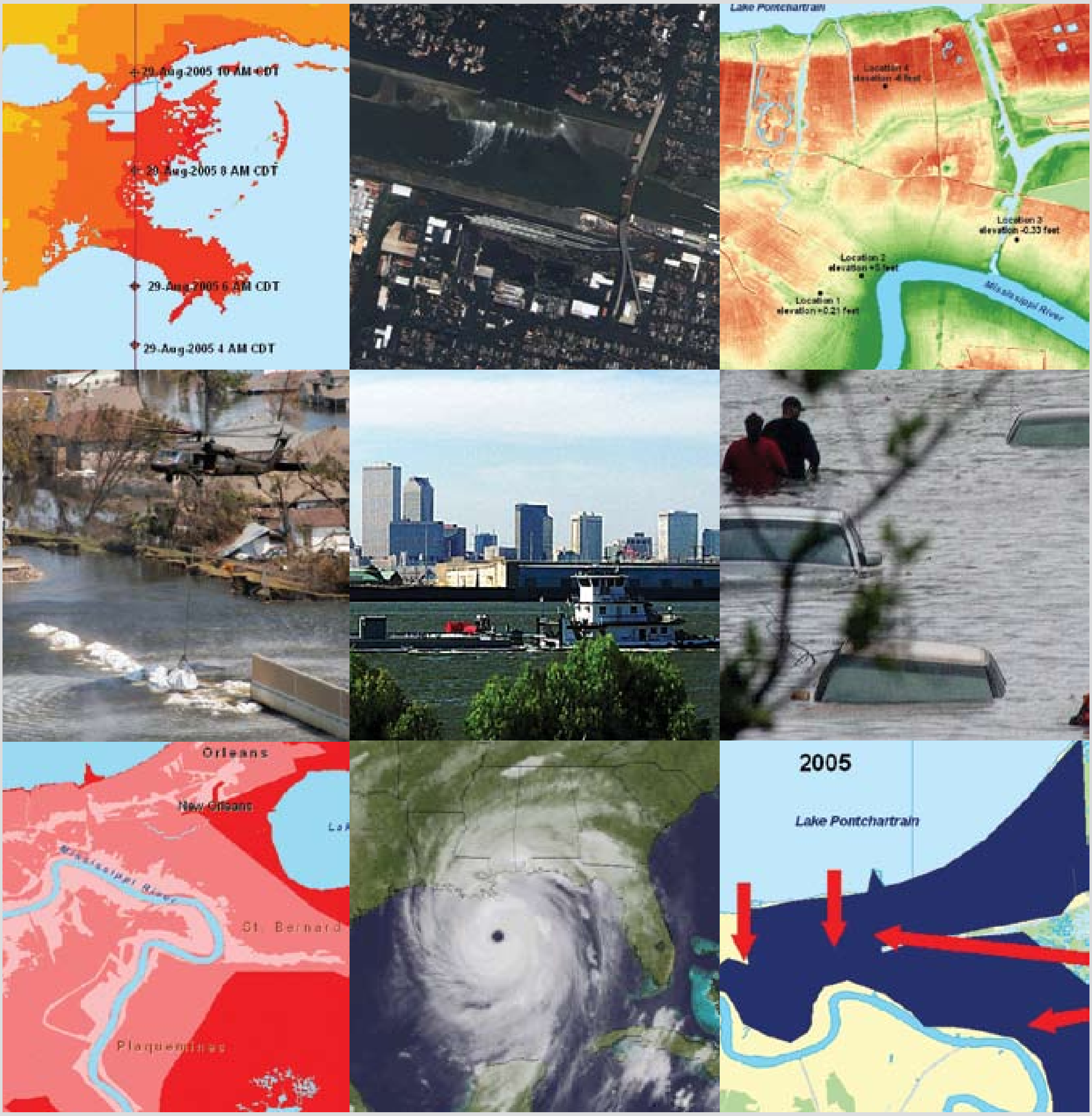
Flood Risk in New Orleans

Implications for Future Management and Insurability



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ACKNOWLEDGEMENTS

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Image Sources

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About RMS

Risk Management Solutions (RMS) is the world's leading provider of independent expertise, products, and services for the quantification and management of catastrophe risk. RMS offers technology and services to the insurance industry, as well as advice to policy makers and regulators, to allow the better management of catastrophe risk associated with natural and man-made perils, such as earthquakes, hurricanes, floods, and terrorist attacks. Founded at Stanford University in 1988, today RMS employs more than 1,000 people in offices across North America, Europe, and Asia, carrying out research, developing and running catastrophe models, and serving the needs of business and the community through objective risk assessments.

About the Authors

Dr. Muir-Wood, the Chief Research Officer of RMS, heads the Research Group with the mission to design enhanced methodologies for natural catastrophe modeling and develop models for new areas of risk such as liability. He has more than 20 years experience in developing probabilistic catastrophe models. Author of six books, many scientific publications, and numerous articles, he is Lead Author on Insurance, Finance and Climate Change for the 2007 Intergovernmental Panel on Climate Change (IPCC) Assessment Report.

Dr. Grossi is a member of the Research Group within RMS. She has over 10 years of research experience in catastrophe modeling and risk management, focusing on earthquake risk and more recently on other natural hazard risk. She is a registered Civil Engineer in the State of California and in 2005, she co-edited the book *Catastrophe Modeling: A New Approach to Managing Risk*.

INTRODUCTION

For nearly 20 years, Risk Management Solutions (RMS) has assisted clients, associates, and community leaders in understanding the potentially devastating consequences of catastrophic events such as earthquakes, floods, and terrorist attacks. The insurance industry, in particular, uses our catastrophe modeling technology to quantify the impact of these events on portfolios of risk, and then, using that knowledge, takes steps to manage the risk.

Catastrophe models are powerful tools for assessing risk at both the individual and aggregate level, and allow for the exploration and mitigation of exposure and risk correlation. The 2005 flooding of New Orleans ranks alongside the Great San Francisco Earthquake and Fire of 1906, and the 1927 Mississippi Flood: disasters on an iconic scale that lead to fundamental changes in catastrophe risk management culture. RMS is committed to assisting in this cultural change by developing and publishing objective assessments of the flood risk in the city of New Orleans from hurricane storm surges. The redevelopment of New Orleans depends on achieving a level of transparency around the future trajectory of flood risk, so those living and investing in the city can have the confidence that the risk is being effectively managed.

This report also considers the role of insurance, the planning process, and the government in providing physical and economic protection from flood risk. Information on risk should underpin planning the future of New Orleans. In a world in which the climate is changing, the analysis of future risk needs to inform economic decisions today.

While this report concerns a single city along the U.S. Gulf Coast, the problems are shared by many other coastal cities around the world: cities such as Venice, Alexandria, and Dhaka, similarly located on deltas and also prone to geologically rapid subsidence. Then there is a much longer list of cities at risk from rising sea levels and more intense storms, including cities all along the U.S. Atlantic and Gulf coasts.

The spotlight of world attention today is on how New Orleans resolves to sustain itself in a situation of rising risk. There are opportunities to pioneer solutions that maintain the viability of the city while at the same time ensuring that risk to the city's citizens and businesses is maintained below acceptable and published thresholds. As the leading independent provider of global risk information, RMS will be working to ensure that risk analytics continue to remain at the heart of decisions about development, flood protection, and insurability. ■

Hemant Shah

President & CEO
Risk Management Solutions

EXECUTIVE SUMMARY

Hurricane Katrina marks a turning point for the city of New Orleans. While the city had been flooded by hurricane storm surges three times in the past century, the flooding was most extensive in 2005 when more than 80% of the city was left underwater after the passage of Hurricane Katrina.

After each of the earlier storm surge floods in the city in 1915, 1947, and 1965, modest programs of investment in improved flood defenses were followed by decades of relative neglect. Throughout the post-flood periods, tens of thousands of new buildings were developed in the partially protected flood plains, effectively increasing the number of people and properties exposed to flooding from hurricane storm surges. As the years passed it must have appeared that flood risk had been vanquished, yet no comprehensive flood risk analysis was ever performed to discover the true situation – the risk was continuing to rise.

To avoid further repetition of this disastrous cycle, the strategy for the rebuilding and development of New Orleans must now be informed by a proper assessment of the flood risk – not only the risk today but what it will be in the future.

The threat to New Orleans from flooding is increasing due to a combination of three physical temporal factors. First, as a result of its location on thick recent delta sediments along the edge of an oceanic basin, the city is sinking at geologically rapid rates. Second, over the last decade, global sea level rise has increased as a result of climate change and is predicted to accelerate into the future. And third, the level of Atlantic basin hurricane activity has also risen, with the biggest increases for the strongest storms (with the largest surges), particularly in and around the Gulf of Mexico. These factors all serve to increase the storm surge flood hazard faced by New Orleans, and will significantly raise the risk of flooding in the city through the 21st century.

Those who hold a stake in the future of the city, including the policy makers who are responsible for its safety and prosperity, must plan for a future that is more hazardous than the past. The risks the city faces now and in the future must be quantified, and the results disseminated so that people and businesses can take action to ensure their personal safety and financial welfare is adequately safeguarded.

Many people manage risks to their property through insurance, and this report illustrates how the risk analysis involved in assessing insurability can be a useful tool for policy makers concerned with determining acceptable levels of risk. 'Insurability' reflects the degree to which insurers would risk their own capital against the probability of loss, taking into account uncertainty in the measurement of that risk. Faced with the scientific uncertainties around levels of hurricane activity, storm surge hydrodynamics, and levee failure processes, there will also inevitably be uncertainty in all flood risk estimates. However, the use of catastrophe models to quantify the risk allows the individual components of risk (hazard, exposure, vulnerability) to be separated, so that the uncertainties are explored along with alternative strategies for risk mitigation.

To frame the debate it is important to acknowledge that information about risk is inherently political. People concerned with the ability to sell their properties and politicians focused on the need to sustain inward investment will prefer that information on rising levels of risk is not publicized. Yet, the occurrence of a catastrophe such as Katrina, with its appalling loss of life and systemic economic consequences, highlights how, in the long term, it is to the benefit of all society to evaluate and understand the totality of the risks that are faced. Yet the pain points that will be encountered in passing from a state of 'risk naivety' to having a fully 'risk informed' population should not be underestimated. In the aftermath of a major catastrophe, when the memory of the destruction and chaos is still fresh, is the best time to commit to maintain transparency in providing regularly updated risk information.

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1 NEW ORLEANS: STAYING ABOVE WATER

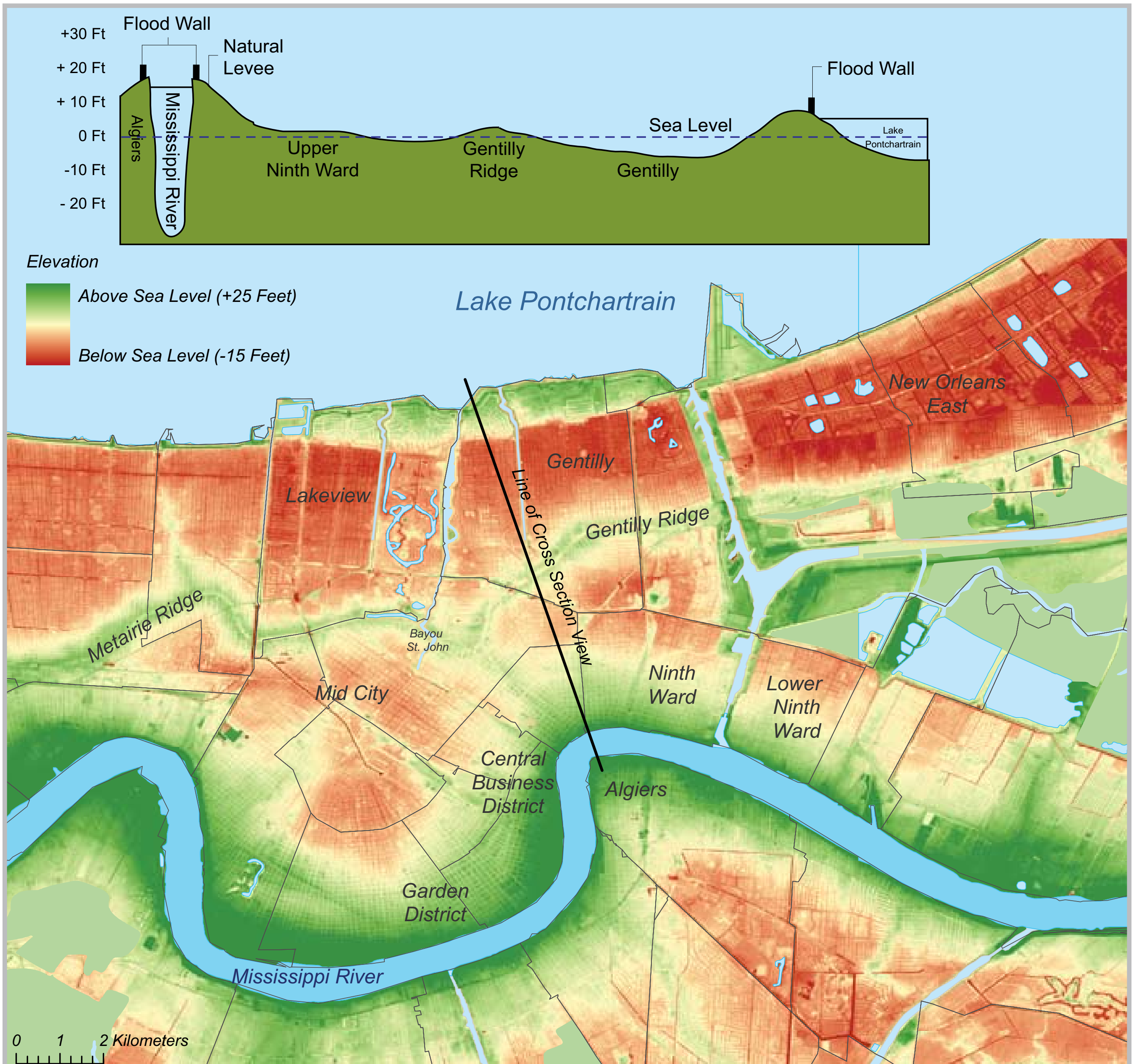
1.1 Development of New Orleans

The predicament of New Orleans can only be understood in its historical context, as a city developed around the central fight against flood risk, but which has consistently underappreciated the level of that risk. One of New Orleans' most renowned historians, Pierce Lewis, described New Orleans as the "inevitable city on an impossible site." With the need for a major city at the mouth of the Mississippi River to facilitate trade with the interior of the U.S., the problem was and remains the lack of a good location for such a concentration of people and infrastructure.

1.1.1 Topography of New Orleans

The topography of the city of New Orleans is first determined by the natural levee of the Mississippi River. With each Mississippi flood, water spilled out of the river, depositing its sediment to raise the natural levee to an original average 10 to 15 ft (3 to 4.6 m) above sea level, and 1 to 2 miles in width, sloping very gently into the backswamp. In the New Orleans area today, the Mississippi River flows 10 ft (3 m) to 15 ft (4.6 m) above sea level.

Between the river and the shores of Lake Pontchartrain, there is also a shallow ridge that marks an abandoned distributary of the Mississippi River that left the main



Topography of New Orleans, showing elevations below and above sea level in cross section looking west (above) and in plan (below) channel about 20 mi (32 km) upstream of the French Quarter. This ridge, known as the Metairie and Gentilly Ridges, provided a causeway for an east-west highway and a natural barrier that obstructed all but the highest storm surges passing into the original site of the city.

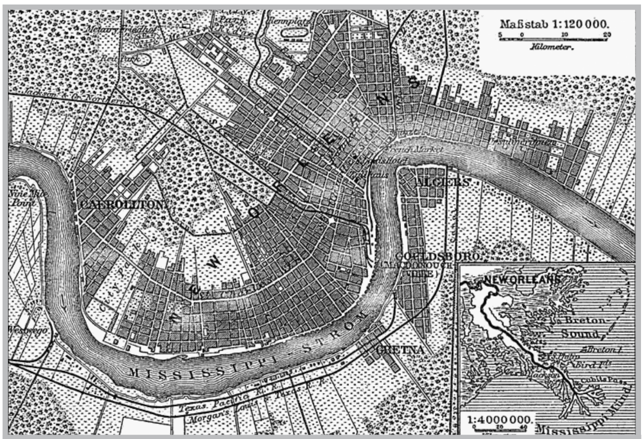
The remaining portions of the city were part of the backswamp that regularly flooded. The original backswamp between Metairie Ridge and the main Mississippi River levee was a shallow bowl, with its center close to sea level prone to filling up with water after heavy rains. Before the time of the first pumps, the water overflowed to the north through the Metairie Ridge into the tidal creek of Bayou St. John. This channel also provided the principal route for a storm surge advancing from the north to pass into the heart of the city.

1.1.2 Founding and Expansion of New Orleans

New Orleans was founded by the French in 1718 at the natural levee embankment on a tight outer bend of the lower Mississippi River. The site was only big enough for a village, providing a path through the trees for carrying loads from the river to the tidal creek of Bayou St. John that ran for a few miles into Lake Pontchartrain. The swamps between the river and the lake flooded almost every spring from water overflowing the levees upstream. After the Louisiana Settlement of 1803, the town quickly became the largest U.S. city in the south, expanding its footprint along the flanks of the levees as they followed the meandering river east and west to become the Crescent City.

From the middle of the 19th century, developers eyed the marshlands that fringed the city to the north. Recognizing that pumps would be required to keep these areas from flooding, a series of three drainage channels were cut running south from Lake Pontchartrain into which water could be pumped. In 2006, these are known as the 17th Street, Orleans Avenue and London Avenue canals. By the 1880s, with a population approaching a quarter of a million people, almost half of the city had been developed within the marshlands. The pumps, however, were unreliable, and as a result the low lying parts of the city were repeatedly flooded after heavy rains.

The breakthrough came soon after 1900 when the Chief Engineer of New Orleans, A.B. Wood, developed giant electricity-powered screw siphon pumps to remove flood water from the city. The 12 ft (3.7 m) version was first developed in 1913 with a pumping capacity of 500 cusecs (cubic feet per second), followed by a 14 ft (4.3 m) version in 1928 with double the capacity. The original pump houses were situated at the southern end

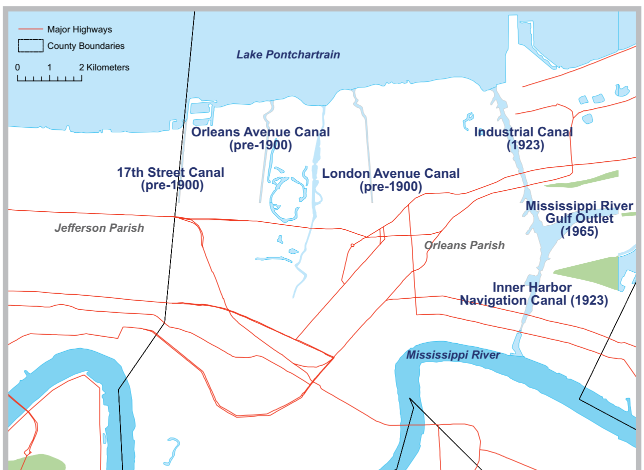


The layout of New Orleans in 1888, before the installation of pumps to remove flood waters from the city

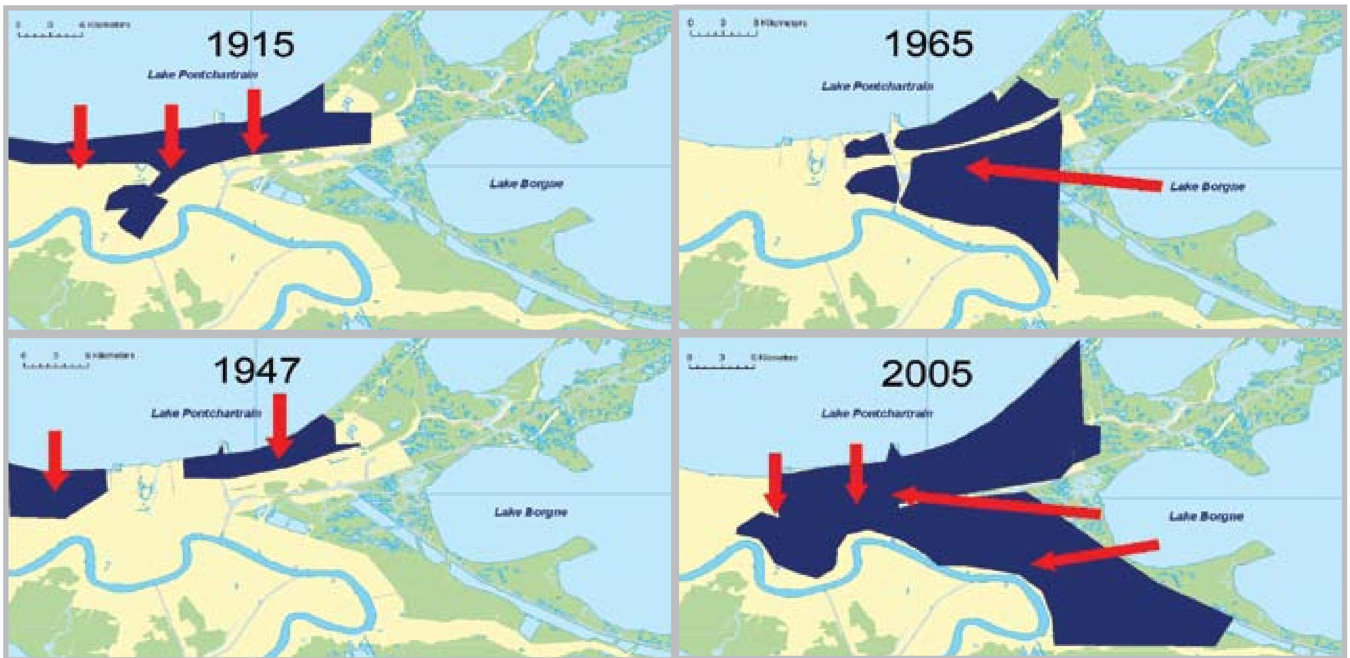
of the channels that passed into Lake Pontchartrain and remained in place and in use at the time of Hurricane Katrina.

Increases in pumping capacity at the beginning of the 20th century saw the city expand across the swamplands right up to the lake's shore. From 1900 through 1930, the population of Orleans Parish grew over 60% to 460,000 people. Trade and industry also expanded, and in 1923 a shipping channel named the Industrial Canal was constructed along the eastern edge of the city. This canal connected with the varying height of the river through locks of the Inner Harbor Navigation Canal (IHNC), which were only large enough to take the barge traffic of the time.

The port of New Orleans continued to expand, and in 1965, to circumvent the restriction of the locks, the U.S. Army Corps of Engineers (USACE) completed construction of the Mississippi River Gulf Outlet (MRGO) shipping channel, providing a shorter route from New Orleans to the Gulf of Mexico. The MRGO entered the city from the east, half way down the Industrial Canal. In contrast to the IHNC, which was 30 ft (9 m) deep



The main canals in New Orleans: 17th Street, Orleans Avenue, and London Avenue canals, the Industrial and Inner Harbor Navigation canals, and the Mississippi River Gulf Outlet



Historical flooding in New Orleans due to hurricane storm surges in 1915, 1947, 1965 and 2005

and 75 ft (23 m) wide, this channel was cut 650 ft (198 m) wide and 500 ft (152 m) across at its base, with a 36-ft (11-m) water depth appropriate for ocean going ships. However, the unconsolidated sides of the cut continued to collapse and as a result, material had to be continually dredged from the bottom of the channel to maintain navigability. Over time the profile of MRGO has become more than twice as wide as originally designed. Moreover, with no flood gates, the MRGO also inadvertently increased the opportunity for storm surge floods to penetrate into the city.

As the port expanded, so did the population of New Orleans. After 1945, the Lakeview and Gentilly areas behind the lakefront emerged as desirable locations to live. Over the next 30 years, these areas experienced rapid growth, adding over 100,000 residents to the city. Additionally, in the 1950s and 1960s, New Orleans East was reclaimed and substantial numbers of residential dwellings were built on this former swampland. The population of Orleans Parish reached its peak in 1960, with a total of 625,000. At the time of Hurricane Katrina in 2005, the populations of Orleans Parish and Jefferson Parish were fairly equal, each at approximately 450,000.

1.2 Flooding in New Orleans since 1900

Since the beginning of the 20th century, while the southern Louisiana coastline has been flooded by hurricane storm surges numerous times, the four most significant flooding events in New Orleans occurred in 1915, 1947, 1965, and 2005.

In 1915, as a result of a category 4 hurricane, the city experienced its first serious flooding by storm surge that sent a 15 to 20-ft (4.6 to 6.1-m) wave up the Mississippi River, overwhelming the river levees downstream of New Orleans. In Lake Pontchartrain, water reached 6-ft (1.8-m) above sea level and overflowed the low protective embankments to flood the northern part of the city, including the low-lying downtown area to depths up to 8 ft (2.4 m). Water remained in the city for four days, and was removed by the available pumps once electrical power was restored. This event spurred investment in new pump stations and the raising of the levees along the drainage canals (17th Street, Orleans Avenue, and London Avenue canals) and the Pontchartrain shoreline.

In 1947, New Orleans flooded again when a category 3 hurricane passed directly over the city. Flood defenses along Lake Pontchartrain failed at a number of locations to the northwest of the city. The western wall of the 17th Street Canal failed, flooding neighborhoods in Jefferson Parish up to 6 ft (1.8 m). In all, 30 mi^2 (78 km^2) of Jefferson Parish were flooded, prompting the evacuation of 15,000 people. To the east, 9 mi^2 (23 km^2) of Orleans Parish were flooded, although most of this land was not developed and water did not enter the downtown area. Since the water was in a part of the city away from the location of the major pumps, the flood waters remained for weeks and were only removed through digging and blasting holes in the flood defenses. As it had after the 1915 flood, the city invested in improvements to flood defenses and land reclamation along the shores of Lake Pontchartrain, which sparked a major expansion of the city to the north. The levees were heightened along the south shore of Lake Pontchartrain bordering the city and extended westward across Jefferson Parish.

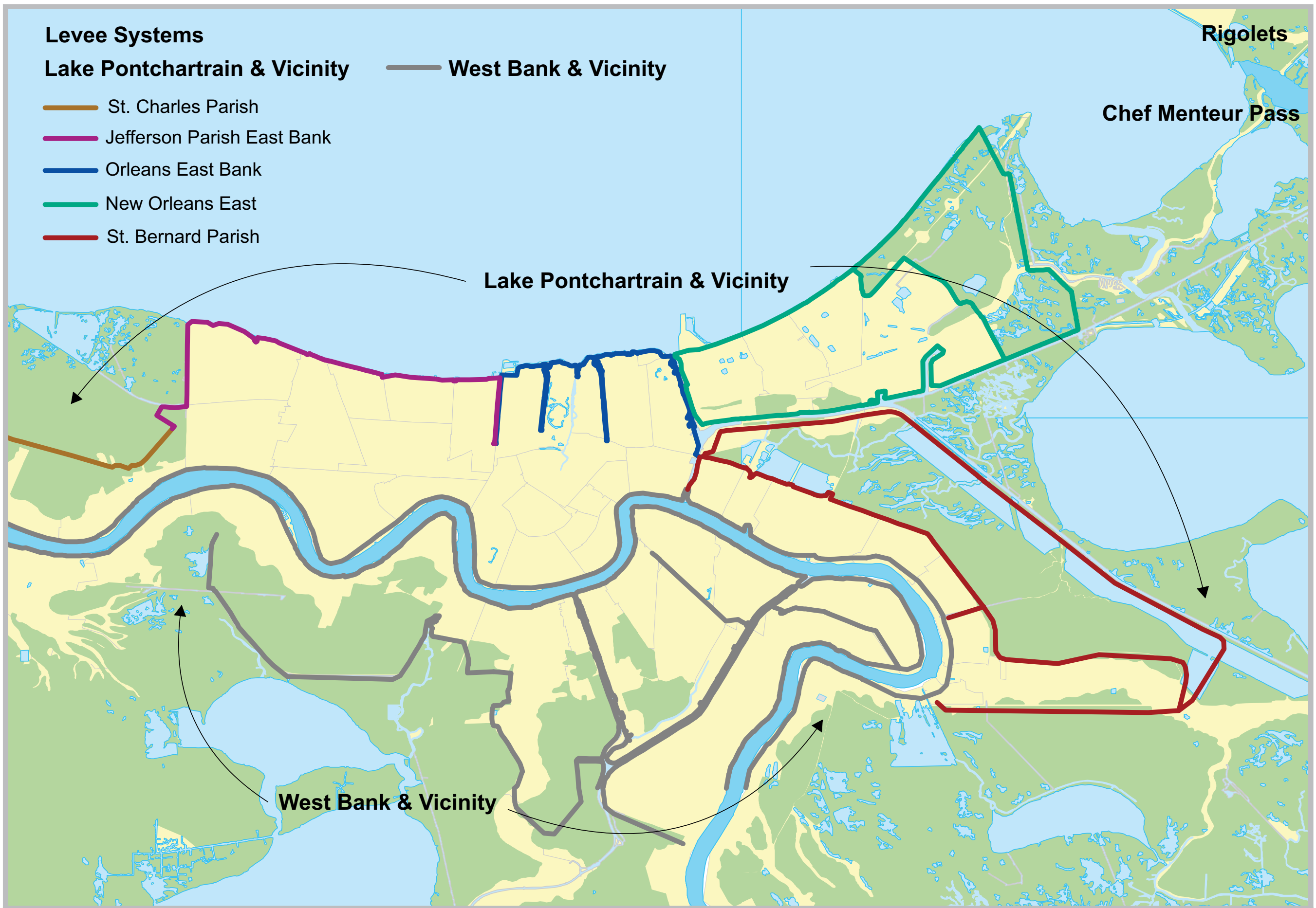
In 1965, the city was flooded by Hurricane Betsy, a category 3 storm. However, this time the defenses along Lake Pontchartrain held. This hurricane had arrived within months of the completion of the MRGO, which provided a funnel up which the storm surge from Lake Borgne to the east was directed towards the city. It was the first time the city had been flooded from this route. The earth embankments along the Industrial Canal were breached at numerous locations, flooding the entire eastern part of the city on either side of the canal. As a result, 13,000 houses were flooded leaving 60,000 homeless. The surge reached up to 12 ft (3.7 m) above sea level and left water levels of up to 9 ft (2.7 m) deep in parts of the city. There were 58 deaths in New Orleans with a total of 81 people killed by the storm across all affected regions. It was the first U.S. natural disaster to exceed $1 billion in damages, and led to new initiatives for flood protection with the passage of the Flood Control Act of 1965 by the U.S. Congress.

New Orleans never fully recovered from Hurricane Betsy. The population never regained the peak of more than 625,000 that it had in the early 1960s. As people whose homes were flooded in Betsy moved out of the lowest parts of the city, residential housing prices and quality of amenities reduced so that these areas increasingly tended to become the preserve of the old and the poor. Forty years later, these were the people who were most affected by Hurricane Katrina.

1.3 Levee Enhancement after Hurricane Betsy

There are three U.S. Army Corps of Engineers (USACE) levee systems in Southern Louisiana: the Lake Pontchartrain and Vicinity, the West Bank and Vicinity, and the New Orleans to Venice hurricane protection projects. The system that is of most importance to the flood defense of New Orleans is the Lake Pontchartrain and Vicinity project, which covers St. Bernard, Orleans, Jefferson, and St. Charles parishes, generally between Lake Pontchartrain and the Mississippi River. It also includes flood defenses around the 17th Street, Orleans Avenue, London Avenue, and Industrial canals, as well as the Inner Harbor Navigation Canal (IHNC).

The enhancements to the levee system surrounding New Orleans following Hurricane Betsy have their origins in the 1955 Congressional act that authorized the investigation of the coastal areas of the southern and eastern U.S. susceptible to hurricane hazard. Based on this investigation in 1964, the Chief of Engineers



Two of the three levee systems protecting southern Louisiana: the New Orleans and Vicinity and the West Bank and Vicinty hurricane protection projects of the New Orleans District submitted a report to the Secretary of the Army outlining a plan for the protection of New Orleans known as 'The Barrier Plan.' This plan included the construction of control structures (e.g., barrier and flood control gates) along the eastern portions of Lake Pontchartrain, in the Rigolets and Chef Menteur Pass areas, and levees along the lake in St. Charles Parish and New Orleans East. The report also recommended improvements to the existing flood protection in Jefferson and Orleans parishes, floodwalls flanking the IHNC, and the construction of new levees along the southern side of the Mississippi River Gulf Outlet (MRGO).

The goal of the Lake Pontchartrain and Vicinity project was to prevent storm surges from entering the lake and overflowing the 9 to 14-ft (2.7 to 4.3-m) lakefront levees. Six weeks after Hurricane Betsy, the Flood Control Act of 1965 authorized the project, and the following year construction began. At the time, it was estimated that it would take 13 years to complete. However, over the course of the project, there were delays due to design changes and environmental concerns, which culminated in a 1977 federal court decision which barred the USACE from constructing the control structures in the Rigolets and Chef Menteur Pass areas.

As a result, the barrier plan for the project was abandoned, and an alternative project plan, known as the high level plan, began construction in the mid-1980s. This called for higher levee heights, ranging from 16 to 19 ft (4.9 to 5.8 m) above mean sea level along Lake Pontchartrain. However, the plan did not recommend a final solution to the inadequacy of the embankments along the 17th Street, London Avenue, and Orleans Avenue canals. In 1992, it was determined that protection should be in the form of raised floodwalls and the flood proofing of bridges crossing the canals. At the time of Hurricane Katrina in 2005, construction was still ongoing and was estimated to be between 60% and 90% finished across various aspects of the project, with an anticipated completion date of 2015.

1.3.1 Standard Project Hurricane

Even after the renewed focus on flood protection for the city following Hurricane Betsy, there was no comprehensive use of risk analysis techniques to design and plan the new defenses. After Betsy, flood defenses were intended to withstand the storm surge associated with the 'standard project hurricane,' which was chosen to represent the most severe meteorological conditions considered reasonably characteristic for that region. In other words, the design was based on an engineer's judgment as to a 'reasonable' level of protection, instead of being designed to provide protection to some assigned level of probability. Since the 1960s, the USACE has used the standard project hurricane concept as a basis for the design of hurricane protection systems along all of the eastern and southern coasts of the United States.

Standard Project Hurricane Meteorological Parameters	
Central Pressure	934 mb
Radius to Maximum Winds	30 nautical miles
Forward Speed	Varied by location, 5, 6, or 11 knots
Calculated Wind Speed	100 miles per hour

Parameters used to define the standard project hurricane for the New Orleans and Vicinity hurricane protection project

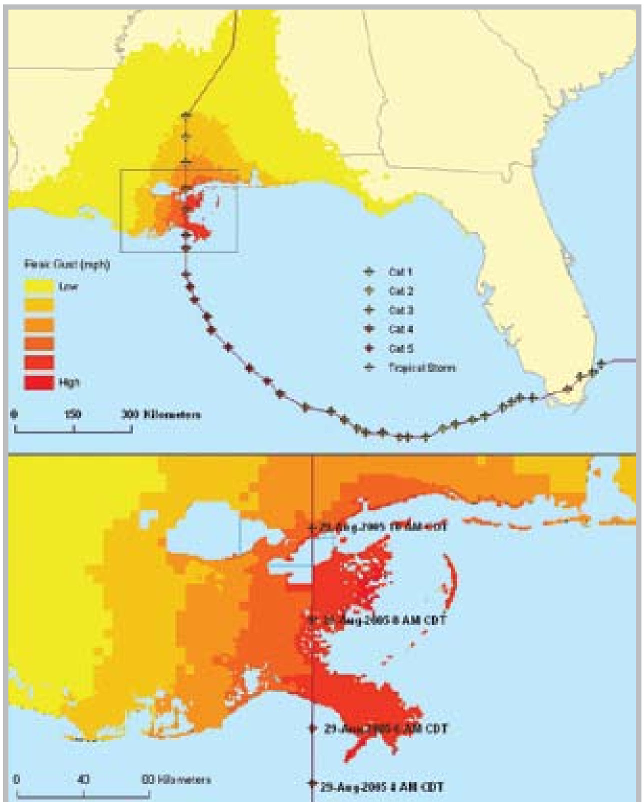
The USACE, in conjunction with the U.S. Weather Bureau (now the National Weather Service), considered the standard project hurricane as a steady state storm sampled from within a 400-mile (645-km) zone along the central U.S. Gulf Coast from Cameron, Louisiana to Pensacola, Florida. Based on an analysis of the historical storms hitting the region between 1900 and 1956, the standard project hurricane for New Orleans and its vicinity was established in 1959. Although the Saffir-Simpson Scale was developed ten years after the standard project hurricane was first defined, this storm has been compared to a fast moving category 3 hurricane with sustained winds of up to 130 mph (209 km/hr). Over time, the specifications for the storm were updated, but not fundamentally changed. For example, after Hurricane Betsy in 1965, revised windfield parameters were issued, but the other parameters defining the storm, including the central pressure, the radius of maximum winds, the forward velocity, the direction of approach, and the wind speed remained unchanged.

Somewhat fortuitously, the choice of parameters for the standard project hurricane was appropriate to the low level of hurricane activity that followed the 1960s. Only nine intense hurricanes made landfall along the Gulf Coast from 1971 to 2000. While the return period of protection was never fully defined (although there is reference to a 100-year storm surge), the annual probability of exceeding the design storm was probably around 1 in 200 over this period. By the time construction began in the mid-1980s, it was clear that some of the data that had been employed for arriving at the standard project hurricane was flawed. Unfortunately, neither the probabilistic methodologies, nor the computational resources, were available to the USACE at that time to determine what a risk-based design level should be for a region with such a complex coastline and wide range of hurricane sizes, intensities, tracks, and forward speeds. ■

2 THE GREAT NEW ORLEANS FLOOD OF 2005

Following its first landfall as a category 1 hurricane on the Florida peninsula on August 25, 2005, Hurricane Katrina entered the Gulf of Mexico. There the hurricane underwent a dramatic intensification over the unusually warm Gulf waters, down to a central pressure of 902 mb and category 5 winds on Sunday, August 28, 2005. The hurricane weakened slightly to a category 4 storm and made its second landfall on the Gulf Coast, southeast of New Orleans, at 6:10 am CDT on August 29, 2005. The center of the storm then crossed the Mississippi River Delta and the Chandeleur Sound, coming onshore again near the Louisiana-Mississippi border four hours later at 10:00 am CDT. Because the center of the storm passed to the east of New Orleans, the city suffered lower winds (maximum gusts of around 100 mph, or 160 km/hr) than prevailed to the right of the track.

Out in the Gulf of Mexico, the storm surge and wave potential of Hurricane Katrina significantly exceeded that of the standard project hurricane used to design the New Orleans flood defenses. Even while the hurricane weakened to a category 3 storm as it passed New Orleans, the storm surge maintained some of its offshore characteristics, reaching maximum elevations of more than 25 ft (7.6 m) along the south-facing Mississippi Coast. A number of factors contributed to this extraordinary height: the sustained intensity of the storm, the large radius to maximum winds, and the local bathymetry of the Louisiana-Mississippi embayment.



The path of Hurricane Katrina, showing first and second landfalls in Florida and Louisiana (above) and a close-up of the second landfall in Louisiana (below)

Hurricane Katrina first overwhelmed the levee system protecting Plaquemines Parish at the outlet of the Mississippi River. The major levees and floodwalls were massively overtopped and many failed. Design levels for the flood defenses in southern Plaquemines Parish averaged about 13.5 ft (4 m), with measured peak water levels up to 19.5 ft (5.9 m). Fortunately, this area along the lower Mississippi River is sparsely populated and was mostly evacuated. The maximum water levels were reached between 5:45 am and 6:45 am CDT on August 29. By 7:00 am CDT, most of Plaquemines Parish was underwater.

As the center of the storm moved north, easterly winds first pushed a storm surge into Lake Borgne. This storm surge was relatively short-lived, as the winds shifted around to the north and then northwest. The counterclockwise direction of the winds also produced a storm surge along the southern shoreline of Lake Pontchartrain, where water levels rose more slowly and persisted much longer.

2.1 First Phase of Flooding

New Orleans was first hit by the storm surge, arriving up the Mississippi River Gulf Outlet (MRGO) from Lake Borgne to the east, between 4:00 am and 6:00 am CDT, when easterly winds ahead of the center of the storm were at their peak. Along the 11-mi (17.7-km) stretch of levees fronting the southern side of the MRGO, which protected St. Bernard Parish, the surge reached more than 18 ft (5.5 m), with strong waves battering and overwhelming the earth and sheet pile levees. As a result, by 6:00 am CDT on August 29, St. Bernard Parish had been submerged. Many houses were pushed off their foundations by the speed of the advancing flood waters.

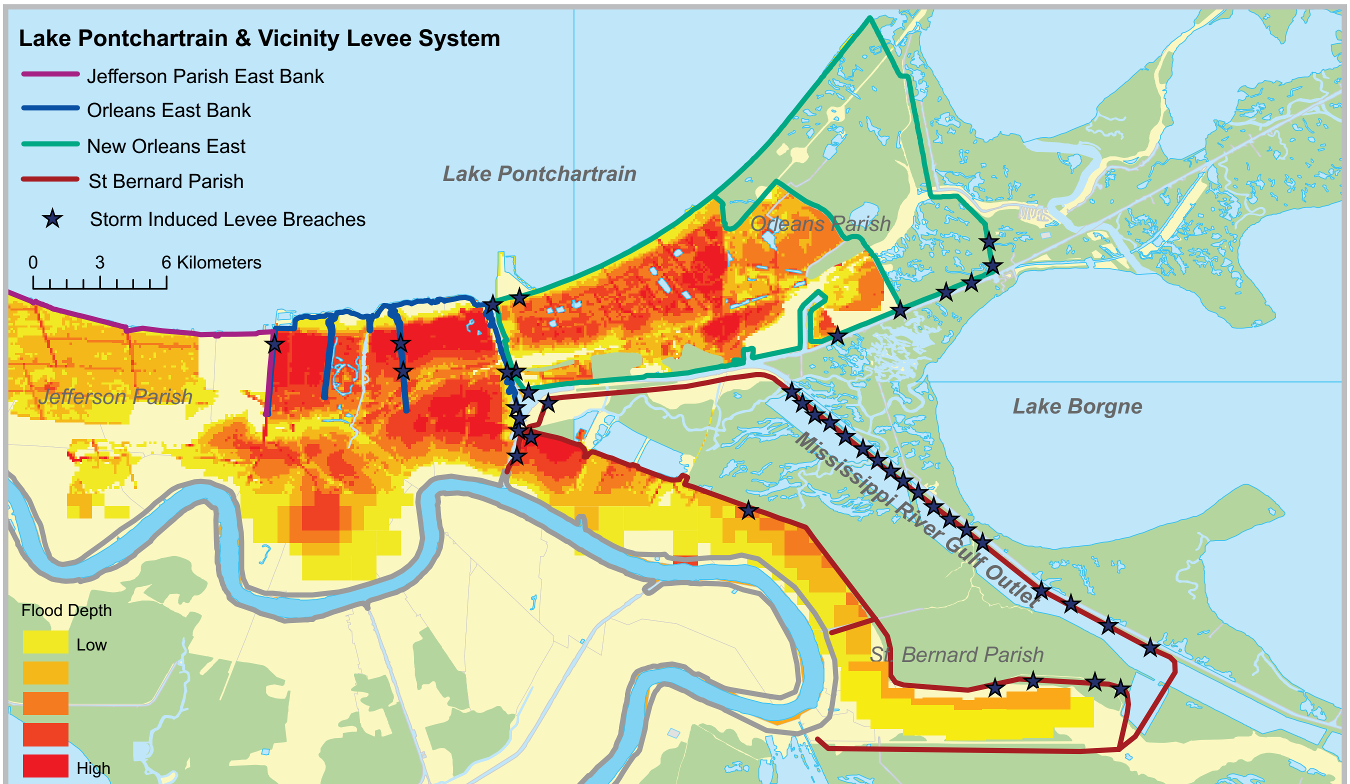
As the storm surge worked its way westward along the MRGO east-west channel (past the intersection with the Gulf Intracoastal Waterway or GIWW), it was measured at 16.5 ft (5 m) high at the Paris Road Bridge, approximately 4 mi (6.4 km) to the east of the junction with the Inner Harbor Navigation Canal (IHNC). At this point, the flood defenses were 15.5 ft (4.7 m). Near the intersection of the MRGO and the IHNC, at approximately 4:45 am CDT, the first breaching occurred on the western side of the IHNC, allowing water to spread into the area to the north of the French Quarter. It is estimated that between 10% and 20% of the water which flowed into the downtown area came from openings in the flood defenses at these locations (as a majority of the water came through breaches in the 17th Street and London Avenue canals in the second phase of flooding).

On the eastern side of the IHNC, at the western edge of the Lower Ninth Ward, 15-ft (4.6-m) high water levels spilled over the 14-ft (4.3-m) defenses, and at around 7:45 am CDT, catastrophic breaching occurred as the foundations of the levees were ripped out and the rush of water floated off buildings several blocks away. Around the same time, the surge overtopped and breached the levees at a number of locations on the northern side of MRGO along the southern edge of the New Orleans East area. On either side of the IHNC, flooding affected the same areas as Hurricane Betsy in 1965, although in 2005 water levels reached 3 to 4 ft (0.9 to 1.2 m) higher than in the earlier storm.

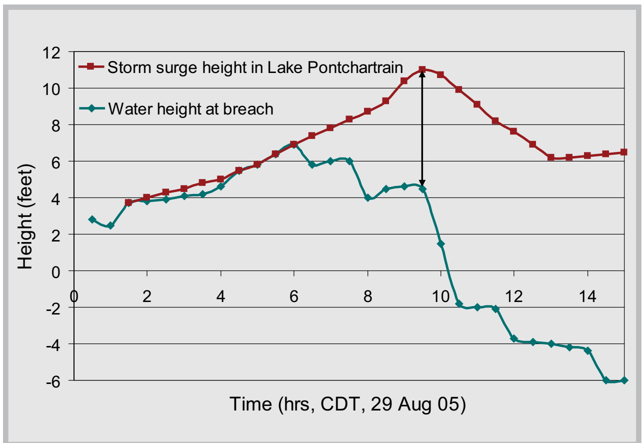
2.2 Second Phase of Flooding

The second phase of flooding in New Orleans came from the north via Lake Pontchartrain, with three breaches along the drainage canals that had originally been dug in the late 19th century to allow water pumped out of the low lying downtown areas to flow back into Lake Pontchartrain. The purpose of these canals was now to be inverted, as two of them became the principal conduits for the flooding of much of New Orleans. Given that they passed through some of the lowest lying parts of the city, the flooding was more sustained, as water continued to pour into the downtown area even after the storm surge had largely subsided. Although there were many breaches along the New Orleans flood protection system during Hurricane Katrina, these failures have received the greatest attention due to their impact on downtown New Orleans and their particular modes of failure.

While water levels were insufficient to overtop the floodwalls that lined these canals (some reports indicate that water reached as high as 11 ft, or 3.4 m, where the concrete walls atop the earthen levees measured a minimum of 12.5 ft, or 3.8 m), at three locations sections of the floodwalls were breached. The first breach occurred between 7:00 am and 8:00 am CDT along the eastern flank of the London Avenue Canal near its southern inland end. The opening measured approximately 80 ft (24.4 m) in length, and the failure mode was the result of underseepage and erosion of the underlying earthen levee. The second 300-ft (91.4-m) wide breach occurred before 8:30 am CDT on the western flank of the London Avenue Canal floodwall toward the north end. This breach appears to have been the result of the instability of the floodwall and its sheet pile foundation, which tilted and allowed water to flow in a gap between the wall and the underlying embankment and causing further erosion and slumping.



The impact of Hurricane Katrina: maximum flood depths in protected regions of New Orleans and its vicinity developed by RMS and flood levee breaches documented in the Independent Levee Investigation Team Report (ILIT, 2006)



Water levels at northern end of 17th Street Canal (Lake Pontchartrain) and southern end of 17th Street Canal, indicating hydraulic gradient that existed between the lake and the breach

Breaching of the 17th Street Canal in New Orleans (Courtesy NOAA)

The third and most notorious breach occurred on the eastern side of the 17th Street Canal near its northern end at around 9:00 am CDT (although some overstress in the floodwalls was observed as early as 6:30 am CDT on the western side of the canal). The failure mode of this 450-ft (137-m) opening was again due to a build up of water pressure behind the canal side of the floodwall, opening a gap between the floodwall and the underlying earthen embankment. The water pressure caused further erosion and degredation of the strength of the underlying peat layers and allowed the progressive failure of multiple panels of the flood wall. Water continued to flow into the city from Lake Pontchartrain for more than a day before the waters of Lake Pontchartrain fell and water began to flow in and out at every tide. Pumping equipment was restored and brought into the city within a week so that the majority of the 250 billion gallons (946 billion liters) that had flowed into the city had been removed by September 24, and the city was claimed dry on October 12, 2005.

2.3 Consequences of Flooding

The flooding of New Orleans accounted for around 800 of the approximately 1,300 lives lost in Louisiana during Hurricane Katrina. Much of the loss of life occurred in the poorest neighborhoods that had been flooded by Hurricane Betsy and abandoned by the middle classes in 1965. However, the breaching of the 17th Street Canal flooded a large area of northern New Orleans not flooded in Hurricane Betsy and containing middle-class neighborhoods whose residents had not recognized the inherent flood risk.

In the aftermath of Hurricane Katrina, over 80% of the metropolitan area of greater New Orleans was flooded, including 65% of the 147,000 residential properties. Of these 95,000 properties, 55% sustained over 4 ft (1.2 m) of water, meaning that the building was effectively a write off for insurance recoveries. The total economic cost for residential structures in New Orleans is estimated between \$8 and \$10 billion, with federal flood insurance likely to supply \$4 to \$5 billion, and the remaining \$3 to \$6 billion being uninsured. Between 34,000 and 35,000 of the flooded homes did not have flood insurance, including many that were flooded but not in a defined flood zone according to the Flood Insurance Rate Maps (FIRMs) developed by FEMA.

2.4 Lessons Learned

Hurricane Katrina was one of the most destructive natural disasters to occur in the United States, but one in which large amounts of the damage and loss of life, in particular in New Orleans, reflect the failings of human systems of engineering, planning, and disaster management. A number of investigations have already been conducted in order to understand these failings, and their results published. Each stressed the need to identify lessons to be learned from the disaster to reduce the chances of a recurrence in the future. A number of major points have emerged relating to flood risk in New Orleans, stressing the need for risk-based approaches to flood management.

2.4.1 Need for Risk-Based Approach to Flood Management

The Federal Emergency Management Agency (FEMA), which is responsible for the national preparedness and response to natural disasters in the United States, published a lengthy report on the impact of Hurricane Katrina in July 2006 (FEMA, 2006). The main conclusions were that the flood levels resulting from the hurricane "far exceeded the current design flood elevations along a significant proportion of the Gulf Coast of Mississippi and caused levee failures in Louisiana," and that, in most of areas studied, flood and wave effects damaged and destroyed buildings "well beyond" the Special Flood Hazard Areas (SFHAs) indicated on the latest FIRMs.

The report acknowledged that flood levels from Hurricane Katrina in many areas exceeded the 100-year Base Flood Elevations (BFEs) shown on current FIRMs by up to 15 ft (4.6 m). As a result, many buildings that had been constructed with their lowest floor above the BFE were still destroyed or severely damaged by flood waters. Moreover, after recognizing that the BFEs established before the hurricane did not provide an adequate basis for guiding long-term development after the flood, FEMA issued interim Katrina Flood Recovery Maps in April 2006, showing revised Advisory Base Flood Elevations (ABFEs), to be used until new FIRMs are completed.

The report made a number of recommendations, including the revision of current flood mapping and hazard identification, particularly in coastal areas. It also called for flood insurance provisions and premiums to "reflect the actual risk during base flood conditions," noting that "actual risk refers to those flood conditions that would potentially exist if the levees provided minimum, or no, protection."

A very detailed "Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System" was carried out by the Interagency Performance Evaluation Task Force (IPET), set up by the USACE. The IPET report (USACE, 2006), published in June 2006, concluded that Hurricane Katrina had overwhelmed the hurricane protection system because it "exceeded design criteria, but the performance was less than the design intent."

The IPET report indicated that the protection of New Orleans had been based on the "traditional approach" which is "component-performance-based, uses standards to define performance, and relies on factors of safety to deal with uncertainty." However, it recommended that a "risk-based planning and design approach would provide a more viable capability to inform decisions on complex infrastructure such as hurricane protection systems." The report warned that the level of risk is highly dependent on how residents and policy makers act, because in densely populated areas "simply increasing system reliability may not reduce risks to acceptable levels and increasing consequences [associated with the risk] through continued flood plain development can offset any risk gains."

Breach at north end of London Avenue Canal after water levels equilibrated (Courtesy USACE)

Another report coordinated by the New Orleans District of the USACE reiterated the need for a risk-based approach to Louisiana coastal protection and restoration (LACPR, 2006). While the report represented an initial response to a late 2005 Congressional directive to the Secretary of the Army to produce a plan for the protection of coastal Louisiana against a "storm surge equivalent to a category 5 hurricane," it concluded that "[a]nalyzing the efficiency and effectiveness of hurricane risk reduction by using the probability of storms and level of risk reduction instead of using a criteria or standards such as standard project hurricane offers a more realistic and understandable approach for engineers, government leaders, and the public."

A separate review of the performance of the New Orleans flood protection systems during Hurricane Katrina was carried out by the Independent Levee Investigation Team (ILIT, 2006), led by the University of California at Berkeley, and partly funded by the National Science Foundation. The report outlined eight main sources of failure in the Flood Defense System for the Greater New Orleans Area (NOFDS), including the inadequate recognition of the hazards and required safeguards, and the substantial underestimation of the risks associated with hurricane storm surge and wave induced flooding.

Among its recommendations, the ILIT report highlighted the need to develop a NOFDS "founded on advanced Risk Assessment and Risk Management principles for all phases in the life-cycle including concept development, design, construction, operation, and maintenance." It noted that "Advanced Risk Management approaches should be used to provide decision makers with information to define what levels of protection should be provided for which areas, and how much can and should be spent for those purposes."

In February 2006, the U.S. federal government issued its own report on the lessons learned from Hurricane Katrina (White House, 2006). Its recommendations primarily focused on better coordination between governmental agencies at the local, state, and federal

Hurricane Katrina on August 28, 2005 in the Gulf of Mexico (Courtesy NASA)

levels and a review of the policies and procedures for emergency response activities. There is a call for a National Preparedness System to respond to future events similar to Hurricane Katrina. However, the report does not discuss how the future flood risk for New Orleans should be better managed to reduce the chances of a repeat of the disaster in 2005.

2.4.2 Impact on Assessment and Management of Catastrophe Risk

The damage and loss from Hurricane Katrina and the subsequent flooding of New Orleans has resulted not only in a call for risk-based approaches to flood management, but in a reassessment of risk assessment methodologies and the management of catastrophe risk.

The unusual magnitude of the storm surge in Hurricane Katrina, which was larger than that normally associated with the level of winds experienced, as well as evidence that the population of intense hurricanes has increased in the Gulf of Mexico, indicates a more general underestimation of flood risk along this coastline. RMS research into the risk of flooding in southern Louisiana and New Orleans has confirmed that predicting storm surge risk around the complex coastline of the Mississippi River Delta region involves a range of challenges in parameterization and modeling. Moreover, the risk of flooding in New Orleans from Lake Borgne via the MRGO is now recognized to be higher than formerly identified. ■

3 FLOOD RISK IN NEW ORLEANS

For the purposes of this study, flood risk in New Orleans has been explored using the RMS stochastic hurricane and storm surge generation models. The work on storm surge flood hazard in the city has focused on determining levels of risk at different geographical locations within the city today and how this risk is expected to change into the future.

3.1 Modeling Storm Surge Flood Risk in New Orleans

The treatment of flood risk in New Orleans is complex, requiring three separate classes of models. First, a comprehensive stochastic hurricane track model is required, accompanied by a high resolution windfield model that can provide a time-stepped output on wind speed and direction at every location throughout the passage of each storm. The comprehensive set of stochastic hurricane tracks, intensities and windfields in the RMS® U.S. Hurricane Model were used as the basis for the hazard modeling.

Second, the storm surges themselves are modeled as they advance onto a particular section of coastline and are modified by the topography of the coastline and seafloor. The RMS storm surge modeling methodology was employed to determine the expected surge height along the coastline, from which water levels were attenuated over water and land. The model was adapted to the specific conditions of surge propagation along the north-facing coastline of southeast Louisiana.

For the area along the IHNC in eastern New Orleans, close to the junction with MRGO waterway, storm surge heights were calibrated to be consistent with those generated in a study undertaken by the National Weather Service (NWS), exploring maximum storm surge height relative to the category of the storm (U.S. Navy, 1983; modified 2005). At this location the surge height in Hurricane Katrina was at the threshold for what the NWS predicted could be expected during a category 3 hurricane.

Lastly, there are multiple pathways by which high surge water levels encounter the many miles of flood levees that protect the city. For each section of defense, vulnerability and breaching models are required to determine probabilities of failure and likely breach size relative to the height of the surge outside of the defenses.

As experienced along the 17th Street and London Avenue canals in Hurricane Katrina, levee vulnerability relationships need to consider the potential for failure and breaching to occur at water levels lower than the defense crest. Over the course of a storm surge, breaching models constrain the volume of water flow through the defenses to determine the flood levels inside the city. However, it is now understood that, all else being equal, breach sizes tend to reflect the extent of the inland floodplain, as the breach will continue to expand as long as water is driven to flow at high velocities through the hydraulic gradient at the breach (Muir-Wood and Bateman, 2005).

New Orleans presents two fronts along which storm surges have the potential to flood the city. The weakest link is in the southeast of the city where the expanded Mississippi River Gulf Outlet (MRGO) shipping channel leads directly into the Inner Harbor Navigation Canal (IHNC) from the open sea of Lake Borgne. Only storm surges with this pathway have been included in the study. The city is also vulnerable to surges from Lake Pontchartrain to the north, although in general there is a strong correlation between water levels in Lake Borgne, fully open to the Gulf of Mexico, and those in the partially-confined Lake Pontchartrain. Only for slow moving tracks located close to the city would the surge in Lake Pontchartrain be higher than in Lake Borgne.

Furthermore, following Hurricane Katrina, the USACE applied protective remedies by blocking off the northern ends of the three drainage canals passing south from Lake Pontchartrain, thus reducing the potential for floodwaters to enter the city from this direction. Meanwhile, nothing has been done to resist the arrival of surges from Lake Borgne via the MRGO. Surges on the southwest side of Lake Borgne are associated with the easterly winds found ahead of any major hurricane with a northerly to northeasterly track crossing the southeast corner of Louisiana to the east of New Orleans. For typical forward speeds, such surges tend to be relatively short-lived, since wind directions change quickly as the hurricane passes. This is important when considering the most realistic way in which to model the entry of water over and through the flood levees into the city, as the short duration ensures that water levels cannot equilibrate inside and outside the defenses at the peak height of the surge. Rather than model each section of levee independently, a simple holistic model of levee fragilities, probabilities of breaching, and the ingress of water into the city has been employed relating water levels of the storm surge to the height that floodwater is expected to rise within the city.

One key calibration of this procedure has come from the water levels inside and outside the flood levees in Hurricane Katrina. In the model, a 16-ft (4.9-m) storm surge, which is slightly higher than the surge in the Inner

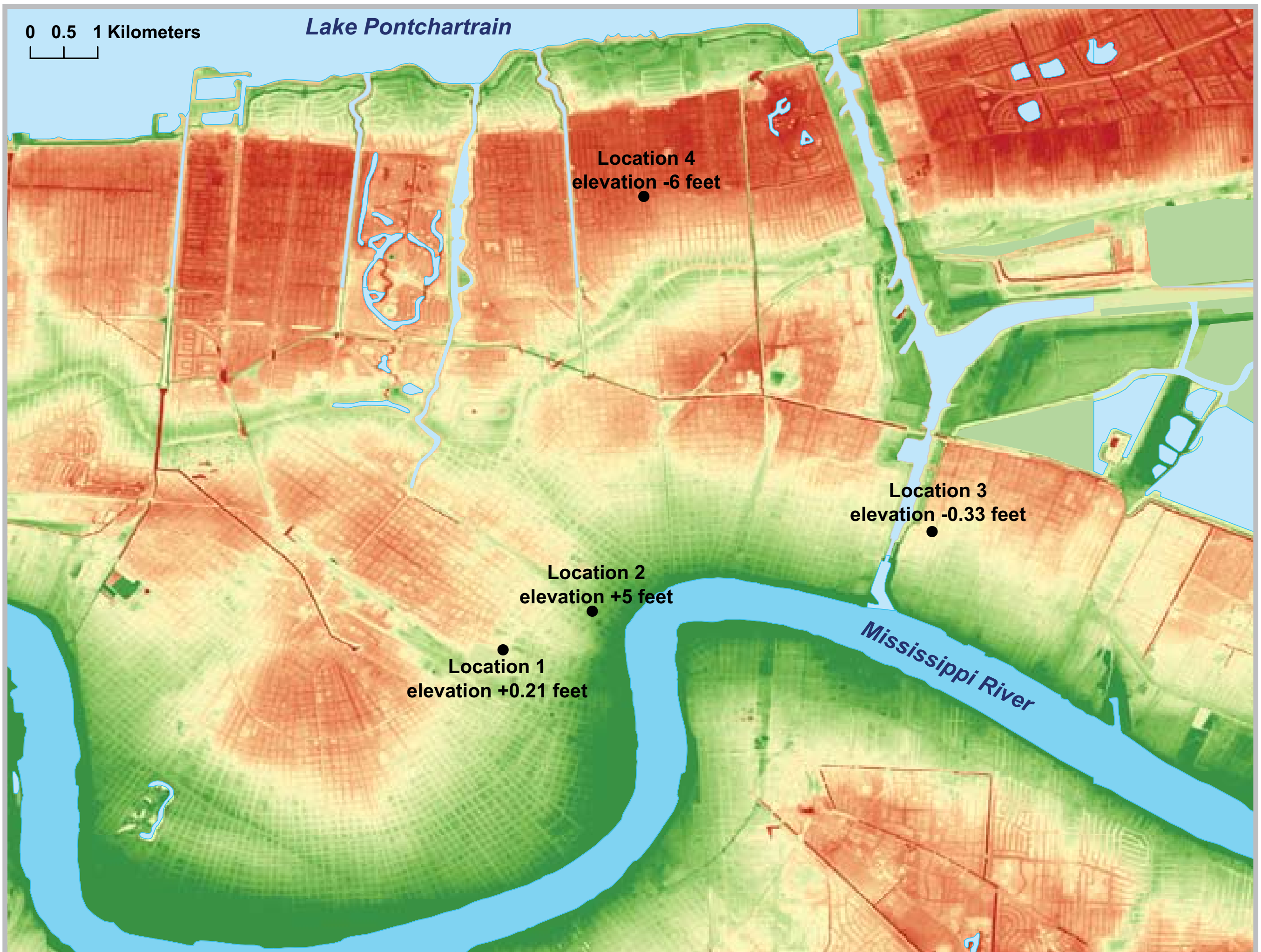
Harbor area during Hurricane Katrina, generates water levels reaching 6 ft (1.8 m) above sea level within the city of New Orleans.

3.2 Baseline Risk Assessment Results

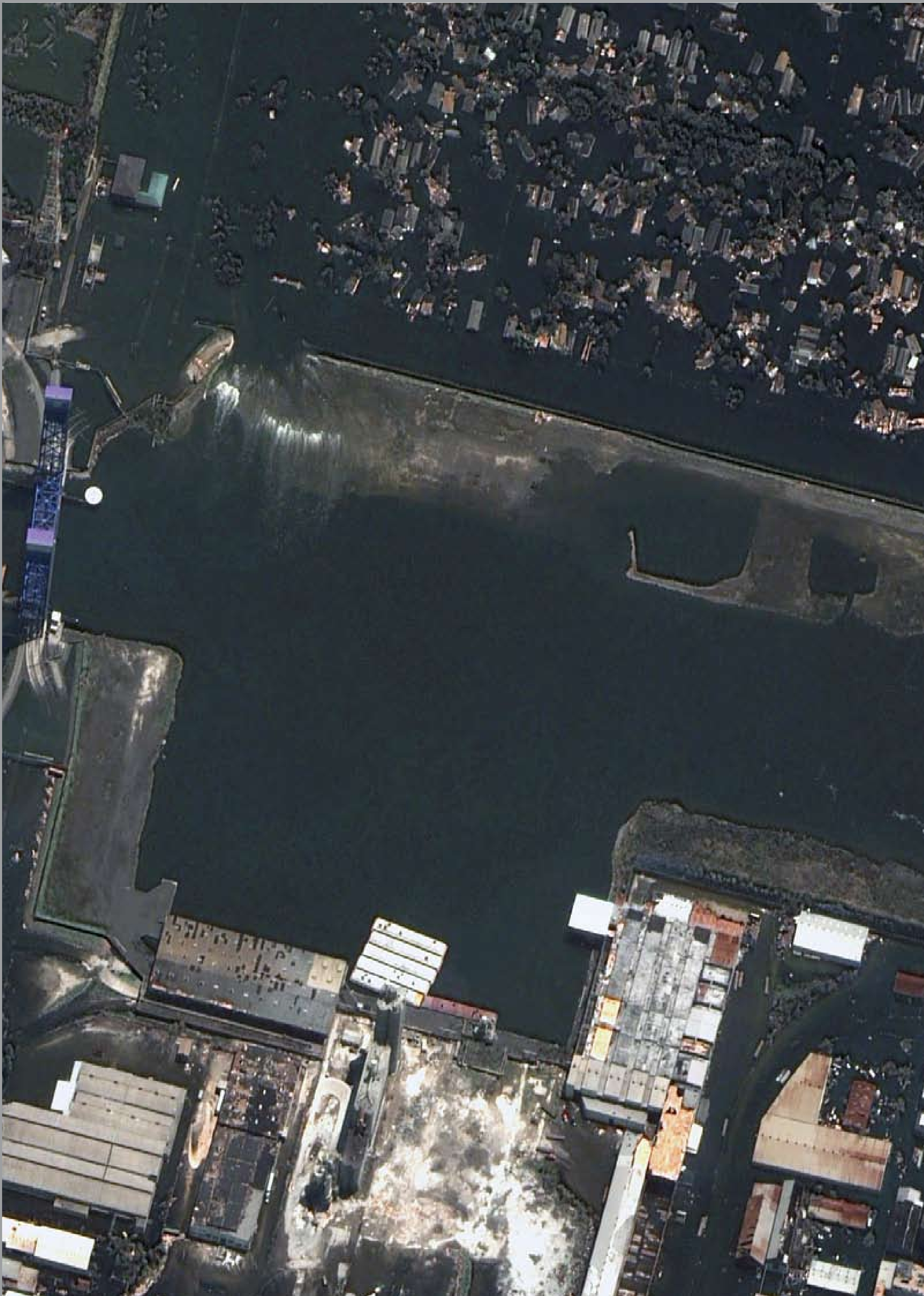
For the purposes of this study, the primary areas analyzed were those protected by the Lake Pontchartrain and Vicinity hurricane protection project, including the downtown region containing the Central Business District and the Garden District (i.e., Orleans East Bank), New Orleans East and portions of St. Bernard Parish, and the Lower Ninth Ward. An analysis of flood risk was completed using the hazard and levee fragility assumptions as outlined in the previous section to estimate flood depths within the protected region.

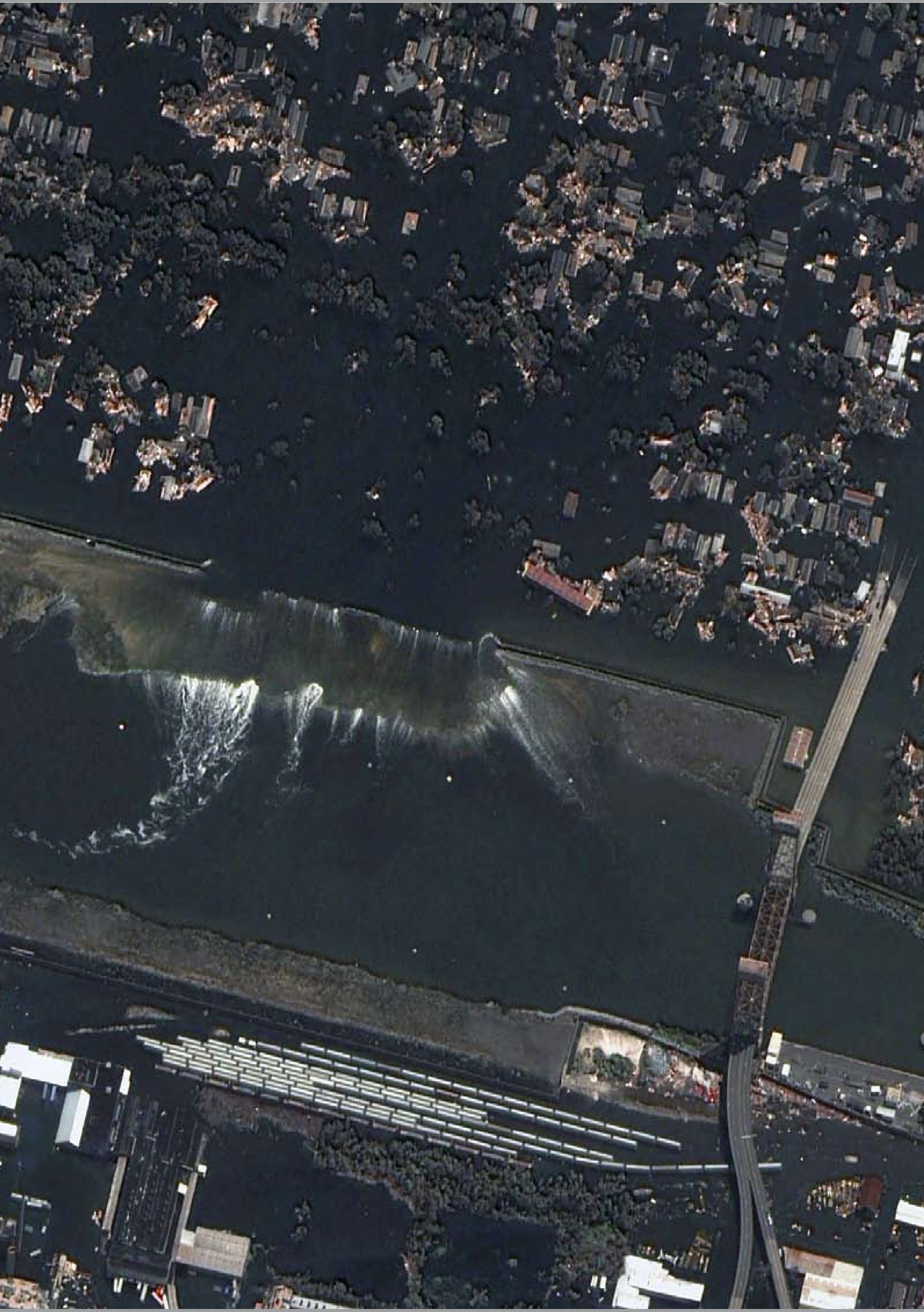
Flood maps of relative risk throughout the region were developed based on high resolution digital elevation maps, showing expected flood depths at various return periods. For example, the 100-year return period flood map shows the extent of flooding that is expected on average once every 100 years, corresponding to an annual exceedance probability (EP) of 1% (For more information on exceedance probabilities, see The Exceedance Probability Curve: A Metric of Risk on page 21). Maps of flood depths for the 100-year, 250-year, and 500-year return periods were generated, based on the 'medium term' 5-year hurricane activity corresponding to the 2007-2011 period, as contained within the RMS® U.S. Hurricane Model.

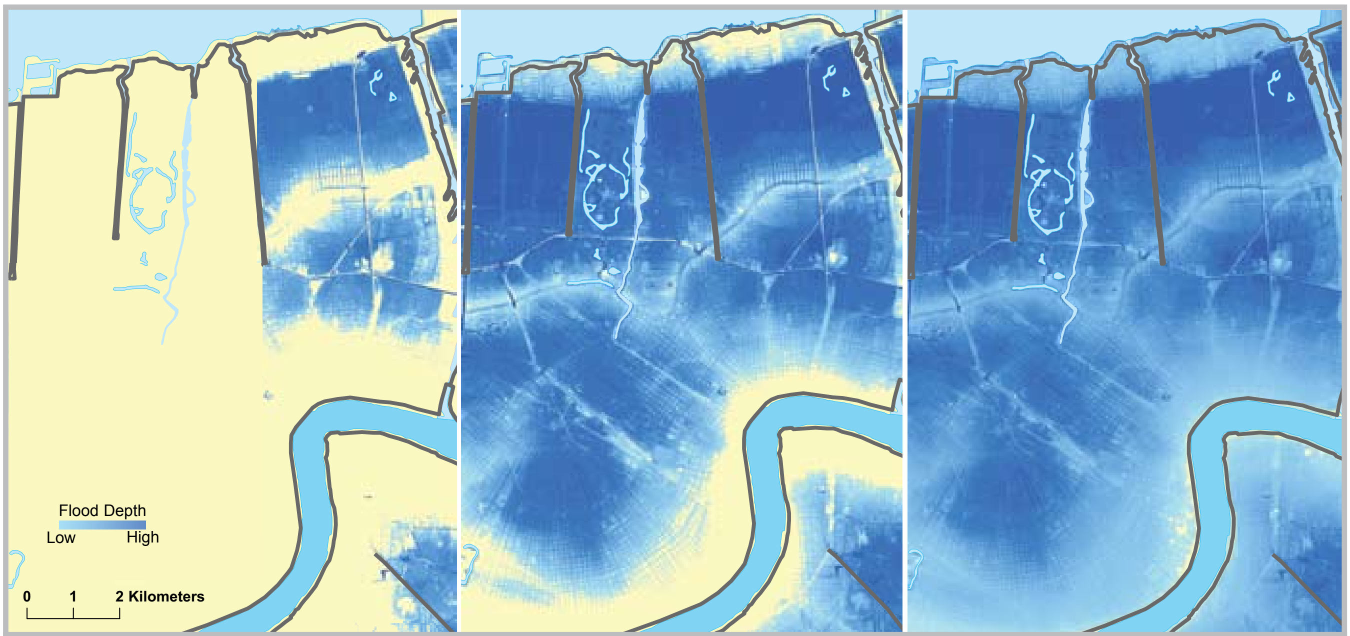
Additionally, four locations within the city of New Orleans were chosen for a more detailed study of predicted flood depth return periods, employing the simple metric of the modeled return period of first flooding from a storm surge at that location. The locations chosen were the Superdome (Location 1 at 0.21 ft, or 0.06 m above sea level), the heart of the French Quarter along Bourbon Street (Location 2 at around 5 ft, or 1.5 m above sea level), the heart of the Lower Ninth Ward (Location 3 at -0.33 ft, or -0.1 m below sea level), and the intersection of Filmore Avenue and Elysian Fields in northeast New Orleans (Location 4, one of the lower points in the city at -6 ft, or -1.8 m).



Locations within New Orleans chosen for further study: the Superdome (Location 1), the French Quarter (Location 2), the Lower Ninth Ward (Location 3), and the Gentilly Area (Location 4)







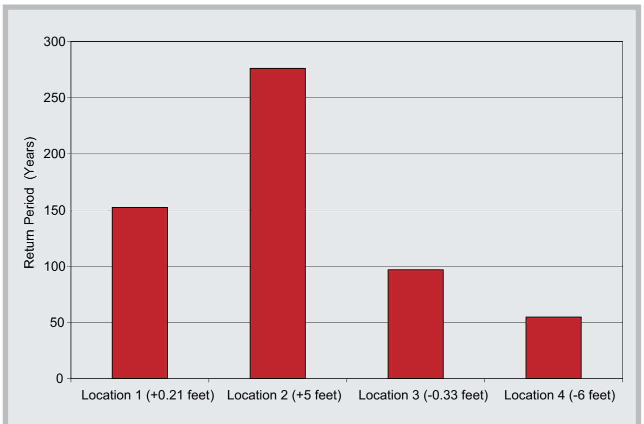
From left to right: Maps of flooding at the 100-year, 250-year, and 500-year return periods assuming medium term hurricane activity from 2007 to 2011 for the down-town region protected by the Orleans East Bank portion of the New Orleans and Vicinty hurricane protection project

Each of these locations was chosen for their strategic position and relative elevations.

The return period of first flooding is a good indicator of risk, as it represents the probability that sufficient water enters the city through overtopping and/or breaching of the flood defenses, filling the bowl of the city to that elevation. The return period of first storm surge flooding for current, 'medium term' hurricane activities is found to be around 55 years for the lowest parts of the city, increasing up to 275 years for the highest point selected along Bourbon Street, which remained above the flood waters from Katrina.

3.3 Future Storm Surge Flood Risk

Looking forward several decades, there are a number of factors related to storm surge hazard that can be expected to change the risk of flooding in New Orleans. These include increases in the mean sea level of the region due to geological subsidence and eustatic (or global) sea level rise and increases in hurricane activity in the Gulf of Mexico.



Baseline risk assessment results, showing return period of first flooding for four locations in New Orleans assuming medium term hurricane activity (2007-2011) and current level of flood defenses

3.3.1 Changes in Mean Sea Level

In the middle of the 19th century, when the city of New Orleans began to expand into the swamplands between the natural Mississippi levees and the shores of Lake Pontchartrain, this land was all above sea level. One hundred and fifty years later, in 2006, the average elevation across the city is 6 ft (1.8 m) below sea level. This simple observation demonstrates rapid regional subsidence over this period at rates of around 4 ft (1.2 m) per century. Yet, the consequences of ongoing subsidence have not been part of the policy decisions for flood protection of the city. Subsidence has not previously been actively monitored, nor the existence of subsidence taken into consideration when planning and updating flood levees and flood walls.

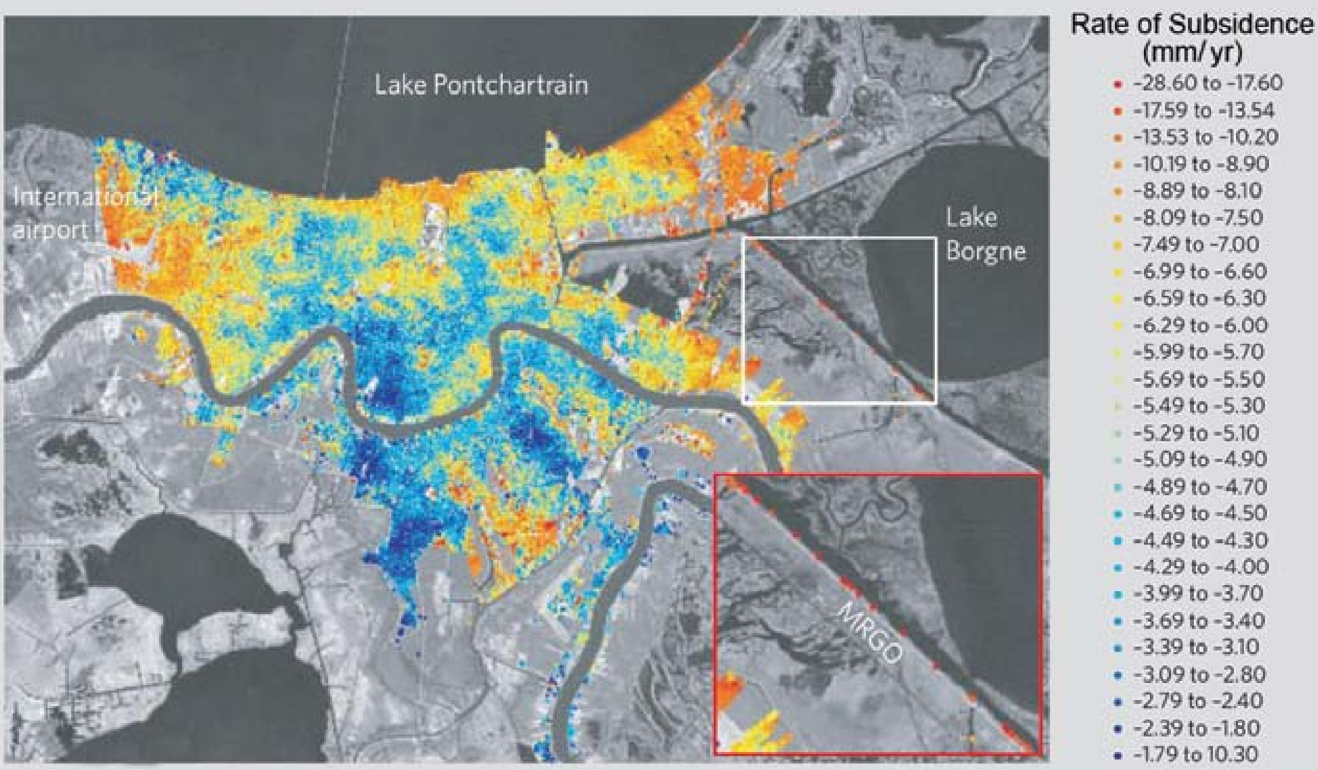
One of the most important findings of the Interagency Performance Evaluation Taskforce (IPET) report on the flooding of New Orleans has been the comprehensive mapping of elevation changes in the city (USACE, 2006). In fact, it was found that a number of flood defenses built as recently as 2000 were 1.3 ft (0.4 m) or more lower than intended because the benchmarks against which the elevations were set were themselves sinking.

The most comprehensive perspective on subsidence in the city has come from the analysis of satellite radar (interferometry) data. In this study (Dixon et al., 2006), which looked at measurements between 2002 and 2005, the average rate of absolute subsidence across the city of New Orleans was found to be 0.2 in +/- 0.1 in (5.6 mm +/- 2.5 mm) per year. However, higher rates of subsidence were found in the Lakeview region along the southern shores of Lake Pontchartrain, while in parts of St. Bernard and Orleans parishes land was subsiding at more than 0.8 in (20 mm) per year, including locations along the levee system that bounds the MRGO. A number of the levee breaches in Katrina corresponded with the locations of some of the highest rates of subsidence.

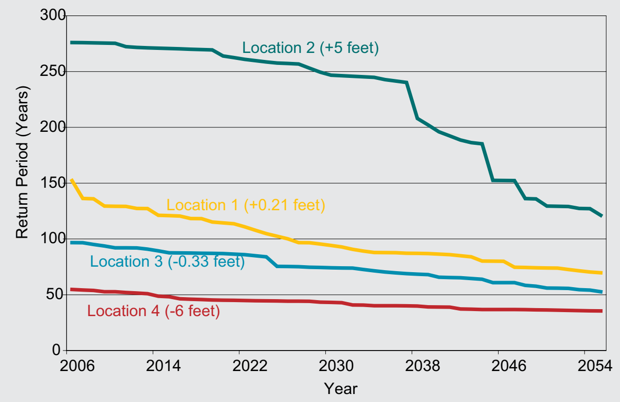
The radar study confirmed what had already been learned from studies of the elevation changes of individual benchmarks – that higher rates of subsidence were found where the former marshland had been loaded by buildings, roads, and levee causeways. However loading does not explain the background geologically rapid subsidence found across the whole of southern Louisiana, which has to have some broad 'tectonic' origin, on which is superimposed some local and superficial effects related to peat shrinkage and the compaction of recent sediments. Dokka (2006) has proposed that the primary subsidence of southeast Louisiana is related to slow slumping, along underlying listric faults of a major section of the continental margin almost 200 miles (320 km) across towards the Gulf of Mexico. Whatever the cause, it is reasonable to assume that subsidence rates observed today can be projected into the future, and therefore it becomes possible to extrapolate how much subsidence will occur by a given date through the coming century.

Subsidence, however, only captures part of the actual rise in sea levels expected in this region, because superimposed there is the global change in sea levels. The observed rate of global sea level rise has increased since 1990, from around 0.07 in (1.8 mm) per year for the 100 years prior to 1990 to more than 0.1 in (3 mm) per year. This rate is predicted to accelerate through the next century from a combination of deep ocean warming and glacier/ice sheet melting. Hence, the overall rate of sea level rise from these two factors combined is currently a minimum of around 0.35 in (9 mm) per year for New Orleans, but at the levees themselves likely 0.55 in (14 mm) per year or more. The recent observation that ice sheets are already melting faster than was predicted (Nghiem et al., 2006) highlights how sea level has the potential to rise at two or three times current levels by the middle of the 21st century.

In this study, a sensitivity analysis was performed to test the levels of risk in the city as relative sea level (combining subsidence and eustatic sea level rises)



Map showing rate of subsidence from 2002 through 2005 for permanent scatterers in New Orleans and the surrounding region; rates are given in mm per year, and the red frame inset shows magnified view of the region west of Lake Borgne as indicated by white frame (Dixon et al., 2006; Image courtesy Nature Publishing Group)



Sensitivity analysis of future flood risk, showing changes in return period of first flooding over time at four locations in New Orleans, assuming medium term hurricane activity (2007-2011), current level of flood defenses, and an average subsidence rate of 0.4 in per year (10 mm per year)

increases at a rate of 0.4 in (10 mm) per year. Based on this assumption, by the year 2036 the relative sea level at the city will have risen 1 ft (0.3 m). If sea levels start to rise more quickly, this sea level would be reached at an earlier date.

The modeling of the effect of relative sea level change on flood risk contains two elements. First, for the same storm surge height (above sea level), as the relative elevation of the flood defenses is reduced, their capacity to resist flooding is degraded. For example, a storm surge that was previously at the same level as the defenses would now be 1 ft (0.3 m) higher than the defense crest, leading to significant flow and erosion, probable breaching, and higher volumes of water entering the city. Second, the elevations of the four locations chosen within the city will also be reduced by the amount of subsidence and sea level rise, so that relative to the height of the flooding above sea level, actual flood depths will also be increased by 1 ft (0.3 m).

As a result of the combination of these factors, flood risk at all four modeled locations in the city is found to rise significantly as a result of subsidence and sea level rise. Across all four locations, a one foot rise in relative sea level reduces the return period of first flooding on average by 25%.

3.3.2 Hurricane Activity in the Gulf of Mexico

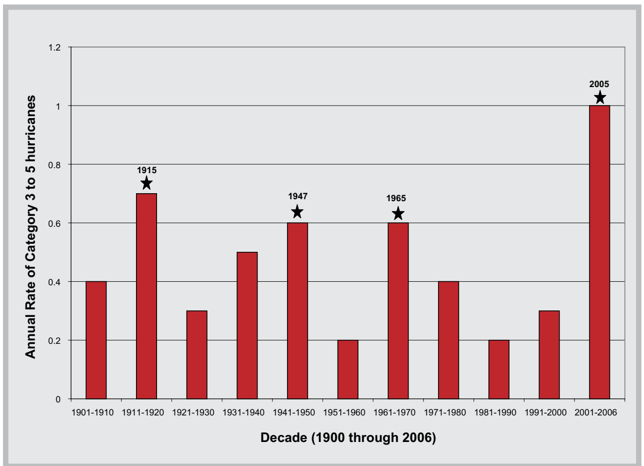
The second factor impacting flood risk in New Orleans concerns the activity of hurricanes in the Gulf region, and the probability of hurricanes making landfall on the Louisiana Coast. Only storm surges from hurricanes of strong category 3 or higher have the potential to flood the city. Therefore, the principal concern is around the activity rate of intense hurricanes, most critically category 4 and 5 storms.

In reviewing the landfall rates of hurricanes between 1901 and 2000 along the Gulf Coast from Texas to the southern tip of Florida, the average annual rate of category 3 to 5 intensity storms was 0.42. Decadal average activities have fluctuated and the three storm surge floods that affected New Orleans in 1915, 1947, and 1965 each arrived in the three decades (1911-1920, 1941-1950, and 1961-1970) of highest activity in the 20th century. The medium-term activity rates that are now the default in the RMS® U.S. Hurricane Model, and have also been employed in this analysis, represent a 35% increase in the historical rates for category 3 to 5 hurricanes in the Gulf Coast relative to the 1900-2005 long-term historical average (Risk Management Solutions, 2006). In the six years from 2001 to 2006, the number of landfalling category 3 to 5 hurricanes was 1 per year, around 80% higher than the long-term average. In 2004 and 2005, there was an annual average of 3.5 category 3 to 5 storms along this coastline.

All climate models run with increased concentrations of greenhouse gases indicate further rises in sea surface temperatures (SSTs) in the Gulf of Mexico through the 21st century. Based on the strong correlation between SSTs in the main development region (i.e., the region encompassing the tropical Atlantic Ocean and the Caribbean Sea) and hurricane numbers and intensities, this is expected to increase the annual number of intense category 3 to 5 hurricanes at landfall in the Gulf, relative to the rates observed since 1900. Various studies have attempted to constrain this projected increase. One widely accepted modeling study by Knutson and Tuleya (2004) indicated that by the middle of the second half of the 21st century, there would be a shift in the overall distribution of peak intensities of hurricanes, with the largest relative increases for the most intense storms. The magnitude of this increase remains uncertain – but simply comparing the two distributions (i.e., probability density functions) of storms by central pressure in Knutson and Tuleya's study suggests a three-fold increase in the number of storms with central pressures below 920 mb (i.e., a category 5 storm).

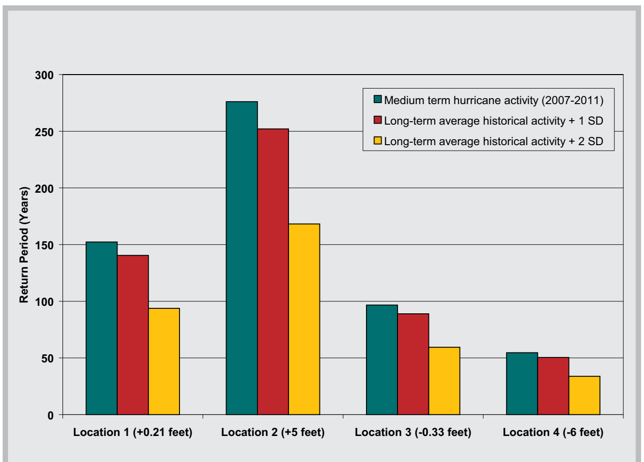
The prospect that more intense hurricanes of category 3 or higher will show the largest increases in frequency has particular implications for New Orleans, as long as the city remains protected by flood levees not designed to withstand the storm surges from worst case tracks of category 4 or 5 hurricanes. The four category 5 hurricanes seen in the 2005 season could be an indicator of potential seasons to come (see Emanuel, 2006).

In this study, the implications of potential future increases in hurricane activity have been explored, using



Decadal variations in annual rates of category 3 to 5 landfalling hurricanes along the Gulf Coast (from the southern tip of Florida to the Texas-Mexico border)

stress tests based on the actual distribution of 5-year averages of landfalling category 3 to 5 storms along the Gulf Coast from 1900-2005. Two stress tests have been applied: one involving a one standard deviation increase in activity rates beyond the 1900-2005 historical average, and the other considering a two standard deviation increase. Applied on top of the medium term 2007-2011 activity rates already employed in the RMS model, one standard deviation reflects a 50% increase of category 3 to 5 storms, while two standard deviations represent a 125% increase. (The stress test considering a two standard deviation increase still represents an activity rate only around 60% of the population of category 3 to 5 storms landfalling in the Gulf during the 2004 and 2005 hurricane seasons). Increases in the activity of the most intense storms further reduce the return periods of first flooding in the city. For the highest elevation



Sensitivity analysis of flood risk, showing return period of first flooding for four locations in New Orleans assuming medium term hurricane activity (2007-2011), long-term historical average hurricane activity plus one standard deviation (+ 1 SD) and long-term historical average hurricane activity plus 2 standard deviations (+ 2 SD)

location considered in the French Quarter, under a two standard deviation increase in severe hurricanes relative to the historical average, the return period of first flooding reduces to 170 years. For the lowest location in the city the return period of first flooding falls to 35 years.

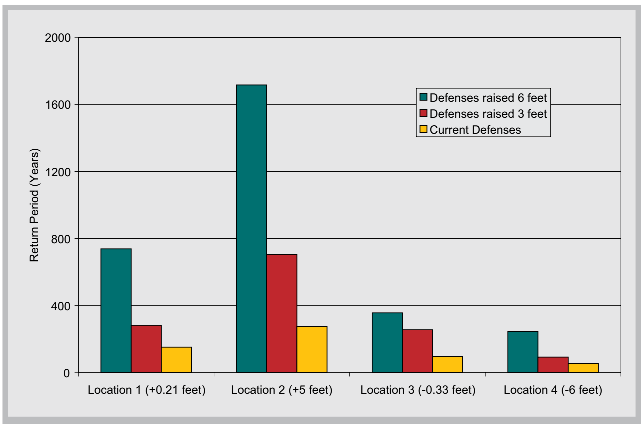
3.4 Implications of Improvements in the Levee System

The sensitivity tests looking at changes in sea levels and hurricane activities have been based on the assumption that the fundamental fabric of the levee systems that surround New Orleans remains the same as existed prior to Hurricane Katrina (i.e., the levees are unimproved beyond the work already performed by the USACE during 2005 and 2006). It is clear, however, that the level of protection provided by the levees, including the way in which storm surges can impact these flood defenses, is likely to be improved going forward. It is therefore sensible to explore the implications of some alternative strategies around the protection of New Orleans through the raising of the flood levees.

Here, two levels of improvement are applied. In the first, all flood protection systems around the city are raised by 3 ft (0.9 m); in the second, defenses are raised by 6 ft (1.8 m). The fragility of the levees is modeled assuming that given the greater hydraulic gradient across the defenses associated with taller levees, at any water level relative to the defense crest, breaching will be more likely. In addition, when breaching occurs, it will be more catastrophic, allowing more water into the city. As a result, the increased height of the defense is represented as providing only around 70% of the effective increase in the form of flood protection.

Considering these two levels of improvement, results suggest that flood risk can be reduced significantly with raised flood defenses. Measurements of return periods of first flooding for the four locations in New Orleans increase on average by 125% for a 3 ft (0.9 m) rise in flood defenses and increase by 375% for a 6 ft (1.8 m) rise in flood defenses.

Other changes in the level of protection that have been proposed but have not been explicitly modeled here include increasing the extent of protective marshland between the open sea and the east of the city, including restricting the flow of water through MRGO. All such proposals should be tested in terms of the degree to which they reduce the probability of flooding in the city as well as their ability to continue to generate land in the face of rising sea levels.



Sensitivity analysis of flood risk, showing return period of first flooding for four locations in New Orleans assuming medium term hurricane activity (2007-2011) with current flood defenses and raises in flood defenses of 3 ft (0.9 m) and 6 ft (1.8 m)

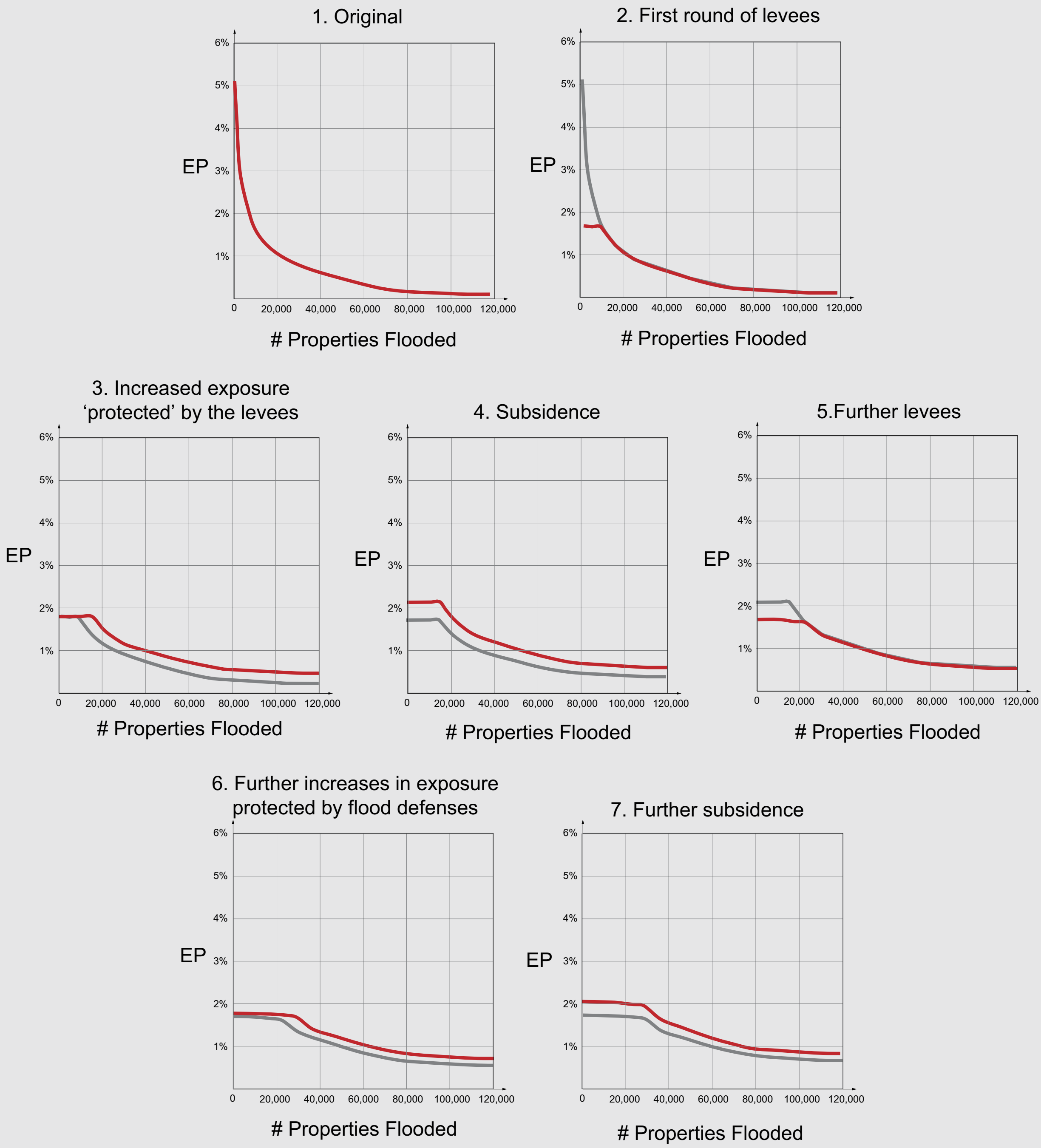
3.4.1 Cost-Benefit Analyses for Improved Levee Protection

Arguments about improving the level of protection for New Orleans will depend on cost-benefit analyses around the associated reductions in risk. While it is possible to identify and explore some of the issues that would need to be included in such analyses it would first require knowing what will be the future value, locations, and elevations of properties within a rebuilt New Orleans. There will be significant reductions in the values of exposure at greatest risk if all redevelopment is carefully controlled and zoned so that the lowest lying areas are abandoned and all new development forced to be located at higher elevations.

The fact that the redevelopment of New Orleans will be highly dependent on the perceived level of risk makes it even more difficult to carry out a rigorous cost-benefit analysis. As a consequence, initial studies have mainly highlighted the high sensitivity of the results to assumptions on future environmental and societal changes (e.g., Hallegatte, 2006).

Cost estimates to provide different levels of protection are also currently very imprecise, and are sometimes broadly referenced in terms of protection against different hurricane categories – taken to mean protection against the worst case storm surge conceivably associated with a particular track, forward speed, and size combination of an extreme storm in that category. For example, the worst case category 4 storm surge in the Inner Harbor area of the Inner Harbor Navigation Canal (IHNC), as identified by the National Weather Service, was around 4 ft (1.2 m) higher than the worst case category 3. Meanwhile, the worst case category 5 surge was 10 ft (3 m) higher. ■

The Exceedance Probability Curve: A Metric of Risk



The annual exceedance probability (EP) curve specifies the probability that a certain level of loss will be exceeded in a year. (For more information on EP curves and catastrophe modeling, see Grossi and Kunreuther, 2005). Using an EP curve, the flood risk for New Orleans can be illustrated over time showing the pattern of flood loss. First, (1) the original EP curve without any flood defenses; then (2) a truncated EP curve indicating protection against the most frequent storm surge events after the first round of levees; (3) an extended EP curve indicating increases in loss due to increased exposure protected by flood defenses; (4) a raised EP curve indicating increases in risk due to subsidence over time; (5) a second truncated EP curve indicating increased protection with a second round of levees; (6) a second extended EP curve indicating increases in loss due to increased exposure protected by flood defenses; and (7) a second raised EP curve indicating increases in risk due to further subsidence over time. In this example it can be seen that the 1% annual probability of exceedance (i.e., 1 in 100, or 100-year return period) of 20,000 properties flooded has increased fourfold over the pattern of the two cycles of levee building, new development, and further subsidence. Meanwhile the floodplain has been continuously protected against all floods with a 2% annual exceedance probability (i.e., 1 in 50, or return period of 50 years).

4 INSURING U.S. FLOOD RISK

4.1 Insurability of Risk

In developed countries, insurance is a principal mechanism for individuals and organizations to manage risk from natural hazard events. In exchange for a small regular premium, protection is provided against a potentially large but unforeseen loss in the future. There are certain conditions that must be met, however, before insurance providers are willing to offer coverage against uncertain events, in particular natural hazard events.

The first condition is the ability to identify and estimate the chances of the unforeseen event occurring, and the extent of the associated losses. The second condition is the ability to set risk-based premiums free from price constraints. If both conditions are satisfied, a risk is considered insurable. Catastrophe models, calibrated against historical data, assist in meeting these conditions, distinguishing rates by location, occupancy, and building type, among other parameters.

In particular, technical rates for flood risk can vary by an order of magnitude over a few feet of elevation, and insurers can utilize high resolution information on location and elevation to determine the technical rate for the risk.

4.2 Federal Flood Insurance

Throughout the 20th century, U.S. insurers had experimented in providing coverage for flood risk. However, by mid-century, in the absence of tools for technical risk rating or portfolio diversification, flood insurance was considered unprofitable and abandoned. Following catastrophic floods in the early 1960s (including the 1965 flooding of New Orleans from Hurricane Betsy), the National Flood Insurance Program (NFIP) was established by the U.S. Congress in 1968, whereby homes and businesses could purchase coverage for water damage.

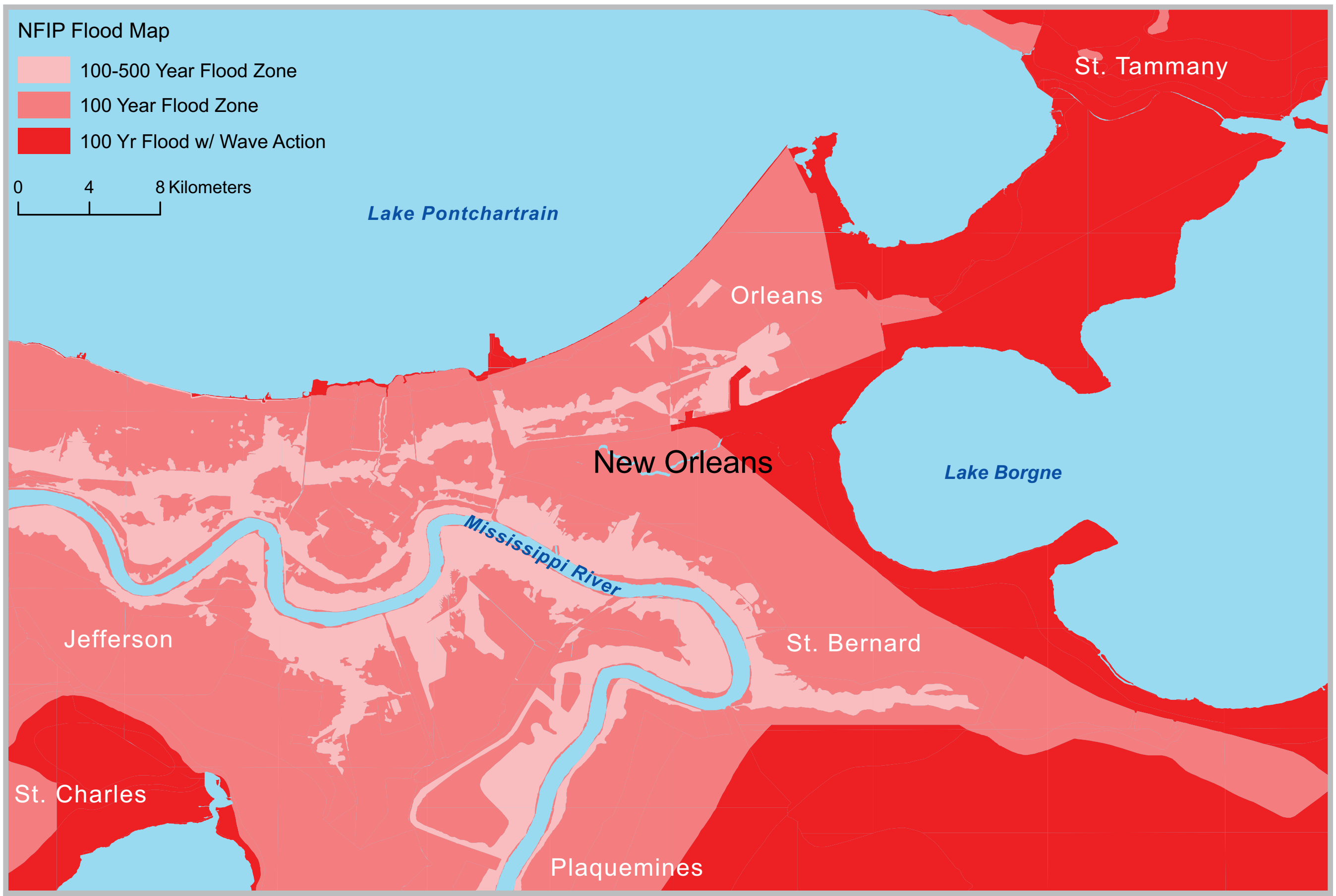
Flooding in New Orleans from Hurricane Katrina (2005)

Currently administered by FEMA, part of the Department of Homeland Security (DHS), the initial (and ongoing) stipulation for the NFIP's continuation was that the local community make a commitment to regulate the location and design of future floodplain construction to increase safety from flood hazards. The federal government established a series of building and development standards for floodplain construction to serve as minimum requirements for participation in the program.

In the NFIP, private insurers market the majority of flood policies, and the premiums are deposited in a federally operated Flood Insurance Fund which then pays all legitimate claims. To encourage communities to participate in the program, and to maintain property values of structures, those residing in the area prior to the issuance of a Flood Insurance Rate Map (FIRM) had their premiums subsidized (known as pre-FIRM construction). While the percentage of homes requiring a subsidy has declined over time, in 2004 26% of buildings covered by the NFIP were subsidized (in comparison to 1978 where it was closer to 75%) for which premiums were charged at around 40% of the technical rate. Additionally, in 1994, the U.S. Congress established an annual limit on premium increases, furthering the differences between charged premiums and premiums based on technical rates of flood risk.

A major problem with the current system of flood risk mapping is the incorporation of the latest information on risk. When there is evidence that risk levels are rising or that risk was previously underestimated, it can be difficult to get the appropriate adjustments approved. In a period of persistently higher hurricane activity and rising sea levels, the coastal storm surge flood zones at any return period will extend further inland than are shown on the official maps. As a result, the construction of buildings at dangerously low elevations will continue to be permitted, the prices charged for flood risk along coastal regions will understate the technical risk, and many people living outside a designated flood zone have the potential to find their properties flooded and damaged. All of this happened along the coast of Mississippi on August 29, 2005.

The impact of the subsidized rates and the understated coastal risk help explain why the NFIP has failed to accumulate sufficient cash reserves to pay insurance claims in heavy loss years. Instead,



Flood Insurance Rate Map (FIRM) in New Orleans and surrounding parishes in 2005, indicating 100-500 year flood zone (Zone B), 100-year flood zone (Zone A), and 100-year flood zone with wave action (Zone V)

money must be borrowed from the U.S. Treasury (with required repayment of the borrowed amount with interest). When the NFIP was established, the borrowing limit was set at $1 billion. However, in March 2006, the U.S. Congress passed legislation to allow the NFIP to borrow up to $20.8 billion from the U.S. Treasury in order to meet the estimated 225,000 claims from hurricanes Katrina and Rita. There seems little prospect that this money will be recovered. ■

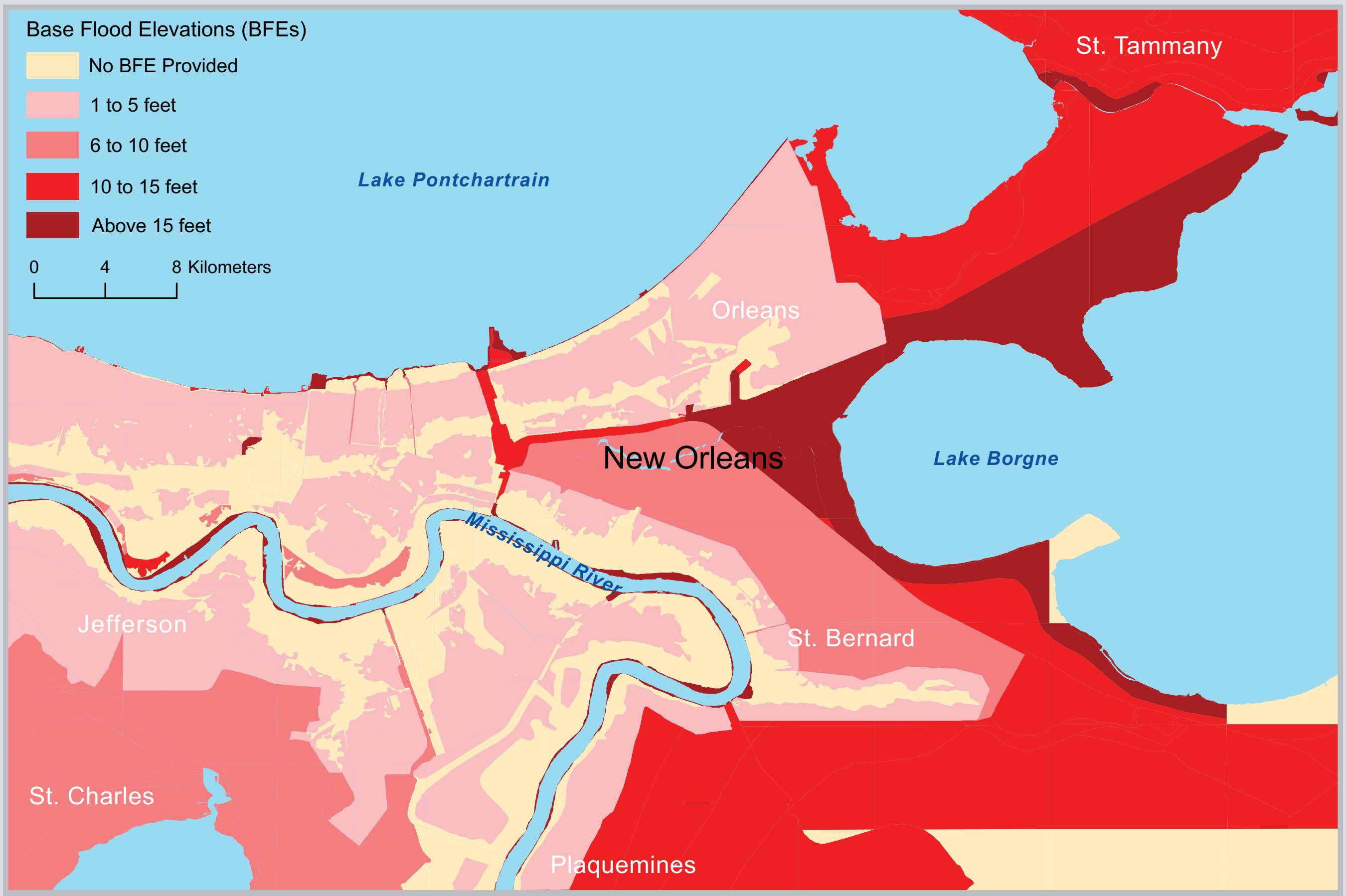
The National Flood Insurance Program

The NFIP provides insurance coverage for approved communities that institute floodplain management strategies (approximately 75% of all communities in the U.S.). In 2006, FEMA administered 4.5 million polices under the NFIP and was authorized by the U.S. Congress to continue doing so through 2008.

Pricing of building coverage is based on a combination of the amount of coverage purchased (up to $250,000 on residential buildings and $500,000 for non-residential buildings) and the deductible level ($500, $1,000, or higher). Additionally, differentiation of pricing for flood risk is established using: (1) the age of the structure (whether the building is post-FIRM construction, or pre-FIRM construction and eligible for subsidy); (2) the building occupancy (single family residential, multi-family residential, non-residential); (3) a description of building at ground level (no basement/enclosure or with basement/enclosure); (4) for post-FIRM construction only, the elevation of the lowest floor of the building with respect to the Base Flood Elevation (BFE), or the expected flood level with a 1% annual probability of exceedance (i.e., 100-year return period); and (5) the flood risk zone shown on the Flood Insurance Rate Map or FIRM.

For properties located in zones D or X on the flood map (labeled B or C in older maps), insurance coverage is not required, although it is available for purchase. These zones are either areas in which flood hazard is undetermined (zone D), or outside the 100-year floodplain (zones B, C, and X). These areas could be protected from the 100-year flood by levees or reside in the 500-year floodplain. In zones delineated as a Special Flood Hazard Area (SFHA), with an A or V prefix (e.g., A, A1 to A30, AE, AH, AO, AR, A99, V, VE, or V1 to V30), 100-year flooding is expected and federal law requires flood insurance as a condition of a federally insured mortgage. V zones are the most hazardous zones, often on the coast and subject to storm surge. In contrast, A zones are subject to rising water from a nearby body of water (e.g., river or lake).

In the numbering of A zones and V zones, the higher the number following the A or V, the more likely a property is to flood (i.e., it is better to be in A1 than A30). However, there is no distinction between A1 and A30 or V1 and V30 for insurance pricing. A zones are areas expected to flood with rising waters with a 1% probability of exceedance; V zones are expected to flood with a 1% probability assuming the additional hazard



Base Flood Elevations (BFEs) for the Flood Insurance Rate Map (FIRM) in New Orleans and surrounding parishes in 2005 due to storm-induced 'velocity wave action' (e.g., storm surges 3 ft, or 0.9 m, and higher). It is assumed that waves caused by a 100-year return period storm will be less than 3 ft (0.9 m) high in adjacent A zones.

Base Flood Elevations (BFEs) are typically listed on FIRMs in zones A and V. On FIRMs published before 1981, the BFEs only give still water levels without the additional height for wave action (in V zones). Maps published from January 1, 1981 onward indicate whether the additional height for wave action is included on the map. The additional elevation due to wave action in V zones varies from a minimum of 2.1 ft (0.6 m) to 0.55 times the still water depth at the site.

Flood Risk Zones in New Orleans

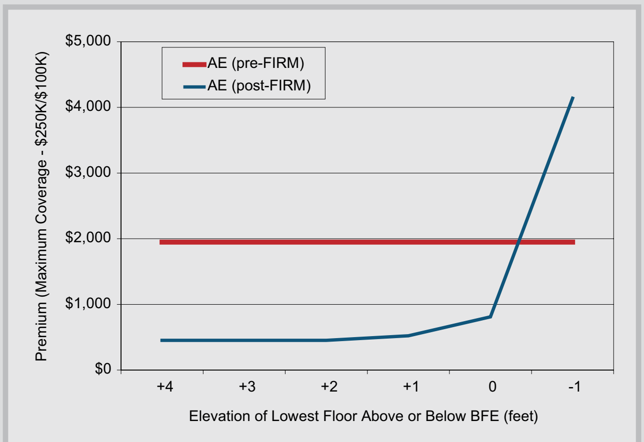
In New Orleans in 2005, while a percentage of the city was designated as zone B, most areas of the city were designated as zones A or V with BFEs provided on the flood map. In 2006, FEMA announced it was in the process of issuing new flood maps for the city of New Orleans. Until such time as these maps are available, FEMA has issued Advisory BFEs, which direct areas "protected by levees to elevate substantially damaged homes and businesses to 3 ft (0.9 m) above the highest adjacent existing grade on site or the current BFE on the FIRM, whichever is higher."

The differences in premiums between zones A and V depend on many factors, including the amount of purchased coverage. For example, using the latest rate tables from the NFIP manual (effective May 1, 2006), the premiums for $50,000 of building coverage on a pre-FIRM construction home in a zone VE could be 30% higher than it would be on the same structure in an adjacent zone AE. For a higher building coverage (limit of $250,000), the premiums for coverage in a zone VE are over twice the premiums charged for a home in a zone AE. If the building was built after 1981, and its lowest floor is elevated above the BFE, premium discounts are given.

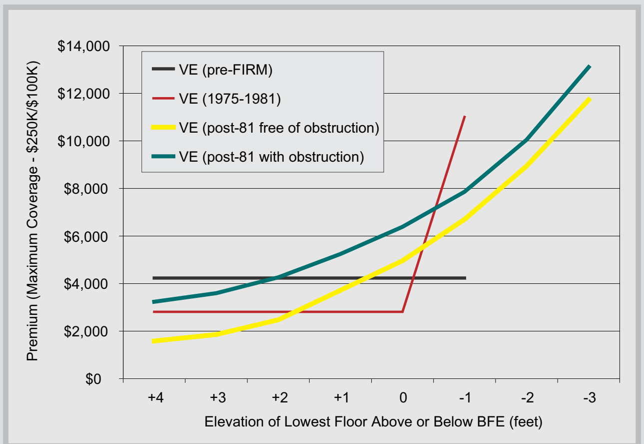
In considering the various factors used to calculate flood premiums for the maximum coverage ($250,000 building/$100,000 contents) on a one-story, single family residential structure with no basement, the three key parameters are: (1) the flood zone (AE or VE); (2) the date of construction (pre-FIRM or post-FIRM, which is subdivided into 1975-1981 and post-1981 construction for V zones); and (3) the elevation of the lowest floor above or below the BFE.

According to the rate tables in the 2006 NFIP manual, the minimum annual premium is approximately $450, given that the building is in zone AE, built following the issuance of the flood maps, and has an elevation of the lowest floor 2 ft (0.6 m) or more above the BFE. The maximum annual premium is over $13,000 if the building is in zone VE, built after 1981, and with the lowest floor of the structure built with an obstruction (e.g., equipment) 3 ft (0.9 m) below the BFE.

In the pricing of the policies in zones AE and VE, there is clearly a subsidy for pre-FIRM construction, where the premium is the same (slightly under $2,000 for zone AE and around $4,200 for zone VE) for all elevations from 4 ft (1.2 m) above the BFE to 1 ft (0.3 m) below the BFE. For post-FIRM construction, premiums vary by elevation, reaching the maximum of over $4,000 at 1 ft (0.3 m) below BFE for zone AE, and over $11,000 at 1 ft (0.3 m) below BFE for a structure built between 1976 and 1981 in zone VE. If one considers a building constructed post-1981, the premium could be an additional $2,000 at 3 ft (0.9 m) below BFE. Of course, the premium could be even higher for lower elevations. However, the rate tables do not provide values below a certain elevation and these structures must be submitted to the NFIP for rating. ■



NFIP premiums for full coverage on a residential home in Flood Zone A built before and after the flood insurance rate maps were published (pre-FIRM and post-FIRM); premiums for homes with elevations 1 ft (0.3 m) or more below the base flood elevation are not shown, as these must be submitted for rating



NFIP premiums for full coverage on a residential home in Flood Zone V by year built (pre-FIRM, 1976-1981, post-81 free of obstruction, post-81 with obstruction); premiums for homes with elevations 3 ft (0.9 m) or more below the base flood elevation are not shown, as these must be submitted for rating

5 MANAGING FLOOD RISK IN NEW ORLEANS

Whether by design or neglect, the attitude of a society or community towards investment and improvements in flood protection represents a philosophy of flood risk management. Different philosophies of flood risk management reflect the degree to which the risk is evaluated, and inform decisions about the level of protection that is afforded. No protective system can be considered absolute, as there will always be implicit or explicit cost-benefit decisions taken with regards to what level of protection is appropriate. The majority of flood risk management decisions are for situations where it is practical to consider that the underlying flood risk will not vary through time. There are, however, special challenges in those situations where flood risk is for some reason increasing – as in New Orleans.

5.1 Reactive Investment Strategies

The simplest philosophy of flood risk management is that of the 'reactive investment strategy.' It is, in effect, a backward-looking strategy to flood risk management, but one that has been successfully adopted for protecting settlements in many flood plains. In the aftermath of any major flood, defenses are raised in a phase of reactive investment. The experience of the flood demonstrates to all those affected the benefits of investing to reduce the potential for a recurrence. Flood defenses are generally raised to the height where they would prevent a repetition of the event just experienced, but not offer significantly greater protection against hypothetical worst case scenarios.

In an environment where the true flood risk remains unchanged, such a reactive investment strategy means that the average time period between floods should increase over time, as flood defenses are progressively raised. The longer time periods between floods will encourage complacency around the risk as builders and property owners assume the defenses have effectively removed the threat of further flooding. This leads to greater losses when a flood eventually occurs, as there is more exposure at risk. A reactive investment strategy, therefore, often leads to individual event losses that become sparser but larger. Additionally, the more time that has elapsed since the last major flood, the more the level of protection may become degraded.

What happens where flood risk is actually increasing through time? In such situations, once a phase of post-flood defense improvements has been completed, the level of risk inexorably increases year on year. New Orleans is a city in this category.

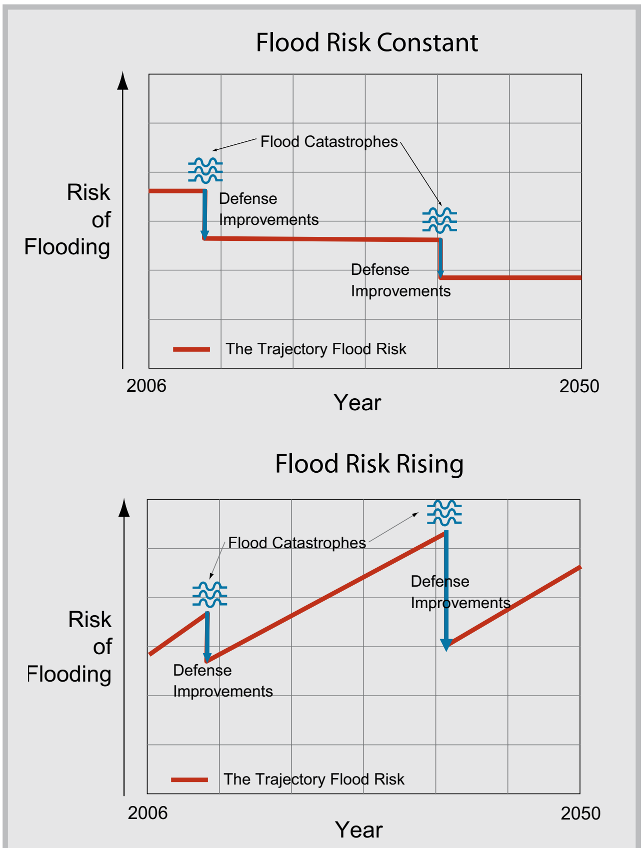
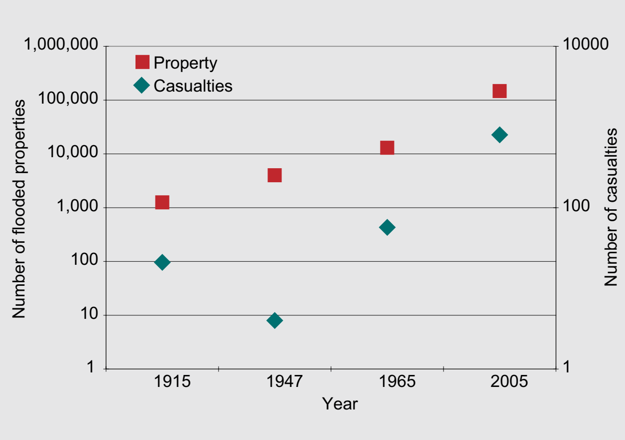


Illustration of a reactive investment strategy, showing changes in the risk of flooding over time where flood risk is constant (above) and flood risk is rising (below)

Flood risk management in the city of New Orleans through the 20th century was never founded on risk-based approaches, but rather developed reactively in response to specific catastrophic floods. After each flood, modest investments were made in improved defenses that reduced the immediate risk of flooding. However, each episode of risk reduction encouraged the development of tens of thousands of properties into the partially protected flood plain. This, in turn, pushed up the level of catastrophe risk in the city. This is demonstrated by the magnitude of losses in each of the four storm surge floods that affected the city after 1900 (in 1915, 1947, 1965, and 2005). The number of properties flooded increased with each event, and since 1947 the number of people killed has increased as well. (The higher death rate in 1915 was principally a result of windblown debris).

Since the early 1990s, the inexorable process of subsidence, sea level rise, and the significant increase in the number of intense hurricanes in the Gulf more than doubled the probability that in any year the city would be flooded. For the future of New Orleans, while one component of the rise in future flood risk attributable to



Number of flooded properties and number of casualties for historical flooding in New Orleans (log scale)

subsidence and sea level rise is relatively predictable, the other related to hurricane activity is not so well-defined (although few climatologists anticipate that Gulf activity rates will fall over the next few decades). The trajectory of future flood risk is a band of curves that continues to widen into the future, with the upper end defined by accelerating sea level rise and raised levels of hurricane activity.

5.2 Risk-Based Strategies

Once flood risk is reasonably measured, it becomes possible to embark on some more informed strategies of flood risk management. A principal shortcoming of a purely reactive strategy arises from 'building inertia,' because the relocation of building stock is an extremely slow and difficult process. In the case of increasing flood risk, a location that appeared safe at one point in time can be revealed to be dangerous a few decades later. For pre-existing properties, there may be an uncomfortable choice between implementing costly protection measures or accepting a loss in value. These potential future losses should be considered before each development project is initiated.

5.2.1 Risk Thresholds

In a risk-based approach to flood protection founded on 'risk thresholds,' the defenses are maintained to ensure that the risk never rises above some predetermined threshold. The risk assessment is repeated every few years with new inputs on all factors that may have changed, including changes in mean land and water levels, the probabilities of extreme events, and the quality of the defenses. Investments in improved defenses are timed so as to prevent risk rising above the predefined and published threshold. A lower bound may also be chosen for the level of risk that defenses should provide immediately after they are improved, so that investments are not larger than is warranted to provide appropriate levels of protection.

The Netherlands is the country that has moved closest to a risk-based perspective on flood protection. Following the experience of the 1953 storm surge flood, when more than 1,800 people were drowned and much of the southwest corner of the country flooded, the Dutch government made the investment in flood defenses a national priority. In the "Water Defence Act," the government declared that the probabilities of failure for each section of defenses were to be kept below 1 in 10,000 for the coastal defenses, and 1 in 1,250 for the embankments that lined the Rhine and Meuse rivers. In recognition of the sensitivity of flood risk in the Netherlands to rising sea levels and potential increases in the frequency of extreme flows on the Rhine and Meuse rivers, work within the government has focused on the development of a more comprehensive risk-based approach to flood defense improvement under the circumstances when levels of exposure and levels of risk are rising (see Eijgenraam, 2006).

Interestingly, the concept of the insurability of flood risk in the Netherlands is not currently relevant because there is no flood insurance in the country. However, there is significant risk and arguably the introduction of a flood insurance system would help encourage the independent assessment of the risk. Along the Rhine and Meuse rivers, it is generally acknowledged that the level of risk is much higher than the intended level of protection for the river flood defenses would imply. In 1995, 250,000 people were evacuated as it was feared that defenses along the Rhine River were about to become overwhelmed as a result of exceptional river levels.

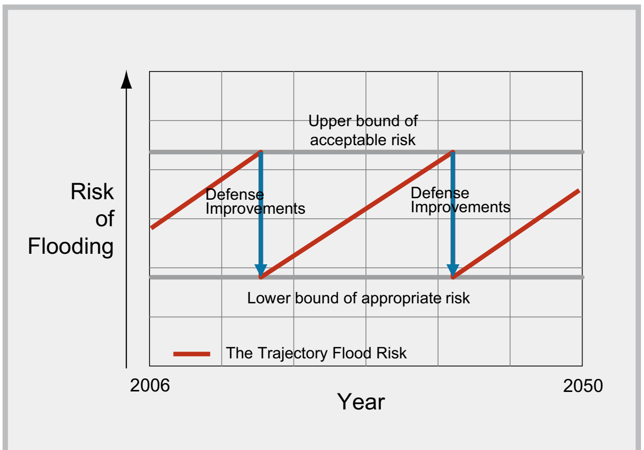


Illustration of a risk-based approach to flood management, using risk thresholds (i.e., upper bound of acceptable risk and lower bound of appropriate risk) as flood risk is rising over time

5.2.2 Target Loss-Based Approaches

In a loss-based approach to defining the level of flood protection (Eijgenraam, 2006), it is the overall magnitude of the potential loss from a flood that is maintained below some threshold. This target could be measured in terms of the numbers of people who would be displaced by a flood, or the number of properties that would be inundated, or even the costs of flood losses. This method allows for a more precise allocation of resources, since efforts are concentrated on the most populated locations or the areas with the greatest economic values. Just as governments have continued to improve the quality of lives over time through investments in public health, environmental quality, or transport safety, so the level of flood protection should be increased in response to the numbers of people who are at risk of being flooded in a single catastrophe.

For example, suppose a town has the potential for 1,000 properties to be flooded based on the 100-year return period flood in 1960. As the number of houses in the flood plain increases over time, to maintain a constant risk cost metric the flood protection system would need to be improved to ensure that by the year 2006, the 100-year loss was maintained at a maximum of 1,000 properties. Meanwhile, the risk for an average house in the town would have decreased. However, given the role of government to aim to reduce risk over time, it would be appropriately ambitious for the government to commit more ambitious targets to reduce loss over time. For example, if the 100-year flood could affect 1,000 properties in 1960, by the year 2006, investments in improved flood risk protection might mean that the 100-year flood would only impact 100 properties. It should be the hallmark of an informed developed country, such as the U.S., to provide such progressive reductions in risk for its citizens, including those in New Orleans.

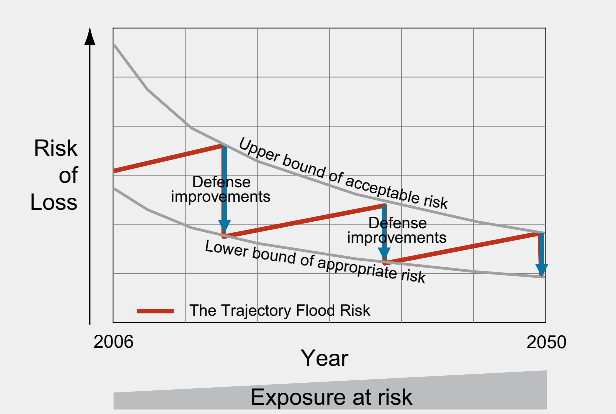


Illustration of risk-based approach to flood management, using target losses (i.e., upper bound loss and lower bound loss) as flood risk and exposure are both rising over time

5.3 Implications for the Future of New Orleans

The 2005 flooding of New Orleans following Hurricane Katrina is an iconic U.S. disaster, ranking alongside the Great San Francisco Earthquake and Fire of 1906, or the 1927 Mississippi Flood. The recovery period following such catastrophes should be a turning point for improved risk mitigation. The question remains for New Orleans as to whether the city can now become an exemplar for effective flood risk management in conditions of rising risk in the coastal zone. The city will only have a prosperous future if it first monitors and forecasts the level of flood risk to which it is subject.

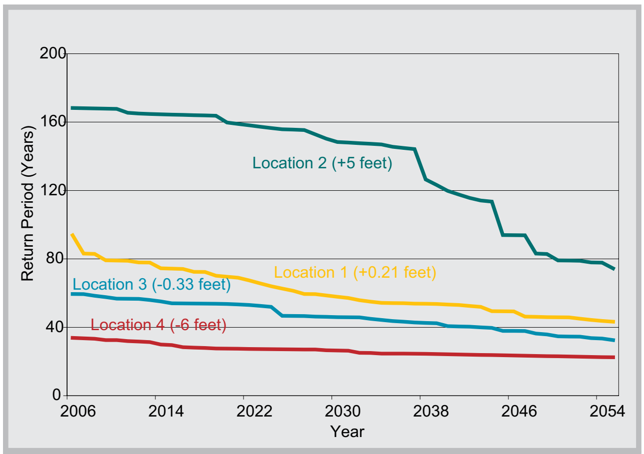
5.3.1 Implications for Policy Makers

Many of the plans drawn up in the aftermath of Hurricane Katrina have recognized the need to take account of the future risk, yet none of them appear to have explicitly recognized that the flooding hazard will inevitably increase with continued subsidence, rises in global sea level, and likely raised hurricane activity. The Louisiana Recovery Authority (LRA) is coordinating the recovery efforts and the Unified New Orleans Plan (UNOP) is being developed for use by the LRA to guide the investment of federal funds in the rebuilding of communities in Orleans Parish. Among the aims of UNOP are to "encourage the redesign and reconstruction of the region's hurricane flood protection system," and to "provide information to citizens and investors to make personal and business decisions about recovery."

Policy makers involved in these initiatives will need to recognize those components of the flood risk that they cannot control, such as the flood hazard, and those that they can influence, such as the elevations of properties and the vulnerabilities to inundation. There is much that can be done to alleviate future flood losses by making buildings flood proof, or able to withstand temporary inundation without damage. They will need to seek and receive independent, expert advice on flood risk from organizations such as RMS, so that they can properly understand the extent to which their actions can affect the level of risk. As the flood hazard is increasing, after the levees are raised or properties elevated, the level of risk will continue to rise once again. The concept of the time-constant flood risk map provided by FEMA is no longer able to reflect how all the components of risk, including variations in the hurricane hazard, are changing through time.

5.3.2 Implications for Insurability

Currently, residential and low value commercial



Sensitivity analysis of future flood risk, showing changes in return period of first flooding over time at four locations in New Orleans, assuming long-term historical average hurricane activity plus 2 standard deviations, current level of flood defenses, and an average subsidence rate of 0.4 in per year (10 mm per year)

property owners buy their flood insurance through the National Flood Insurance Program (NFIP). Only high value properties, beyond a limit of $250,000 limit for residential and $500,000 for commercial, are covered by additional insurance purchased through the private market.

The increasing flood risk in New Orleans presents challenges for both the public and private providers of insurance. Will both types of providers continue to offer cover for all areas, or will the risk be considered too great? Will the rates and terms of insurance policies be differentiated to accurately reflect the risk, or will other factors, such as affordability, be allowed to influence availability? Will rates evolve to reflect how the risk is changing over time?

5.3.3 Implications for Residents of New Orleans

In the aftermath of Katrina, for those who live and work in the city it will not be news that New Orleans is exposed to a higher risk than previously appreciated. Following previous storm surge floods in 1915, 1947, and 1965, after a few years in which there was significant investment in improved flood defences, the question of raising the levees began to fall down the list of priorities. After Katrina, flood risk education needs to be maintained, year after year.

The citizens of New Orleans should have the right to demand that they are not subject to higher levels of risk than some published standard – in much the same way that those who live in the vicinity of nuclear power plant expect and obtain minimum standards of safety. If the city permits development at some location, it should also guarantee to maintain the level of risk below specified thresholds throughout the life of that property. If it cannot so guarantee that protection, the development should not be allowed.

The city of New Orleans is at a cross roads. It can either embrace transparency around flood risk and flood risk management, or, as has happened on three previous occasions over the past century, it can simply resume business as usual and pray that the floods stay away. The terms of the next disaster are defined in the response to the previous catastrophe. Will New Orleans be the first city "lost to climate change," or the first U.S. city to surmount the challenges of its location in an environment of rising coastal risk? ■

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GLOSSARY

Catastrophe Model: A computer-based model for estimating losses from natural or man-made hazards, such as earthquakes, floods, hurricanes and acts of terrorism. A large 'stochastic' set of catastrophe events is generated and using hazard footprints of each simulated event, losses are calculated based on the vulnerability of the relevant exposure.

Correlated Losses: The simultaneous occurrences of losses to a number of people and/or properties from one particular catastrophe or disaster, usually due to their proximity.

Exceedance Probability (EP) Curve: A graphic representation of the distribution of frequency and severity expected from a population of severe events, expressed as the likelihood that a certain level of loss will be surpassed during a future time period. The most common form of EP curve used in the insurance industry is the probability that a monetary loss will be surpassed on an annual basis.

Exposure: The people and/or property at risk from a natural or man-made hazard, based on their location.

Hazard: The probability of a peril event of particular magnitude or severity occurring at a particular location.

Loss: The total harm, death, damage or economic cost caused to people and/or property resulting from a particular hazard.

Peril: A type of naturally-occurring or man-made event (e.g., earthquake, flood, hurricane, terrorist attack) that has the potential to cause harm or loss to people or property.

Return Period: The expected length of time between recurrences of two events with similar characteristics. The return period can refer to hazard events such as hurricanes or earthquakes, or it can refer to specific levels of loss (e.g. a $100 million loss in this territory has a return period of 50 years).

Risk: The probability of loss to people and/or property from a particular hazard, based on a combination of hazard, exposure and vulnerability.

Storm Surge: The rising of the mean water level caused principally by the action of persistent high winds driving a bulge of water ahead of a major windstorm that can become amplified along a shelving coastline.

Vulnerability: The degree to which people and/or property are susceptible to loss as a result of a hazard.

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