if space below the elevated floor is enclosed. Note: until flood regulations are changed, breakaway walls in Coastal A Zones must be equipped with flood openings.

Additional guidance for design and construction in Coastal A Zones can be found in FEMA 499, *Home Builder's Guide to Coastal Construction* (http://www.fema.gov/fima/mat/fema499.shtm). The publication is a series of 31 fact sheets that provide recommended design and construction practices for foundations, connections, building envelope, etc. Fact Sheet 2 summarizes recommended practices for Coastal A Zones, and references other fact sheets that provide more details.

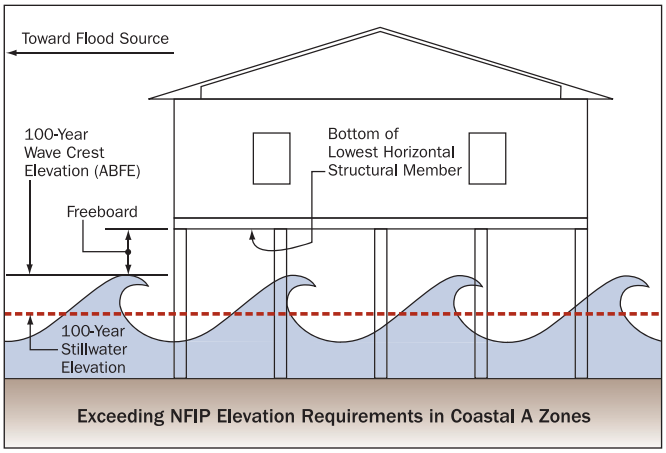


Figure 7. Recommended post-Katrina building standards in Coastal A Zones.



Figure 8. Post-Katrina investigations showed that many buildings were attached to foundation piers with light gauge metal straps. These straps failed in many instances. A stronger (preferably bolted) connection is recommended when attaching Coastal A Zone buildings to their foundations.

Table 1. Foundation Recommendations for Coastal A Zones (Users should read across from a foundation type to see under what soil and base flood conditions that foundation is acceptable. A foundation must be capable of resisting all base flood conditions likely to exist at the site, or it should not be used. For example, a properly constructed pier on a shallow footing will generally withstand 1.5- to 3.0-foot wave heights, but should not be used where soils are erodible, and where high velocity flow is possible, or where large floodborne debris may be present.)

Foundation Type	Base Flood Condition Present		
	Wave Heights Between 1.5 and 3.0 Feet*	Velocity Flow, Erodible Soils	Large Debris
Fill	no	no	no
Slab on grade	no	no	no
Crawlspace, shallow footing	no	no	no
Foundation walls, shallow footing	no	no	no
Stemwall, shallow footing	yes	no	yes
Stemwall, deep footing**	yes	yes	yes
Pier, shallow footing	yes	no	no
Pier, deep footing**	yes	yes	no
Post, shallow embedment	no	no	no
Pile/Column, deep embedment**	yes	yes	yes

*Wave heights greater than 3.0 feet mapped as V Zone: fill, slab, crawlspace, wall foundations not permitted.

**Deep means sufficiently deep to withstand erosion and scour, including that induced by the presence of the foundation itself.

Identifying Coastal A Zones

Coastal A zones are not shown on present day Flood Insurance Rate Maps (FIRMs) or mentioned in a community's Flood Insurance Study (FIS) Report. Those maps and studies show zones VE, AE, and X (or older designations V1-30, A1-30, B, and C). Therefore, until Coastal A Zone designations or wave height contours are incorporated into Flood Insurance Studies, the community official, designer, or owner will have to determine whether or not a site will be subject to Coastal A Zone conditions during the base flood.

In order for a Coastal A Zone to be designated, two conditions are required:

1) a water depth sufficient to support waves between 1.5 and 3.0 feet high, and

2) the actual presence of wave heights between 1.5 and 3.0 feet.

Condition 1 requires stillwater depths (vertical distance between the 100-year stillwater elevation and the ground elevation) of 2 to 4 feet at the site.

Condition 2 requires wave heights at the shoreline greater than 1.5 to 3.0 feet (under the 100-year flood conditions), sufficient water depth between the shoreline and the site and few, if any obstructions (buildings, dense tree stands, etc.) that may block or dampen the waves, between the shoreline and the site.

Figure 9 illustrates the relationships between the stillwater flood elevation, ground elevations, associated 1 percent annual chance (100-year) stillwater flood depths, ABFEs, and associated flood hazard zones (see Hurricane Katrina Recovery Advisory *Reconstruction Guidance Using Hurricane Katrina Surge Inundation and ABFE Maps*).

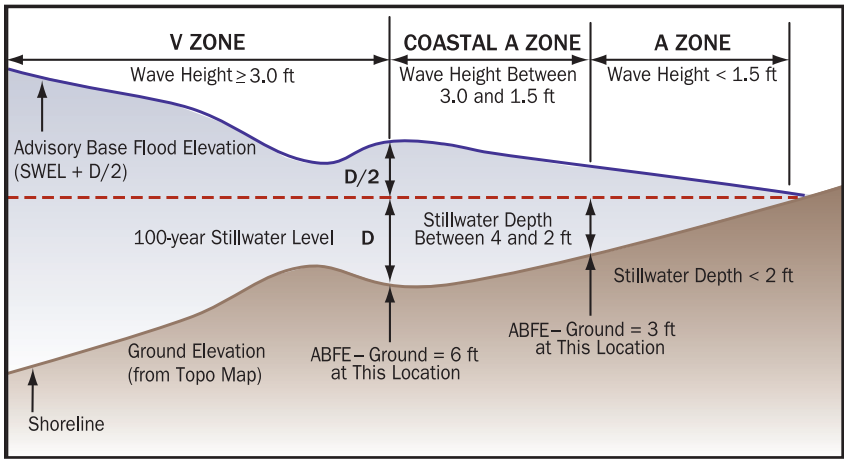


Figure 9. Cross-section showing 1 percent annual chance stillwater elevation, stillwater depth and ABFE, and inland limits of V Zone and Coastal A Zone.

Communities, designers, and owners can obtain the information necessary to make a post-Katrina Coastal A Zone determination by observing the site and its surroundings, knowing site ground elevations, and using 1 percent annual chance stillwater elevations from the Advisory Base Flood Elevation (ABFE) guidance (see Table 2). Figure 10 shows how site and surrounding conditions would influence a Coastal A Zone determination.

Table 2. Updated 1 Percent Annual Chance (100-Year) Stillwater Elevations for Use in Calculating ABFEs (see Figure 9)

County	Updated 100-year Stillwater Elevations (SWEL), (ft NGVD*)	
	Gulf of Mexico Shoreline	Back Bay Shorelines
Jackson	14	12
Harrison	18	16
Hancock	20	18

*National Geodetic Vertical Datum



Figure 10. Although the site on the left is mapped Zone AE, proximity to the Gulf of Mexico shoreline and limited obstructions to waves indicate the site could be classified as a Coastal A Zone. The site on the right is over 4,000 feet from the Gulf shoreline and over 1,000 feet from the bayou, mapped as Zone AE, and has a base flood stillwater level sufficient to support >1.5-foot wave heights – but obstructions to waves (e.g., trees and other buildings between the site and the shoreline), and distance from the sources of flooding would indicate the area is not a Coastal A Zone.

The ABC's of Returning to Flooded Buildings

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Hurricane Katrina produced widespread flooding from both storm surge and levee breaches. The combination of water intrusion and delayed re-entry due to evacuation requirements and power interruption has created a situation that demands careful planning by individuals returning to flood damaged buildings. The following tips are designed to assist impacted individuals when they are able to reach their flooded property. Additional information can be found in the Hurricane Katrina Recovery Advisory, *Initial Restoration for Flooded Buildings*.

Anticipate what you will need

- Personal protective equipment including safety shoes or boots (rubber boots may be best if you are not sure if the water has been pumped out), work gloves, eye protection, rubber gloves for cleaning or when using sanitizing chemicals, a hard hat, and respiratory protection in case there is mold or bacteria contamination (respirators with HEPA cartridges or dust masks with a rating of N-95 or higher should be used). These can be obtained from hardware stores or home improvement stores. If materials containing asbestos are suspected, it will be necessary to use a respirator with a HEPA cartridge in accordance with Federal requirements.
- Tools for entry and cleaning such as a pry bar, shovel, and a flashlight with extra batteries (Figure 1)
- Camera or video recorder for recording conditions for use in insurance claims
- Hand and face cleaning supplies such as alcohol swabs or hand sanitizer gel
- Cleaning supplies for salvagable materials including potable water, chemical cleaners/sanitizers, sponges, buckets, and wiping rags
- Packing supplies to protect fragile salvaged items during transport
- First aid kit
- Pen and paper, tape, scissors, and small plastic storage bags for writing down serial numbers and saving samples of discarded materials to support insurance claims



Figure 1. Tools for entry and cleaning

Be realistic about your limitations

- Even initial assessment and salvage can be hot, heavy work.
- If at all possible, work with another person while in the house. Unforeseen hazards can exist, so having help nearby is prudent.
- Avoid entry, even with personal protective equipment, if you have serious pre-existing health issues:
  - Asthma/allergies
  - Heart problems
  - Compromised immune system
  - Open cuts or wounds
- Get help moving large items such as furniture and appliances.
- Do not underestimate the impact of psychological shock and physical effort:
  - Identify someone in advance who you can talk to about your situation and feelings
  - See the resource section for some potential contacts

Check the situation for hazards

- Downed power lines
- Gas leaks
- Evidence of structural damage such as sagging ceilings, large wall or floor cracks, walls out of plumb, etc.
- Unstable materials
    - Furniture and even vehicles can be stacked in hazardous positions (Figure 2)
- Chemical spills
    - Paints, solvents, lawn fertilizers, pesticides
- Vermin such as snakes, rats, fire ants, bee colonies, etc.
- Other hazards
    - Rotting food
    - Dead animals



Figure 2. Furniture stacked by flood waters creates a safety hazard.

Document conditions

- Photos or videos are best
    - Shoot multiple pictures of each room from different corners
    - Make sure the photos will be clear before changing the conditions
    - Use a camera with a time/date stamp for photos if possible
- Make written notes of the dates that you were at the building
- Save samples of high-quality contents such as carpets to support insurance claims

Extract the salvageable items

- Focus on high value items that were not water impacted and items that have special significance. If an entire item cannot be saved, consider parts that could be saved. For example, if a family heirloom such as an antique chest cannot be saved, consider saving the non-porous handles or hinges for use on a replacement piece.
- Porous items that were not water logged or moldy should be the second priority.
- Non-porous items such as glassware, silverware, and plastic furniture that need to be cleaned should be separated. (Note: Contaminated items should be cleaned on site if possible. Transporting wet/contaminated items presents the risk of cross contamination of the vehicle and location where the item is moved.)
- Be aware of termites. If a termite infestation is found, consult a professional exterminator. When discarding or salvaging wood, paper, and other cellulose, protect your property and keep Formosan subterranean termites from spreading. For additional information, refer to the Louisiana Ag Center. *(http://www.louisianafloods.org/en/family_home/hazards_and_threats/recovery_assistance/insect_pest_management/Keeping+Formosan+Termites+from+Spreading+after+Hurricanes.htm)*

Facilitate restoration

- Do what you can to salvage the contents on the property.
- See American Red Cross, *Repairing Your Flooded Home*, *http://www.redcross.org/services/disaster/0,1082,0_570_,00.html*

Get help

- The following resources may be useful in providing technical support during your recovery from a flooding event:
    - American Red Cross (*http://www.redcross.org*)
    - FEMA (*http://www.fema.gov*)
    - Association of Specialists in Cleaning & Restoration (*http://www.ascr.org*)
    - Louisiana State University AgCenter - Cooperative Extension Service (*http://www.LouisianaFloods.org*)
    - National Association of Home Builders (*http://www.nahb.org/category.aspx?sectionID=843*)
    - National Association of the Remodeling Industry (*http://www.nari.org*)
- The following resources may be useful in providing financial and/or psychological support during your recovery from a flooding event:
    - American Red Cross (*http://www.redcross.org*)
    - Salvation Army (*http://www.salvationarmyusa.org/usn/www_usn.nsf*)
    - FEMA (*http://www.fema.gov*)
    - Small Business Administration (*http://www.sba.gov*)
    - State/local health departments - such as the North Carolina Department of Health and Human Services (*http://www.dhhs.state.nc.us/docs/hurricaneoccupant.htm*)

Attachment of Brick Veneer in High-Wind Regions

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To recommend practices for installing brick veneer that will enhance wind resistance in high-wind areas.

Key Issues

- Brick veneer is frequently blown off walls of residential and commercial buildings (Figure 1). When brick veneer fails, wind-driven water can enter and damage buildings, and building occupants can be vulnerable to injury from windborne debris (particularly if walls are sheathed with plastic foam insulation or wood fiberboard in lieu of wood panels). Pedestrians in the vicinity of damaged walls can also be vulnerable to injury from falling veneer (Figure 2).
- Common failure modes include tie (anchor) fastener pull-out (Figure 3), failure of masons to embed ties into the mortar (Figure 4), poor bonding between ties and mortar and mortar of poor quality (Figure 5), and tie corrosion (Figure 6).
- Ties are often installed before brick laying begins. When this is done, ties are often improperly placed above or below the mortar joints. When misaligned, the ties must be angled up or down in order for the ties to be embedded into the mortar joints (Figure 7). Misalignment not only reduces embedment depth but also reduces the effectiveness of the ties because wind forces do not act parallel to the ties themselves.
- Corrugated ties typically used in residential veneer construction provide little resistance to compressive loads. Use of compression struts would likely be beneficial, but off-the-shelf devices do not currently exist. Two-piece adjustable ties (Figure 8) provide significantly greater compressive strength than corrugated ties.



Figure 1. Failed brick veneer. Plastic foam wall sheathing was installed over the wood studs (plywood was temporarily installed after the brick failure).



Figure 2. The upper portion of the brick veneer at this apartment building collapsed. Pedestrian and vehicular traffic in the vicinity of the damaged wall were vulnerable to injury and damage if remaining portions of the wall were to collapse during subsequent storms.



Figure 3. This tie remained embedded in the mortar joint while the smooth-shank nail pulled from the stud.

- Many buildings that exhibited damaged veneer were not in compliance with current building codes. Building code requirements for brick veneer have changed over the years. Model codes prior to 1995 permitted brick veneer in any location, with no wind speed restrictions. Wall area per tie in some model codes was greater than the current maximum. The current masonry code referenced in model building codes, Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402 (ACI 530) addresses brick veneer in two manners: rational design and prescriptive requirements. Essentially all brick veneer in residential and low-rise construction follows the prescriptive requirements. The first edition of American Concrete Institute's (ACI's) 530 limited the use of prescriptive design to areas with a basic wind speed of 110 mph or less. The 2005 edition of ACI 530 extended the prescriptive requirements to include a basic wind speed of 130 mph, with lower area per tie limits. In locations with a basic wind speed above 130 mph, the rational design approach must be used. Compliance with ACI 530-05 should reduce wind damage.
- The following Brick Industry Association (BIA) Technical Notes provide guidance on brick veneer: Technical Notes 28 – Anchored Brick Veneer, Wood Frame Construction, Technical Notes 28B – Brick Veneer/Steel Stud Walls, and Technical Notes 44B – Wall Ties (available online at www.bia.org). These Technical Notes provide attachment recommendations, but the recommendations are not specific for high-wind regions and are, therefore, inadequate.

Construction Guidance

The brick veneer wall system is complex in its behavior. There are limited test data on which to draw. The following guidance is based on professional judgment, wind loads specified in ASCE 7-02 "Design Loads for Buildings and Other Structures," fastener strengths specified in the American Forest and Paper Association's (AF&PA's) National Design Specification for Wood Construction, and brick veneer standards contained in ACI 530-05. In addition to the general guidance given in BIA Technical Notes 28 and 28B, the following are recommended:

Note: In areas that are also susceptible to high seismic loads, brick veneer should be evaluated by an engineer to ensure it can resist seismic and wind design loads.

Stud Spacing: For new construction, space studs 16" on center, so that ties can be anchored at this spacing.



Figure 4. These four ties were never embedded into the mortar joint.



Figure 5. This tie was embedded in the mortar, but the bond was poor.



Figure 6. There were several ties in this portion of the wall, but they failed due to severe corrosion.

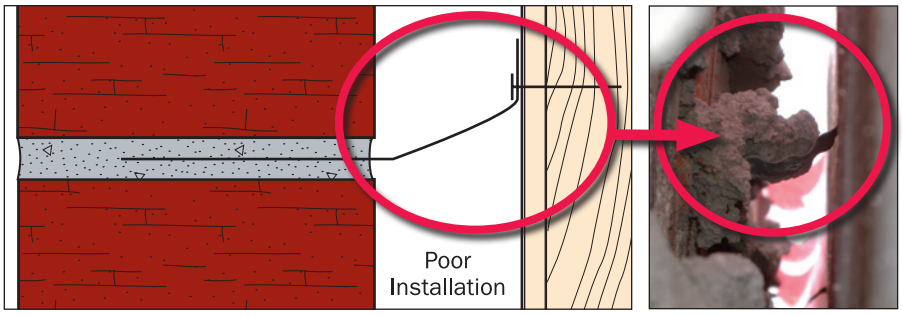


Figure 7. Misalignment of the tie reduces the embedment and promotes veneer failure.

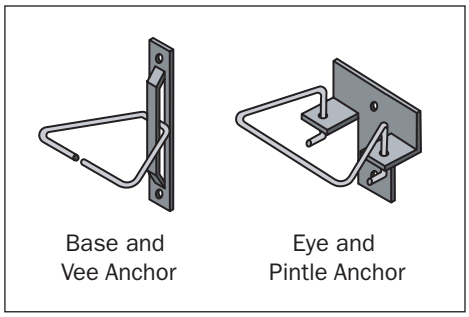


Figure 8. Examples of two-piece adjustable ties

Tie Fasteners: Ring-shank nails are recommended in lieu of smooth-shank nails. A minimum embedment of 2" is suggested.

Ties: For use with wood studs: two-piece adjustable ties are recommended. However, where corrugated steel ties are used, use 22-gauge minimum, 7/8" wide by 6" long, complying with ASTM A 366 with a zinc coating complying with ASTM A 153 Class B2. For ties for use with steel studs, see BIA "Technical Notes 28B – Brick Veneer/Steel Stud Walls." Stainless steel ties should be used in areas within 3,000 feet of the coast.

Tie Installation

- Install ties as the brick is laid so that the ties are properly aligned with the mortar joints.
- Install brick ties spaced per Table 1. Studs should be installed at 16" spacing. Veneer tie locations for 24" stud spacing are included for repairing damaged veneer on existing buildings with the wider stud spacing.
- Locate ties within 8" of door and window openings and within 12" of the top of veneer sections.
- Bend the ties at a 90-degree angle at the nail head in order to minimize tie flexing when the ties are loaded in tension or compression (Figure 9).
- Embed ties in joints so that mortar completely encapsulates the ties. Embed a minimum of 1.5" into the bed joint, with a minimum mortar cover of 5/8" to the outside face of the wall (Figure 10).

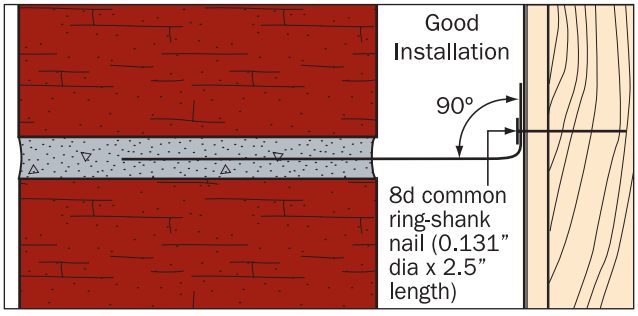


Figure 9. Bend ties at nail heads

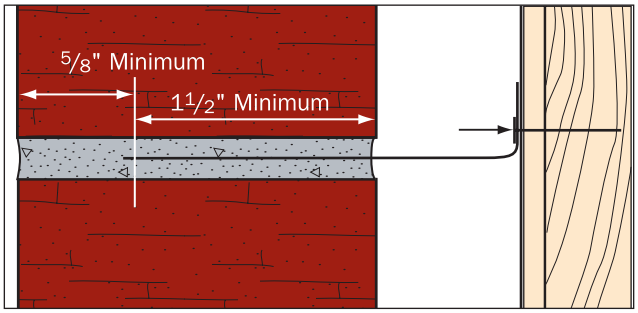


Figure 10. Tie embedment

Table 1. Brick Veneer Tie Spacing

Wind Speed (mph) (3-Second Peak Gust)	Wind Pressure (psf)	Maximum Vertical Spacing for Ties	
		16" stud spacing	24" stud spacing
90	17.8	18.0[a]	16.0[a]
100	22.0	18.0[a]	16.0[a]
110	26.6	18.0[a]	14.8
120	31.6	18.0[a]	NA[b]
130	37.1	15.9	NA[b]
140	43.0	13.7	NA[b]
150	49.4	10.2	NA[b]

Notes:

1. The tie spacing is based on wind loads derived from Method 1 of ASCE 7-02, for the corner area of buildings up to 30' high, located in Exposure B with an importance factor (I) of 1.0 and no topographic influence. For other heights, exposure, or importance factor, an engineered design is recommended.
2. Fastener strength is for wall framing with a Specific Gravity G=0.55 with moisture contents less than 19% and the following adjustment factors, Ct=0.8; and CD, CM, Ceg, and Ctn=1.0.
3. Nail embedment depth of 2" for 2.5" long 8d common (0.131" diameter) ring-shank fasteners

[a] Maximum spacing allowed by ACI 530-05

[b] 24" stud spacing exceeds the maximum horizontal tie spacing of ACI 530-05 prescribed for wind speeds over 100 mph

Attachment of Rooftop Equipment in High-Wind Regions

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To recommend practices for designing and installing rooftop equipment that will enhance wind resistance in high-wind regions.

> **Note:** For attachment of lightning protection systems, see Hurricane Katrina Recovery Advisory on Rooftop Attachment of Lightning Protection Systems in High-Wind Regions.

Key Issues

Rooftop equipment frequently becomes detached from rooftops during hurricanes. Water can enter the building at displaced equipment (see Figure 1); displaced equipment can puncture and tear roof coverings (thus allowing water to leak into the building). Equipment blown from a roof can damage buildings and injure people. Damaged equipment may no longer provide service to the building.



Figure 1. This gooseneck was attached with only two small screws. A substantial amount of water was able to enter the building during the hurricane.

Construction Guidance

Mechanical Penthouse: By placing equipment in mechanical penthouses rather than being exposed on the roof, equipment within penthouses is shielded from high-wind loads and windborne debris (see Figure 2). Therefore, use of mechanical penthouses designed and constructed in accordance with a current building code are recommended, particularly for critical and essential facilities.

Design Loads and Safety Factors: Loads on rooftop equipment should be determined in accordance with the 2005 edition of ASCE 7.

Note: For guidance on load calculations, see "Calculating Wind Loads and Anchorage Requirements for Rooftop Equipment," ASHRAE Journal, volume 48, number 3, March 2006.

A minimum safety factor of 3 is recommended for critical and essential facilities, and a minimum safety factor of 2 is recommended for other buildings. Loads and resistance should also be calculated for heavy pieces of equipment (see Figure 2).



Figure 2. This 30' x 10' x 8' 18,000-pound HVAC unit was attached to its curb with 16 straps (one screw per strap). Although the wind speeds were estimated to be only 85 to 95 miles per hour (3-second peak gust), it blew off the building.

Simplified Attachment Table: To anchor fans, small HVAC units, and relief air hoods, the following minimum attachment schedule is recommended (see Table 1) (note: the attachment of the curb to the roof deck also needs to be designed to resist the design loads):

Table 1. Number of #12 Screws for Base Case Attachment of Rooftop Equipment

Case No.	Curb Size and Equipment Type	Equipment Attachment	Fastener Factor for Each Side of Curb or Flange
1	12"x 12" Curb with Gooseneck Relief Air Hood	Hood Screwed to Curb	1.6
2	12"x 12" Gooseneck Relief Air Hood with Flange	Flange Screwed to 22 Gauge Steel Roof Deck	2.8
3	12"x 12" Gooseneck Relief Air Hood with Flange	Flange Screwed to 15/32" OSB Roof Deck	2.9
4	24"x 24" Curb with Gooseneck Relief Air Hood	Hood Screwed to Curb	4.6
5	24"x 24" Gooseneck Relief Air Hood with Flange	Flange Screwed to 22 Gauge Steel Roof Deck	8.1
6	24"x 24" Gooseneck Relief Air Hood with Flange	Flange Screwed to 15/32" OSB Roof Deck	8.2
7	24"x 24" Curb with Exhaust Fan	Fan Screwed to Curb	2.5
8	36"x 36" Curb with Exhaust Fan	Fan Screwed to Curb	3.3
9	5'-9"x 3'- 8" Curb with 2'- 8" high HVAC Unit	HVAC Unit Screwed to Curb	4.5*
10	5'-9"x 3'- 8" Curb with 2'- 8" high Relief Air Hood	Hood Screwed to Curb	35.6*

Notes to Table:

1. The loads are based on the 2005 edition of ASCE 7. The resistance includes equipment weight.

2. The Base Case of the tabulated numbers of #12 screws (or ¼ pan-head screws for flange-attachment) is a 90-mph basic wind speed, 1.15 importance factor, 30' building height, Exposure C, using a safety factor of 3.

3. For other basic wind speeds, or for an importance factor of 1, multiply the tabulated number of #12 screws by $\left(\frac{V_D^2 \times I}{90^2 \times 1.15}\right)$ to determine the required number of #12 screws or (¼ pan-head screws) required for the desired basic wind speed, V_D (mph) and importance factor, I.

4. For other roof heights up to 200', multiply the tabulated number of #12 screws by (1.00 + 0.003 [h - 30]) to determine the required number of #12 screws or ¼ pan-head screws for buildings between 30' and 200'.

Example A: 24" x 24" exhaust fan screwed to curb (table row 7), Base Case conditions (see Note 1): 2.5 screws per side; therefore, round up and specify 3 screws per side.

Example B: 24" x 24" exhaust fan screwed to curb (table row 7), Base Case conditions, except 120 mph and importance factor of 1: 120^2 x 1 ÷ 90^2 x 1.15 = 1.55 x 2.5 screws per side = 3.86 screws per side; therefore, round up and specify 4 screws per side.

Example C: 24" x 24" exhaust fan screwed to curb (table row 7), Base Case conditions, except 150' roof height: 1.00 + 0.003 (150' - 30') = 1.00 + 0.36 = 1.36 x 2.5 screws per side = 3.4 screws per side; therefore, round down and specify 3 screws per side.

* This factor only applies to the long sides. At the short sides, use the fastener spacing used at the long sides.

Fan Cowling Attachment: Fans are frequently blown off their curbs because they are poorly attached. When fans are well attached, the cowlings frequently blow off (see Figure 3). Unless the fan manufacturer specifically engineered the cowling attachment to resist the design wind load, cable tie-downs (see Figure 4) are recommended to avoid cowling blow-off. For fan cowlings less than 4 feet in diameter, 1/8-inch diameter stainless steel cables are recommended.



Figure 3. Cowlings blew off two of the three fans shown in this photo. Cowlings can tear roof membranes and break glazing.



Figure 4. To overcome blow-off of the fan cowling, this cowling was attached to the curb with cables.

For larger cowlings, use 3/16-inch diameter cables. When the basic wind speed is 120 mph or less, specify two cables. Where the basic wind speed is greater than 120 mph, specify four cables. To minimize leakage potential at the anchor point, it is recommended that the cables be adequately anchored to the equipment curb (rather than anchored to the roof deck). The attachment of the curb itself also needs to be designed and specified.

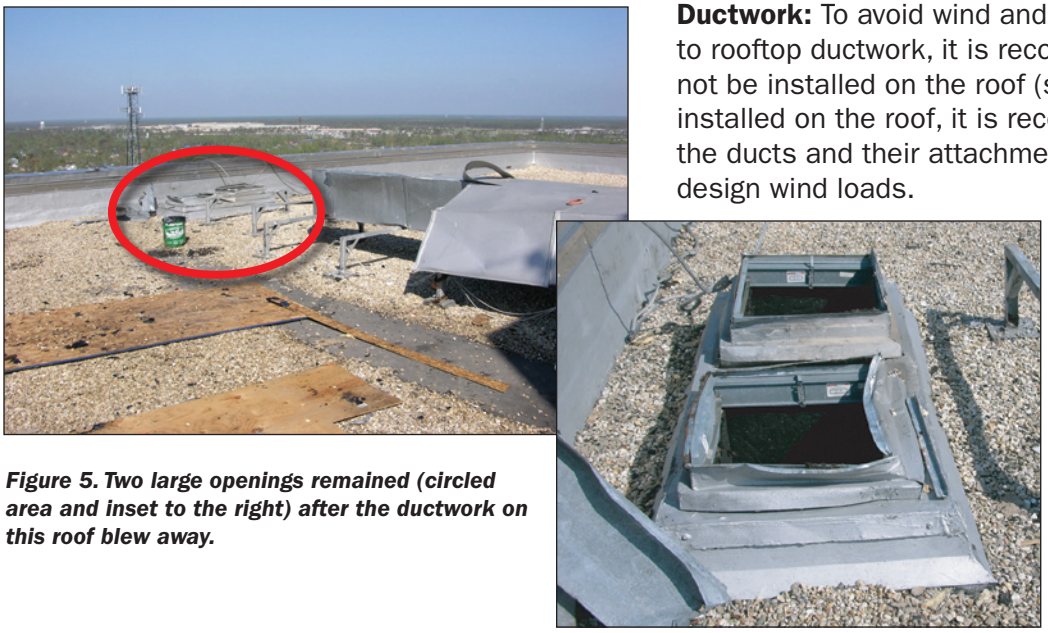


Figure 5. Two large openings remained (circled area and inset to the right) after the ductwork on this roof blew away.

Ductwork: To avoid wind and windborne debris damage to rooftop ductwork, it is recommended that ductwork not be installed on the roof (see Figure 5). If ductwork is installed on the roof, it is recommended that the gauge of the ducts and their attachment be sufficient to resist the design wind loads.

Condensers: In lieu of placing rooftop-mounted condensers on wood sleepers resting on the roof (see Figure 6), it is recommended that condensers be anchored to equipment stands. (Note: the attachment of the stand to the roof deck also needs to be designed to resist the design loads.) In addition to anchoring the base of the condenser to the stand, two metal straps with two side-by-side #14 screws or bolts at each strap end are recommended (see Figure 7).



Figure 6. Sleeper-mounted condensers displaced by high winds.

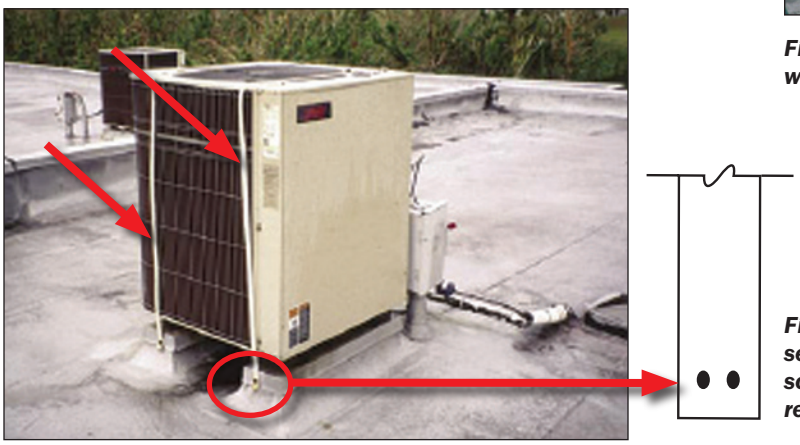


Figure 7. This condenser had supplemental securement straps (see arrows). Two side-by-side screws with the proper edge and end distances are recommended at the end of the strap.

Vibration Isolators: When equipment is mounted on vibration isolators, an isolator that has sufficient resistance to meet the design uplift loads should be specified and installed, or an alternative means to accommodate uplift resistance should be provided (see Figure 8).

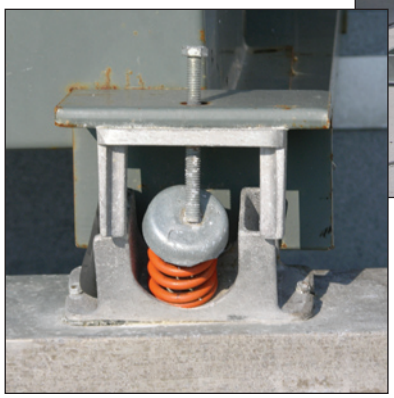




Figure 8. The equipment on this stand was resting on vibration isolators that provided lateral resistance but no uplift resistance (above). A damaged vibration isolator is shown in the inset (left).

Access Panel Attachment: Access panels frequently blow off. To minimize blow-off of access panels, job-site modification will typically be necessary (for example, the attachment of hasps and locking devices such as a carabiner). The modification details will need to be tailored for the equipment, which may necessitate detail design after the equipment has been delivered to the job site. Modification details should be approved by the equipment manufacturer.



Figure 9. Several of the equipment screen panels were blown away. Loose panels can break glazing and puncture roof membranes.

Equipment Screens: Equipment screens around rooftop equipment are frequently blown away (see Figure 9). Equipment screens should be designed to resist the wind loads derived from ASCE 7.

Note: The extent that screens may reduce or increase wind loads on equipment is unknown. Therefore, the equipment behind screens should be designed to resist the loads previously noted.

Other resources: Three publications pertaining to seismic restraint of equipment provide general information on fasteners and edge distances:

- Installing Seismic Restraints for Mechanical Equipment (FEMA 412)
- Installing Seismic Restraints for Electrical Equipment (FEMA 413)
- Installing Seismic Restraints for Duct and Pipe (FEMA 414)

Rooftop Attachment of Lightning Protection Systems in High-Wind Regions

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To recommend practices for installing lightning protection systems (LPS) that will enhance wind resistance in high-wind regions.

Key Issues

- Lightning protection systems frequently become disconnected from rooftops during hurricanes. Displaced LPS components can puncture and tear roof coverings, thus allowing water to leak into buildings (see Figures 1 and 2). Also, when displaced, the LPS is no longer capable of providing lightning protection in the vicinity of the displaced conductors ("cables") and air terminals ("lightning rods").
- Lightning protection standards such as NFPA 780 and UL 96A currently provide inadequate guidance for attachment of LPS to rooftops in high-wind regions.
- Some LPS manufacturers provide guidance for attachment, while other manufacturers refer to the roofing material manufacturer for attachment guidance. Some roofing material manufacturers provide guidance for attachment, while other manufacturers refer to the LPS manufacturer for attachment guidance. In most cases, the attachment guidance provided by LPS and roofing material manufacturers is inadequate for hurricane-prone regions.
- LPS conductors are typically attached to the roof at 3 foot intervals. Because the conductors are flexible, when they are exposed to high winds, the conductors exert dynamic loads on the conductor connectors ("clips"). Guidance for calculating the dynamic loads does not exist. The attachment guidance that follows is therefore based on professional judgment.
- LPS conductor connectors typically have prongs to anchor the conductor. When the connector is well-attached to the roof surface, during high winds the conductor frequently bends back the malleable connector prongs (see Figure 3). Conductor connectors have also debonded from roof surfaces during high winds. Based on observations after Hurricane Katrina and other hurricanes, it is apparent that pronged conductor connectors do not provide reliable attachment.



Figure 1. This displaced air terminal punctured the membrane in several locations.



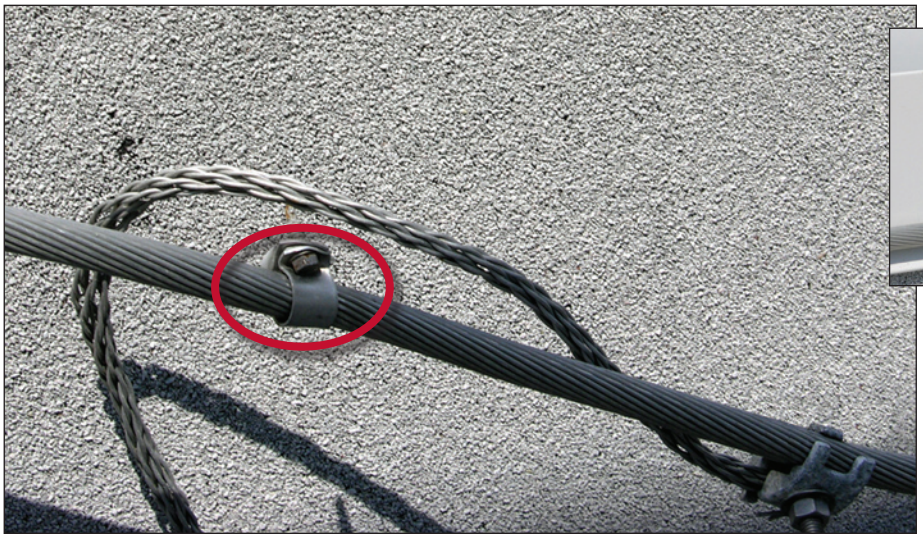
Figure 2. View of an abraded end of a conductor that became disconnected.



Figure 3. During high winds, the conductor deformed the prongs and pulled away from this conductor connector.

Construction Guidance

Parapet attachment: When the parapet is 12-inch high or greater, it is recommended that the air terminal base plates and conductor connectors be mechanically attached with #12 screws that have 1.25 inch minimum embedment into the inside face of the parapet nailer and properly sealed for watertight protection. In lieu of conductor connectors that have prongs, it is recommended that mechanically attached looped connectors be installed (see Figure 4).



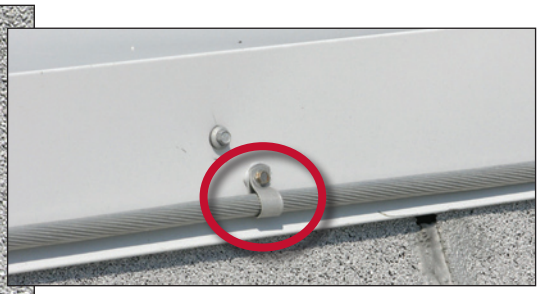


Figure 4. This conductor was attached to the coping with a looped connector (above). However, a gasket was not installed between the connector and the coping. Also, because the connector screws were too short to engage the wood nailer, the screws pulled out and the conductor was displaced in some areas (figure at left).

Attachment to built-up, modified bitumen and single-ply membranes: For built-up and modified bitumen membranes, attach air terminal base plates with asphalt roof cement. For single-ply membranes, attach air terminal base plates with pourable sealer (type recommended by the membrane manufacturer).

In lieu of attaching conductors with conductor connectors, it is recommended that conductors be attached with strips of membrane installed by the roofing contractor. For built-up and modified bitumen membranes, use strips of modified bitumen cap sheet, approximately 9-inch wide minimum. If strips are torch-applied, avoid overheating the conductors. For single-ply membranes, use self-adhering flashing strips, approximately 9” wide minimum. Start the strips approximately 3 inches from either side of the air terminal base plates. Place strips that are approximately 3’ long, followed by a gap of approximately 3 inches (see Figure 5).

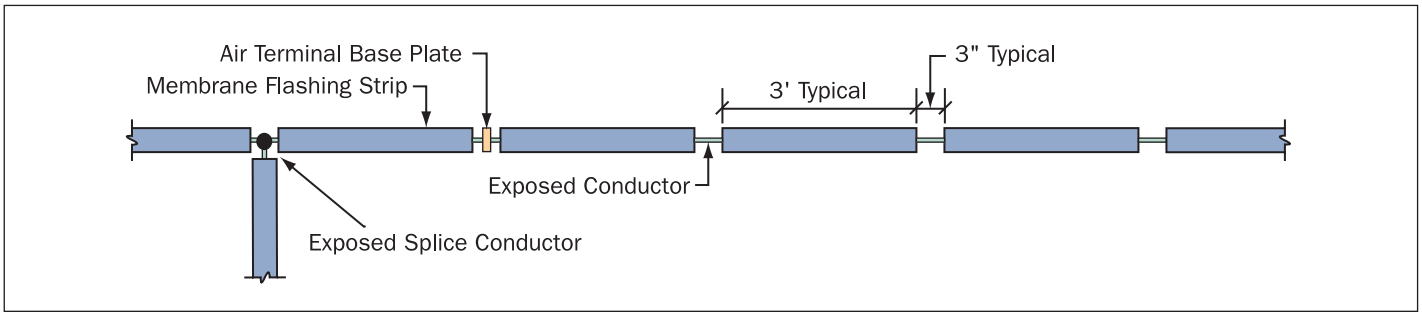


Figure 5. Plan showing conductor attachment.

Note: As an option to securing the conductors with stripping plies, conductor connectors that do not rely on prongs (such as the one shown in Figure 6) could be used. However, because the magnitude of the dynamic loads induced by the conductor are unknown and because of the lack of data on the resistance provided by adhesively-attached connectors, attachment with stripping plies is the preferred option because the stripping plies shield the conductor from the wind.

If adhesive-applied conductor connectors are used, it is recommended that they be spaced more closely than the 3 foot spacing required by NFPA 780 and UL 96A. Depending upon wind loads, spacings in the range of 6 to 12 inches on center may be needed in the corner regions of the roof, with spacings in the range of 12 to 18 inches on center at roof perimeters (see ASCE 7 for size of corner regions).

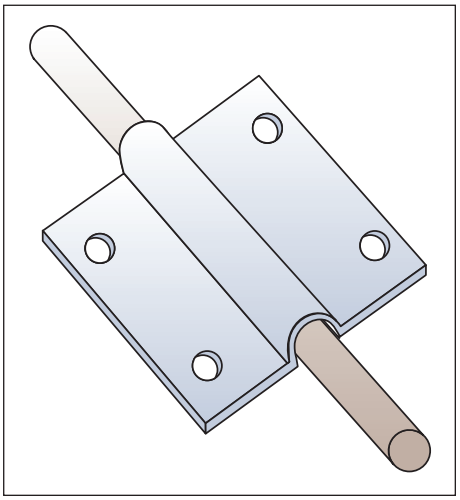


Figure 6. Adhesively-attached conductor connector that does not use prongs.



Figure 7. A failed prong-type splice connector. If conductors become detached from the roof, they are likely to pull from pronged splice connectors.



Figure 8. To avoid free ends of connectors being whipped around by wind, bolted splice connectors are recommended because they provide a more reliable connection.

Mechanically Attached Single-Ply Membranes: It is recommended that conductors be placed parallel and within 8 inches of membrane fastener rows. Where the conductor falls between or is perpendicular to membrane fastener rows, install an additional row of membrane fasteners where the conductor will be located and install a membrane cover-strip over the membrane fasteners. Place the conductor over the cover-strip and secure the conductor as recommended above.

Note: By following the above recommendations, additional rows of membrane fasteners beyond those needed to attach the membrane may be needed to accommodate layout of the conductors. The additional membrane fasteners and cover-strip should be coordinated with and installed by the roofing contractor.

Standing Seam Metal Roofs: It is recommended that pre-manufactured mechanically attached clips that are commonly used to attach various items to roof panels be used. After anchoring the clips to the panel ribs, the air terminal base plates and conductor connectors are anchored to the panel clips. In lieu of conductor connectors that have prongs, it is recommended that mechanically attached looped connectors be installed.

Conductor Splice Connectors: In lieu of pronged splice connectors (see Figure 7), bolted splice connectors are recommended (see Figure 8). It is recommended that strips of flashing membrane (as recommended above) be placed approximately 3 inches from either side of the splice connector to minimize conductor movement and avoid the possibility of the conductors from becoming disconnected. To allow for observation during maintenance inspections, do not cover the connectors.

Periodic Inspection and Maintenance: Each spring, it is recommended that the lightning protection system be inspected to verify that connectors are still attached to the roof surface and still engage the conductors. Also check to ensure that splice connectors are still secure. Inspections are also recommended after high wind events.

Strengthening Attachment of Existing Systems: On critically important buildings that use adhesively-attached connectors and pronged splice connectors, it is recommended that attachment modifications based on the Construction Guidance be made in order to provide more reliable securement.

Designing for Flood Levels Above the BFE

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To recommend design and construction practices that reduce the likelihood of flood damage in the event that flood levels exceed the Base Flood Elevation (BFE).

Key Issues

- BFEs are established at a flood level, including wave effects, that has a 1-percent chance of being equaled or exceeded in any given year, also known as the 100-year flood or base flood. Floods more severe and less frequent than the 1-percent flood can occur in any year.
- Flood levels during some recent storms have exceeded BFEs depicted on the Flood Insurance Rate Maps (FIRMs), sometimes by several feet (see Figure 1). In many communities, flooding extended inland, well beyond the 100-year floodplain (Special Flood Hazard Area (SFHA)) shown on the FIRM (see Figure 2).
- Flood damage increases rapidly once the elevation of the flood extends above the lowest floor of a building, especially in areas subject to coastal waves. In a V Zone, a coastal flood with a wave crest 3 to 4 feet above the bottom of the floor beam (approximately 1 to 2 feet above the walking surface of the floor) will be sufficient to substantially damage or destroy most light-framed residential and commercial construction (see Figure 4).
- There are design and construction practices that can eliminate or minimize damage to buildings when flood levels exceed the BFE. The most common approach is to add freeboard to the design (i.e., to elevate the building higher than required by the FIRM).

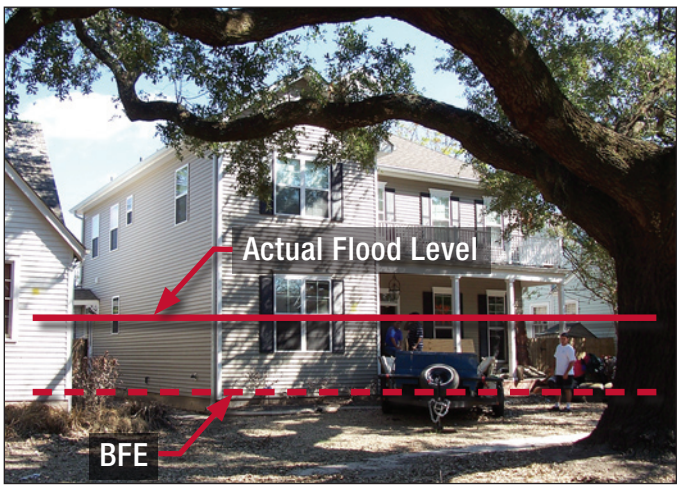


Figure 1. Levee failures and overtopping during Hurricanes Katrina and Rita (2005) resulted in flood levels (solid red line) several feet above the BFE (dashed red line) over large portions of the greater New Orleans area.

Figure 2. Map showing storm surge inundation by Hurricane Katrina at Long Beach (blue shading). Katrina flooding extended beyond the limits of the mapped 100-year floodplain (SFHA) (photo source: NOAA).



- There are other benefits of designing for flood levels above the BFE: reduced building damage and maintenance: longer building life; reduced flood insurance premiums; reduced displacement and dislocation of building occupants after floods (and need for temporary shelter and assistance); reduced job loss; and increased retention of tax base.

Flood Insurance Rate Maps and Flood Risk

Hurricanes Ivan (2004) and Katrina (2005) have demonstrated that constructing a building to the minimum National Flood Insurance Program (NFIP) requirements – or constructing a building outside the SFHA shown on the FIRMs – is no guarantee that the building will not be damaged by flooding. This is due to two factors: 1) flooding more severe than the base flood occurs, and 2) some FIRMs, particularly older FIRMs, may no longer depict the true base flood level and SFHA boundary.

The black line in Figure 3 shows the probability that the level of the flood will exceed the 100-year flood level during time periods between 1 year and 100 years; there is an 18-percent chance that the 100-year flood level will be exceeded in 20 years, a 39-percent chance it will be exceeded in 50 years, and a 51-percent chance it will be exceeded in 70 years. As the time period increases, the likelihood that the 100-year flood will be exceeded also increases.

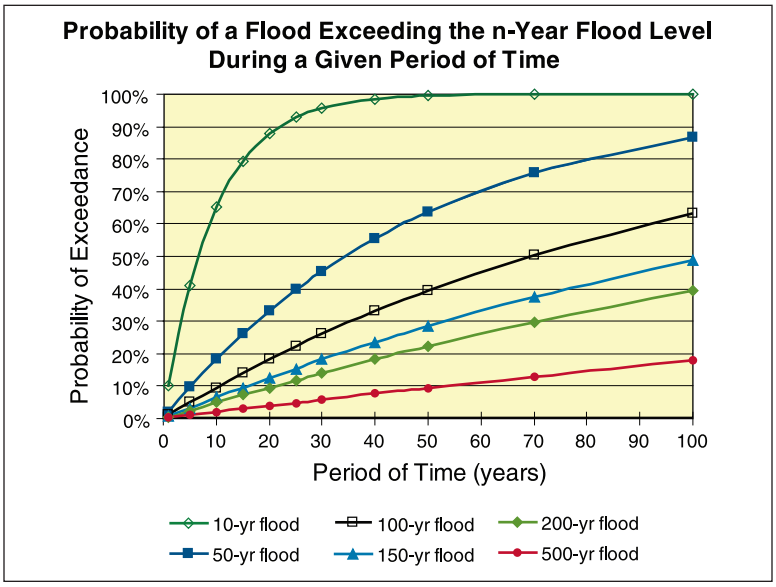


Figure 3. Probability that a flood will exceed the n-year flood level over a given period of time (Note: this analysis assumes no shoreline erosion, and no increase in sea level or storm frequency/severity over time).

Figure 3 also shows the probabilities that floods of other severities will be exceeded. For example, taking a 30-year time period where there is a 26-percent chance that the 100-year flood level will be exceeded, there is an 18-percent chance that the 150-year flood will be exceeded, a 14-percent chance that the 200-year flood will be exceeded, and a 6-percent chance that a flood more severe than the 500-year flood will occur.

FIRMs depict the limits of flooding, flood elevations, and flood hazard zones during the base flood. As seen in Figure 3, buildings elevated only to the BFEs shown on the FIRMs have a significant chance of being flooded over a period of decades. Users should also be aware that the flood limits, flood elevations, and flood hazard zones shown on the FIRM reflect ground elevations, development, and flood conditions at the time of the Flood Insurance Study (FIS).[1]

Consequences of Flood Levels Exceeding the BFE

Buildings are designed to resist most environmental hazards (e.g., wind, seismic, snow, etc.), but are generally designed to avoid flooding by elevating the building above the anticipated flood elevation. The difference in design approach is a result of the sudden onset of damage when a flood exceeds the lowest floor elevation of a building. Unlike wind – where exposure to a wind speed slightly above the design speed does not generally lead to severe building damage – occurrence of a flood level even a few inches above the lowest floor elevation generally leads to significant flood damage, therefore, the recommendation to add freeboard.

This is especially true in cases where waves accompany coastal flooding. Figure 4 illustrates the expected flood damage (expressed as a percent of a building's pre-damage market value) versus flood depth above the bottom of the lowest

FIRMs do not account for the following:

- Shoreline erosion, wetland loss, subsidence, and relative sea level rise
- Upland development or topographic changes
- Degradation or settlement of levees and floodwalls
- Changes in storm climatology (frequency and severity)
- The effects of multiple storm events

Thus, what was once an accurate depiction of the 100-year floodplain and flood elevations may no longer be so.

[1] Sections 7.8.1.3 and 7.9 of FEMA's *Coastal Construction Manual* (FEMA 55, 2000 ed.) provide guidance on evaluating a FIRM to determine whether it still provides an accurate depiction of base flood conditions, or whether it is obsolete.

horizontal structural member supporting the lowest floor (e.g., bottom of the floor beam), for a V Zone building and for a riverine A Zone building.[2]

One striking difference between the two curves is that a V Zone flood depth (wave crest elevation) 3 to 4 feet above the bottom of the floor beam (or approximately 1 to 2 feet above the top of the floor) is sufficient to cause substantial (>50 percent) damage to a building. In contrast, A Zone riverine flooding (without waves and high velocity) can submerge a structure without causing substantial damage. This difference in building damage is a direct result of the energy contained in coastal waves striking buildings – something obvious to those who saw the wave damage that Hurricane Katrina caused in Mississippi and Louisiana (see Figure 5).

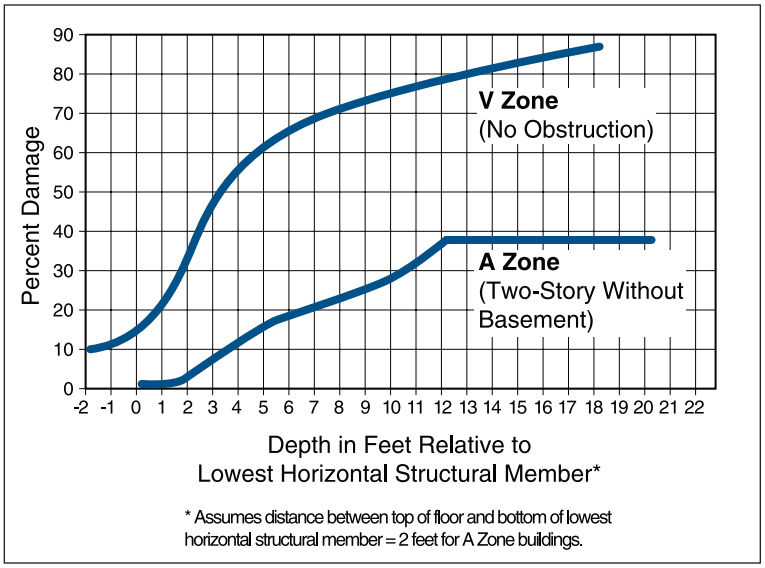


Figure 4. Flood depth versus building damage curves for V Zones and riverine A Zones (Source: FEMA 55, Coastal Construction Manual).



Figure 5. Hurricane Katrina damage to buildings in coastal Mississippi. The upper left, upper right, and lower left photos are of buildings that were close to the Gulf shoreline and subjected to storm surge above the floor and large waves striking the building walls. The lower right photo is of a building almost 1 mile from the Gulf, and subjected to storm surge flooding only.

[2] Since the normal floor reference for A Zone buildings is the top of the lowest floor, the A Zone curve was shifted for comparison with the V Zone curve.

In cases where buildings are situated behind levees, a levee failure can result in rapid flooding of the area. Buildings near a levee breach may be exposed to high velocity flows, and damages to those buildings will likely be characterized by the V Zone damage curve in Figure 4. Damages to buildings farther away from the breach will be a result of inundation by floodwaters, and will likely resemble the A Zone curve in Figure 4.

General Recommendations

The goal of this Advisory is to provide methods to minimize damage to buildings in the event that coastal flood levels rise above the BFE. Achieving this goal will require adherence to one or more of the following general recommendations:

- **In all areas where flooding is a concern**, inside and outside the SFHA, **elevate the lowest floor so that the bottom of the lowest horizontal structural member is at or above the Design Flood Elevation (DFE).** Do not place the top of the lowest floor at the DFE, since this guarantees flood damage to wood floor systems, wood floors, floor coverings, and lower walls during the design flood, and may lead to mold/contamination damage (see Figure 6).
- **In flood Zones V and A,** use a DFE that results in **freeboard** (elevate the lowest floor above the BFE) (see Figure 7).
- In flood Zones V and A, **calculate design loads and conditions** (hydrostatic loads, hydrodynamic loads, wave loads, floating debris loads, and erosion and scour) under the assumption that the flood level will exceed the BFE.
- In an **A Zone subject to waves and erosion** (i.e., a Coastal A Zone), use a pile or column foundation (see Figure 7).
- Outside the SFHA (in **flood Zones B, C, and X**), **adopt flood-resistant design and construction practices** if historical evidence or a review of the available flood data shows the building could be damaged by a flood more severe than the base flood (see Figure 8).
- **Design and construct buildings using the latest model building code, ASCE 7-05** *Minimum Design Loads for Buildings and Other Structures* and **ASCE 24-05** *Standard for Flood Resistant Design and Construction*.
- **Follow the recommendations in FEMA 499,** *Home Builder's Guide to Coastal Construction Technical Fact Sheets* Series (available at http://www.fema.gov/rebuild/mat/mat_fema499.shtm).
- **Use the pre-engineered foundations shown in FEMA 550,** *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations*).



Figure 6. Other concerns when flood levels rise above the lowest floor are mold and biological/chemical contamination. These may render an otherwise repairable building unrepairable, or will at least make the cleanup, restoration, and repairs much more expensive and time-consuming.

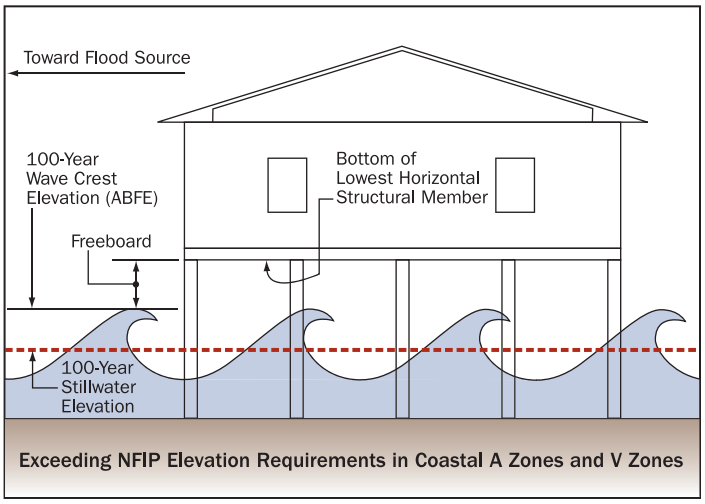


Figure 7. Recommended construction in Coastal A Zones and V Zones.

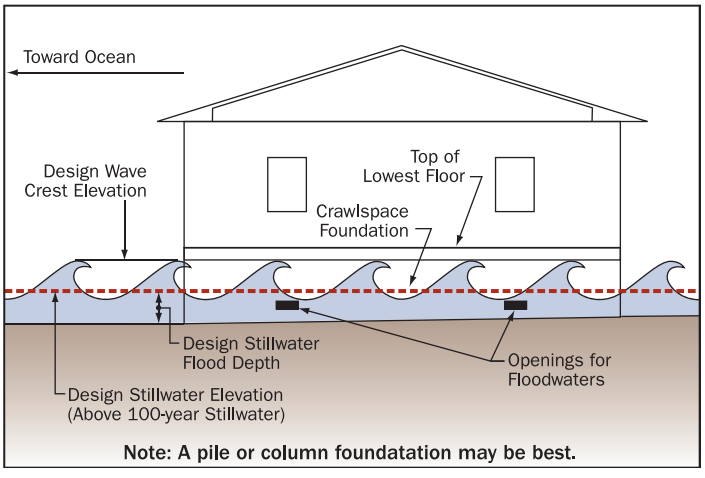


Figure 8. Recommended construction in Zones B, C, and X.

- Use **strong connections between the foundation and the elevated building** to prevent the building from floating or washing off the foundation, in the event that flood levels do rise above the lowest floor.
- Use **flood damage resistant building materials and methods** above the lowest floor. For example, consider using drainable, dryable interior wall assemblies (see Figure 9). This allows interior walls to be opened up and dried after a flood above the lowest floor, minimizing damage to the structure. For cavity and mass wall assemblies, the methods and materials in Figures 10 and 11 are recommended.

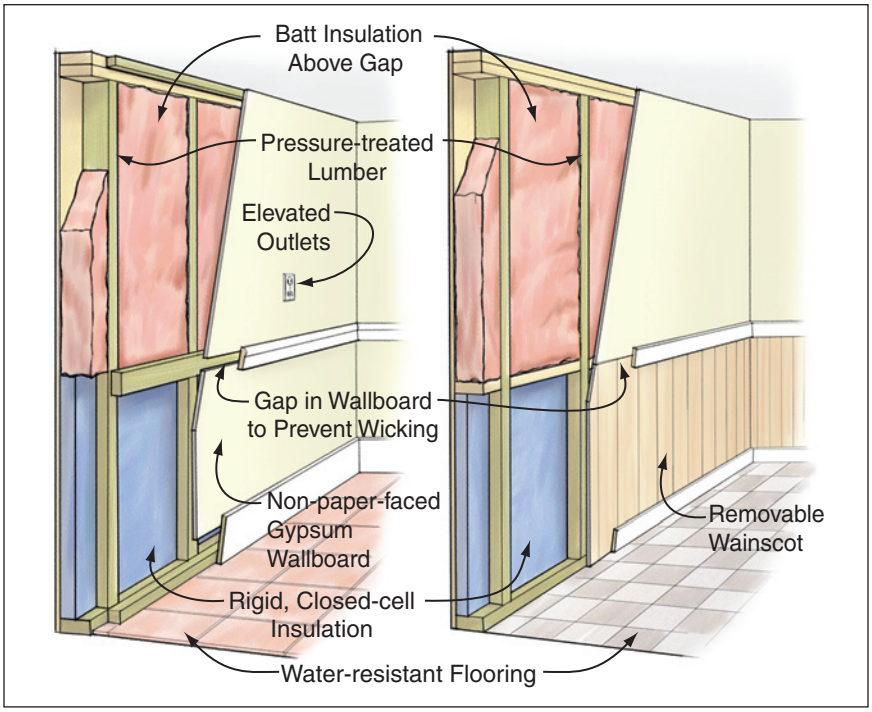


Figure 9. Recommended wet floodproofing techniques for interior wall construction. The following flood damage resistant materials and methods will prevent wicking and limit flood damage: 1) construct walls with horizontal gaps in wallboard; 2) use non-paper-faced gypsum wallboard below gap, painted with latex paint; 3) use rigid, closed-cell insulation in lower portion of walls; 4) use water-resistant flooring with waterproof adhesive; and 5) use pressure treated wood framing (Source: LSU AgCenter and Coastal Contractor Magazine).

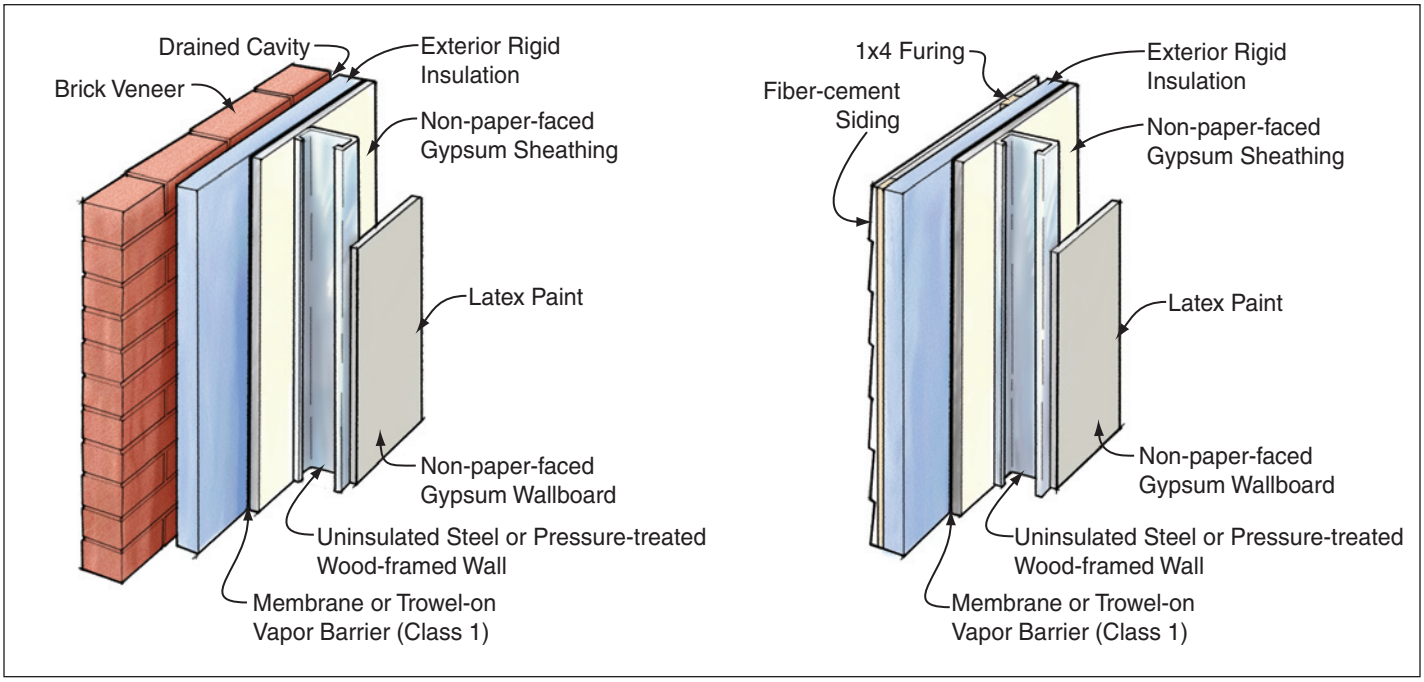


Figure 10. Recommended flood-resistant exterior cavity wall construction. The following materials and methods will limit flood damage to exterior cavity walls: 1) use brick veneer or fiber-cement siding, with non-paper-faced gypsum sheathing (vinyl siding is also flood-resistant but is less resistant to wind damage); 2) provide cavity for drainage; 3) use rigid, closed-cell insulation; 4) use steel or pressure treated wood studs and framing; and 5) use non-paper-faced gypsum wallboard painted with latex paint (Source: Coastal Contractor Magazine and Building Science Corporation).

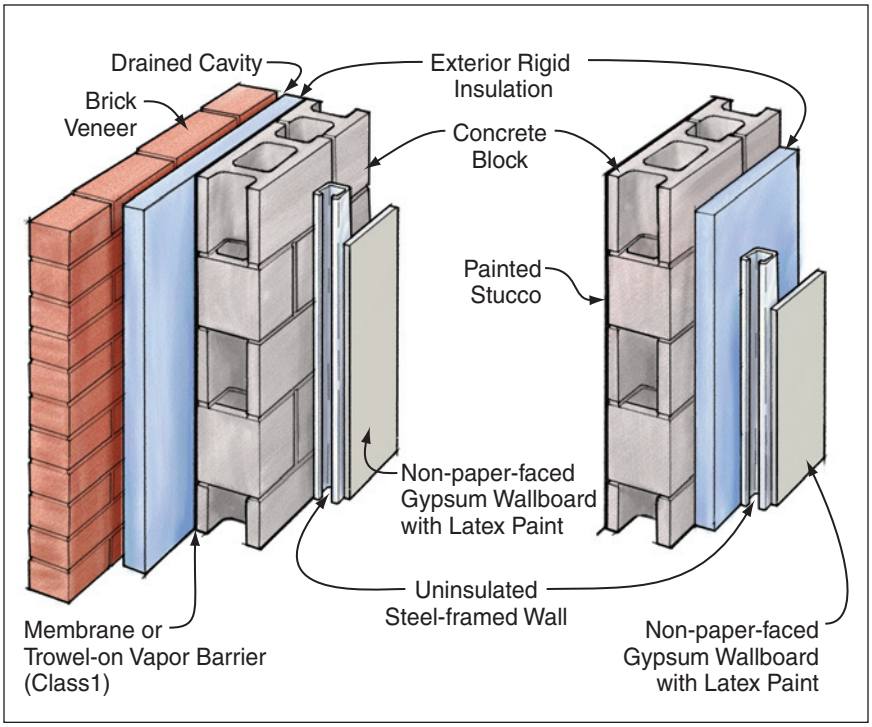


Figure 11. Recommended flood-resistant exterior mass wall construction. The following materials and methods will limit flood damage to exterior mass walls: 1) use concrete masonry with stucco or brick veneer (provide drainage cavity if brick veneer is used); 2) use rigid, closed-cell insulation; 3) use steel framing; and 4) use non-paper-faced gypsum wallboard painted with latex paint (Source: Coastal Contractor Magazine and Building Science Corporation).

- **New and replacement manufactured homes should be installed in accordance with the provisions of the 2005 edition of NEPA 225**, *Model Manufactured Home Installation Standard* (http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=225&cookie%5Ftest=1). The standard provides flood, wind, and seismic resistant installation procedures. It also calls for elevating A Zone manufactured homes with the bottom of the main chassis frame beam at or above the BFE, not with the top of the floor at the BFE.

How High Above the BFE Should a Building be Elevated?

Ultimately, the building elevation will depend on several factors, all of which must be considered before a final determination is made:

- **The accuracy of the BFE shown on the FIRM:** If the BFE is suspect, it is probably best to elevate several feet above the BFE; if the BFE is deemed accurate, it may only be necessary to elevate a couple of feet above the BFE.
- **Availability of Advisory Base Flood Elevations (ABFEs):** ABFEs have been produced for coastal areas following Hurricanes Ivan, Katrina, and Rita. These elevations are intended to be interim recommendations until new FISs can be completed. Some communities have adopted ABFEs, but not all (see the Hurricane Katrina Recovery Advisory posted at http://www.fema.gov/pdf/rebuild/mat/reconst_guidance.pdf).
- **Future conditions:** Since the FIRM reflects conditions at the time of the FIS, some owners or jurisdictions may wish to consider future conditions (such as sea level rise, wetland loss, shoreline erosion, increased storm frequency/intensity, and levee settlement/failure) when they decide how high to elevate.
- **State or local requirements:** The state or local jurisdiction may require a minimum freeboard through its floodplain management regulations.
- **Building code requirements:** The International Building Code (IBC) requires buildings be designed and constructed in accordance with ASCE 24 (*Standard for Flood Resistant Design and Construction*). ASCE 24 requires between 0 and 2 feet of freeboard, depending on the building importance and the edition of ASCE 24 referenced.[3]
- **Critical and essential facilities:** Given the importance of these facilities, some of which must remain operational during a hurricane, they should be elevated higher than most commercial and residential buildings.

[3] The 1998 edition of ASCE 24 is referenced by the 2003 edition of the IBC, and requires between 0 and 1 feet of freeboard. The 2005 edition of ASCE 24 is referenced by the 2006 edition of the IBC, and requires between 0 and 2 feet of freeboard.

- **Building owner tolerance for damage, displacement, and downtime:** Some building owners may wish to avoid building damage and disruption, and may choose to elevate far above the BFE (see Figures 12 and 13).



Figure 12. Ocean Springs, Mississippi, home elevated approximately 14 feet above the BFE. Katrina flooding was 4 feet below the elevated floor (photo taken after the storm surge had dropped several feet. Courtesy of Ocean Springs, Mississippi, fire chief).

Figure 13. Pass Christian, Mississippi, home elevated on reinforced concrete columns in Zone A, with the bottom of the floor beam elevated approximately 9 feet above the BFE. Although Katrina flooding was approximately 4 feet above the top of the lowest elevated floor, the home sustained no structural damage. All other buildings in the vicinity were destroyed.



The *Hurricane Katrina Summary Report on Building Performance* (FEMA 548) recommends that critical and essential facilities be elevated to the 500-year flood elevation or based on the requirements of ASCE 24-05, whichever is higher. This recommendation may also be appropriate for residential and commercial structures, as well.

The 500-year elevation can be approximated as 1.5 times the 500-year stillwater depth (500-year stillwater elevation minus the ground elevation) added to the ground elevation. This procedure is similar to the procedure used to calculate ABFEs, but with a different stillwater level.

If the 500-year stillwater elevation (feet North American Vertical Datum of 1988 [NAVD] or feet National Geodetic Vertical Datum of 1929 [NGVD]) is not available, a rule of thumb can be used to approximate it as 1.25 times the 100-year stillwater elevation (feet NAVD or feet NGVD).

Coastal A Zones

The Coastal A Zone is the area where wave heights between 1.5 and 3.0 feet are expected during the base flood. It is recommended that buildings in this area, with a few exceptions, be designed and constructed similar to V Zone buildings. See the Hurricane Katrina Recovery Advisory at http://www.fema.gov/pdf/rebuild/mat/coastal_a_zones.pdf for details.

Other Considerations

As previously stated, in addition to reduced building damage, there are other reasons to design for flood levels above the BFE:

- Reduced building maintenance and longer building life
- Reduced flood insurance premiums
- Reduced displacement and dislocation of building occupants after floods (and need for temporary shelter and assistance)
- Reduced job loss
- Increased retention of tax base

Until flooded, many homeowners and communities don't think about these benefits. However, one of the most persuasive (to homeowners) arguments for elevating homes above the BFE is the reduction in annual flood insurance premiums. In most cases, flood premiums can be cut in half by elevating a home 2 feet above the BFE, saving several hundred dollars per year in A Zones, and $2,000 or more per year in V Zones. In V Zones, savings continue to increase with added freeboard.

Flood Insurance Premium Reductions Can Be Significant

Example 1: V Zone building, supported on piles or piers, no below-BFE enclosure or obstruction. $250,000 building coverage, $100,000 contents coverage.		**Example 2:** A Zone building, slab or crawlspace foundation (no basement). $200,000 building coverage, $75,000 contents coverage.	
Floor Elevation above BFE	**Reduction in Annual Flood Premium***	**Floor Elevation above BFE**	**Reduction in Annual Flood Premium***
1 foot	25%	1 foot	39%
2 feet	50%	2 feet	48%
3 feet	62%	3 feet	48%
4 feet	67%	4 feet	48%

* Compared to flood premium with lowest floor at BFE

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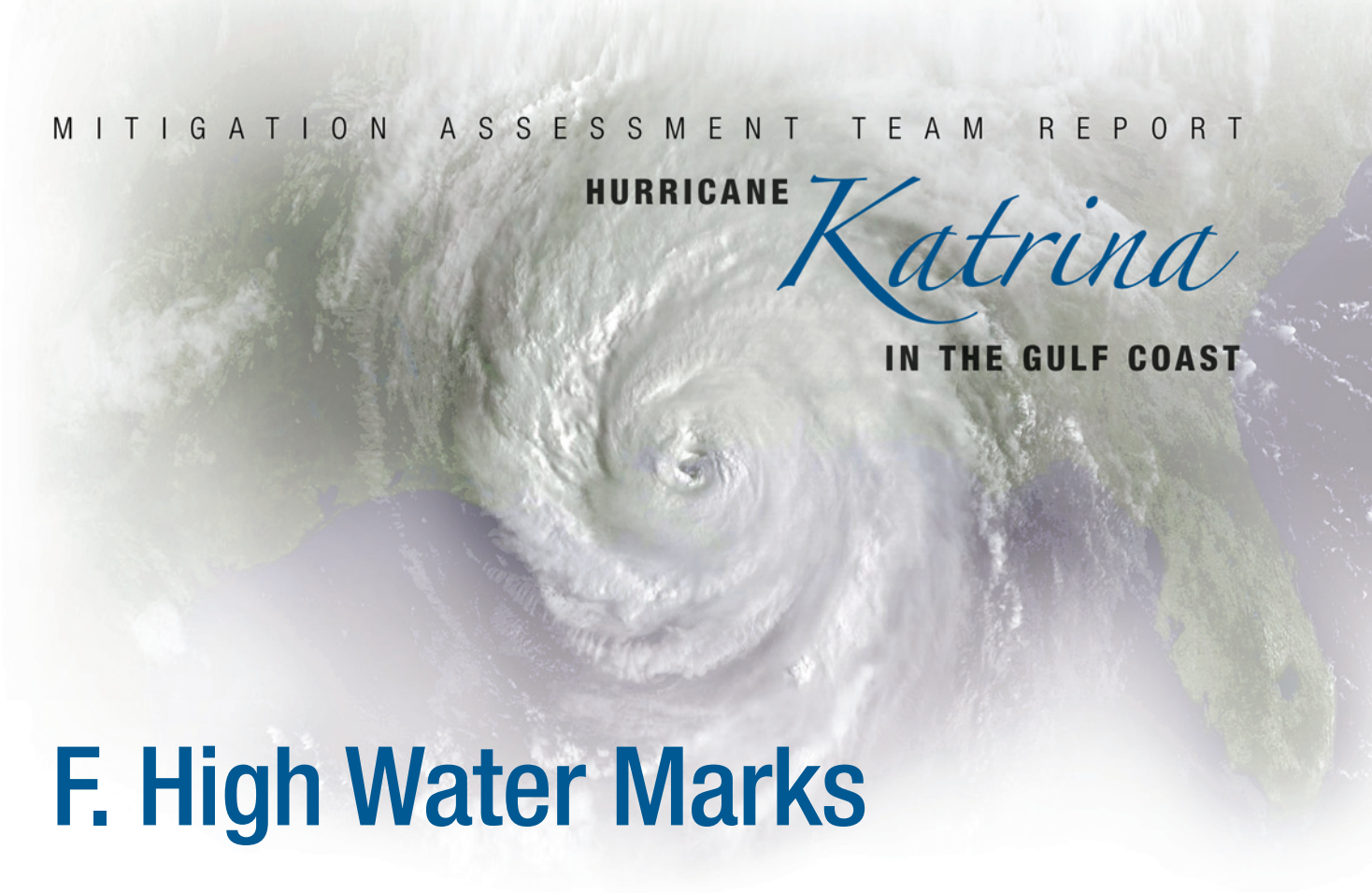
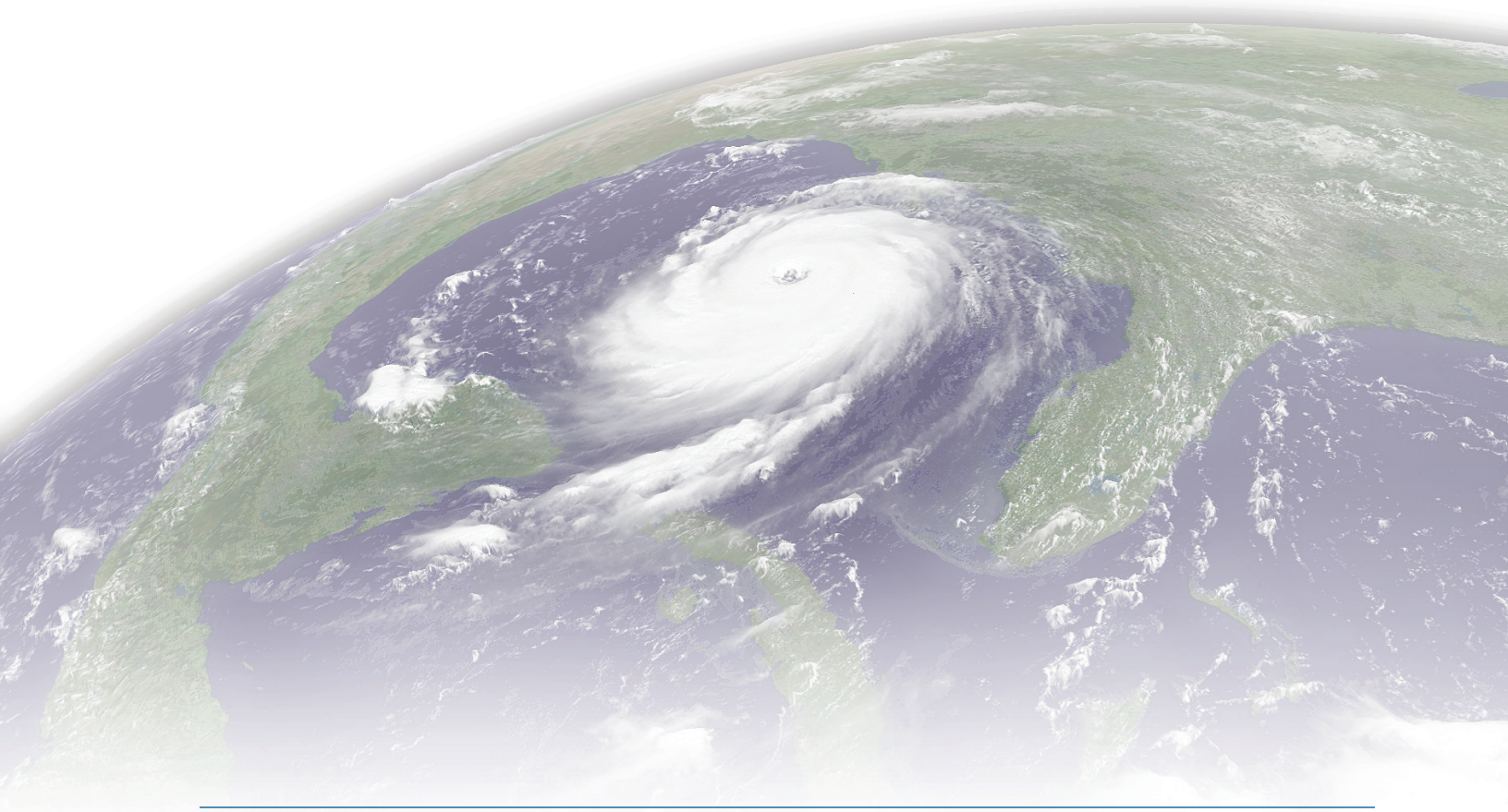


F. High Water Marks

The maps/figures presented in this appendix for the States of Alabama, Louisiana, and Mississippi are based on the Hurricane Katrina Rapid Response Coastal and Riverine High Water Mark Collection Draft Report, March 2006.

High Water Marks in Alabama



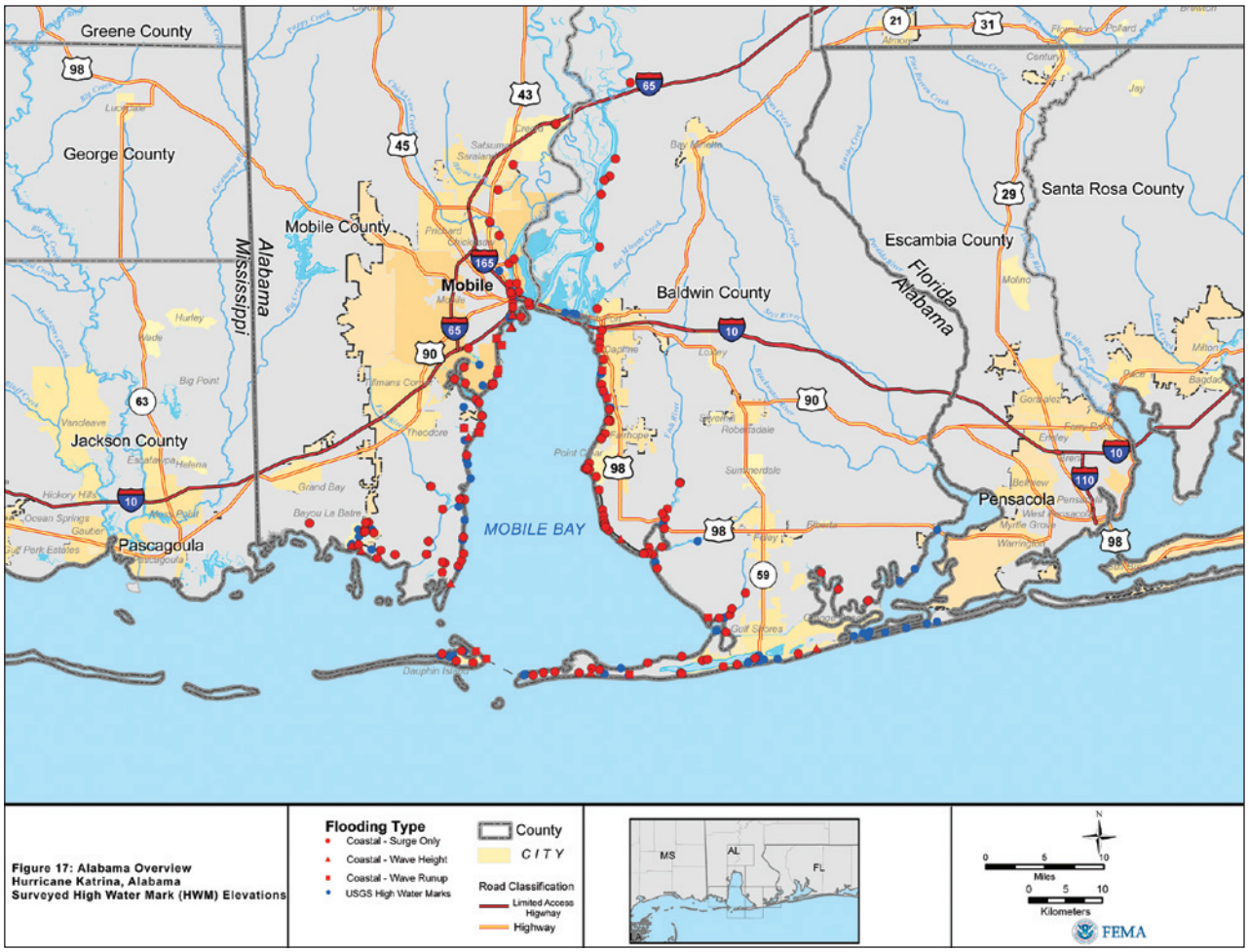


Figure 17: Alabama Overview
Hurricane Katrina, Alabama
Surveyed High Water Mark (HWM) Elevations

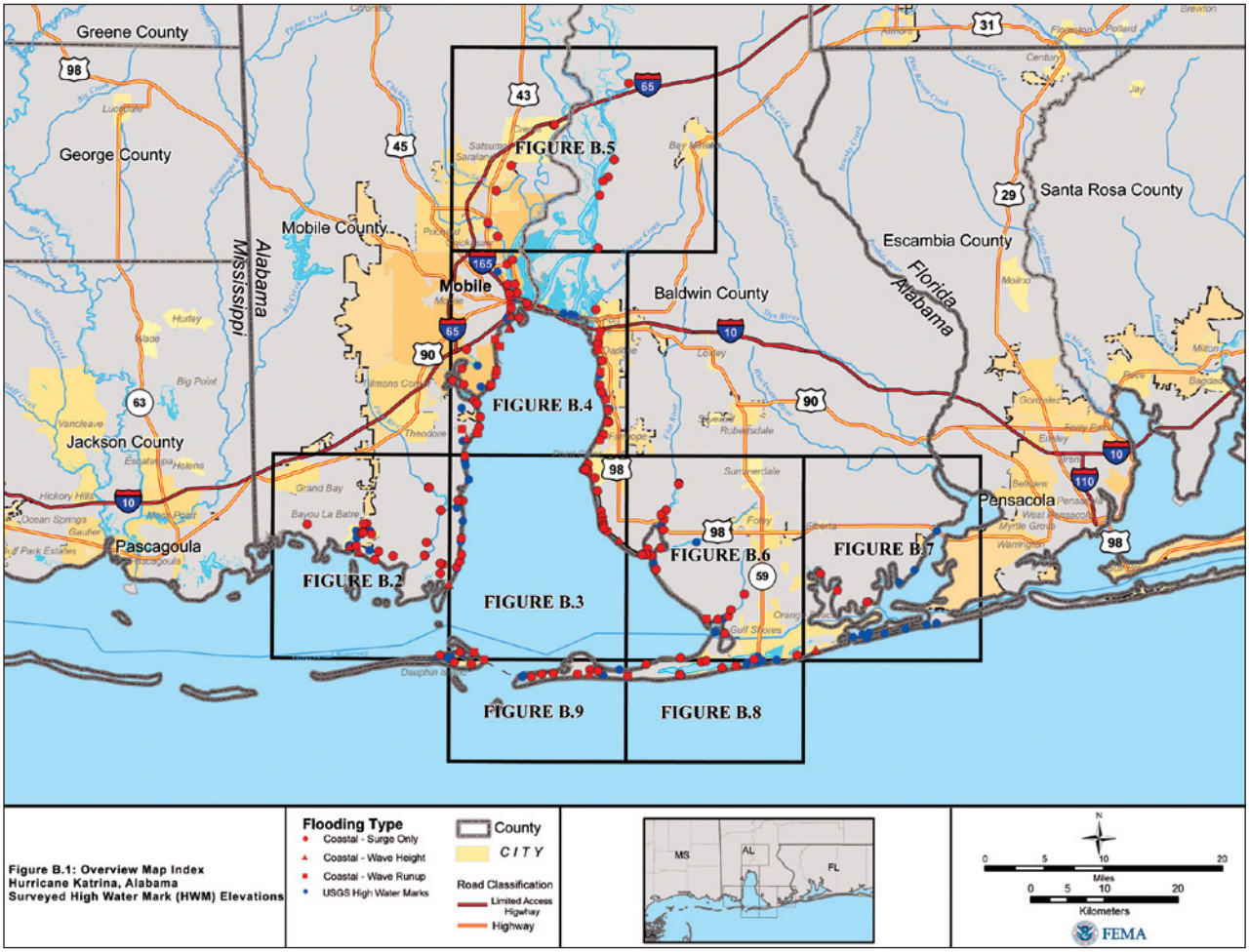


Figure B.1: Overview Map Index
Hurricane Katrina, Alabama
Surveyed High Water Mark (HWM) Elevations



Figure B.2: Hurricane Katrina, Alabama Mobile County, Alabama Surveyed High Water Mark (HWM) Elevations



Figure B.3: Hurricane Katrina, Alabama Mobile & Baldwin Counties Surveyed High Water Mark (HWM) Elevations



Figure B.4: Hurricane Katrina, Alabama Mobile & Baldwin Counties Surveyed High Water Mark (HWM) Elevations

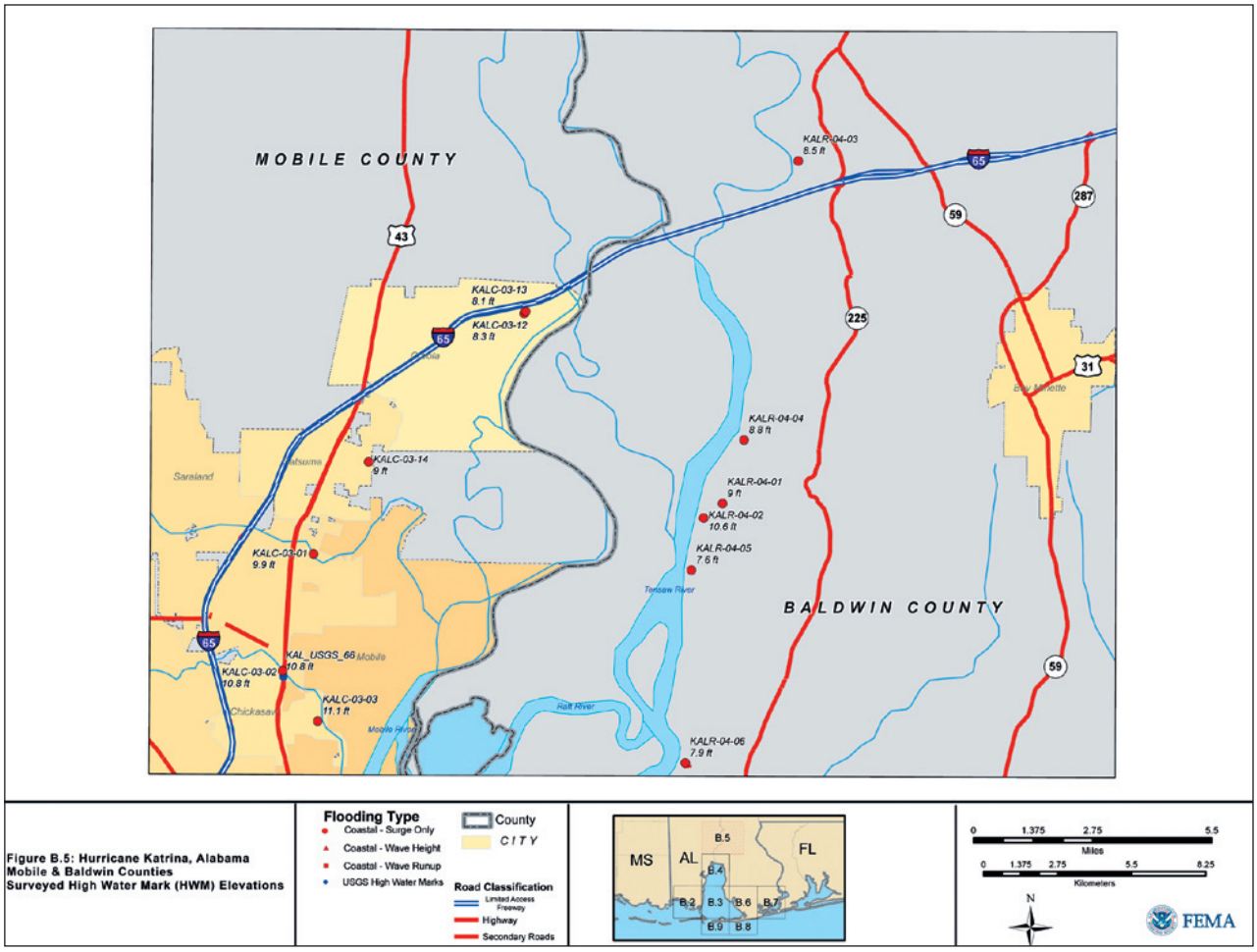


Figure B.5: Hurricane Katrina, Alabama Mobile & Baldwin Counties Surveyed High Water Mark (HWM) Elevations



Figure B.6: Hurricane Katrina, Alabama
Baldwin County
Surveyed High Water Mark (HWM) Elevations

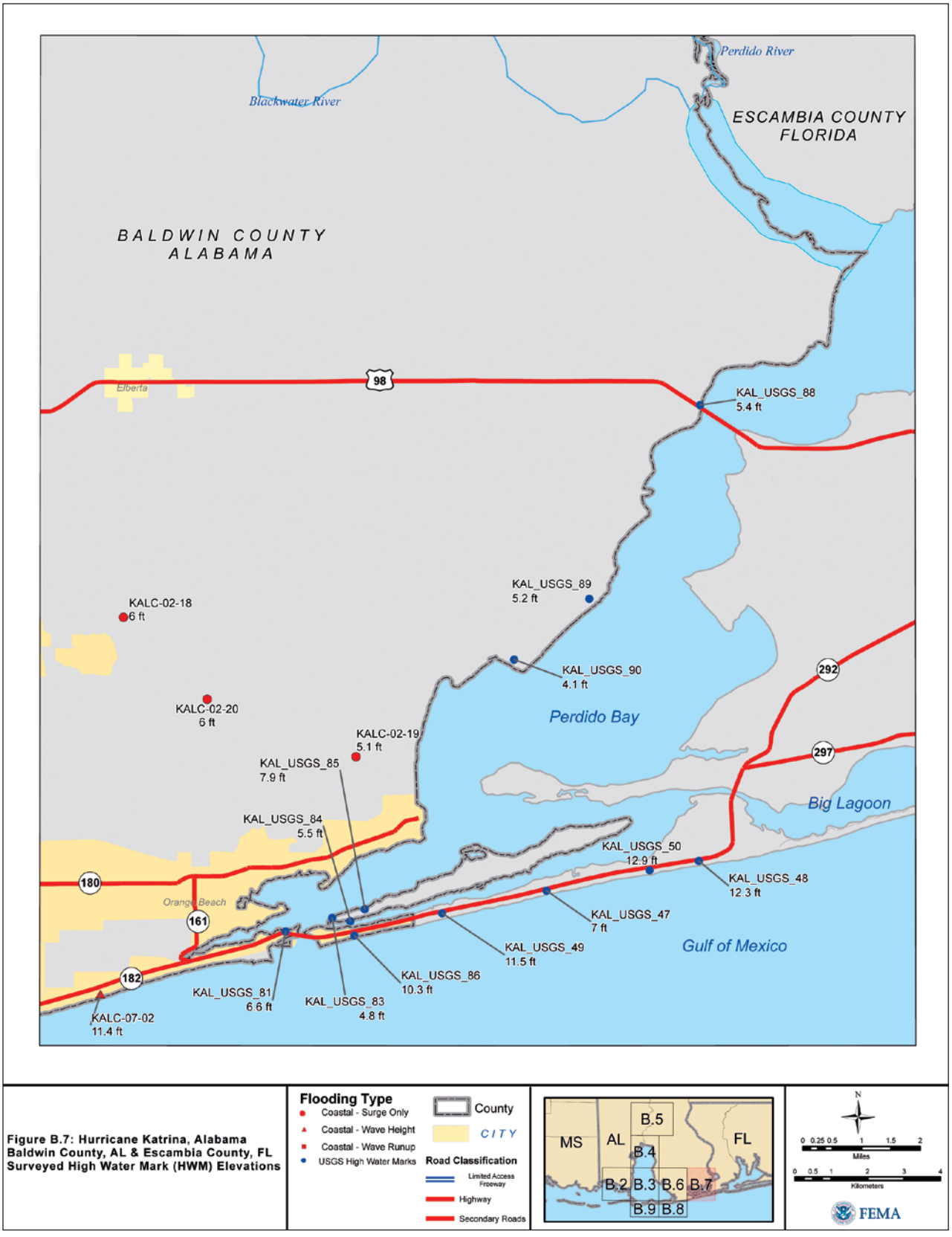


Figure B.7: Hurricane Katrina, Alabama Baldwin County, AL & Escambia County, FL Surveyed High Water Mark (HWM) Elevations

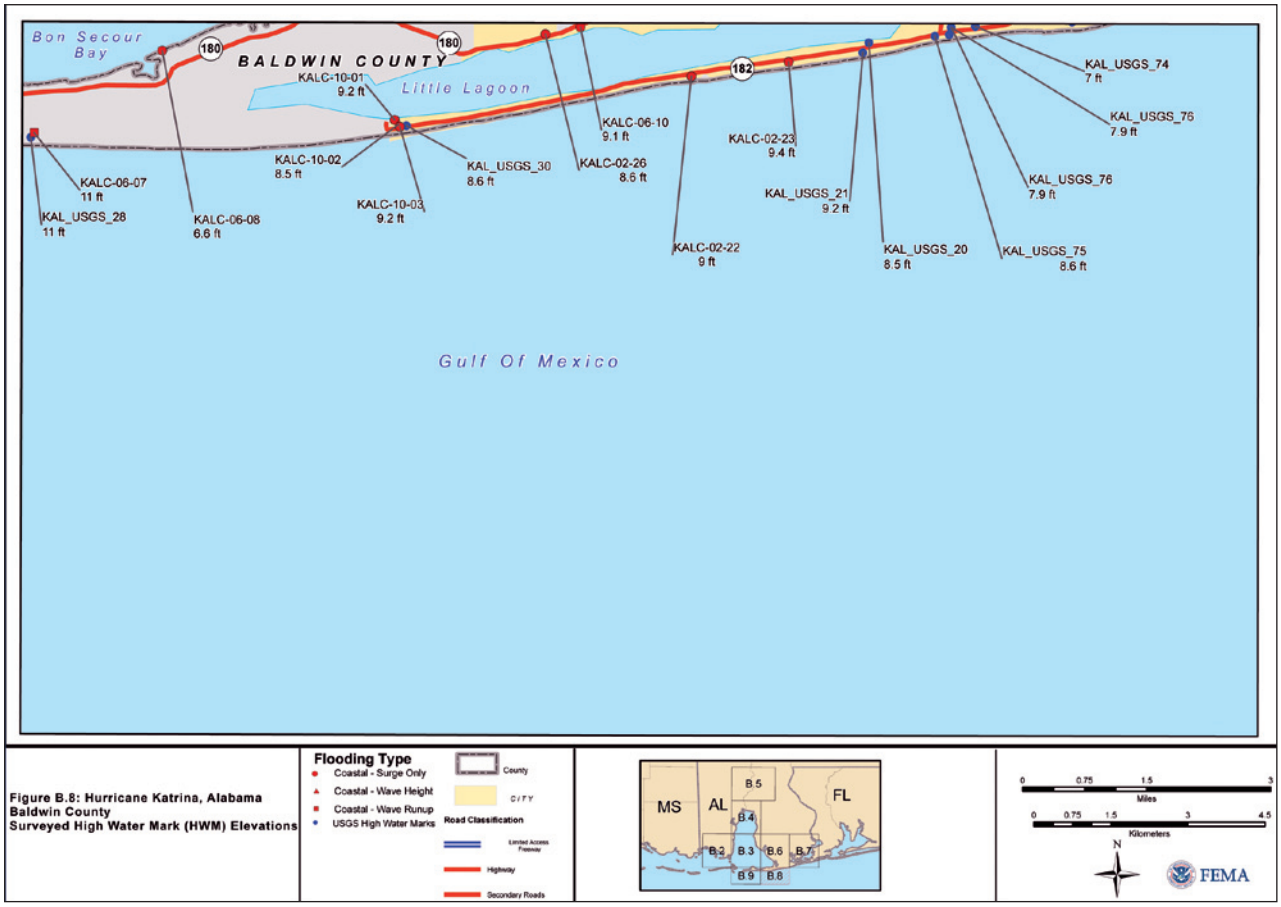


Figure B.8: Hurricane Katrina, Alabama
Baldwin County
Surveyed High Water Mark (HWM) Elevations

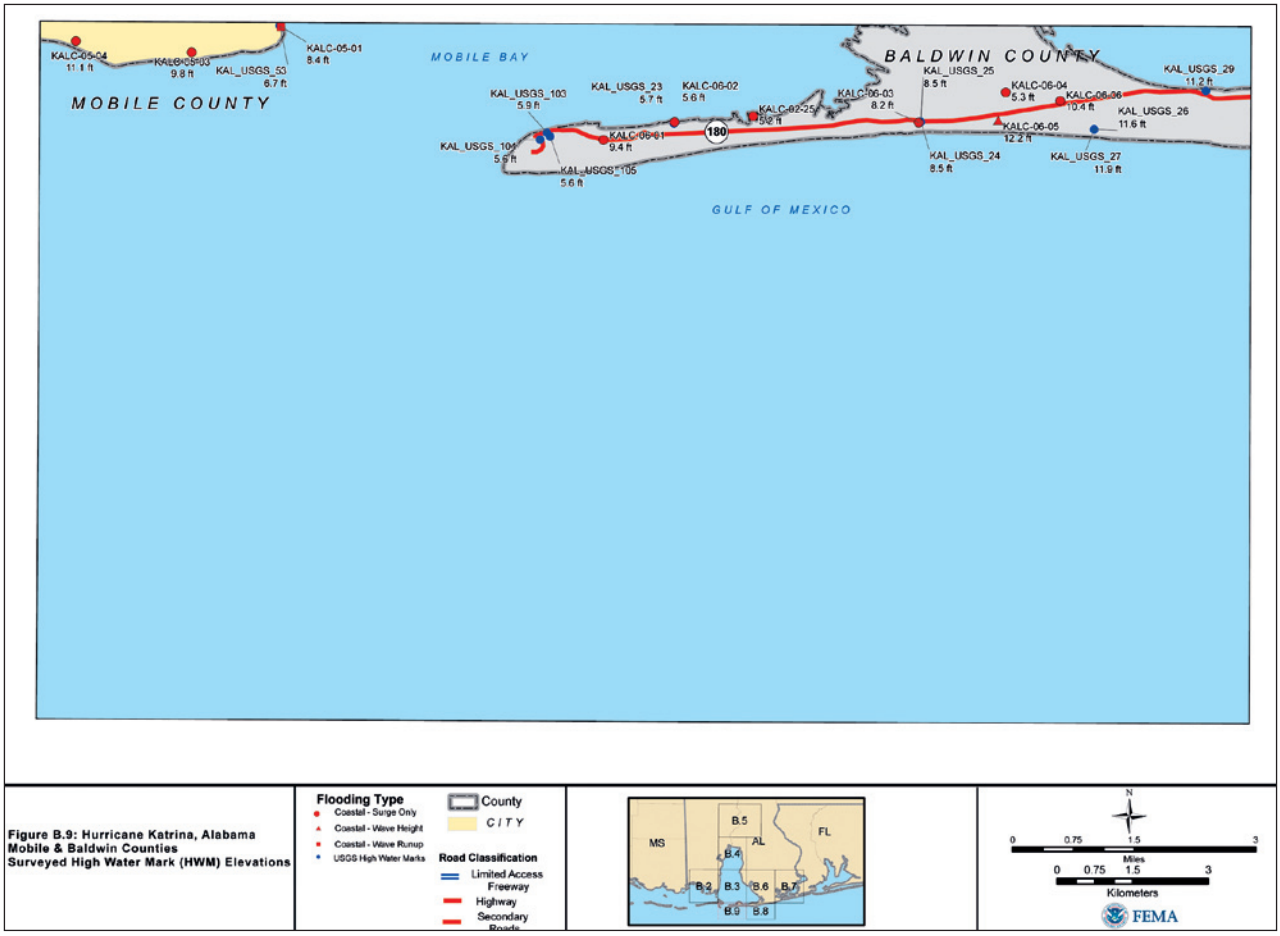
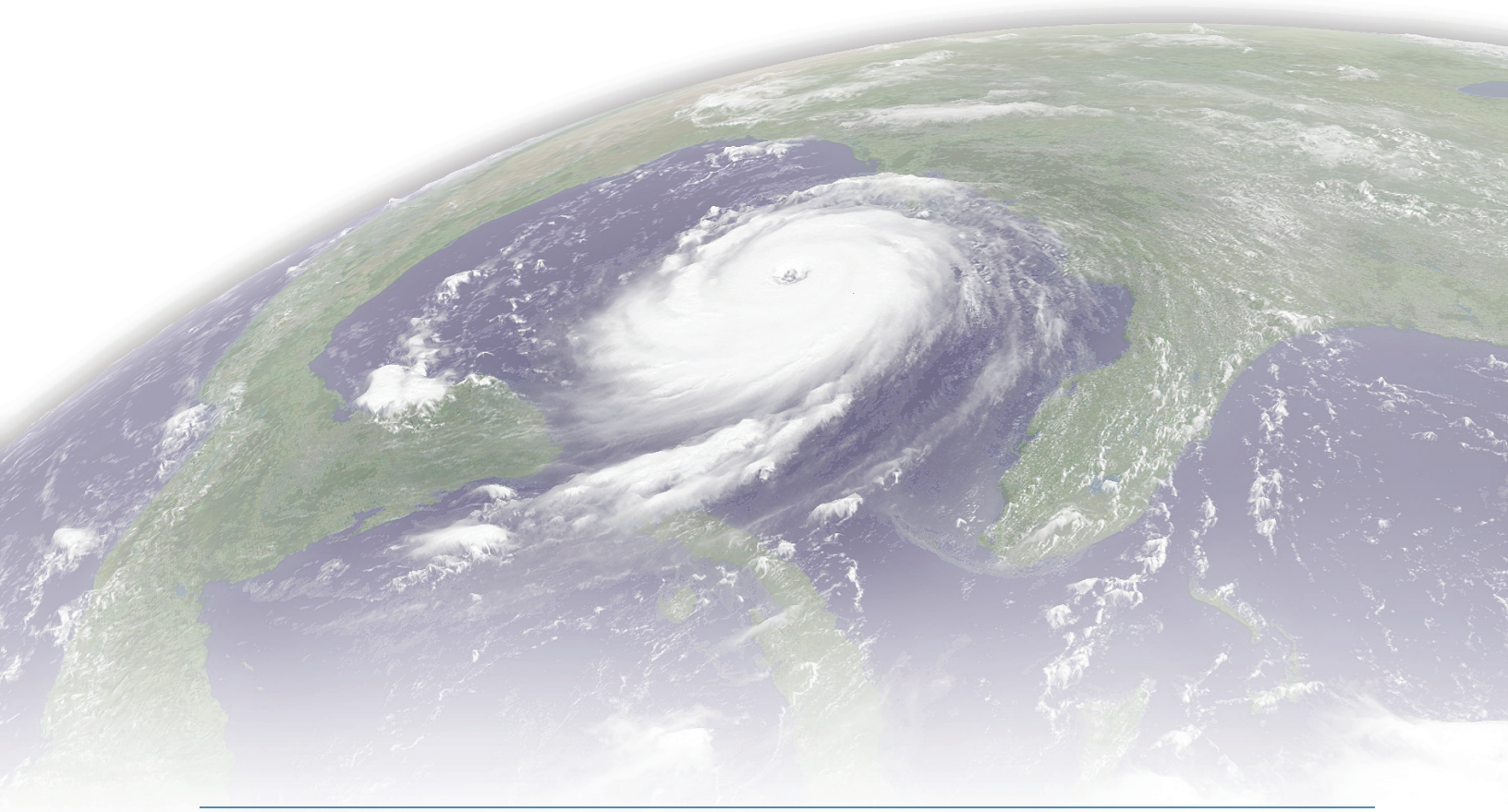
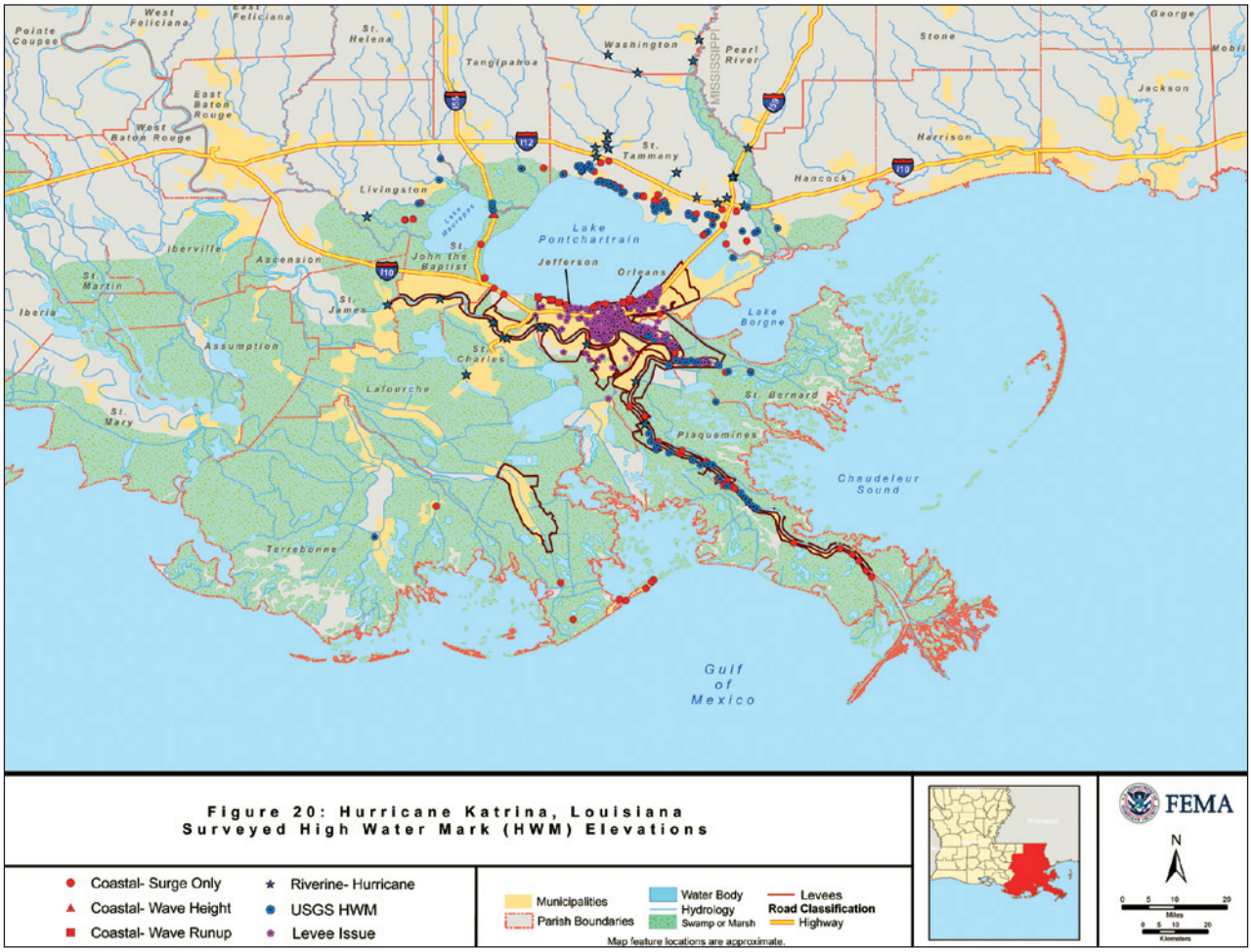


Figure B.9: Hurricane Katrina, Alabama Mobile & Baldwin Counties Surveyed High Water Mark (HWM) Elevations

High Water Marks in Louisiana




West Feliciana
East Feliciana
Pointe Coupee
St. Helena
Tangipahoa
Washington
Pearl River
MISSISSIPPI
Stone
George
Jackson
East Baton Rouge
West Baton Rouge
Harrison
St. Tammany
Hancock
Livingston
Lake Maurepas
Lake Pontchartrain
Iberville
Ascension
St. John the Baptist
Jefferson
Orleans
St. Martin
St. James
Lake Borgne
Iberia
Assumption
St. Charles
Lafourche
St. Bernard
St. Mary
Plaquemines
Chaudeleur Sound
Terrebonne
Gulf of Mexico
Figure 20: Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
Riverine- Hurricane
USGS HWM
Levee Issue
Municipalities
Parish Boundaries
Water Body
Hydrology
Swamp or Marsh
Levees
Road Classification
Highway
Map feature locations are approximate.
FEMA
N
Miles
Kilometers

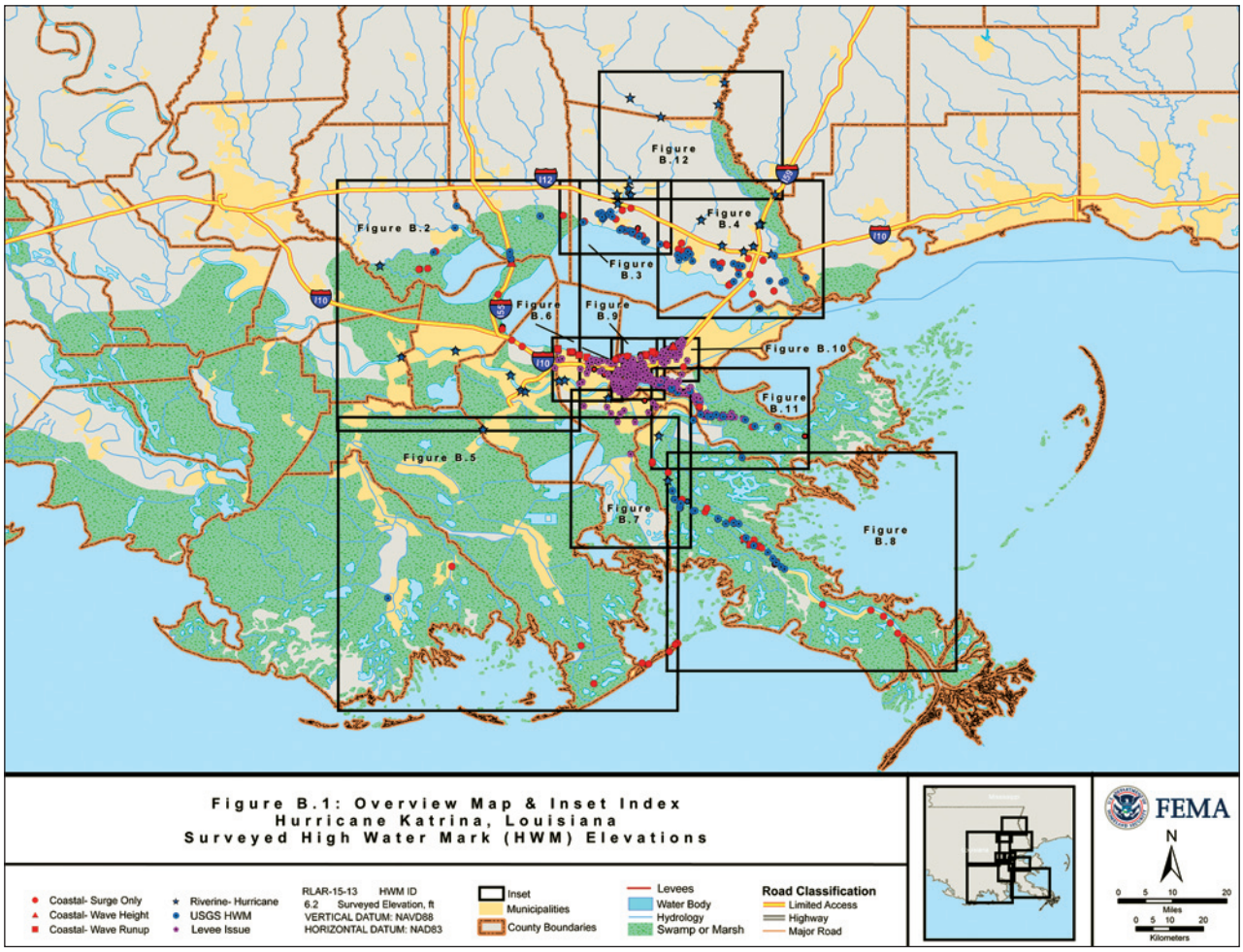


Figure B.12
Figure B.2
Figure B.4
Figure B.3
Figure B.6
Figure B.9
Figure B.10
Figure B.11
Figure B.5
Figure B.7
Figure B.8
Figure B.1: Overview Map & Inset Index
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
Riverine- Hurricane
USGS HWM
Levee Issue
RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Inset
Municipalities
County Boundaries
Levees
Water Body
Hydrology
Swamp or Marsh
Road Classification
Limited Access
Highway
Major Road
FEMA
N
0 5 10 20
Miles
0 5 10 20
Kilometers

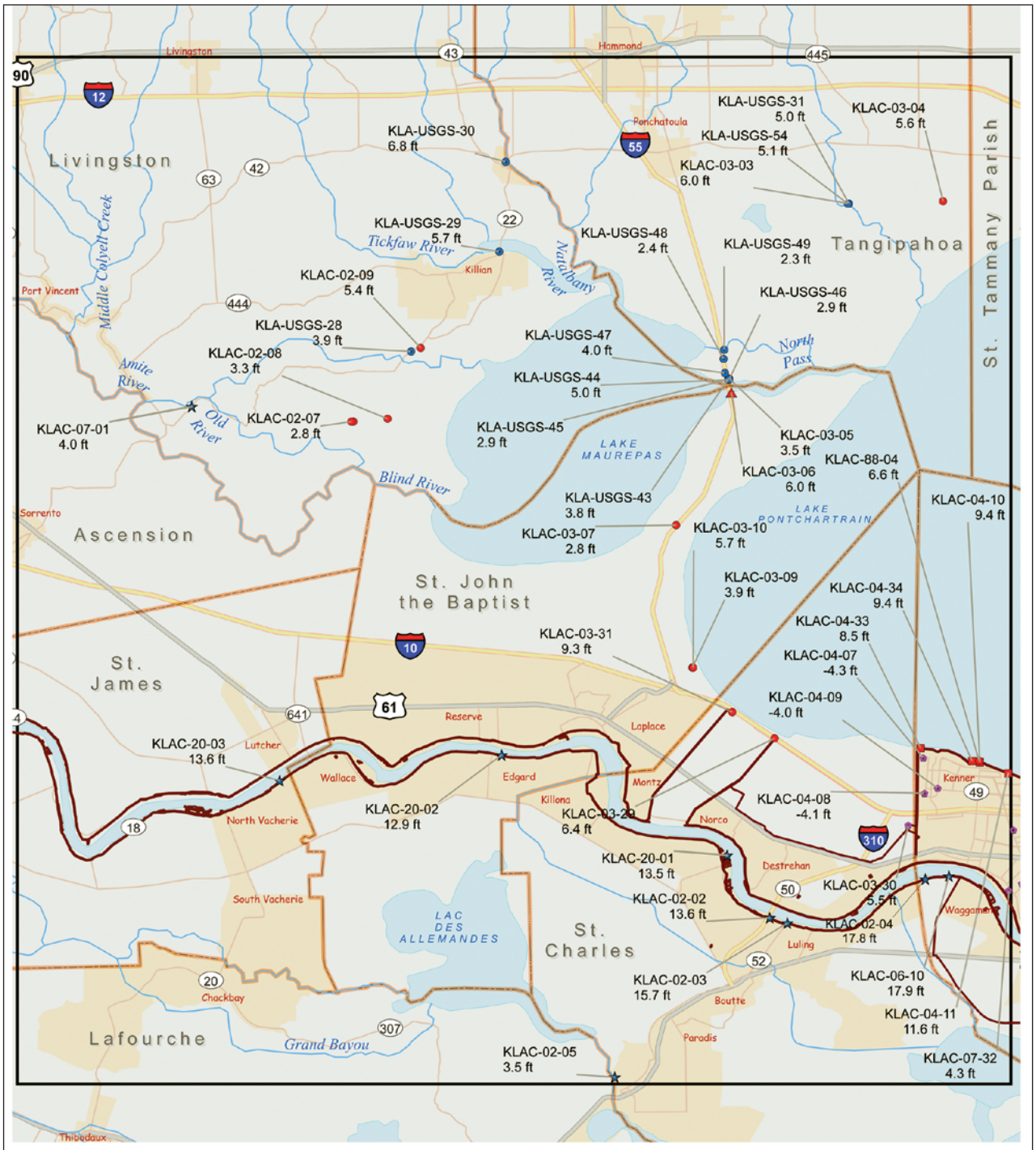
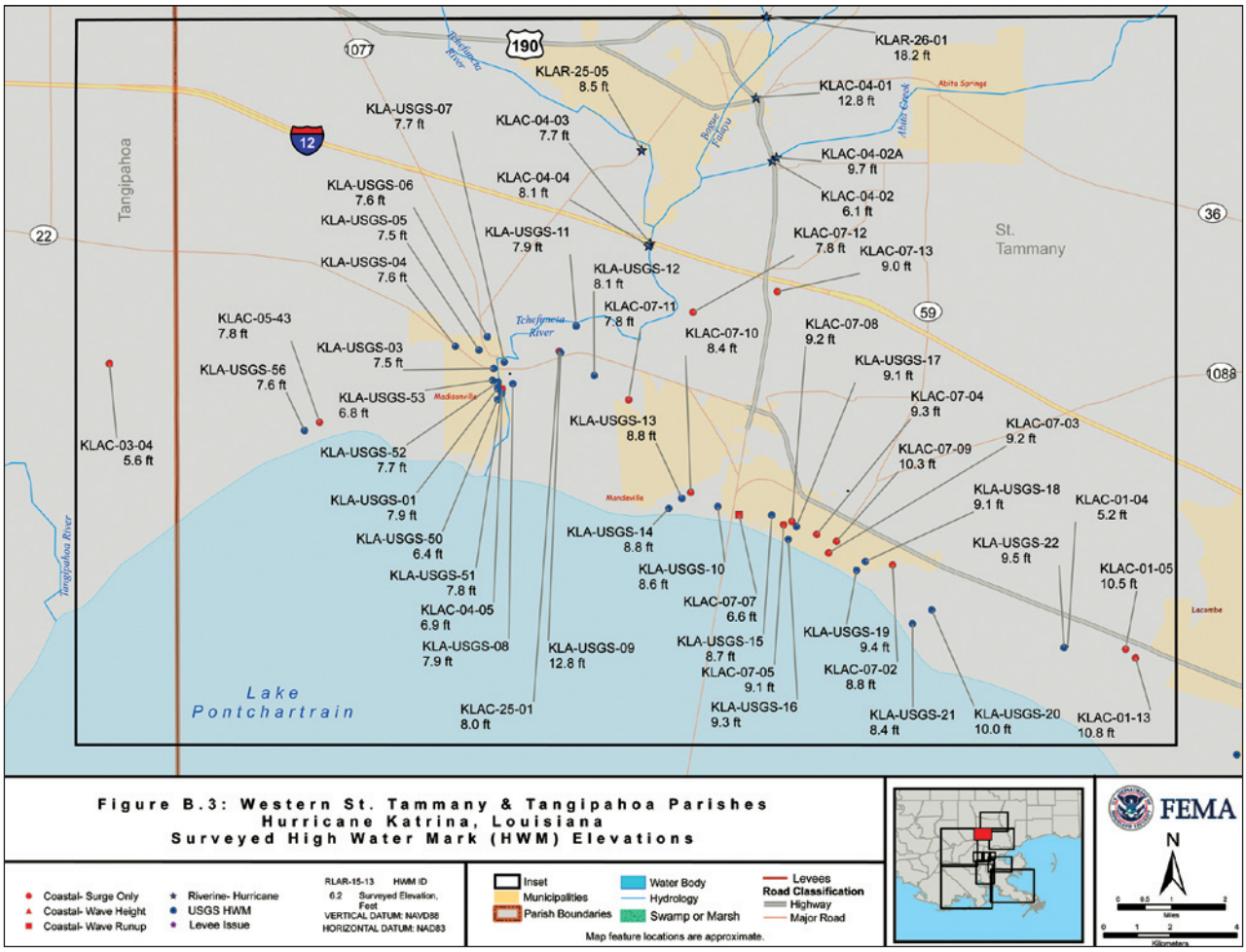


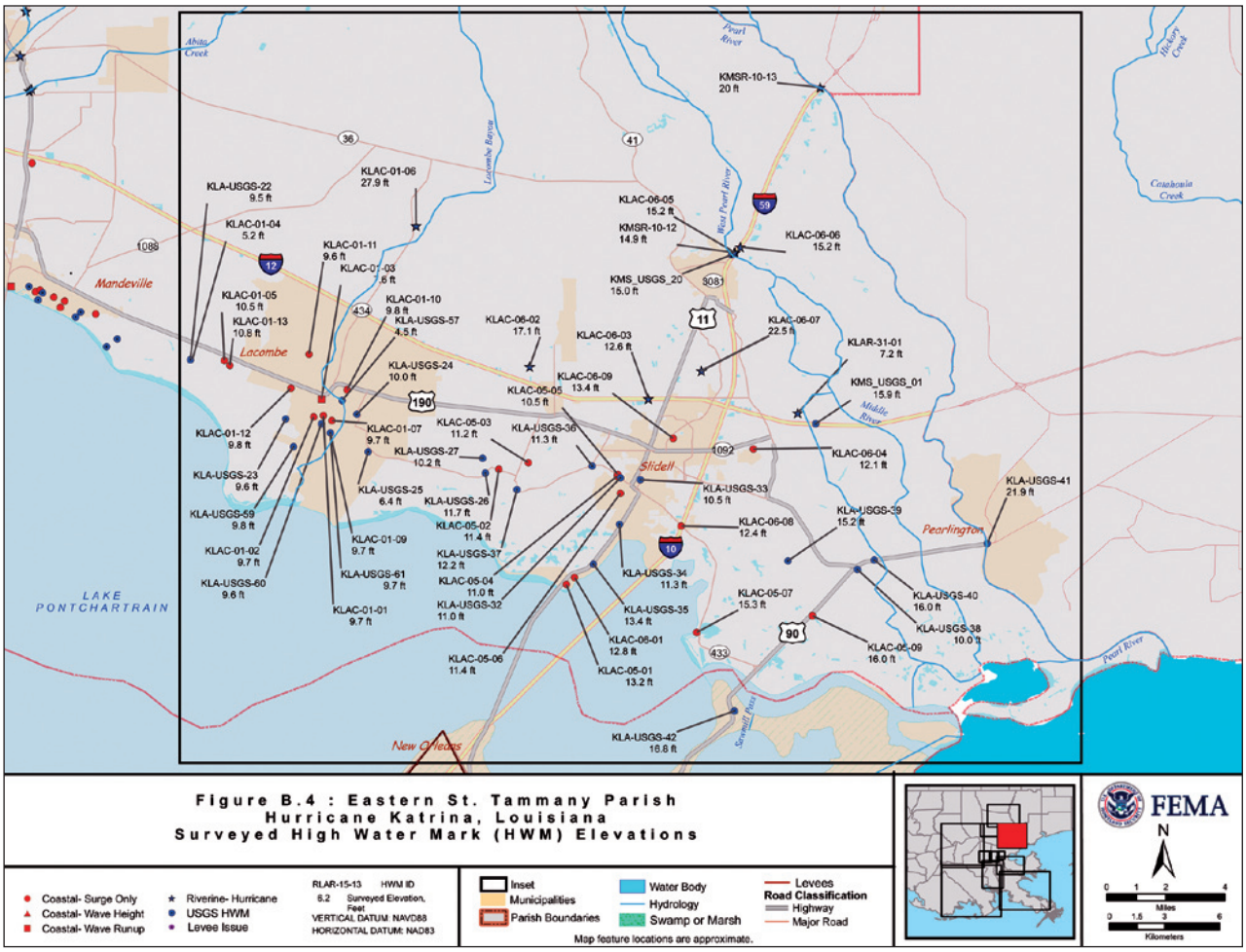
Figure B.2: Livingston, Tangipahoa, Ascension, St. James, St. John, St. Charles & Jefferson Parishes Hurricane Katrina, Louisiana Surveyed High Water Mark (HWM) Elevations

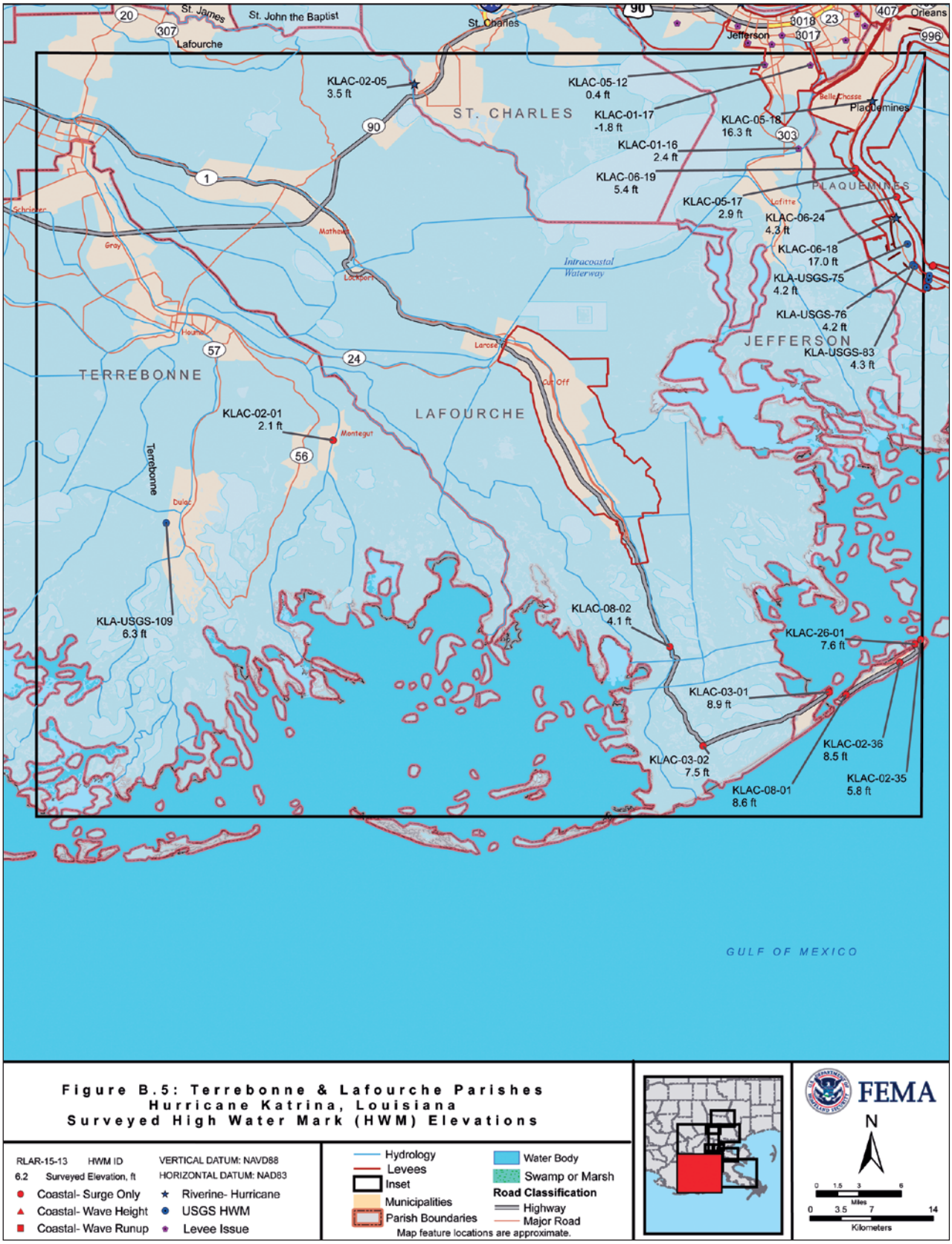
RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Riverine- Hurricane
USGS HWM
Levee Issue

Hydrology
Levees
Inset
Municipalities
Parish Boundaries
Water Body
Swamp or Marsh
Road Classification
Highway
Major Road
Map feature locations are approximate.

FEMA
N
0 1 2 4 Miles
0 2 4 8 Kilometers


KLAR-26-01
18.2 ft
KLAR-25-05
8.5 ft
KLAC-04-01
12.8 ft
KLA-USGS-07
7.7 ft
KLAC-04-03
7.7 ft
KLAC-04-02A
9.7 ft
KLAC-04-04
8.1 ft
KLAC-04-02
6.1 ft
KLA-USGS-06
7.6 ft
KLA-USGS-05
7.5 ft
KLA-USGS-11
7.9 ft
KLAC-07-12
7.8 ft
KLAC-07-13
9.0 ft
KLA-USGS-04
7.6 ft
KLA-USGS-12
8.1 ft
KLAC-07-11
7.8 ft
KLAC-07-10
8.4 ft
KLAC-07-08
9.2 ft
KLAC-05-43
7.8 ft
KLA-USGS-03
7.5 ft
KLA-USGS-17
9.1 ft
KLA-USGS-56
7.6 ft
KLA-USGS-53
6.8 ft
KLAC-07-04
9.3 ft
KLAC-07-03
9.2 ft
KLA-USGS-13
8.8 ft
KLAC-03-04
5.6 ft
KLA-USGS-52
7.7 ft
KLAC-07-09
10.3 ft
KLA-USGS-18
9.1 ft
KLAC-01-04
5.2 ft
KLA-USGS-01
7.9 ft
KLA-USGS-14
8.8 ft
KLA-USGS-22
9.5 ft
KLA-USGS-50
6.4 ft
KLA-USGS-10
8.6 ft
KLAC-01-05
10.5 ft
KLA-USGS-51
7.8 ft
KLAC-07-07
6.6 ft
KLAC-04-05
6.9 ft
KLA-USGS-19
9.4 ft
KLA-USGS-15
8.7 ft
KLA-USGS-08
7.9 ft
KLA-USGS-09
12.8 ft
KLAC-07-05
9.1 ft
KLAC-07-02
8.8 ft
KLAC-25-01
8.0 ft
KLA-USGS-16
9.3 ft
KLA-USGS-21
8.4 ft
KLA-USGS-20
10.0 ft
KLAC-01-13
10.8 ft
Lake Pontchartrain
Tangipahoa
St. Tammany
Tchefuncta River
Tchefuncta River
Bayou Fidgeu
Abita Creek
Abita Springs
Madisonville
Mandeville
Lacombe
107
190
12
22
36
59
1088
Figure B.3: Western St. Tammany & Tangipahoa Parishes
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
Riverine- Hurricane
USGS HWM
Levee Issue
RLAR-15-13 HWM ID
6.2 Surveyed Elevation, Feet
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Inset
Municipalities
Parish Boundaries
Water Body
Hydrology
Swamp or Marsh
Levees
Road Classification
Highway
Major Road
Map feature locations are approximate.
FEMA
N
Miles
Kilometers


KMSR-10-13
20 ft
KLAC-01-06
27.9 ft
KLA-USGS-22
9.5 ft
KLAC-01-04
5.2 ft
KLAC-01-11
9.6 ft
KLAC-01-03
KLAC-01-05
10.5 ft
KLAC-01-13
10.8 ft
KLAC-01-10
9.8 ft
KLA-USGS-57
4.5 ft
KLAC-06-02
17.1 ft
KLAC-06-05
15.2 ft
KMSR-10-12
14.9 ft
KLAC-06-06
15.2 ft
KMS_USGS_20
16.0 ft
KLAC-06-03
12.6 ft
KLAC-06-07
22.5 ft
KLAR-31-01
7.2 ft
KLA-USGS-24
10.0 ft
KLAC-05-05
10.5 ft
KLAC-06-09
13.4 ft
KMS_USGS_01
15.9 ft
KLAC-01-12
9.8 ft
KLAC-01-07
9.7 ft
KLAC-05-03
11.2 ft
KLA-USGS-36
11.3 ft
KLA-USGS-27
10.2 ft
KLAC-06-04
12.1 ft
KLA-USGS-23
9.6 ft
KLA-USGS-25
6.4 ft
KLA-USGS-26
11.7 ft
KLA-USGS-33
10.5 ft
KLA-USGS-41
21.9 ft
KLA-USGS-59
9.8 ft
KLAC-05-02
11.4 ft
KLAC-06-08
12.4 ft
KLA-USGS-39
15.2 ft
KLAC-01-02
9.7 ft
KLAC-01-09
9.7 ft
KLA-USGS-37
12.2 ft
KLA-USGS-61
9.7 ft
KLAC-05-04
11.0 ft
KLA-USGS-34
11.3 ft
KLA-USGS-40
16.0 ft
KLA-USGS-60
9.6 ft
KLAC-01-01
9.7 ft
KLA-USGS-32
11.0 ft
KLA-USGS-35
13.4 ft
KLAC-05-07
15.3 ft
KLA-USGS-38
10.0 ft
KLAC-06-01
12.8 ft
KLAC-05-09
16.0 ft
KLAC-05-06
11.4 ft
KLAC-05-01
13.2 ft
KLA-USGS-42
16.8 ft
Mandeville
Lacombe
Slidell
Pearlington
LAKE PONTCHARTRAIN
New Orleans
Abita Creek
Pearl River
West Pearl River
Bayou Liberty
Middle River
Tchefuncte River
Bogue Chitto
Scranuff Point
Pearl River
Figure B.4 : Eastern St. Tammany Parish
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
Riverine- Hurricane
USGS HWM
Levee Issue
RLAR-15-13 HWM ID
8.2 Surveyed Elevation, Feet
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Inset
Municipalities
Parish Boundaries
Water Body
Hydrology
Swamp or Marsh
Levees
Road Classification
Highway
Major Road
Map feature locations are approximate.
FEMA
N
Miles
Kilometers


St. James
St. John the Baptist
St. Charles
Jefferson
Orleans
Lafourche
ST. CHARLES
PLAQUEMINES
JEFFERSON
TERREBONNE
LAFOURCHE
KLAC-02-05
3.5 ft
KLAC-05-12
0.4 ft
KLAC-01-17
-1.8 ft
KLAC-05-18
16.3 ft
KLAC-01-16
2.4 ft
KLAC-06-19
5.4 ft
KLAC-05-17
2.9 ft
KLAC-06-24
4.3 ft
KLAC-06-18
17.0 ft
KLA-USGS-75
4.2 ft
KLA-USGS-76
4.2 ft
KLA-USGS-83
4.3 ft
KLAC-02-01
2.1 ft
KLA-USGS-109
6.3 ft
KLAC-08-02
4.1 ft
KLAC-26-01
7.6 ft
KLAC-03-01
8.9 ft
KLAC-02-36
8.5 ft
KLAC-03-02
7.5 ft
KLAC-08-01
8.6 ft
KLAC-02-35
5.8 ft
Intracoastal Waterway
GULF OF MEXICO
Figure B.5: Terrebonne & Lafourche Parishes
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
Riverine- Hurricane
USGS HWM
Levee Issue
Hydrology
Levees
Inset
Municipalities
Parish Boundaries
Water Body
Swamp or Marsh
Road Classification
Highway
Major Road
Map feature locations are approximate.
FEMA
N
Miles
Kilometers

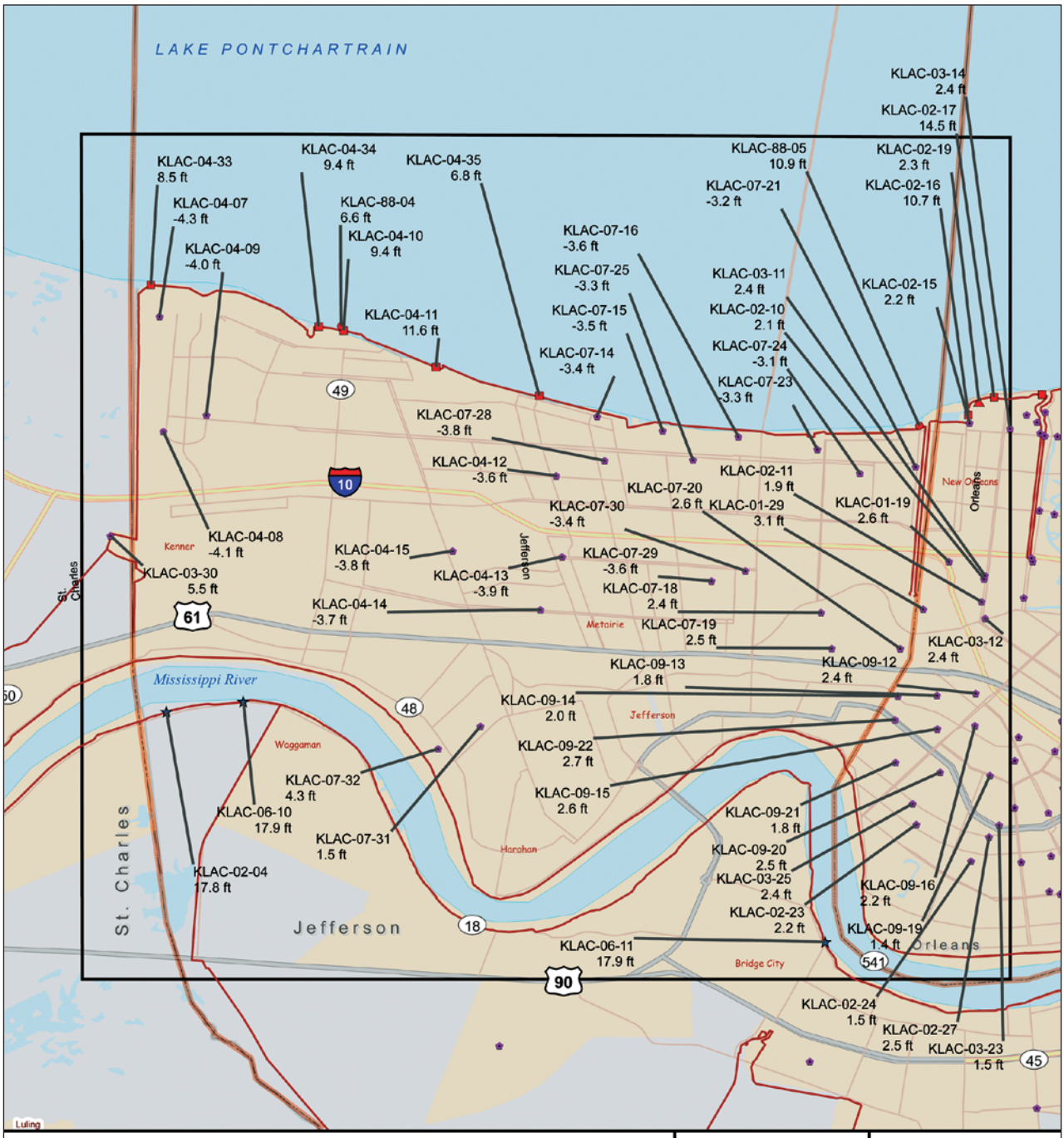


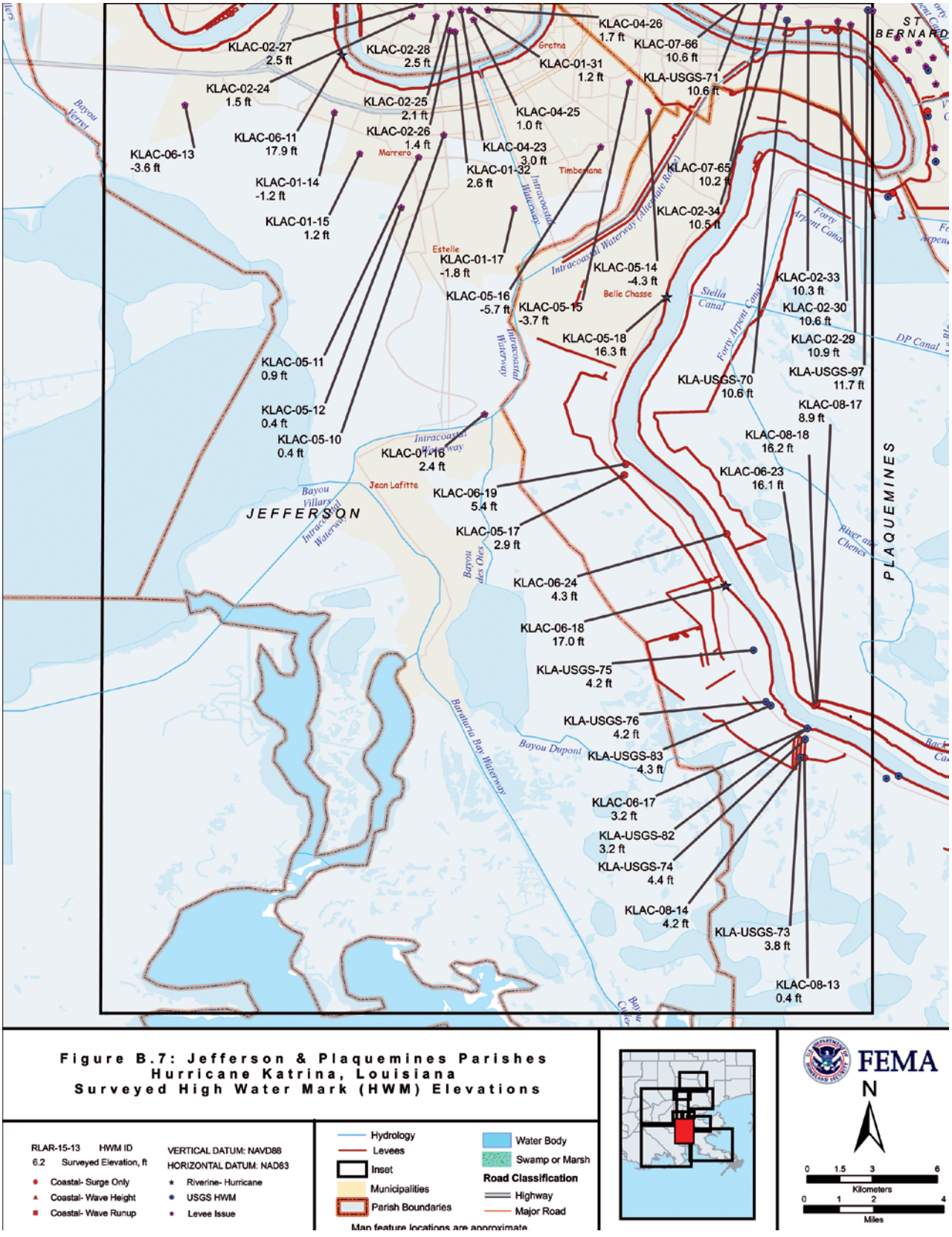
Figure B.6: St. Charles, Jefferson & Orleans Parishes Hurricane Katrina, Louisiana Surveyed High Water Mark (HWM) Elevations

RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup

VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Riverine- Hurricane
USGS HWM
Levee Issue

Hydrology
Levees
Inset
Municipalities
Parish Boundaries
Water Body
Swamp or Marsh
Road Classification
Highway
Major Road
Map feature locations are approximate.

FEMA
N
0 0.5 1 2 Kilometers
0 0.5 1 2 Miles


KLAC-02-27
2.5 ft
KLAC-02-28
2.5 ft
KLAC-04-26
1.7 ft
KLAC-07-66
10.6 ft
KLAC-01-31
1.2 ft
KLA-USGS-71
10.6 ft
KLAC-02-24
1.5 ft
KLAC-02-25
2.1 ft
KLAC-04-25
1.0 ft
KLAC-06-13
-3.6 ft
KLAC-06-11
17.9 ft
KLAC-02-26
1.4 ft
KLAC-04-23
3.0 ft
KLAC-01-32
2.6 ft
KLAC-07-65
10.2 ft
KLAC-01-14
-1.2 ft
KLAC-02-34
10.5 ft
KLAC-01-15
1.2 ft
KLAC-01-17
-1.8 ft
KLAC-05-14
-4.3 ft
KLAC-02-33
10.3 ft
KLAC-05-16
-5.7 ft
KLAC-05-15
-3.7 ft
KLAC-02-30
10.6 ft
KLAC-05-18
16.3 ft
KLAC-02-29
10.9 ft
KLAC-05-11
0.9 ft
KLA-USGS-70
10.6 ft
KLA-USGS-97
11.7 ft
KLAC-05-12
0.4 ft
KLAC-08-17
8.9 ft
KLAC-05-10
0.4 ft
KLAC-01-16
2.4 ft
KLAC-08-18
16.2 ft
KLAC-06-23
16.1 ft
KLAC-06-19
5.4 ft
KLAC-05-17
2.9 ft
KLAC-06-24
4.3 ft
KLAC-06-18
17.0 ft
KLA-USGS-75
4.2 ft
KLA-USGS-76
4.2 ft
KLA-USGS-83
4.3 ft
KLAC-06-17
3.2 ft
KLA-USGS-82
3.2 ft
KLA-USGS-74
4.4 ft
KLAC-08-14
4.2 ft
KLA-USGS-73
3.8 ft
KLAC-08-13
0.4 ft
JEFFERSON
PLAQUEMINES
ST BERNARD
Gretna
Marrero
Timberlane
Estelle
Belle Chasse
Jean Lafitte
Bayou Villars
Bayou des Oies
Bayou Dupont
Barataria Bay Waterway
Intracoastal Waterway
Intracoastal Waterway (Algiers Alternate Route)
Forty Arpent Canal
Stella Canal
DP Canal
River aux Chenes
Bayou Verret
Figure B.7: Jefferson & Plaquemines Parishes
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Riverine- Hurricane
USGS HWM
Levee Issue
Hydrology
Levees
Inset
Municipalities
Parish Boundaries
Water Body
Swamp or Marsh
Road Classification
Highway
Major Road
Map feature locations are approximate
FEMA
N
0 1.5 3 6
Kilometers
0 1 2 4
Miles

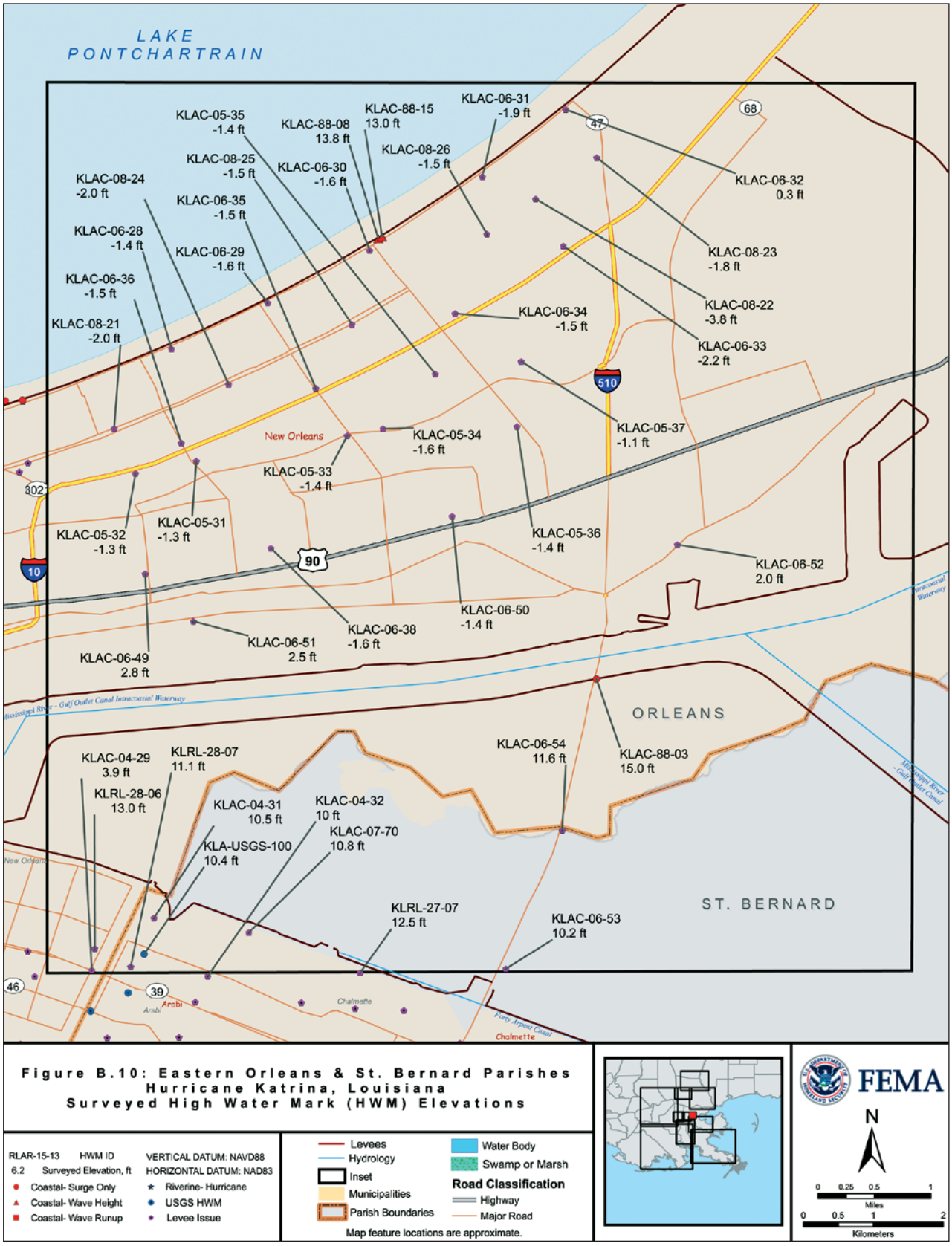

KLA-USGS-75 4.2 ft
KLA-USGS-76 4.2 ft
KLAC-06-24 4.3 ft
KLAC-06-18 17.0 ft
KLA-USGS-83 4.3 ft
KLA-USGS-62 16.4 ft
KLAC-08-18 16.2 ft
KLAC-08-17 8.9 ft
KLAC-06-23 16.1 ft
KLA-USGS-82 3.2 ft
KLAC-06-17 3.2 ft
KLA-USGS-74 4.4 ft
KLA-USGS-80 5.6 ft
KLAC-08-16 13.6 ft
KLAC-08-15 15.7 ft
KLA-USGS-101 12.8 ft
KLA-USGS-102 13.1 ft
KLA-USGS-103 13.4 ft
KLA-USGS-92 11.4 ft
KLAC-06-22 13.7 ft
KLA-USGS-81 3.5 ft
KLAC-06-20 12.5 ft
KLA-USGS-78 5.6 ft
KLAC-06-15 11.9 ft
KLA-USGS-79 5.4 ft
KLAC-08-08 7.1 ft
KLAC-08-10 8.3 ft
KLAC-06-14 13.2 ft
KLA-USGS-87 11.8 ft
KLAC-08-13 0.4 ft
KLAC-08-14 4.2 ft
KLA-USGS-73 3.8 ft
KLA-USGS-77 7.0 ft
KLA-USGS-91 7.0 ft
KLA-USGS-89 12.1 ft
KLAC-02-35 5.8 ft
KLAC-26-01 7.6 ft
KLA-USGS-88 15.0 ft
KLAC-02-36 8.5 ft
KLAC-06-21 12.0 ft
KLA-USGS-85 11.8 ft
KLAC-29-05 7.3 ft
KLAC-08-12 5.8 ft
KLAC-29-04 6.5 ft
KLAC-08-09 3.0 ft
KLA-USGS-84 14.8 ft
KLAC-29-03 4.8 ft
KLAC-08-11 5.9 ft
KLAC-29-07 2.4 ft
KLAC-29-02 4.4 ft
KLAC-29-01 5.1 ft
Jefferson
Plaquemines
St. Bernard
Orleans
Grand Isle
Port Sulphur
Empire
Buras-Triumph
Boothville-Venice
GULF OF MEXICO
Bayou la Loutre
Violet Canal
Bayou Terre aux Boeufs
Bayou Gauche
Bayou Grande Cheniere
Bayou Ronquille
Bayou Dupre
Bayou Mimi
Bayou Rigolettes
Bayou Sauvage
Bayou Biloxi
Bayou Terre



Figure B.9: Orleans, Jefferson, & St. Bernard Parishes Hurricane Katrina, Louisiana Surveyed High Water Mark (HWM) Elevations

RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Riverine- Hurricane
USGS HWM
Levee Issue

Levees
Hydrology
Inset
Municipalities
Parish Boundaries
Water Body
Swamp or Marsh
Road Classification
Highway
Major Road
Map feature locations are approximate.


LAKE PONTCHARTRAIN
KLAC-05-35 -1.4 ft
KLAC-88-08 13.8 ft
KLAC-88-15 13.0 ft
KLAC-06-31 -1.9 ft
KLAC-08-25 -1.5 ft
KLAC-06-30 -1.6 ft
KLAC-08-26 -1.5 ft
KLAC-08-24 -2.0 ft
KLAC-06-35 -1.5 ft
KLAC-06-32 0.3 ft
KLAC-06-28 -1.4 ft
KLAC-06-29 -1.6 ft
KLAC-08-23 -1.8 ft
KLAC-06-36 -1.5 ft
KLAC-08-22 -3.8 ft
KLAC-06-34 -1.5 ft
KLAC-08-21 -2.0 ft
KLAC-06-33 -2.2 ft
KLAC-05-37 -1.1 ft
New Orleans
KLAC-05-34 -1.6 ft
KLAC-05-33 -1.4 ft
KLAC-05-32 -1.3 ft
KLAC-05-31 -1.3 ft
KLAC-05-36 -1.4 ft
KLAC-06-52 2.0 ft
KLAC-06-50 -1.4 ft
KLAC-06-38 -1.6 ft
KLAC-06-51 2.5 ft
KLAC-06-49 2.8 ft
ORLEANS
KLAC-06-54 11.6 ft
KLAC-88-03 15.0 ft
KLAC-04-29 3.9 ft
KLRL-28-07 11.1 ft
KLRL-28-06 13.0 ft
KLAC-04-31 10.5 ft
KLAC-04-32 10 ft
KLAC-07-70 10.8 ft
KLA-USGS-100 10.4 ft
KLRL-27-07 12.5 ft
KLAC-06-53 10.2 ft
ST. BERNARD
Arabi
Chalmette
Figure B.10: Eastern Orleans & St. Bernard Parishes
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations
RLAR-15-13 HWM ID
6.2 Surveyed Elevation, ft
Coastal- Surge Only
Coastal- Wave Height
Coastal- Wave Runup
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Riverine- Hurricane
USGS HWM
Levee Issue
Levees
Hydrology
Inset
Municipalities
Parish Boundaries
Water Body
Swamp or Marsh
Road Classification
Highway
Major Road
Map feature locations are approximate.
FEMA
N
Miles
Kilometers

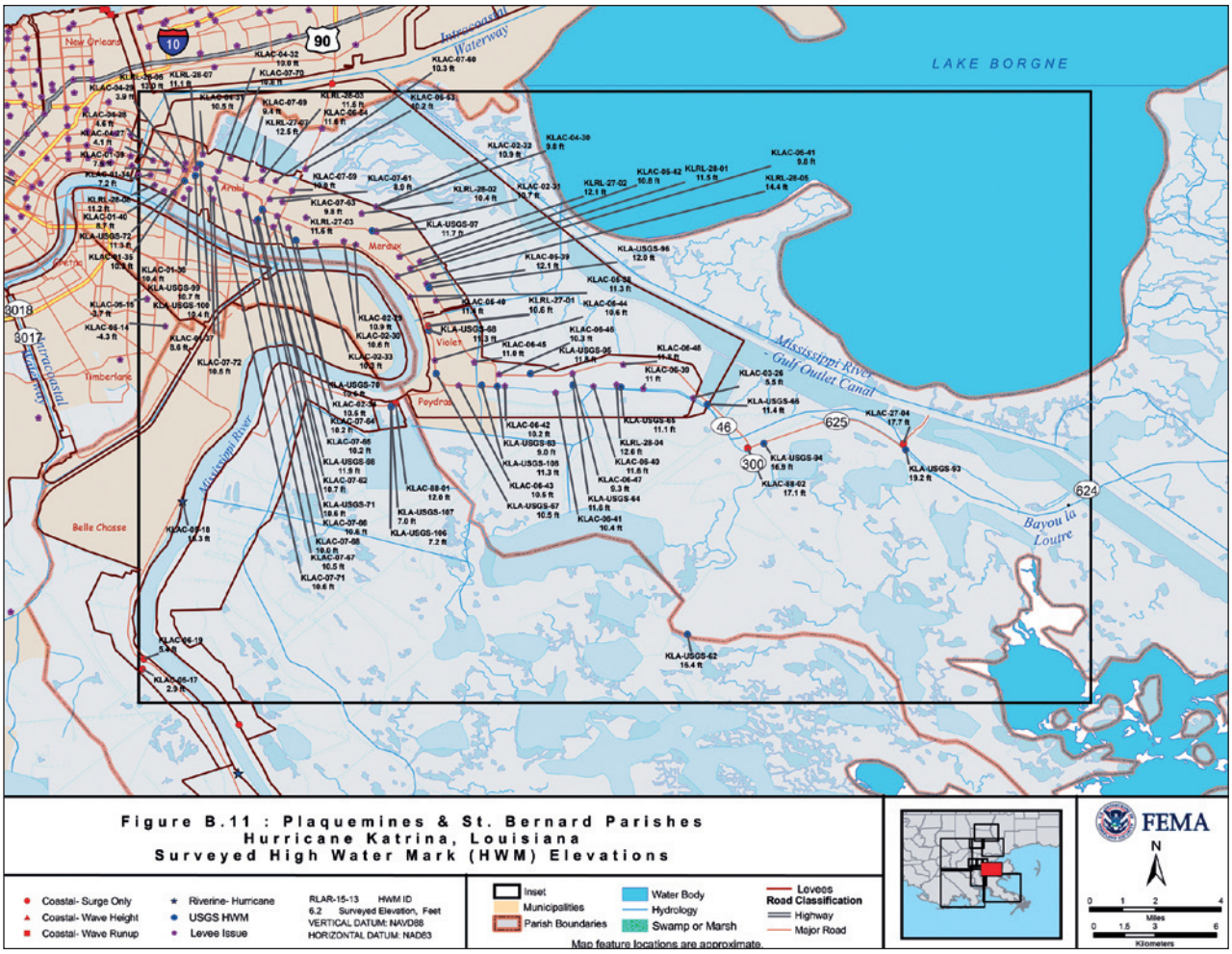


Figure B.11 : Plaquemines & St. Bernard Parishes
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations

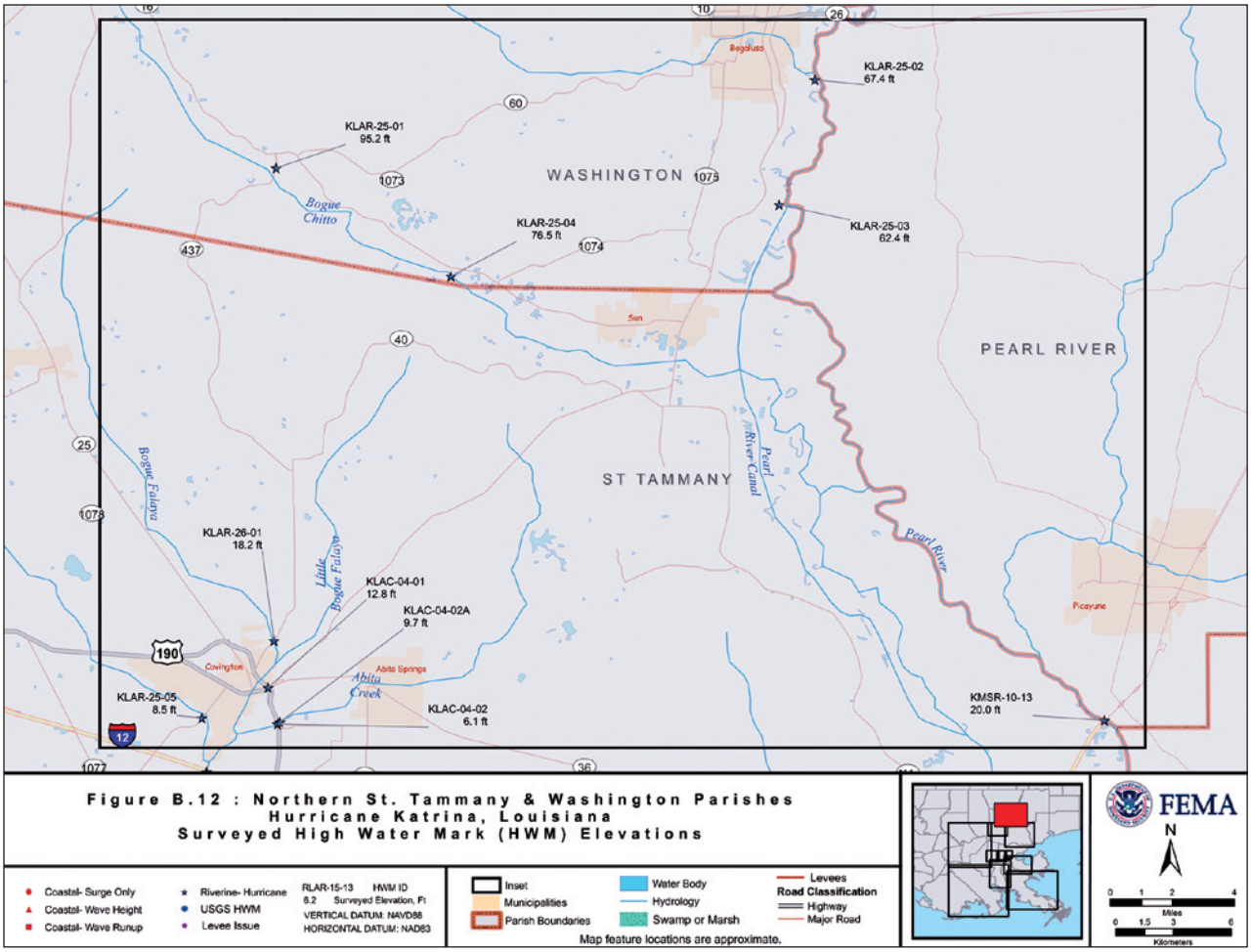
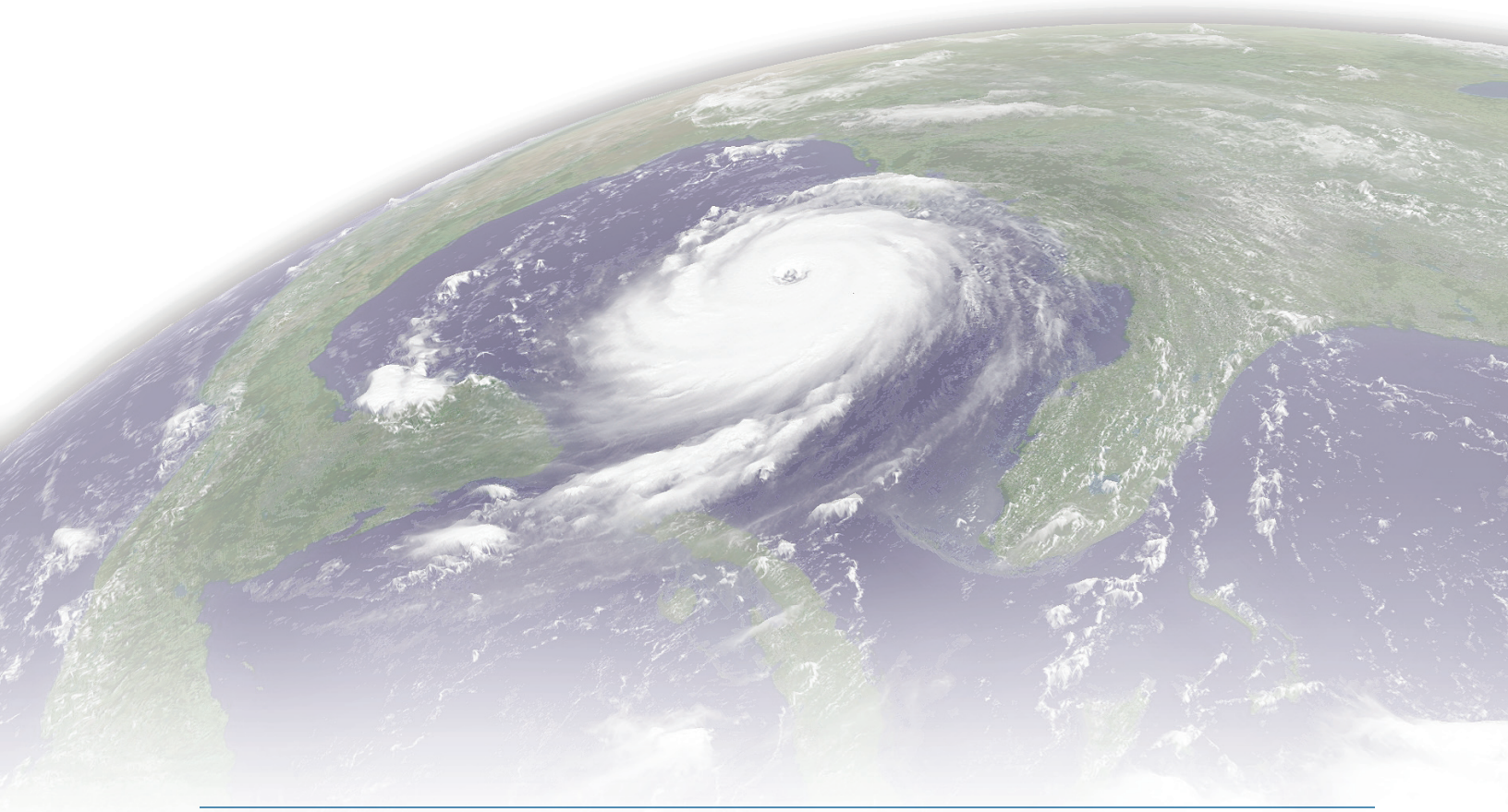
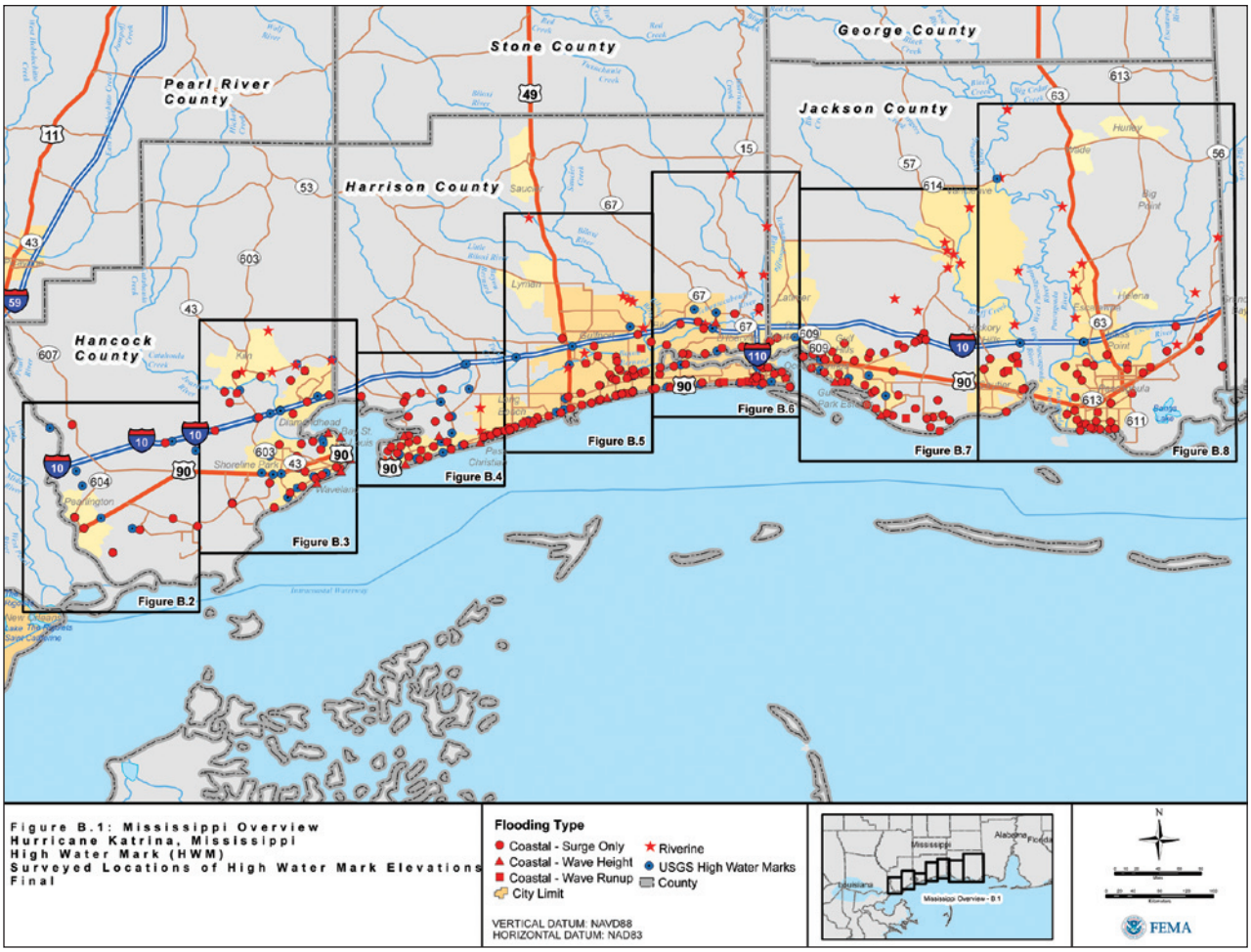


Figure B.12 : Northern St. Tammany & Washington Parishes
Hurricane Katrina, Louisiana
Surveyed High Water Mark (HWM) Elevations

High Water Marks in Mississippi




Stone County
George County
Pearl River County
Jackson County
Harrison County
Hancock County
Figure B.2
Figure B.3
Figure B.4
Figure B.5
Figure B.6
Figure B.7
Figure B.8
Figure B.1: Mississippi Overview
Hurricane Katrina, Mississippi
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final
Flooding Type
Coastal - Surge Only
Coastal - Wave Height
Coastal - Wave Runup
City Limit
Riverine
USGS High Water Marks
County
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Mississippi Overview - B.1
N
FEMA

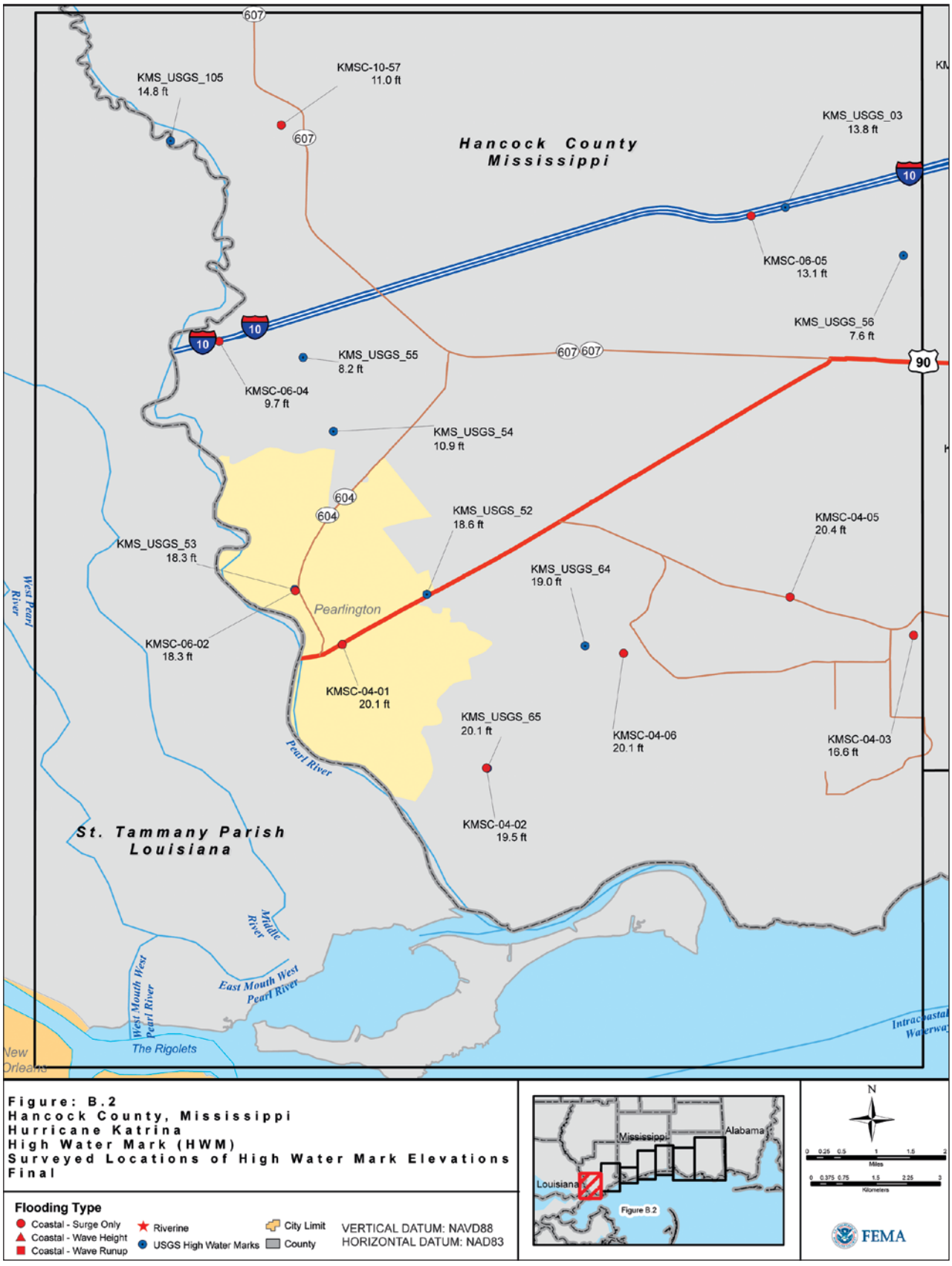

KMS_USGS_105
14.8 ft
KMSC-10-57
11.0 ft
KMS_USGS_03
13.8 ft
Hancock County
Mississippi
KMSC-06-05
13.1 ft
KMS_USGS_56
7.6 ft
KMS_USGS_55
8.2 ft
KMSC-06-04
9.7 ft
KMS_USGS_54
10.9 ft
KMS_USGS_52
18.6 ft
KMSC-04-05
20.4 ft
KMS_USGS_53
18.3 ft
KMS_USGS_64
19.0 ft
Pearlington
KMSC-06-02
18.3 ft
KMSC-04-01
20.1 ft
KMS_USGS_65
20.1 ft
KMSC-04-06
20.1 ft
KMSC-04-03
16.6 ft
KMSC-04-02
19.5 ft
St. Tammany Parish
Louisiana
West Pearl River
Pearl River
Middle River
East Mouth West Pearl River
West Mouth West Pearl River
The Rigolets
New Orleans
Intracoastal Waterway
607
604
10
90
Figure: B.2
Hancock County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final
Flooding Type
Coastal - Surge Only
Coastal - Wave Height
Coastal - Wave Runup
Riverine
USGS High Water Marks
City Limit
County
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Mississippi
Alabama
Louisiana
Figure B.2
N
Miles
Kilometers
FEMA



Figure: B.3
Hancock County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final

Flooding Type
- Coastal - Surge Only
- Coastal - Wave Height
- Coastal - Wave Runup
- Riverine
- USGS High Water Marks
- City Limit
- County

VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83

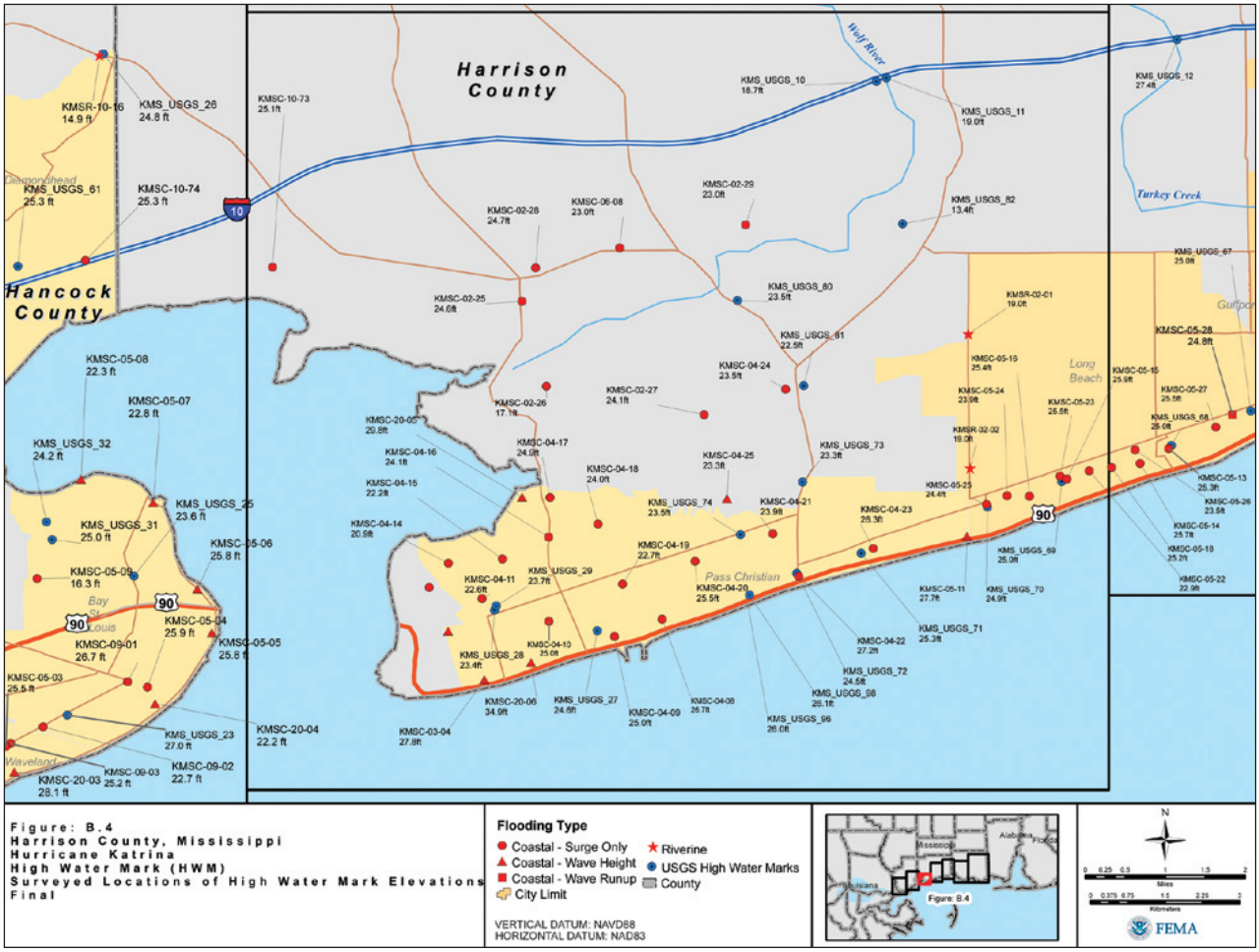

Harrison County
Hancock County
Wolf River
Turkey Creek
Long Beach
Pass Christian
Bay St. Louis
Waveland
Gulfport
KMSR-10-16 14.9 ft
KMS_USGS_26 24.8 ft
KMSC-10-73 25.1ft
KMS_USGS_10 18.7ft
KMS_USGS_11 19.0ft
KMS_USGS_12 27.4ft
KMS_USGS_61 25.3 ft
KMSC-10-74 25.3 ft
KMSC-02-28 24.7ft
KMSC-06-08 23.0ft
KMSC-02-29 23.0ft
KMS_USGS_82 13.4ft
KMS_USGS_67 25.0ft
KMSC-02-25 24.6ft
KMS_USGS_80 23.5ft
KMSR-02-01 19.0ft
KMS_USGS_81 22.5ft
KMSC-05-28 24.8ft
KMSC-05-08 22.3 ft
KMSC-04-24 23.5ft
KMSC-05-15 25.4ft
KMSC-05-15 25.9ft
KMSC-05-07 22.8 ft
KMSC-02-27 24.1ft
KMSC-02-26 17.1ft
KMSC-05-24 23.0ft
KMSC-05-23 26.5ft
KMSC-05-27 25.5ft
KMS_USGS_32 24.2 ft
KMSC-20-05 29.8ft
KMSR-02-02 19.0ft
KMS_USGS_68 25.0ft
KMSC-04-16 24.1ft
KMSC-04-17 24.0ft
KMSC-04-25 23.3ft
KMS_USGS_73 23.3ft
KMSC-04-18 24.0ft
KMSC-04-15 22.2ft
KMSC-05-25 24.4ft
KMSC-05-13 25.3ft
KMS_USGS_25 23.6 ft
KMS_USGS_74 23.5ft
KMSC-04-21 23.9ft
KMSC-04-23 25.3ft
KMSC-05-26 23.5ft
KMS_USGS_31 25.0 ft
KMSC-04-14 20.9ft
KMSC-05-14 25.7ft
KMSC-05-06 25.8 ft
KMSC-04-19 22.7ft
KMS_USGS_69 25.0ft
KMSC-05-18 25.2ft
KMSC-05-09 16.3 ft
KMSC-04-11 22.6ft
KMS_USGS_29 23.7ft
KMSC-04-20 25.5ft
KMSC-05-11 27.7ft
KMS_USGS_70 24.9ft
KMSC-05-22 22.9ft
KMSC-05-04 25.9 ft
KMSC-05-05 25.8 ft
KMSC-09-01 26.7 ft
KMS_USGS_71 25.3ft
KMSC-04-22 27.2ft
KMS_USGS_28 23.4ft
KMSC-04-10 25.0ft
KMS_USGS_72 24.5ft
KMSC-05-03 25.5 ft
KMS_USGS_98 25.1ft
KMSC-20-06 34.9ft
KMS_USGS_27 24.6ft
KMSC-04-09 25.0ft
KMSC-04-08 26.7ft
KMS_USGS_96 26.0ft
KMS_USGS_23 27.0 ft
KMSC-20-04 22.2 ft
KMSC-03-04 27.8ft
KMSC-09-02 22.7 ft
KMSC-09-03 25.2 ft
KMSC-20-03 28.1 ft
Figure: B.4
Harrison County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final
Flooding Type
Coastal - Surge Only
Coastal - Wave Height
Coastal - Wave Runup
City Limit
Riverine
USGS High Water Marks
County
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Figure: B.4
N
Miles
Kilometers
FEMA



Figure: B.5
Harrison County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final

Flooding Type

- Coastal - Surge Only
- Coastal - Wave Height
- Coastal - Wave Runup
- Riverine
- USGS High Water Marks
- City Limit
- County

VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83


Harrison County
Jackson County
Hurricane Creek
Tuxachanie Creek
Tchoutacabouffa River
Biloxi River
Bayou Bernard
Gulfport
Biloxi
D'Iberville
Latimer
St. Martin
Ocean Springs
Gulf Hills
KMSR-10-10 57.4ft
KMSR-10-09 32.5ft
KMSR-02-03 16.1ft
KMSC-10-41 22.0ft
KMSC-10-40 20.9ft
KMSC-10-52 21.0ft
KMSC-10-39 15.9ft
KMSC-10-38 17.1ft
KMSC-10-37 17.9ft
KMSC-10-51 14.6ft
KMSC-10-45 20.9ft
KMSC-10-48 21.4ft
KMSC-10-21 18.8ft
KMSC-06-16 20.7ft
KMSC-10-20 20.1ft
KMSC-10-47 21.0ft
KMSC-10-46 20.2ft
KMSC-10-22 19.7ft
KMSC-10-36 20.1ft
KMS_USGS_103 18.2ft
KMS_USGS_104 15.9ft
KMS_USGS_88 21.4ft
KMS_USGS_15 16.1ft
KMS_USGS_42 18.7ft
KMS_USGS_33 19.7ft
KMS_USGS_63 19.2ft
KMS_USGS_14 18.8ft
KMS_USGS_38 22.5ft
KMS_USGS_94 20.4ft
KMS_USGS_89 21.3ft
KMS_USGS_40 23.1ft
KMS_USGS_39 22.5ft
KMS_USGS_41 23.2ft
KMS_USGS_37 22.5ft
KMS_USGS_35 21.0ft
KMS_USGS_36 22.0ft
KMS_USGS_43 23.6ft
KMS_USGS_78 24.2ft
KMS_USGS_79 23.9ft
KMS_USGS_85 18.8ft
KMS_USGS_86 23.8ft
KMSC-02-17 8.7ft
KMSC-06-10 11.7ft
KMSC-02-18 15.5ft
KMSC-03-09 17.4ft
KMSC-02-19 18.7ft
KMSC-02-21 18.6ft
KMSC-02-24 12.1ft
KMSC-02-22 20.4ft
KMSC-02-20 19.0ft
KMSC-02-23 18.9ft
KMSC-07-24 19.3ft
KMSC-07-25 18.8ft
KMSC-07-26 19.1ft
KMSC-07-21 22.8ft
KMSC-07-22 22.7ft
KMSC-07-23 23.4ft
KMSC-07-20 22.2ft
KMSC-07-19 23.4ft
KMSC-15-06 25.7ft
KMSC-09-12 23.6ft
KMSC-09-29 18.6ft
KMSC-09-21 15.9ft
KMSC-09-28 18.2ft
KMSC-09-17 15.5ft
KMSC-09-22 15.4ft
KMSC-09-10 23.3ft
KMSC-09-11 24.7ft
KMSC-09-09 25.0ft
KMSC-09-16 23.8ft
KMSC-09-14 23.2ft
KMSC-09-15 23.5ft
KMSC-09-18 18.2ft
KMSC-09-19 18.0ft
KMSC-09-20 16.6ft
KMSC-09-23 16.6ft
KMSC-10-50 16.6ft
KMSC-03-08 16.7ft
KMSC-06-09 11.7ft
KMSC-03-07 26.2ft
KMSC-10-62 19.9ft
KMSC-10-42 21.1ft
KMSC-10-43 20.1ft
KMSC-10-44 20.2ft
KMSC-10-53 20.1ft
KMSC-04-33 20.6ft
KMSC-04-32 20.0ft
KMSC-04-31 20.9ft
KMSC-04-30 20.6ft
KMSC-04-29 20.8ft
KMSC-04-27 19.7ft
KMSC-04-25 21.1ft
KMSC-15-01 20.6ft
KMSC-15-02 20.5ft
KMSC-03-01 20.8ft
KMSC-08-16 19.0ft
KMSC-08-17 22.2ft
KMSC-08-14 19.4ft
KMSC-15-05 22.5ft
KMSC-08-15 21.7ft
KMSC-15-04 21.0ft
KMSC-03-02 25.8ft
KMSC-04-26 23.7ft
KMSC-06-14 21.4ft
KMSC-06-15 20.5ft
KMSC-06-13 22.0ft
10
90
110
Figure: B.6
Figure: B.6
Harrison County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final
Flooding Type
Coastal - Surge Only
Coastal - Wave Height
Coastal - Wave Runup
Riverine
USGS High Water Marks
City Limit
County
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Mississippi
Alabama
Louisiana
N
0 0.25 0.5 1 1.5 2
Miles
0 0.375 0.75 1.5 2.25 3
Kilometers
FEMA


Jackson County
Bluff Creek
Moungers Creek
Pascagoula River
Latimer
Gulf Hills
St. Martin
Ocean Springs
Biloxi
Gulf Park Estates
Hickory Hills
Gautier
KMSR-10-06 29.7ft
KMSR-10-05 19.6ft
KMSR-10-04 11.0 ft
KMSR-10-08 7.1ft
KMSR-10-03 11.7ft
KMSC-10-17 9.4ft
KMSC-10-26 21.0 ft
KMSC-10-27 11.4ft
KMS_USGS_16 14.4ft
KMSC-10-29 15.6ft
KMSC-10-28 18.9ft
KMSC-10-21 18.8ft
KMS_USGS_88 21.4ft
KMSC-10-48 21.4ft
KMSC-06-16 20.7ft
KMSC-10-20 20.1ft
KMSC-06-23 16.4ft
KMSC-06-22 16.4ft
KMSC-08-07 15.8ft
KMSC-06-11 15.3ft
KMSC-10-07 13.3ft
KMSC-10-08 14.0 ft
KMSC-10-47 21.0ft
KMSC-10-23 18.4ft
KMSC-10-35 18.6ft
KMSC-10-25 2.0 ft
KMSC-10-46 20.2ft
KMSC-10-22 19.7ft
KMSC-10-34 19.5ft
KMSC-10-24 18.9ft
KMSC-06-24 16.1ft
KMSC-06-25 18.1ft
KMSC-10-33 22.5ft
KMSC-10-30 17.2ft
KMSC-10-31 16.5ft
KMSR-10-02 14.5ft
KMSC-10-10 14.3ft
KMSC-04-29 20.8ft
KMSC-04-27 19.7ft
KMSC-10-36 20.1ft
KMSC-10-32 22.0 ft
KMSC-08-08 18.9ft
KMSR-10-01 14.5ft
KMSC-02-16 19.4ft
KMSC-06-19 22.4ft
KMS_USGS_90 21.6ft
KMS_USGS_91 17.3ft
KMSC-08-06 14.3ft
KMSC-06-14 21.4ft
KMS_USGS_94 20.4ft
KMSC-03-06 21.1ft
KMSC-08-10 19.4ft
KMSC-03-12 18.8ft
KMS_USGS_89 21.3ft
KMSC-06-17 20.1ft
KMSC-06-18 21.3ft
KMSC-02-13 19.0 ft
KMSC-10-09 14.4ft
KMSC-06-15 20.5ft
KMSC-08-09 19.3ft
KMSC-08-05 14.5ft
KMSC-06-13 22.0ft
KMSC-02-15 19.2ft
KMS_USGS_92 19.1ft
KMSC-04-26 23.7ft
KMSC-02-12 18.4ft
KMS_USGS_43 23.6ft
KMSC-03-13 20.4ft
KMSC-08-11 19.7ft
KMSC-03-05 21.1ft
KMSC-08-12 21.2ft
KMSC-03-11 18.6ft
KMSC-03-10 18.2ft
KMSC-02-14 19.9ft
KMSC-08-13 17.6ft
KMSC-06-21 18.3ft
KMSC-02-10 20.5ft
KMSC-02-11 16.9ft
10
90
90
Figure: B.7
Jackson County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final
Flooding Type
Coastal - Surge Only
Coastal - Wave Height
Coastal - Wave Runup
Riverine
USGS High Water Marks
City Limit
County
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
Mississippi
Alabama
Louisiana
Figure: B.7
N
Miles
FEMA



Figure: B.8
Jackson County, Mississippi
Hurricane Katrina
High Water Mark (HWM)
Surveyed Locations of High Water Mark Elevations
Final

Flooding Type

- Coastal - Surge Only
- Coastal - Wave Height
- Coastal - Wave Runup
- Riverine
- USGS High Water Marks
- City Limit
- County

VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83

HURRICANE *Katrina*

IN THE GULF COAST



G. Procedure Memorandum 34 – Interim Guidance for Studies Including Levees

Federal Emergency Management Agency

Washington, D.C. 20472

August 22, 2005

MEMORANDUM FOR: Regional Directors
Regions I - X

FROM: David I. Maurstad, Acting Director
Mitigation Division

SUBJECT: Procedure Memorandum 34 — Interim Guidance for Studies Including Levees

Background: Throughout the United States, levees protect numerous communities and large expanses of agricultural land from floods. Their importance in mitigating flood hazards and their relevance to the National Flood Insurance Program (NFIP) are indisputable. However, riverine and coastal levees, in the aggregate, stretch for tens of thousands of miles, and information on their location, structural integrity, and certification often is outdated or missing altogether.

Issue: To address this challenge, a Levee Coordination Committee—including representatives from FEMA, other Federal agencies, and States—is examining current levee regulations and assisting in the development of a long-term policy that protects citizens and property, while accommodating the needs of the NFIP. This memorandum helps to clarify the entities responsible for providing information on levees identified during a mapping project.

Action Taken: Until the new policy is developed, this memo provides interim guidance to minimize delays in near-term mapping studies. The attached flow chart supplements FEMA's procedure memorandums 30 and 32. This information is in conformance with Section 65.10 of the NFIP regulations.

Supplement to Procedure Memo 30—FEMA Levee Inventory System.
Mapping partners – CTPs, IDIQs, OFAs, etc. -- should continue providing information about levees located in or adjacent to study areas. Information should be provided via the FEMA Levee Inventory System (FLIS) according to Procedure Memorandum 30 and the instructions available on the FLIS Web site located at http://flis.pbsjdfirm.com. The FLIS will be accessed via the MIP after release 3.0.

Levee coordinates should be gathered at a level of detail consistent with GIS accuracy and digital Flood Insurance Rate Map (FIRM) standards. Mapping partners who do not already have access to the FLIS can contact the National Service Provider at (703) 960-8800.

August 22, 2005

Supplement to Procedure Memo 32—Levee Review Protocol.

The protocol for levee reviews, particularly the details provided in Table 1 of Procedure Memorandum 32, is revised according to the attached flow chart.

Identification of Levees

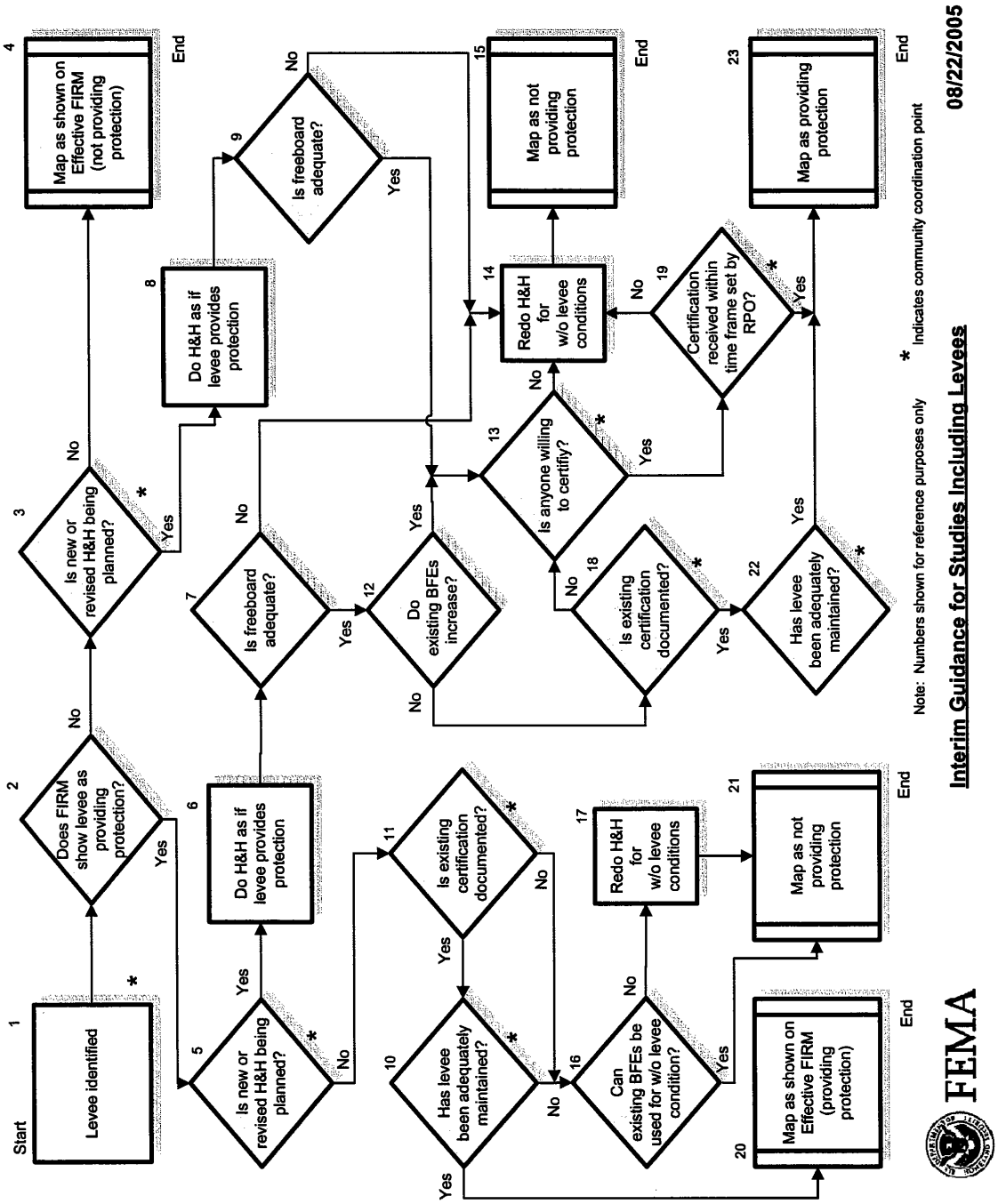
It is critical that all levees within the scope of the mapping project be identified early in the mapping project, ideally no later than the scoping meeting. The role of all mapping partners, including coordination with the State and other Federal partners (e.g., U.S. Army Corps of Engineers), related to review of levee certification should be clearly identified as part of the scoping process. When levees are identified at the scoping meeting the community must be informed of the data requirements for FEMA to recognize a levee as providing protection from the 1-percent-annual-chance flood (base flood) on the FIRM. In accordance with 44 CFR Section 65.10(a), it is the responsibility of the community or other party seeking recognition of a levee system at the time of a flood risk study or restudy to provide the data outlined in 44 CFR Section 65.10. FEMA will not be conducting detailed examinations of levees to determine how a structure or system will perform in a flood event. In addition, the community or party seeking recognition should be provided with a deadline for submitting the data and informed that if the data are not submitted by the deadline, the levee cannot be recognized as providing protection from the base flood as part of the current mapping effort. However, a revision could be initiated once data are available.

Early identification of levees allows the mapping partner to outline to the community, or party seeking recognition, their responsibilities and FEMA's expectations to minimize study delays. In order to aid our mapping partners in properly assessing how to handle levee mapping issues, we have generated the below flowchart.

cc: See Distribution List

Distribution List (electronic distribution only):

Office of the Mitigation Division Director
Risk Assessment Branch
Risk Identification Branch
Flood Insurance and Mitigation Divisions in FEMA Regional Offices
Office of Legislative Affairs
Office of General Counsel
National Service Provider
Systems Engineering and Technical Assistance Contractor
Map Service Center


Start
1
Levee identified
2
Does FIRM show levee as providing protection?
3
Is new or revised H&H being planned?
4
Map as shown on Effective FIRM (not providing protection)
End
5
Is new or revised H&H being planned?
6
Do H&H as if levee provides protection
7
Is freeboard adequate?
8
Do H&H as if levee provides protection
9
Is freeboard adequate?
10
Has levee been adequately maintained?
11
Is existing certification documented?
12
Do existing BFEs increase?
13
Is anyone willing to certify?
14
Redo H&H for w/o levee conditions
15
Map as not providing protection
16
Can existing BFEs be used for w/o levee condition?
17
Redo H&H for w/o levee conditions
18
Is existing certification documented?
19
Certification received within time frame set by RPO?
20
Map as shown on Effective FIRM (providing protection)
21
Map as not providing protection
22
Has levee been adequately maintained?
23
Map as providing protection
Yes
No
*
Note: Numbers shown for reference purposes only
* Indicates community coordination point
Interim Guidance for Studies Including Levees
08/22/2005
FEMA

HURRICANE *Katrina* IN THE GULF COAST

H. Continuity of Operations (COOP) and Environmental Issues for Infrastructure

In every community, infrastructure plays a key role in operations of critical facilities as well as sustaining everyday functions of the government, citizens, and businesses. Without basic utilities such as electricity and water, community functions can become crippled and critical facilities can lose the ability to provide vital services such as health care and public safety.

During disaster events that are severe in magnitude (longer return intervals) and scope (area) like Hurricane Katrina, utility systems are generally offline for longer periods of time than for the more frequent or smaller storms. Often, substantial infrastructure not typically affected in smaller storms is damaged or destroyed. These "big ticket" systems are needed to enable the smaller parts of the system to operate. Only the larger contractors have the cashflow and bonding capacity to handle much larger scale projects expected if a utility system major overhaul

or repair is required. Furthermore, the less typical or more complex the system, the more focused the skill set that is required. Because these larger and more complex systems were not anticipated to be damaged in such a fashion, larger storm events also awaken the owners to the realization that they were more threatened or at higher risk than originally thought. This may result in rethinking the situation and increasing the capacity or reducing the risk to such high priority systems for future events. These efforts require time to study the situations, design options, brief decision-makers, gather any funding required for high-price repairs or upgrades, and implement the plan. However, for all of the time that systems remain offline or at partial capacity, there are negative impacts to regional economics.

H.1 Electrical Power Systems

Electricity is generally distributed from power stations to users via transmission lines, substations, transformers, and secondary services. During major storms, including hurricanes, wind and flooding can impact power systems by knocking down power lines or directly damaging transformers or substations. Approximately 70 percent of all power outages are caused by weather-related events.

Interruption in service not only disrupts peoples' lives and businesses, but can also be life-threatening for those who are dependent on electrically-powered medical equipment, such as respirators. Longer duration loss of power has a wider impact on the whole community and its economy; during outages, businesses cannot fully function and many residents can be out of work for several days or even weeks.

For critical and essential facilities such as hospitals or police stations, the loss of power can severely dampen functioning capacity. Hospitals are required to have emergency generators, which must be sized to carry specific electrical loads based on the design occupancy. On the other hand, police stations, Emergency Operations Centers (EOCs), and other key government facilities are usually equipped with generators, but the generators only provide a fraction of the power normally used, requiring the facilities to run at limited capacity. Facilities must plan and prioritize ahead of time to address how they will provide essential services with limited power, how they will plan for water supply needs (e.g., drinking water, water for food preparation and chillers, etc.) and what contingencies they have for those services they cannot provide.

H.1.1 Regional Impacts

As a result of Katrina, over 1.7 million people in the Gulf states and 1.3 million customers in southeastern Florida lost power when the storm made landfall. Electrical distribution systems were heavily impacted in Mississippi by Hurricane Katrina. Fuel pipelines were damaged, resulting in fuel shortages throughout the southeast. These fuel shortages came very close to shutting down electrical utility pole treatment operations, which are critical to the restoration of power. FEMA expedited coordination with local and state officials, and utility pole and oil company executives to ensure that tens of thousands of gallons of various fuel types necessary for utility pole treatment continued to be supplied when and where needed. Without such quick coordination, the electrical system restoration would have taken much longer. It is these unexpected

incidences caused by major storms that have unanticipated, yet potentially severe consequences in restoration, repair, or reconstruction.

H.2 Water Supply Systems

Water is delivered to users from treatment plants via water distribution systems composed of pipes, storage tanks, and pumps. Water distribution systems depend on electricity to power the pumps that deliver the water to the end user. Most systems are equipped with backup generators powered by fuel, which require human intervention for refueling and are, therefore, vulnerable during storm events such as hurricanes. The systems can also be directly impacted if pumps are flooded and contaminated, or if water mains are damaged.

Water is obviously essential to sustain basic daily activities within communities, and for many critical and essential facilities such as hospitals, water must be available in order to provide the most basic health care services to the community. For example, the loss of domestic water prevented the use of air conditioning units and curtailed operations at the Garden Park Medical Center in Gulfport. The air conditioning units at the nearby Gulfport Memorial Hospital remained operational because the hospital was connected to a municipal well as an alternate water source.

H.2.1 Regional Impacts

Because of damaged caused by Katrina, a water main in downtown New Orleans broke, resulting in the loss of potable water within the city. Additionally, many coastal towns sustained heavy damage to potable water systems. Since the storm surge impacted areas much farther inland than originally thought possible, as part of recovery, these towns have to rethink how best to replace the water lines and where to place them. This requires researching potential new sites, purchasing right-of-ways, determining where the higher hazard limits are (such as velocity zones), deciding what amount of risk (based on the hazard limits) to deem acceptable (this is done by community decision-makers), and determining how best to either avoid risks or design to mitigate against them. There are parts of systems that simply cannot be economically designed or constructed to withstand major storms such as Hurricane Katrina. In these situations, the designers must provide options to the decision-makers, who must then decide what levels of risk they are willing to accept. This process, which includes gathering information as to the hazards, risks, damages, grant programs, and funding avenues; developing the concepts and options using the information gathered; briefing the appropriate decision-makers and receiving feedback; and modifying solutions and designs as appropriate until ultimate decisions are made, takes time.

With so much debris created by major events (millions of cubic yards), high and wide piles of debris can be everywhere. Debris removal contractors sometimes pick up debris prior to evaluating what exactly is being picked up. With their heavy machinery blindly delving into large debris piles, they sometimes unwittingly pull up fire hydrants and other system components, further damaging the system, during recovery operations.

H.3 Sewage Treatment Facilities

Sewage treatment facilities process wastewater conveyed from individual businesses, residences, and other community facilities via a system of pipes. Flow to the treatment facilities is generally gravity flow because it is more economical and easy to maintain. As a result, sewage conveyance and treatment systems are typically in low-lying areas. Treated sewage is also generally released into water bodies, so these treatment facilities are often in the floodplain, making them more vulnerable to damage from flooding.

As with water treatment systems, sewage treatment requires electricity for pumping and processing. When electrical power service is interrupted, treatment facilities must depend on generators to remain functional. These facilities require human intervention and a fuel source.

Additionally, breaks in the conveyance system as a result of a major storm event can lead to environmental contamination, as well as the spread of disease, as humans come in contact with unprocessed sewage materials. Also, when sanitary and stormwater sewer systems are combined, the system can become overwhelmed during a major precipitation or flooding event, which can result in an overflow release of untreated sewage at either overflow points designed as part of combined sewer systems or at the treatment plant itself. Similarly, when there is infiltration of stormwater into the sanitary sewer system via cracks in pipes, manholes, or illegal connections, the system might also be pushed beyond capacity, leading to an overflow release at the treatment plant. Overwhelming the system might also lead to sewer backups, which can damage the interior of buildings and pose health risks.

H.3.1 Regional Impacts

In the case of Hurricane Katrina, sewage treatment plants, sewage lift stations, and other system components were heavily impacted. As with the water systems, areas farther inland than originally thought vulnerable were impacted. Those areas already deemed vulnerable received far more floodwaters than expected. With high flood levels and surge velocities come significant amounts of debris, which can impact structures and facilities with tremendous force, leading to further damage to infrastructure.

H.3.2 Facility-Specific Impacts

A wastewater treatment plant in Diamondhead, Hancock County, Mississippi, with ground elevations of roughly 6 feet, had saltwater flooding up to 20+ feet. The saltwater flooding caused destruction of many system components, including pumps and electrical panels, and resulted in hundreds of thousands of dollars in damages. Furthermore, the system did not operate up to capacity, resulting in raw sewage bypassing the treatment facility and traveling directly into nearby rivers and streams. Multiple lift stations were similarly damaged when their pump systems and electrical panels were destroyed by the saltwater.

Mitigation/improvement options are being reviewed for the system. One option is to move the plant to a higher location, which would require purchasing new land, building a redesigned tie-in system to accommodate the new location, and planning for completion of various grant

applications for Federal funds, without which the project could not proceed. For lift stations, there was discussion about what flood levels to design for in terms of elevation and/or protection of electrical panels and critical and essential gear, since Katrina elevations were simply not viable. Options must be designed by architectural and engineering firms who understand the grant programs in order to present viable, achievable, and fundable options in their coordination with decision-makers.

H.4 Pre-Disaster Planning for Critical and Essential Infrastructure

In the preceding sections, the MAT has detailed the issues associated with the loss of critical and essential infrastructure, both to individual facilities and to entire communities. This section will briefly discuss mitigation and planning efforts that can be implemented at any organizational or municipal level to significantly reduce the impacts of future disasters, and why it would be beneficial to any community to undertake these efforts.

H.4.1 Continuity of Operations Plans

One of the most important tools that a community, organization, or individual facility can develop is a Continuity of Operations (COOP) plan. COOP plans have long been a priority of the Federal Government, and Federal Preparedness Circular 65 (July 26, 1999) has made the preparation of COOP plans mandatory for all Federal agencies. According to this document, COOP planning is an effort to ensure that the capability exists to continue critical and essential agency functions across a wide range of potential emergencies. The objectives of a COOP plan include:

a. Ensuring the continuous performance of an agency's critical and essential functions/operations during an emergency

b. Protecting critical and essential facilities, equipment, records, and other assets

c. Reducing or mitigating disruptions to operations

d. Reducing loss of life, and minimizing damage and losses

e. Achieving a timely and orderly recovery from an emergency and restoration of full service to customers

An effective COOP plan will integrate with state Comprehensive Emergency Management Plans (CEMPs) and local contingency plans, and will allow for site-specific refinement. As a community or an individual facility determines its critical and essential functions and operations, the protection of these assets becomes clearer to all involved. The main components of a viable COOP plan are:

- Identification of critical and essential functions
- Delegations of authority/orders of succession

- Alternate facilities
- Interoperable communications
- Vital records and databases
- Tests, training, and exercises

This planning process seeks to bring together all stakeholders within a community or planning region to prioritize services, determine backup assets, and establish best practices for quickly returning critical and essential services to citizens after an incident.

H.4.2 Addressing Losses of Infrastructure in a COOP Plan

A robust COOP plan at the state or municipal level should include protection of utility services as an critical and essential function. As such, the planning process would bring together all stakeholders (i.e., utility providers, government agencies, first responders, and others) to discuss the best practices for resumption of service immediately following an incident. Because basic utilities are integral to such a wide number of other critical and essential functions and to effective communication, the COOP plan should address losses of key utility infrastructure on two levels:

1. **The immediate, post-incident actions** – EOCs should be chosen based on their ability to operate without utilities. Sites with generators, portable bathroom facilities, and supplies of potable water must be chosen or developed in order to adequately address resumption of critical and essential functions.

2. **The longer-term, recovery actions** – An effective COOP plan will have documented best practices for resumption of service in the event of utility infrastructure loss. Some systems, because they cannot be reasonably duplicated or protected before an incident, will have to be repaired or replaced during the recovery phase. A COOP plan should include contact numbers from neighboring municipalities, states, or contractors that can be called upon to assist with recovery efforts. Likewise, emergency supplies that will be needed to restore utilities to certain priority locations can often be pre-positioned in hardened facilities.

Using hurricane planning as a specific example, the scope of such incidents are often such that neighboring towns are not able to adequately support each other and there is widespread damage to critical and essential utility infrastructure. In areas where hurricanes are possible, potential storm inundation and damage should be considered when establishing EOC sites, pre-positioning needed supplies, or developing communications strategies. With a hurricane the size and strength of Katrina, the only effective planning step is to ensure that municipal plans are integrated with state-wide plans and resources from neighboring towns, counties/parishes, and states identified. Not every emergency can be adequately mitigated with the resources available to a town or utility provider; however, the planning process seeks to reduce risk wherever possible and allow for accelerated resumption of services. In incidents similar to Hurricane Katrina, that acceleration may only allow utility service to be restored 6 weeks later, as opposed to 8 weeks, but any improvement is essential to the affected community.

H.4.3 Steps Beyond COOP Planning

A good disaster or emergency preparedness plan will address the larger issues of how to continue operations and provide critical and essential services after a variety of potential impact events. The COOP plan, however, should just be one tool used by communities to achieve proper emergency preparedness. Other steps that can be taken to reduce the impact of future incidents include:

1. **Critical Infrastructure Identification, Assessment, and Mitigation –** Threat and vulnerability assessments should be performed on all assets identified as critical and essential. For utilities, the buildings, delivery systems, and associated infrastructure can all be assessed for potential threats. These data can be used to correctly prioritize limited protection budgets. A high-quality, normalized threat assessment will provide a community with recommendations about which threats can be cost-effectively mitigated. Where possible, critical and essential infrastructure can be hardened or relocated to reduce future risk.

2. **Training and Exercises –** A COOP plan is only effective when stakeholders have been adequately trained. Exercises (tabletop, functional, or full-scale) are excellent ways to test the adequacy of plans and assess the participants. Lessons learned from exercises can be used to improve planning documents and identify correctable weaknesses.

3. **Frequent Stakeholder Communication –** This step is integral to all others and is the only real way of preparing for and responding to emergency incidents. As key stakeholders become familiar with each other, the common benefits of planning are more easily realized. Cooperation on establishing EOCs, communications protocols, and conducting exercises before an incident is the best method of ensuring cooperation during the incident.

All components described in this planning process are fully scalable and can be implemented by communities and/or utilities of all sizes. A rigorous approach to planning and mitigation will greatly reduce the pains of response and the costs of recovery.

HURRICANE Katrina IN THE GULF COAST

I. Description of Sampling and Analytical Methods

As discussed in Chapter 8, samples of materials were collected from a number of flood-damaged buildings. Due to the damage to the materials in most of the buildings from the standing water, a large number of the samples were collected by breaking off a piece of already damaged wall finish. In other cases, a razor knife or drywall saw was used to cut through the surfaces and extract suitably sized samples. All bulk samples were then double sealed in plastic bags for transport to the Wonder Makers office in Kalamazoo, Michigan. Samples were then divided as necessary or prepared for submission to a laboratory for the requested analytical tests.

I.1 Biological Bulk Samples

I.1.1 Fungal Bulk Samples

For each sample collected in the field, a laboratory procedure was necessary to prepare it for analysis for mold, and particulates. The bagged samples were carefully opened under controlled conditions and visually examined. Any visibly suspected biological contamination was captured for analysis by using a commercially available Air-O-Cell cassette connected to a high volume vacuum pump. The pump/cassette sampling apparatus was calibrated to 15 liters per minute (lpm) according to the manufacturer's specifications. The cassette was then carefully

hovered over the surface to collect particles from the visibly impacted areas. Sample analysis was conducted in conformance with Wonder Makers Environmental's written analytical standard operating procedures, using light microscopy techniques. A minimum of 15 percent of the sample trace area was analyzed for each category of particulate (fungal spores, fibers, and opaque particles) identified, with fungal types identified to genus level when possible. An additional 12 to 17 percent of the sample was qualified to improve the accuracy of the analysis, noting any bioaerosols that were not quantified. For sample preparation, the collection slide was removed from the cassette, mounted under a cover slip, media side up, with Calberlas staining solution, and analyzed by direct microscopic examination at 1,000 times (1,000x) magnification with immersion oil used to connect the microscope objective to the cover slip. Sample results were reported as identified fungal spore types and presented in order of preponderance. If no spores were detected or observed during analysis, the result was reported as below minimum detectable limits (BMDL).

I.1.2 Bacterial Surface Swab Samples

As noted in the previous section, the bagged samples had to be prepared for submission to the laboratory. Each bag was carefully opened under controlled conditions and visually examined. Any visibly-suspect biological contamination was captured for analysis by using a commercially available sterile swab. These biological swabs were collected from various surfaces to yield quantitative and qualitative amounts of viable bacterial organisms. Sterile biological swabs and collection ampules containing a general transport medium were provided by a commercial manufacturer. Samples were collected based on a 2-inch by 2-inch template yielding 4 square inches of sample area. Samples were collected by wetting the cotton end in the transport medium and then rolling the swab completely across a surface to bring the entire surface of the swab into contact with the measured surface area. Disposable templates with predetermined dimensions were used to define the sampled area, which was then recorded on the sample collection log. The inoculated swabs were then inserted into the ampules and placed into a cooler containing fresh ice packs for overnight shipment to Aerotech Laboratories, Inc., in Phoenix, Arizona, for sample analysis. Cultures were propagated on standard blood agar medium for enumeration. Aerotech Laboratories is a recognized Environmental Microbiology Proficiency Analytical Testing (EMPAT) and Environmental Microbiology Laboratory Accreditation Program (EMLAP) certified laboratory. Sample results were reported as colony forming units per square centimeter (cfu/cm ^{2}).

I.2 Chemical Samples

Following preparation of the biological bulk samples and biological surface swab samples, the remaining sample materials were forwarded to Clayton Group Services in Detroit, Michigan. If enough sample material was present, the samples were divided and prepped for numerous chemical analyses. As authorized by the Building Engineering Sciences and Technology Team (BESTT), samples were analyzed using EPA methods for organochlorine pesticides, PCBs, diesel range organics (DROs), and 13 common heavy metals. The information was recorded on the chain of custody and collection log and sent with the samples to Clayton Group Services.

I.3 Sampling and Laboratory Test Results

The results of the various laboratory tests conducted on the material samples collected in the field are provided on the pages that follow. Please refer to the legends and notes listed at the end of this appendix when reviewing the sample results.

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Fungal Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-01	Residence at Elysian Fields: Wall Materials Below Water Line (Downstairs living room-east wall/Two layers of plaster, paint, and cloth from below the water line)	GNB (cfu/cm^2):	6,720	Indicator Organisms:	BMDL	Chlordane:	49	BMDL	18,000	Antimony:	BMDL
		GPB (cfu/cm^2):	746	Common/ Target Organisms:	BMDL	alpha-Chlordane:	BMDL			Arsenic:	1,200
		Other:	BMDL	Hyphae:	BMDL	gamma-Chlordane:	5.7			Beryllium:	BMDL
		Total:	7,460			Other:				Cadmium:	670
						DDD:	6.7			Chromium:	3,300
						Heptaclor:	4.0			Copper:	1,000
										Lead:	64,000
										Mercury:	120
										Nickel:	8,600
										Selenium:	910
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	210,000
6379-02	Residence at Elysian Fields: Wall Materials Below Water Line (Downstairs living room – east wall/ Insulation from wall cavity below water line)	GNB (cfu/cm^2):	19,200	Indicator Organisms:	No	Chlordane:	92	BMDL	150,000	Antimony:	650
		GPB (cfu/cm^2):	BMDL	Common/ Target Organisms:	Chaetomium	alpha-Chlordane:	6.0			Arsenic:	17,000
		Other:	BMDL	Hyphae:	Yes	gamma-Chlordane:	16			Beryllium:	850
		Total:	19,200			Other:				Cadmium:	42,000
						Heptaclor:	7.5			Chromium:	25,000
						Methoxychlor:	44			Copper:	81,000
										Lead:	130,000
										Mercury:	260
										Nickel:	14,000
										Selenium:	BMDL
										Silver:	350
										Thallium:	BMDL
										Zinc:	4,800,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Fungal Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-03	Residence at Elysian Fields: Wet Sludge (Living room floor/ Sludge [wet])	GNB (cfu/cm^2):	40,600	Sample was wet and could not be microvacuumed		Chlordane:	25	BMDL	85,000	Antimony:	650
		GPB (cfu/cm^2):	BMDL			alpha-Chlordane:	27			Arsenic:	17,000
		Other:	BMDL			gamma-Chlordane:	47			Beryllium:	850
		Total:	40,600			Other:				Cadmium:	42,000
						DDT:	7.0			Chromium:	25,000
						Heptaclor:	13			Copper:	81,000
						Methoxychlor:	30			Lead:	130,000
										Mercury:	260
										Nickel:	130,000
										Selenium:	14,000
										Silver:	BMDL
										Thallium:	350
										Zinc:	4,800,000
6379-04	Residence at Elysian Fields: Wall Materials Below Water Line (Sunroom, north wall/ Drywall below water line)	GNB (cfu/cm^2):	40,600	Indicator Organisms:	No	Chlordane:	280	BMDL	40,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/ Target Organisms:	Cladosporium	Alpha-Chlordane:	19			Arsenic:	BMDL
		Other:	BMDL		Epicoccum	Gamma-Chlordane:	11			Beryllium:	BMDL
		Total:	40,600	Hyphae:	Yes	Other:				Cadmium:	150
						DDD:	5.7			Chromium:	2,900
						DDT:	6.7			Copper:	550
						Heptaclor:	16			Lead:	390
										Mercury:	71
										Nickel:	8,800
										Selenium:	1,800
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	9,300

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-05	Residence at Elysian Fields: Wall Materials Above Water Line (Sunroom, north wall/ Drywall above water line)	GNB (cfu/cm^2):	247,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	410	BMDL	77,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	Alpha-Chlordane:	30			Arsenic:	190
		Other:	BMDL		Curvularia	Gamma-Chlordane:	14			Beryllium:	BMDL
		Total:	247,000	Hyphae:	Yes	Other:				Cadmium:	160
						DDD:	6.5			Chromium:	4,400
						DDT:	9.0			Copper:	840
						Endosulfan sulfate	5.0			Lead:	390
						Heptaclor:	16			Mercury:	89
										Nickel:	8,400
										Selenium:	1,800
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	9,000
6379-06	Residence at Elysian Fields: Wall Materials Above Water Line (Sunroom, north wall/ Drywall above water line [mold])	GNB (cfu/cm^2):	456,000	Indicator Organisms:	No	Chlordane:	810	BMDL	84,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	Alpha-Chlordane:	73			Arsenic:	170
		Other:	BMDL		Curvularia	Gamma-Chlordane:	87			Beryllium:	BMDL
		Total:	456,000	Hyphae:	Yes	Other:				Cadmium:	100
						DDT:	19			Chromium:	3,200
						Endosulfan sulfate	19			Copper:	780
						Heptaclor:	41			Lead:	380
										Mercury:	66
										Nickel:	8,900
										Selenium:	1,600
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	9,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-07	Residence at Elysian Fields: Dry Sludge (Exterior of house – Front sidewalk 15' east of main door/ Sludge residue [dry])	GNB (cfu/cm^2):	718	Indicator Organisms:	No	Chlordane:	BMDL	BMDL	760,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Epicoccum	Alpha-Chlordane:	BMDL			Arsenic:	9,700
		Other:			Curvularia	Gamma-Chlordane:	BMDL			Beryllium:	1,200
		Bacillus Species	479	Hyphae:	Yes	Other:	BMDL			Cadmium:	2,400
		Total:	1,200							Chromium:	33,000
										Copper:	64,000
										Lead:	170,000
										Mercury:	63
										Nickel:	26,000
										Selenium:	BMDL
										Silver:	1,200
										Thallium:	BMDL
										Zinc:	750,000
6379-08	Residence at Elysian Fields: Wall Materials Above Water Line (Center of west wall upstairs SW bedroom/Skim coat plaster on drywall on top of plaster)	GNB (cfu/cm^2):	2	Indicator Organisms:	No	Chlordane:	250	BMDL	650,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	Alpha-Chlordane:	16			Arsenic:	1,900
		Other:		Hyphae:	No	Gamma-Chlordane:	28			Beryllium:	120
		Bacillus Species	1			Other:				Cadmium:	BMDL
		Total:	3			beta-BHC:	11			Chromium:	3,400
						gamma-BHC	9.5			Copper:	4,800
						DDD:	37			Lead:	3,400
						DDT:	78			Mercury:	79
						Dieldrin:	14			Nickel:	14,000
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	11,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-09	Residence at General Diaz: Wall Materials Below Water Line (South wall of sunroom/Drywall from below water line)	GNB (cfu/cm^2):	164,000	Indicator Organisms:	BMDL	Chlordane:	160	BMDL	110,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/ Target Organisms:	BMDL	alpha-Chlordane:	13			Arsenic:	190
		Other:		Hyphae:	BMDL	gamma-Chlordane:	9.7			Beryllium:	BMDL
		Bacillus Species	18,300			Other:				Cadmium:	BMDL
		Total:	183,000			DDE:	3.3			Chromium:	1,400
						DDT:	5.3			Copper:	610
										Lead:	1,000
										Mercury:	BMDL
										Nickel:	8,100
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	6,100
6379-10	Residence at General Diaz: Wall Materials Above Water Line (South wall of sunroom/Drywall from above water line)	GNB (cfu/cm^2):	41,500	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	2,100	BMDL	1,200,000	Antimony:	300
		GPB (cfu/cm^2):	BMDL	Common/ Target Organisms:	Chaetomium	alpha-Chlordane:	130			Arsenic:	1,100
		Other:	BMDL		Curvularia	gamma-Chlordane:	350			Beryllium:	1,400
		Total:	41,500		Epicoccum	Other:				Cadmium:	BMDL
					Cladosporium	DDT:	35			Chromium:	1,400
					Helminthosporium/ Drechslera	Dieldrin:	150			Copper:	540
				Hyphae:	Yes	Heptaclor:	45			Lead:	750
										Mercury:	BMDL
										Nickel:	8,200
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	4,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-11	Residence at General Diaz: Wet Sludge (Sunroom/ living room/Sludge from floor [wet])	GNB (cfu/cm^2):	64,900	Sample was wet and could not be microvacuumed		Chlordane:	190	BMDL	130,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL			alpha-Chlordane:	18			Arsenic:	23,000
		Other:	BMDL			gamma-Chlordane:	39			Beryllium:	430
		Total:	64,900			Other:				Cadmium:	5,700
						DDT:	40			Chromium:	14,000
						Dieldrin:	19			Copper:	62,000
						Endrin ketone	43			Lead:	120,000
						Heptaclor:	4.0			Mercury:	BMDL
						Methoxychlor:	3.7			Nickel:	130,000
										Selenium:	BMDL
										Silver:	320
										Thallium:	BMDL
										Zinc:	2,300,000
6379-12	Residence at General Diaz: Wall Materials Below Water Line (South wall of sunroom/Wood from wall stud below water level)	GNB (cfu/cm^2):	20,200	Indicator Organisms:	No	Analysis voided due to insufficient sample quantity		Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/ Target Organisms:	Cladosporium					Arsenic:	560
		Other:	BMDL		Basidiospore					Beryllium:	BMDL
		Total:	20,200	Hyphae:	No					Cadmium:	BMDL
										Chromium:	1,200
										Copper:	BMDL
										Lead:	2,500
										Mercury:	Insufficient sample
										Nickel:	640
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	23,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-13	Residence at Memphis Street: Wall Materials Below Water Line (Formal dining room/Drywall below water line)	GNB (cfu/cm^2):	381,000	Indicator Organisms:	No	Chlordane:	BMDL	BMDL	230,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Basidiospore	alpha-Chlordane:	BMDL			Arsenic:	520
		Other:	BMDL	Hyphae:	Yes	gamma-Chlordane:	BMDL			Beryllium:	BMDL
		Total:	381,000			Other:	BMDL			Cadmium:	76
										Chromium:	3,300
										Copper:	820
										Lead:	780
										Mercury:	120
										Nickel:	7,200
										Selenium:	1,300
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	16,000
6379-14	Residence at Memphis Street: Wall Materials Above Water Line (Formal dining room/Drywall above water line)	GNB (cfu/cm^2):	544	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	BMDL	BMDL	210,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	No	alpha-Chlordane:	BMDL			Arsenic:	1,200
		Other:	BMDL	Hyphae:	No	gamma-Chlordane:	BMDL			Beryllium:	150
		Total:	544			Other:	BMDL			Cadmium:	220
										Chromium:	4,800
										Copper:	1,400
										Lead:	780
										Mercury:	180
										Nickel:	13,000
										Selenium:	3,300
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	19,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]	PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-15	Residence at Memphis Street: Dry Sludge (Kitchen/ dining room/Sludge residue from floor)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity	Analysis voided due to insuffi-cient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	2,300
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Basidiospore				Arsenic:	60,000
		Other:			Chaetomium				Beryllium:	760
		Bacillus Species	590		Stachybotrys				Cadmium:	10,000
		Total:	590	Hyphae:	Yes				Chromium:	36,000
									Copper:	220,000
									Lead:	240,000
									Mercury:	140
									Nickel:	18,000
									Selenium:	3,100
									Silver:	870
									Thallium:	340
									Zinc:	32,000,000
6379-16	Residence at Memphis Street: Wall Materials Below Water Line (Dining room/Stud sliver below water line)	GNB (cfu/cm^2):	260,000	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity	Analysis voided due to insuffi-cient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	370
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium				Arsenic:	BMDL
		Other:	BMDL	Hyphae:	No				Beryllium:	BMDL
		Total:	260,000						Cadmium:	BMDL
									Chromium:	920
									Copper:	790
									Lead:	240
									Mercury:	BMDL
									Nickel:	660
									Selenium:	BMDL
									Silver:	BMDL
									Thallium:	BMDL
									Zinc:	28,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-17	Residence at Savoie Court: Wall Materials Below Water Line (Living room – east wall/Drywall and wallpaper below water line)	GNB (cfu/cm^2):	233,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	130	BMDL	82,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	18			Arsenic:	2,500
		Other:	BMDL	Hyphae:	Yes	gamma-Chlordane:	20			Beryllium:	BMDL
		Total:	233,000			Other:	BMDL			Cadmium:	BMDL
										Chromium:	3,800
										Copper:	2,200
										Lead:	830
										Mercury:	65
										Nickel:	11,000
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	21,000
6379-18	Residence at Savoie Court: Wall Materials Below Water Line (Living room – east wall/Drywall and wallpaper below water line)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	88	BMDL	200,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	11			Arsenic:	870
		Other:	BMDL	Hyphae:	Yes	gamma-Chlordane:	16			Beryllium:	150
		Total:	BMDL			Other:	BMDL			Cadmium:	BMDL
										Chromium:	1,800
										Copper:	1,600
										Lead:	900
										Mercury:	70
										Nickel:	13,000
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	26,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-19	Residence at Savoie Court: Miscellaneous Materials (Living room – east wall/ Carpet and pad under drywall sample)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity		Analysis voided due to insuffi-cient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium					Arsenic:	BMDL
		Other:	BMDL	Hyphae:	Yes					Beryllium:	BMDL
		Total:	BMDL							Cadmium:	150
										Chromium:	3,500
										Copper:	15,000
										Lead:	1,900
										Mercury:	410
										Nickel:	2,000
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	45,000
6379-20	Residence at Savoie Court: Wall Materials Above Water Line (Living room – east wall/Wallpaper fold mold)	GNB (cfu/cm^2):	242,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	1,400	BMDL	380,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	No	Alpha-Chlordane:	170			Arsenic:	BMDL
		Other:	BMDL	Hyphae:	No	Gamma-Chlordane:	220			Beryllium:	110
		Total:	242,000			Other:				Cadmium:	700
						Dieldrin:	260			Chromium:	5,400
						Methoxychlor	220			Copper:	6,800
										Lead:	3,600
										Mercury:	BMDL
										Nickel:	6,200
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	300,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-21	Residence at Savoie Court: Wall Materials Above Water Line (Living room – east wall/Stud sliver)	GNB (cfu/cm^2):	27,000	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity		Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium					Arsenic:	3,000
		Other:	BMDL		Myxomycetes					Beryllium:	BMDL
		Total:	27,000	Hyphae:	Yes					Cadmium:	BMDL
										Chromium:	12,000
										Copper:	1,500
										Lead:	4,000
										Mercury:	Insufficient sample
										Nickel:	BMDL
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	13,000
6379-22	Residence at Savoie Court: Wall Materials Below Water Line (Living room – east wall/Wooden baseboard)	GNB (cfu/cm^2):	33,300	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	87	BMDL	270,000	Antimony:	BMDL
		GPB (cfu/cm^2):	3,700	Common/Target Organisms:	Chaetomium	Alpha-Chlordane:	10			Arsenic:	1,100
		Other:	BMDL		Ascospore	Gamma-Chlordane:	15			Beryllium:	BMDL
		Total:	37,000	Hyphae:	Yes	Other:				Cadmium:	BMDL
						Dieldrin:	10			Chromium:	3,700
						Methoxychlor	86			Copper:	3,200
										Lead:	1,000
										Mercury:	BMDL
										Nickel:	3,200
										Selenium:	BMDL
										Silver:	160
										Thallium:	BMDL
										Zinc:	10,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-23	Residence at Savoie Court: Miscellaneous Materials (SW bedroom/"Stalagtite" fungal growth)	GNB (cfu/cm^2):	269,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	280	BMDL	760,000	Antimony:	22,000
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Basidiospore	Alpha-Chlordane:	38			Arsenic:	1,200
		Other:	BMDL		Nigrospora	Gamma-Chlordane:	30			Beryllium:	BMDL
		Total:	269,000	Hyphae:	Yes	Other:				Cadmium:	54
						Endosulfan sulfate	57			Chromium:	4,600
										Copper:	21,000
										Lead:	3,200
										Mercury:	BMDL
										Nickel:	4,900
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	200,000
6379-24	Residence at Savoie Court: Miscellaneous Materials (SW bedroom/White powdery fungal growth on carpet by door frames)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity		Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	No						
		Other:	BMDL	Hyphae:	No						
		Total:	1								

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-25	Residence at Savoie Court: Miscellaneous Materials (SW bedroom/Fungal growth on dresser leg)	GNB (cfu/cm^2):	144	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity		Analysis voided due to insuffi-cient sample quantity	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Ascospore						
		Other:	BMDL	Hyphae:	Yes						
		Total:	144								
6379-26	Residence at Munster Boulevard: Dry Sludge (Dried sludge from driveway)	GNB (cfu/cm^2):	2,430	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	BMDL	BMDL	520,000	Antimony:	BMDL
		GPB (cfu/cm^2):	486	Common/Target Organisms:	Basidiospore	alpha-Chlordane:	BMDL			Arsenic:	8,200
		Other:			Ascospore	gamma-Chlordane:	BMDL			Beryllium:	1,100
		Bacillus Species	1,940		Curvularia	Other:	BMDL			Cadmium:	840
		Total:	4,860		Nigrospora					Chromium:	16,000
					Stachybotrys					Copper:	30,000
					Periconia					Lead:	35,000
				Hyphae:	Yes					Mercury:	BMDL
										Nickel:	26,000
										Selenium:	1,800
										Silver:	330
										Thallium:	BMDL
										Zinc:	170,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-27	Residence at Munster Boulevard: Wet Sludge (Living room inside front door/Wet sludge from inside living room)	GNB (cfu/cm^2):	5,610	Sample was wet and could not be microvacuumed		Chlordane:	BMDL	BMDL	69,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL			alpha-Chlordane:	BMDL			Arsenic:	3,200
		Other:				gamma-Chlordane:	BMDL			Beryllium:	320
		Bacillus Species	1,400			Other:	BMDL			Cadmium:	400
		Total:	7,020							Chromium:	5,600
										Copper:	10,000
										Lead:	12,000
										Mercury:	BMDL
										Nickel:	8,700
										Selenium:	590
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	62,000
6379-28	Residence at Munster Boulevard: Wall Materials Below Water Line (Living room inside front door/Drywall – east wall below water line)	GNB (cfu/cm^2):	456,000	Indicator Organisms:	No	Chlordane:	130	BMDL	170,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Stachybotrys	alpha-Chlordane:	21			Arsenic:	1,500
		Other:	BMDL		Memnonelia	gamma-Chlordane:	24			Beryllium:	BMDL
		Total:	456,000	Hyphae:	Yes	Other:				Cadmium:	BMDL
						DDD:	5.7			Chromium:	910
						DDE:	3.3			Copper:	590
						DDT:	6.0			Lead:	1,300
										Mercury:	120
										Nickel:	5,800
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	18,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-29	Residence at Papania: Flood water from pot in living room	Flood water sample voided due to excess holding time		Flood water sample could not be microvacuumed		Flood water sample voided due to excess holding time		Flood water sample voided due to excess holding time	Flood water sample voided due to excess holding time	Flood water sample voided due to excess holding time	
6379-30	Residence at Munster Boulevard: Flood water from jar in sink	Flood water sample voided due to excess holding time		Flood water sample could not be microvacuumed		Flood water sample voided due to excess holding time		Flood water sample voided due to excess holding time	Flood water sample voided due to excess holding time	Flood water sample voided due to excess holding time	
6379-31	Residence at Munster Boulevard: Flood water from jar in sink	Flood water sample voided due to excess holding time		Flood water sample could not be microvacuumed		Flood water sample voided due to excess holding time		Flood water sample voided due to excess holding time	Flood water sample voided due to excess holding time	Flood water sample voided due to excess holding time	
6379-32	Residence at Cleary Avenue: Wall Materials Below Water Line (East wall of lower floor SE bedroom/Drywall below water line)	GNB (cfu/cm^2):	10,300	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	37	BMDL	190,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Curvularia	alpha-Chlordane:	5.0			Arsenic:	1,200
		Other:		Hyphae:	Yes	gamma-Chlordane:	5.5			Beryllium:	BMDL
		Bacillus Species	1,150			Other:	BMDL			Cadmium:	BMDL
		Total:	11,500							Chromium:	1,200
										Copper:	10,000
										Lead:	1,500
										Mercury:	83
										Nickel:	8,400
										Selenium:	2,000
										Silver:	100
										Thallium:	BMDL
										Zinc:	10,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-33	Residence at Cleary Avenue: Wall Materials Above Water Line (East wall of lower floor SE bedroom/Drywall above water line)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	26	BMDL	200,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Curvularia	alpha-Chlordane:	BMDL			Arsenic:	1,000
		Other:			Alternaria	gamma-Chlordane:	BMDL			Beryllium:	BMDL
		Gram Positive Cocci	Observed		Bipolaris	Other:	BMDL			Cadmium:	BMDL
		Total:	BMDL	Hyphae:	Yes					Chromium:	1,100
										Copper:	9,300
										Lead:	1,400
										Mercury:	66
										Nickel:	8,200
										Selenium:	1,600
										Silver:	110
										Thallium:	BMDL
										Zinc:	11,000
6379-34	Residence at Cleary Avenue: Wall Materials Above Water Line (SE bedroom closet – east wall by entry/ Drywall above water line with mold on both sides)	GNB (cfu/cm^2):	3,330	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	26	BMDL	130,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	BMDL			Arsenic:	1,700
		Other:	BMDL		Cladosporium	gamma-Chlordane:	BMDL			Beryllium:	BMDL
		Total:	3,330	Hyphae:	Yes	Other:	BMDL			Cadmium:	BMDL
										Chromium:	1,700
										Copper:	12,000
										Lead:	1,300
										Mercury:	160
										Nickel:	8,700
										Selenium:	2,100
										Silver:	120
										Thallium:	BMDL
										Zinc:	9,600

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-35	Residence at Cleary Avenue: Miscellaneous Materials (SE bedroom/Carpet below samples 32 and 33)	GNB (cfu/cm^2):	3,380	Indicator Organisms:	No	Chlordane:	BMDL	BMDL	920,000	Antimony:	170,000
		GPB (cfu/cm^2):	1,130	Common/Target Organisms:	Myxomycete	Alpha-Chlordane:	BMDL			Arsenic:	550
		Other:			Rust	Gamma-Chlordane:	BMDL			Beryllium:	BMDL
		Bacillus Species	563	Hyphae:	Yes	Other:				Cadmium:	130
		Gram Positive Cocci	563			DDD:	50			Chromium:	3,800
		Total:	5,630			Endosulfan II:	100			Copper:	6,000
						Endosulfan sulfate:	700			Lead:	4,200
						Methoxychlor:	700			Mercury:	BMDL
										Nickel:	6,300
										Selenium:	650
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	54,000
6379-36	Residence at Cleary Avenue: Wall Materials Above Water Line (Second floor hall ceiling/ Drywall with mold)	GNB (cfu/cm^2):	350,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	BMDL	BMDL	120,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Stachybotrys	alpha-Chlordane:	BMDL			Arsenic:	390
		Other:	BMDL		Basidiospore	gamma-Chlordane:	BMDL			Beryllium:	BMDL
		Total:	350,000	Hyphae:	Yes	Other:	BMDL			Cadmium:	83
										Chromium:	1,800
										Copper:	9,000
										Lead:	2,000
										Mercury:	BMDL
										Nickel:	8,200
										Selenium:	1,500
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	11,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]	PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-37	Residence at Cleary Avenue: Wall Materials Above Water Line (Second floor hall ceiling/Stud sliver)	GNB (cfu/cm^2):	40,600	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Stachybotrys				Arsenic:	2,400
		Other:			Basidiospore				Beryllium:	BMDL
		Total:	40,600		Epicoccum				Cadmium:	150
				Hyphae:	No				Chromium:	1,600
									Copper:	700
									Lead:	1,300
									Mercury:	Insufficient sample
									Nickel:	3,300
									Selenium:	1,200
									Silver:	BMDL
									Thallium:	BMDL
									Zinc:	12,000
6379-38	Residence at Cleary Avenue: Wall Materials Below Water Line (SE lower bedroom/Stud sliver from east wall)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	Aspergillus/ Penicillium	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Stachybotrys				Arsenic:	BMDL
		Other:		Hyphae:	Yes				Beryllium:	270
		Bacillus Species	1						Cadmium:	140
		Total:	1						Chromium:	2,400
									Copper:	BMDL
									Lead:	BMDL
									Mercury:	Insufficient sample
									Nickel:	BMDL
									Selenium:	1,500
									Silver:	BMDL
									Thallium:	BMDL
									Zinc:	8,200

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-39	Residence at Cleary Avenue: Wall Materials Below Water Line (North wall of sunken family room/Masonite paneling)	GNB (cfu/cm^2):	404,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	BMDL	BMDL	450,000	Antimony:	BMDL
		GPB (cfu/ cm^2):	BMDL	Common/Target Organisms:	No	alpha-Chlordane:	BMDL			Arsenic:	310
		Other:	BMDL	Hyphae:	Yes	gamma-Chlordane:	BMDL			Beryllium:	BMDL
		Total:	404,000			Other:				Cadmium:	BMDL
						Methoxychlor:	81			Chromium:	13,000
										Copper:	5,800
										Lead:	47,000
										Mercury:	BMDL
										Nickel:	BMDL
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	31,000
6379-40	Residence at Cleary Avenue: Dry Sludge (West kitchen floor/ Flood residue)	GNB (cfu/cm^2):	BMDL	Indicator Organisms:	No	Analysis voided due to insufficient sample quantity		Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Basidiospore						
		Other:			Curvularia						
		Bacillus Species	5,800		Myxomycete						
		Gram Positive Cocci	2,490		Nigrospora						
		Total:	8,280	Hyphae:	No						

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-41	Fire Station at Louisiana Avenue: Dry Sludge (Sludge from floor)	GNB (cfu/cm^2):	737	Indicator Organisms:	No	Analysis voided due to insufficient sample quantity		Analysis voided due to insufficient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	11,000
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Basidiospore					Arsenic:	45,000
		Other:			Myxomycete					Beryllium:	110
		Bacillus Species	1,840		Nigrospora					Cadmium:	22,000
		Gram Positive Cocci	1,110	Hyphae:	Yes					Chromium:	24,000
		Total:	3,690							Copper:	200,000
										Lead:	1,300,000
										Mercury:	470
										Nickel:	13,000
										Selenium:	1,000
										Silver:	890
										Thallium:	330
										Zinc:	5,400,000
6379-42	Fire Station at Louisiana Avenue: Wall Materials Below Water Line (Drywall from below water line at kitchen stains)	GNB (cfu/cm^2):	327,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	17,000	BMDL	580,000	Antimony:	470
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	2,100			Arsenic:	2,700
		Other:	BMDL		Smut	gamma-Chlordane:	2,900			Beryllium:	BMDL
		Total:	327,000	Hyphae:	Yes	Other:				Cadmium:	200
						Methoxychlor:	840			Chromium:	2,600
										Copper:	4,200
										Lead:	7,400
										Mercury:	BMDL
										Nickel:	8,300
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	180,000

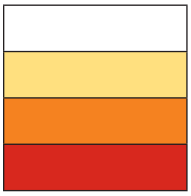
Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-43	Fire Station at Louisiana Avenue: Wall Material Above Water Line (Drywall above water line at kitchen)	GNB (cfu/cm^2):	140,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	1,400	BMDL	220,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	180			Arsenic:	2,100
		Other:			Stachybotrys	gamma-Chlordane:	260			Beryllium:	110
		Bacillus Species	15,600		Arthrinium	Other:	BMDL			Cadmium:	53
		Total:	156,000	Hyphae:	Yes					Chromium:	1,900
										Copper:	1,300
										Lead:	2,300
										Mercury:	BMDL
										Nickel:	7,700
										Selenium:	800
										Silver:	BMDL
										Thallium:	430
										Zinc:	9,800
6379-44	Residence at Octavia: Wall Materials Above Water Line (Main hall to sunken family room – east wall/Wallpaper with fuzzy white growth)	GNB (cfu/cm^2):	410,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	1,200	BMDL	1,500,000	Antimony:	BMDL
		GPB (cfu/cm^2):	45,600	Common/Target Organisms:	Basidiospore	alpha-Chlordane:	150			Arsenic:	930
		Other:	BMDL		Alternaria	gamma-Chlordane:	190			Beryllium:	140
		Total:	456,000		Ascospore	Other:				Cadmium:	BMDL
					Cladosporium	DDD:	21			Chromium:	1,200
				Hyphae:	No					Copper:	1,100
										Lead:	1,700
										Mercury:	310
										Nickel:	5,800
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	5,600

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-45	Residence at Octavia: Wall Materials Below Water Line (Main hall to sunken family room – west wall/Wallpaper below water line)	GNB (cfu/cm^2):	251,000	Indicator Organisms:	No	Chlordane:	2,200	BMDL	990,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	220			Arsenic:	290
		Other:	BMDL	Hyphae:	Yes	gamma-Chlordane:	380			Beryllium:	BMDL
		Total:	251,000			Other:	BMDL			Cadmium:	54
										Chromium:	5,600
										Copper:	1,300
										Lead:	25,000
										Mercury:	10,000
										Nickel:	BMDL
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	74,000
6379-46	Residence at Octavia: Wall Materials Above Water Line (Main hall to sunken family room – west wall/Wallpaper above water line)	GNB (cfu/cm^2):	168,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	1,600	BMDL	980,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	alpha-Chlordane:	200			Arsenic:	360
		Other:	BMDL	Hyphae:	No	gamma-Chlordane:	240			Beryllium:	BMDL
		Total:	168,000			Other:	BMDL			Cadmium:	BMDL
										Chromium:	7,700
										Copper:	1,200
										Lead:	34,000
										Mercury:	230
										Nickel:	BMDL
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	19,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-47	Residence at Octavia: Wall Materials Above Water Line (First floor office – east wall/ Released wallpaper)	GNB (cfu/cm^2):	314,000	Indicator Organisms:	Aspergillus/ Penicillium	Chlordane:	880	BMDL	3,100,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Chaetomium	Alpha-Chlordane:	130			Arsenic:	1,400
		Other:	BMDL		Ascospore	Gamma-Chlordane:	150			Beryllium:	180
		Total:	314,000	Hyphae:	Yes	Other:				Cadmium:	670
						DDT:	250			Chromium:	16,000
										Copper:	8,800
										Lead:	4,800
										Mercury:	32,000
										Nickel:	7,300
										Selenium:	BMDL
										Silver:	100
										Thallium:	BMDL
										Zinc:	210,000
6379-48	Fire Station at South Carrolton Avenue: Dry Sludge (Kitchen in back/Sludge from floor)	GNB (cfu/cm^2):	1,480	Indicator Organisms:	No	Analysis voided due to insufficient sample quantity		Analysis voided due to in-sufficient sample quantity	Analysis voided due to insufficient sample quantity	Antimony:	330,000
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Stachybotrys					Arsenic:	81,000
		Other:			Memnoniella					Beryllium:	310
		Bacillus Species	983		Basidiospore					Cadmium:	24,000
		Total:	2,460	Hyphae:	Yes					Chromium:	100,000
										Copper:	490,000
										Lead:	390,000
										Mercury:	1,600
										Nickel:	44,000
										Selenium:	BMDL
										Silver:	740
										Thallium:	BMDL
										Zinc:	8,500,000

Sample Number	Sample Location (Description)	Culturable Bacterial Swabs[1] (GNB=Gram Negative Bacilli GPB=Gram Positive Bacilli)		Biological Bulks[2]		Pesticides (µg/kg)[3]		PCBs	Diesel Range Organics[4]	Heavy Metals (µg/kg)[5]	
6379-49	Fire Station at South Carrolton Avenue: Wall Materials Below Water Line (Kitchen in back – south wall/ Drywall below water line)	GNB (cfu/cm^2):	23,600	Indicator Organisms:	No	Chlordane:	100	BMDL	130,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	Stachybotrys	alpha-Chlordane:	15			Arsenic:	730
		Other:	BMDL		Cladosporium	gamma-Chlordane:	18			Beryllium:	140
		Total:	23,600	Hyphae:	Yes	Other:	BMDL			Cadmium:	60
										Chromium:	3,300
										Copper:	1,600
										Lead:	2,400
										Mercury:	93
										Nickel:	7,300
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	9,800
6379-50	Fire Station at South Carrolton Ave: Wall Materials Above Water Line (Kitchen in back – south wall/ Drywall above water line)	GNB (cfu/cm^2):	6,130	Indicator Organisms:	BMDL	Chlordane:	130	BMDL	190,000	Antimony:	BMDL
		GPB (cfu/cm^2):	BMDL	Common/Target Organisms:	BMDL	alpha-Chlordane:	13			Arsenic:	1,000
		Other:	BMDL	Hyphae:	BMDL	gamma-Chlordane:	11			Beryllium:	BMDL
		Total:	6,130	Other:	BMDL	Other:	BMDL			Cadmium:	BMDL
										Chromium:	2,500
										Copper:	930
										Lead:	3,600
										Mercury:	65
										Nickel:	8,400
										Selenium:	BMDL
										Silver:	BMDL
										Thallium:	BMDL
										Zinc:	6,000

1. For culturable bacterial swab sample results:



Below the method detection limit (BMDL) is less than 18 cfu/cm$^{2.}$

Moderate is between 18 cfu/cm^2 and 1,000 cfu/cm$^{2.}$

Extensive is between 1,100 cfu/cm^2 and 20,000 cfu/cm$^{2.}$

Extremely high is greater than 20,000 cfu/cm$^{2.}$

2. For fungal bulk sample results:



No Organism Detected

Indicator Organisms associated with potentially significant health problems detected = Aspergillus/Penicillum

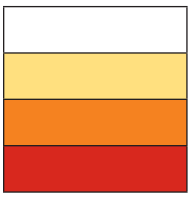
Common Organisms associated with minor health problems/ allergies, including Ascospore, Basidiospore, Cladosporium, Culvaria, Epicoccum, Fusarium, Myxmycete, Nigospora, Periconia, and Smut

Target organisms associated with potentially serious health prolems detcted; which include Chaetomium, Fusarium, Memnomiella, Stachybotrys, and Trichoderma

Hyphae: growth structures in addition to spores detected

3. For pesticide sample results:

Below the minimum detectable limit (BDML) is <17 µg/kg for Chlordane and <3.3µg/kg for other pesticides.



Minimal: Values are less than 10% of the RECAP* screening standard.

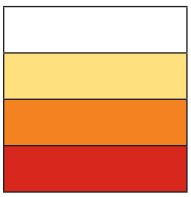
Low: Values are greater than 10% but less than 50% of the RECAP screening standard.

Moderate: Values are greater than 50% but less than 00% of the RECAP screening standard.

High: Values are greater than 100% of the RECAP· screening standard.

4. For diesel range organics (DROs) sample results:

Below the minimum detectable limit (BDML) is <18,000 µg/kg.



Minimal: Values are less than 10% of the RECAP* screening standard.

Low: Values are greater than 10% but less than 50% of the RECAP screening standard.

Moderate: Values are greater than 50% but less than 00% of the RECAP screening standard.

High: Values are greater than 100% of the RECAP· screening standard.

5. For heavy metals sample results:

Below the minimum detectable limit (BDML) is <50 µg/kg for Cadmium; <60 µg/kg for Mercury; <100 µg/kg for Arsenic, Beryllium, and Silver; <200 µg/kg for Lead; <300 µg/kg for Antimony, Chromium, Copper, Nickel, Thallium, and Zinc; <500 µg/kg for Selenium.



Minimal: Values are less than 10% of the RECAP* screening standard.

Low: Values are greater than 10% but less than 50% of the RECAP screening standard.

Moderate: Values are greater than 50% but less than 00% of the RECAP screening standard.

High: Values are greater than 100% of the RECAP screening standard.

* RECAP – Risk Evaluation/Corrective Action Program. This Louisiana Department of Environmental Quality (LDEQ) program is designed to provide guidance for contaminant levels in non-industrial soils based on values from the U.S. Environmental Protection Agency (USEPA) or estimated from other sources such as the LDEQ and health professionals. The RECAP screening standards are intended to be protective of children and adults in typical residential settings with long-term exposure (i.e., 30 years) and identify areas of concern. In addition to the screening standards, the following RECAP Management Option 1 (MO-1) standards are available for soils to determine if the contaminant levels require further evaluation.

Contaminant	RECAP MO-1 Standard µg/kg
Chlordane	1,600
alpha-Chlordane	1,600
gamma-Chlordane	1,600
DDT	1,700
Dieldrin	30
Heptachlor	16
DRO	650,000
Antimony	31,000
Arsenic	12,000
Beryllium	160,000
Cadmium	39,000
Chromium	230,000
Copper	3,100,000
Lead	400,000
Mercury	23,000
Nickel	1,600,000
Selenium	390,000
Silver	390,000
Thallium	5,500
Silver	390,000
Thallium	5,500
Zinc	23,000,000

6. Additional Details and Limitations Regarding Chemical Sample Results: According to Clayton Group Services, the quality control results associated with the samples were within acceptable limits and do not adversely affect the reported results, except as noted in the following bullets.

   - Some samples and/or analyses had to be voided due to insufficient sample quantity. The entire sample had to be voided on Wonder Makers' samples 6379-24, -25 and -40. Mercury, pesticides/PCBs and DROs were voided on Wonder Makers' samples 6379-12, -21, -37 and -38. Pesticides/PCBs and DRO were voided on Wonder Makers' samples 6379-15, -16, -19 and -48.
   - For Wonder Makers' samples 6379-01 to -11, -13 and -14, the holding time for sample preparation for DRO and pesticide/PCB analyses was 15 days after sample collection; which exceeded the EPA's recommended holding time by 1 day.
   - For Wonder Makers' sample 6379-04, the spike recovery for zinc on the matrix spike duplicate (MSD) was 300%, above the statistical limit of 190%, due to matrix interference. The matrix spike (MS) recovery on this sample was within limits, at 107%. The MS/MSD recoveries on samples 6379-34 and -44 were all within acceptable limits for zinc.
   - For Wonder Makers' sample 6379-44, the matrix spike/matrix spike duplicate (MS/MSD) recoveries for mercury were 640% and 880%, above the statistical limit of 144%, due to matrix interference. However, the MS/MSD recoveries on samples 6379-04 and -34 were all within acceptable limits for mercury.
   - For Wonder Makers' samples 6379-01, -04, -05 and -08, the results reported for the organochlorine pesticide DDD are estimated and could be high, due to a high recovery of the continuing calibration verification (CCV) standard. The high CCV recovery was likely caused by the sample matrices.
   - For Wonder Makers' Samples 6379-07, -10, -20, -23, -26, -35, -36, and -42 through -47, the recoveries of the two surrogates (TCMX and DCB) for analysis of pesticides/PCBs were below statistical limits and lower reporting limits could not be achieved, due to matrix interference.
   - For Wonder Makers' Samples 6379-02, -03, -05, -06, -08, -18, -20, -22, -23, -32, -35, -39, -45 through -47, -49 and -50, the lower reporting limit for pesticides/PCBs could not be achieved, due to limited sample quantity.

J. Historic Buildings Pre- and Post-Disaster Mitigation

J.1 Pre-Event Mitigation

Throughout the region, old buildings can be further weakened from storms, which can have a long-term toll beyond the immediate wreckage. The use of pre-hazard mitigation techniques can benefit building owners and the community in various ways and to varying degrees.

Natural hazards such as hurricanes do not have to result in a natural disaster. There are proven design and construction techniques that can reduce or eliminate the threat of damage to buildings from these natural hazards and these techniques should be applied to all historic properties. However, some of the most vulnerable historic buildings are those that stand empty, waiting for restoration. Mothballing, which means to stabilize and temporarily protect a building from further deterioration, when undertaken before the next hurricane or other natural disaster strikes, can significantly reduce the likelihood of damage.

J.1.1 Mothballing

Mothballing is simply undertaking efforts to stabilize a historic structure to prevent further deterioration, although it can apply to any vacant structure deemed worth saving. During a major storm event like Hurricane Katrina, the deterioration and/or destruction of vacant and neglected buildings can be intensified.

J.1.1.1 Mothballing (Background)

Standing empty, a building is subject to progressive deterioration such as roof leaks; malfunctioning roof drainage such as internal drains or gutters and downspouts becoming non-functional; windows deteriorating to the point where many do not keep the elements out; trees growing along the foundation lines; and surface runoff flowing into basement windows. The first step in a program of historic preservation and adaptive reuse, meaning to change the functional use of a building from its original intent, is to arrest this deterioration, make the building sound, and "mothball" it until plans for its future use can be determined. Each vacant property of historic or potential historic value needs a mothballing plan.

J.1.1.2 Mothballing Plan (Application)

The first step toward mothballing is to obtain a listing and evaluation of historical or potentially historical buildings that the State Historic Preservation Office (SHPO) is considering for mothballing.

In mothballing a building, keeping it sound and dry, and arresting progressive deterioration while an adaptive reuse and historic preservation plan is being developed is imperative. The following steps should form a part of any pre-event mitigation plan.

To mitigate water intrusion issues:

- **Roofs:** Inspect and perform temporary repairs as needed. If the roof has deteriorated to the point where re-roofing is necessary, either install a permanent roof if funding permits, or install a temporary roof. Perform followup yearly inspections.
- **Gutters, downspouts, and drains:** Gutters and roof drains should be cleared of debris. Repair sections of gutter that are missing or damaged. Repair missing and damaged downspouts and reconnect to the storm drainage system, if available.
- **Flashing and trim:** Missing or damaged flashing should be repaired or replaced.
- **Doors and windows:** Exterior openings such as doors, windows, and louvers must also be minimally restored. Missing shutters should be replaced and all shutters closed and secured. Wood windows and other wood components suffering from rot, damage, or missing glass panes should be replaced. Glazing compound that has deteriorated to the point where the weather is no longer being excluded at the perimeters of the glass panes should be repaired. Operating hardware such as handles, locks, and latches should be replaced if missing or nonfunctional. Sealants between the window perimeters and the surrounding surfaces that have deteriorated to the point where the weather is no longer being excluded should be replaced. Missing doors, including hardware, should be replaced to keep wind and rain out.

As a less expensive alternative, windows could be boarded (either all windows or only missing windows) until implementation of an adaptive reuse.

- **Wood siding and trim:** Wood siding and trim needs to be reattached where loose to prevent further loss from wind. Wood should be painted to protect it from the elements.
- **Wood flooring:** It could be worthwhile to remove the occasional floorboard to allow for expansion to occur from swelling, without causing permanent damage to the boards if there is a potential for flooding.
- **Masonry walls:** Secure masonry veneers into the façade if they are in danger of falling out; concentrate on those whose deterioration allows water or vermin entry, or where pieces are in danger of falling and causing injury. Execute a regimen of selective tuck pointing of deteriorated mortar at selected areas of the building façade.
- **Additions and alterations:** Building elements that have been installed relatively recently and are not historically significant but are, however, structurally sound and mostly weathertight, should remain, with some nominal repairs for the purpose of mothballing. Upon execution of an adaptive reuse or restoration, the disposition of these elements can be determined.
- **Hazardous material:** It should be noted that some historic buildings may contain asbestos or lead-based paints; proper handling of these hazardous materials will need to be observed during both demolition and restoration.

J.1.1.3 Site Corrections and Miscellaneous Issues

- In places where ground slope against the building façade is either flat or toward the building, increase the grade immediately adjacent to the façade to achieve positive drainage away from the building. In some areas, existing masonry and concrete window wells around basement windows will need to be built up to retain the extra height of the earth.
- On tree-covered sites, remove all insignificant trees within 20 feet of a structure to minimize potential damage from wind-fallen trees. In addition, tree growth close to foundations can weaken the structure because the root growth along the foundation line can undermine the footings.
- Clear site drainage systems of sediment and debris in inlets and pipes.

J.1.2 Priorities and Permutations

Recommendations described previously should be given priority. When taken together, they comprise a comprehensive mothballing plan for arresting ongoing deterioration. It is understood, however, that all of the funds needed to implement this comprehensive plan are not necessarily available. With this in mind, it is necessary to consider a plan whereby those items of greatest need are given highest priority and implemented first, with other items of lesser need implemented second, third, fourth, etc. The schedule of items implemented would have to match the flow of available funds, in a phased approach. High priority should be given to items that will correct progressive deterioration that is most advanced and is occurring at the greatest speed, or will affect components of historic significance, with highest priority given to those items with the highest cost-effectiveness. Lower priority should be given to items that will correct

less advanced or slower progressive deterioration, assuming that these can wait some finite time period until funds become available.

J.1.2.1 Objectives

The objectives of a Condition Assessment and Mothballing Report are to visually assess the general condition of the facility and its building systems, assess the nature and cause of progressive deterioration, and develop a mothballing plan for making the building sound and watertight for the near future, while a plan of adaptive reuse is developed.

J.1.2.2 Scope

To accomplish these objectives, the Scope of Work should include the following tasks:

1 Review available documentation, such as drawings, previous reports, histories, Web sites, and/or reports of building code violations.

2. Interview site management or maintenance personnel knowledgeable of the physical characteristics, maintenance, and repair of the property.

3. Conduct a walk-through survey of the property to obtain information on material systems and components in order to provide a brief description, identifying observable physical deficiencies, and to obtain information needed to develop the mothballing plan.

4. Prepare Opinions of Probable Costs to remedy observed physical deficiencies, and implement the mothballing plan.

5. Prepare the report, documenting the findings and results of the preceding tasks.

J.2 Post-Event Mitigation

The primary damage to historic buildings in a flood disaster is from immersion of building materials in floodwaters, the moving force of which can cause structural collapse. Storm and sanitary sewer backup during flooding is a major cause of damage to buildings. In addition, floods may also cause a fire due to ruptured utility lines; growth of mold and mildew; and swelling, warping, and disintegration of materials due to prolonged presence of moisture.

Following a wind event such as a hurricane, inspect and make repairs as needed to prevent water entry and to mitigate potential life-safety problems.

J.2.1 First Steps

The most important single step is to air out wet buildings, open doors and windows, remove airtight coverings such as aluminum and vinyl siding, and run fans. In refurbishing flooded buildings, it is vital to reinstate the drainage systems to remove water from the structure and foundations. This includes ground drainage, surface drainage, and basements, with the use of sumps, if necessary.

J.2.2 Identification of Problem Areas

It is also important to identify areas in the structure where water and moisture are trapped, so that appropriate measures can be taken to allow drying and prevent decay to vulnerable materials, as well as minimize mold growth. Most historic buildings are inherently durable and are relatively resistant to flooding due to the use of materials such as cypress framing and lime or cement plaster.

- **Wood paneling:** Immediately after the waters recede, any water trapped behind the paneling must be allowed to drain out. This can be done by drilling holes in the bottom of the panels. If there has been extensive saturation of paneling, it may be necessary to dismantle and dry the panels to avoid distortion.
- **Wood floors:** As wood becomes wet, it swells. When wood floors are saturated, they expand and buckle. After a flood, if the immersion has not been too prolonged, it may not be too late to prevent such damage. If the flooring does buckle, it will have to be taken up carefully and stacked, allowing each board to dry to its pre-flooded moisture content. If the boards have not buckled, but have cupped excessively, they will have to be replaced, although minor cupping may be acceptable. If the floor is not of great historic value, resand it to level the surface.
- **Drainage:** Backup and overflow of foul water and sewage systems are not an uncommon consequence of flooding.

J.2.3 Accelerated Drying

There are a number of measures that are commonly used after flooding. These measures improve drying and reduce the time required before refurbishment and reoccupancy can occur. These measures are laid out in order of priority.

1. Drain water clear of the structure and, if required, prevent further water penetration by the use of temporary roof and ground drainage systems.

2. Remove all damp materials and debris from the structure, including all damp carpets, furnishings, and collapsed building materials.

3. Demolish or remove all parts of the structure not to be retained or refurbished. Remove any damp plaster or drywall to expose the structure.

4. Provide through-ventilation to all parts of the structure, including all structural cavities such as sub-floor voids and wall cavities. Prop doors and windows and partially open millwork to allow air circulation.

5. Identify all trapped moisture in the structure. Where possible, remove all impermeable finishes from trapped moisture areas.

6. Use heaters, dehumidifiers, fans, and other devices to facilitate drying. If heating and mechanical systems are online, running them will assist in expediting drying time.

J.2.4 Relocation of Historic Buildings

Although consideration for relocation should be given to historical buildings that are located in an area prone to flooding from hurricanes, all properties that have sustained significant damage from a hurricane should be evaluated for possible relocation as part of the restoration process. Relocating a building to higher ground will reduce the risk of further damage from future hurricanes. Hotel Magnolia (see Figure J-1) underwent relocation after being badly damaged in 1969 from Hurricane Camille. As a result, the hotel experienced only minimal flooding.



Figure J-1.
Built by John Holm in 1847, the Magnolia Hotel, badly damaged from Hurricane Camille in 1969, was moved 100 yards north and restored by the City of Biloxi in 1972. While the main structure remains intact, the wood railing and one wood stair to the second floor porch were damaged; the other wood stair was completely destroyed (Biloxi, Mississippi).

J.2.5 Elevating Historic Buildings

If for whatever reason a historic building is non-movable, consideration should be given to raising the building to a higher elevation, preferably above the flood level. Working with state and local preservation offices, successful designs can be achieved to preserve the aesthetic as well as the historical value of the property. An alternative consideration if the building can't be raised aesthetically is to raise the ground below the structure, effectively raising the building to a higher elevation.

J.2.6 Alternate Protection of Historic Buildings

An alternate to relocation or raising a historic structure is the construction of barriers such as floodwalls or berms or a combination of both. Floodwalls can be constructed around historic districts, protecting several buildings at one time.

J.2.7 Data Base of Historic Buildings

Equally important to both pre-event and post-event mitigation is having a reliable inventory of all historical properties as well as other resources of the area, including maps of historic buildings sites. It is also important to have names and contact information of contact persons responsible for making decisions relative to historic buildings. A reliable inventory can help in quick response as well as collaboration between regional and state agencies concerned with historical preservation, helping to mitigate the damage to flooded historic buildings.

Many programs are written to outline mitigation procedures. However, it is imperative that these programs offer solutions to help communities decide what to do and how to implement the solutions so as not to further damage historic properties.

HURRICANE *Katrina*

IN THE GULF COAST

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