RMS™

Hurricane Katrina: Profile of a Super Cat

Lessons and Implications for Catastrophe Risk Management

August 25-31, 2005

Foreword

RMS estimates that Hurricane Katrina will ultimately result in insured losses of $40 to $60 billion from a wide range of inter-related perils. While this scale of loss will be unprecedented, it should not be a complete surprise. The Gulf Coast from New Orleans to Mobile, Alabama has a high incidence of intense landfalling hurricanes–the chance of a category 4 hurricane making landfall here is comparable to that of South Florida from Palm Beach to Miami. Risk in the U.S. from wind-related damage alone exceeds $70 billion at a 100-year return period.

One month after the event, however, it is already clear that there is much to learn in the wake of this extraordinary catastrophe. Some lessons are not new. As Katrina made landfall, RMS was analyzing over $13 billion in detailed claims data from hurricanes Charley, Frances, Ivan and Jeanne. This wealth of data from the 2004 hurricane season has already informed the calibration of vulnerability relationships, and Hurricane Katrina will yield another pool of claims to support further analysis and calibration. In addition, the issue of data quality is likely to resurface. RMS analysis of data from 2004 revealed common problems with exposures being outdated, incomplete, poorly resolved, or miscoded. Evidence suggests, moreover, that these quality issues tend to lead to underestimations of risk.

Most importantly, the lessons from Katrina will drive innovation in how we model the largest 'Super Catastrophes,' those in the tail of the EP curves. Super Cats are characterized by damage on a massive scale that gives rise to nonlinear loss amplification, correlation, and feedback. These effects can increase losses to property and time element coverages, and 'switch on' exposure to a wider range of insured lines of business. Demand surge metrics, intended to measure the economics of increased demand for reconstruction materials and labor, constitute one necessary element of the model for Super Cats, but need to be supplemented with other agents of loss amplification.

The largest catastrophe events are also more likely to trigger consequential hazards. The idea of cascading consequences within the largest catastrophes was a key feature of the 'Top Ten Risks' study RMS published with *Risk and Insurance Magazine* in 2004. Some of these 'Cat following Cat' events, such as fire following earthquake and coastal storm surge are explicitly included in catastrophe models today. However, models need to capture more of these potential consequences.

RMS provided its clients with guidance on these factors through our Event Response communications in the days and weeks following Katrina. We were the first to articulate the unprecedented scale of Katrina's impact, and to provide the market with a series of objective, transparent, and timely insights regarding the magnitude and framework for understanding losses. Starting with the next release of our U.S. Hurricane Model, we will strive to capture a more comprehensive perspective on losses, including elements associated with Super Cats. In doing so, we will be better able to assess losses for extreme events. Katrina's arrival during another climatologically active and intense hurricane season also has given additional impetus to our research on hurricane activity rates. RMS initiated a review of activity rates earlier this year that has the potential to change how rates are parameterized in the model going forward.

Catastrophe models have helped to advance the culture of exposure management and risk analysis within the insurance industry. Models are powerful tools for assessing risk at both the account and portfolio level and allow for the exploration and mitigation of exposure and risk correlation. Ultimately, however, models are tools, and modeling is a collaborative venture between those who build them and those who use them. As the leaders in our field, we will do our utmost to learn objectively and rigorously from Katrina and other recent hurricanes not only to enhance the models you use, but to support you in making better informed risk management decisions.

October 2005

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The Impact of Hurricane Katrina

Hurricane Katrina was one of the most destructive natural disasters to occur in the United States and is likely to be the most expensive catastrophe loss that the global insurance industry has ever experienced. RMS estimates the event will ultimately result in insured losses between $40 and $60 billion.

Hurricane Katrina was initially identified as a tropical storm in the Bahamas. Tracking across Florida on August 25 as a category 1 hurricane, it then entered the Gulf of Mexico and underwent a dramatic intensification to a central pressure of 902 hPa (category 5) before making landfall on the Gulf Coast. It continued on as a strong storm through the central United States. Katrina lasted nine days from its inception as a tropical depression on August 23 to its dissipation over Canada on August 31.

Katrina was an extremely powerful storm. At landfall in Louisiana its central pressure of 920 hPa was the third lowest recorded at landfall of any U.S. hurricane, and its winds were the eighth strongest recorded at landfall. The U.S. National Hurricane Center (NHC) advised maximum sustained wind speeds of 140 mph, although observed winds onland appeared somewhat below this. At landfall it was also more than one standard deviation larger than the average radius of all storms recorded in the Gulf of Mexico, creating a very big windfield footprint. Hurricane force winds swept across 250 miles of coastline, encompassing three states and reaching more than 100 miles inland. The storm drove forward an unusually severe storm surge reaching over 30 feet in some low-lying places and pushed a wall of violent seawater into the vulnerable bays and inlets of a long stretch of coastline.

Even if New Orleans had not flooded, Hurricane Katrina would have been the most destructive hurricane on record due to its large size and strong winds affecting a major concentration of people, buildings, and infrastructure. New Orleans—the 24th largest metropolitan area in the U.S. with a population of over 1.3 million—was first hit by Katrina's winds then by subsequent flooding. The hurricane's strongest winds and surge also hit the Mississippi towns of Biloxi, Gulfport,

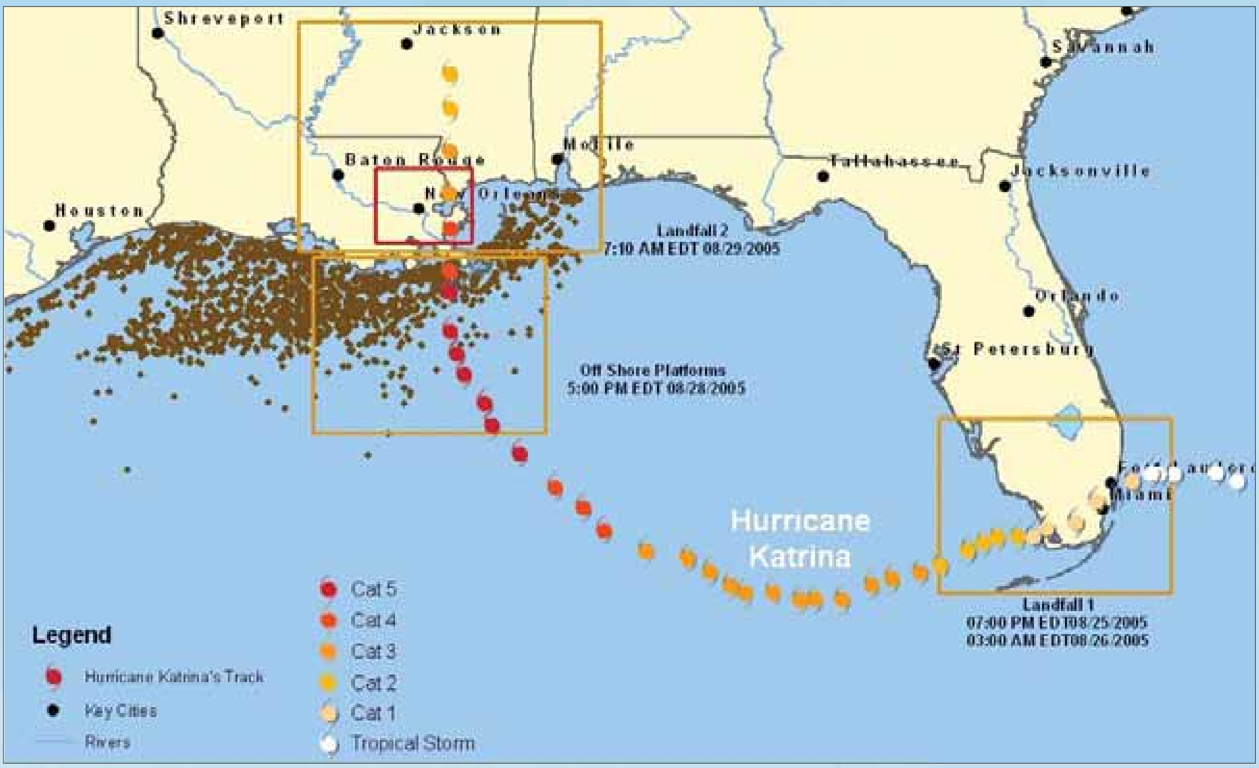


Figure 1. Lifecycle of Hurricane Katrina and locations of the main components of loss

Hurricane Name	Landfall Location	Landfall Period	Pressure (hPa)	1-mn Sustained Winds (mph)
Labor Day	Florida Keys	September 2, 1935	892	~ 160
Camille	Mississippi	August 17, 1969	909	~ 190
Katrina	Louisiana	August 29, 2005	920	140
Andrew	Southeast Florida	August 24, 1992	922	165
Unnamed	Florida Keys, Texas	September, 1919	927	~ 130
Lake Okeechobee	Eastern Florida	September, 1928	929	~ 150

Table 1. Most intense hurricanes by pressure at U.S. landfall since 1900

Hurricane Name	Landfall Location	Landfall Period	Pressure (hPa)	Casualties
Galveston	Galveston, Texas	September 9, 1900	936	8,000
Lake Okeechobee	Eastern Florida	September, 1928	929	1,800+
Katrina	Louisiana	August 29, 2005	920	1,204+ (As of 10/2005)
Unnamed	Florida Keys, Texas	September, 1919	927	600
New England	Northeast	September 21, 1938	946	600
Labor Day	Florida Keys	September 2, 1935	892	408

Table 2. Most deadly U.S. hurricanes since 1900

and Camp Shelby. The ports, oil refineries, resorts, casinos, and associated commercial facilities in the region represent a concentration of high value assets that bore the brunt of the storm. The hurricane force winds (above 74 mph) were felt across an area containing about half a trillion dollars worth of property value. The total footprint of potentially-damaging winds (above 50 mph) contains properties worth about $1.5 trillion.

The Great New Orleans Flood

As the center of the storm moved north, easterly winds pushed a storm surge up the Mississippi River as well as into Lake Pontchartrain, a salt-water lake north of New Orleans. The surge overtopped the levees designed to protect the bowl of New Orleans and caused several to erode and fail. The lake water poured into the city, most of which lies below sea level, taking two days to fill up to the rooftops in some areas. The mayor of New Orleans estimated that 80% of the city was flooded, and a population of more than 100,000 people was unable to evacuate. The floodwaters began draining away a week later, but the trapped population had to endure days of civil disorder, hazardous conditions, and hardship in an unprecedented failure of emergency response. The house-to-house search for bodies ended on October 4, and although some bodies could still be recovered and many remain missing, the official final death toll is 1,193 (1,204 including deaths in Florida), making Katrina the deadliest hurricane since the 1928 Lake Okeechobee Hurricane killed more than 1,800 people.

It is important to note that hurricanes with high death tolls mainly pre-date satellite monitoring and forecasting systems that were thought capable of preventing modern high-casualty events.

Hurricane Katrina: Unfolding of a Super Catastrophe

Aug 25 Early in the day, the storm is upgraded to become the fourth hurricane of 2005. It makes landfall in Florida at 7:00pm EDT, causing wind damage and 11 deaths. A full scale emergency response is launched.

Aug 26 The storm leaves Florida, intensifying off the Florida coast and heading towards Louisiana. The Louisiana governor declares a state of emergency, and offshore platforms are evacuated.

Aug 27 Hurricane Katrina pounds on the offshore oil fields in the south-east area of the Gulf. As the storm approaches Louisiana, New Orleans mayor calls for a voluntary evacuation of the city.

Aug 28 At 6 am, Katrina is upgraded to category 4. Offshore platforms begin to experience the storm. Three hours later, Katrina is upgraded to a category 5 hurricane, and the New Orleans mayor announces mandatory evacuation. At 3 pm, when the hurricane is 100 miles offshore, wind speeds register at 175 mph. By 6 pm, offshore platform damage-some of it extensive-is being reported.

Aug 29 At 3:00 am EDT, Katrina falters 50 miles offshore, and is downgraded later in the day. Extreme storm surge pounds the shoreline, destroying miles of homes across the Mississippi, Alabama, and Louisiana coasts and damaging boats in coastal marinas. Katrina makes second landfall in Louisiana at 6:10 am EDT. At 8:00 am, the hurricane passes over New Orleans, causing some collapses to buildings and extensive wind damage. As the storm moves inland, strong winds subside and the hurricane is downgraded to a category 2. At 2:00 pm, the first floodwall failure at the 17th Street Canal in New Orleans is reported.

Aug 30 The 17th Street, Industrial, and London Avenue canals in New Orleans fail. Water pours into the city, trapping people throughout. Attempts to stem breached levees with sandbags fail. By 8:00 am EDT, 80% of the city is reported flooded, with some flood depths of up to 16 feet. By the end of the day, 1.3 million properties in the three states are without power. Concerns of pollution arise.

Aug 31 As the storm weakens and passes further inland, unrest and civil disorder intensifies in New Orleans. Minor fires break out throughout the city. Instances of looting and poor conditions of the refugees at the Super Dome contribute to worries of further disorder. Louisiana Governor Blanco requests Federal troops for evacuation and rescue. The floodwaters stabilize.

Sept 1 Arrival of emergency supplies for stranded refugees. Rescue teams canvas the city looking for people trapped in their flooded properties.

Sept 2 U.S. Army Corps of Engineers begin work on patching the breached floodwalls at the 17th Street Canal. More supplies and food are distributed. Death toll estimated to be as high as 10,000.

Sept 3 Fires break out in factories in New Orleans, and continue to burn uncontrollably. Flood waters have receded in Jefferson Parish. Officials in New Orleans clear tens of thousands of evacuees from the Louisiana Superdome and Ernest Morial Convention Center.

Sept 4 Multiple fires continue to burn, and health concerns about pollution of city waters arise.

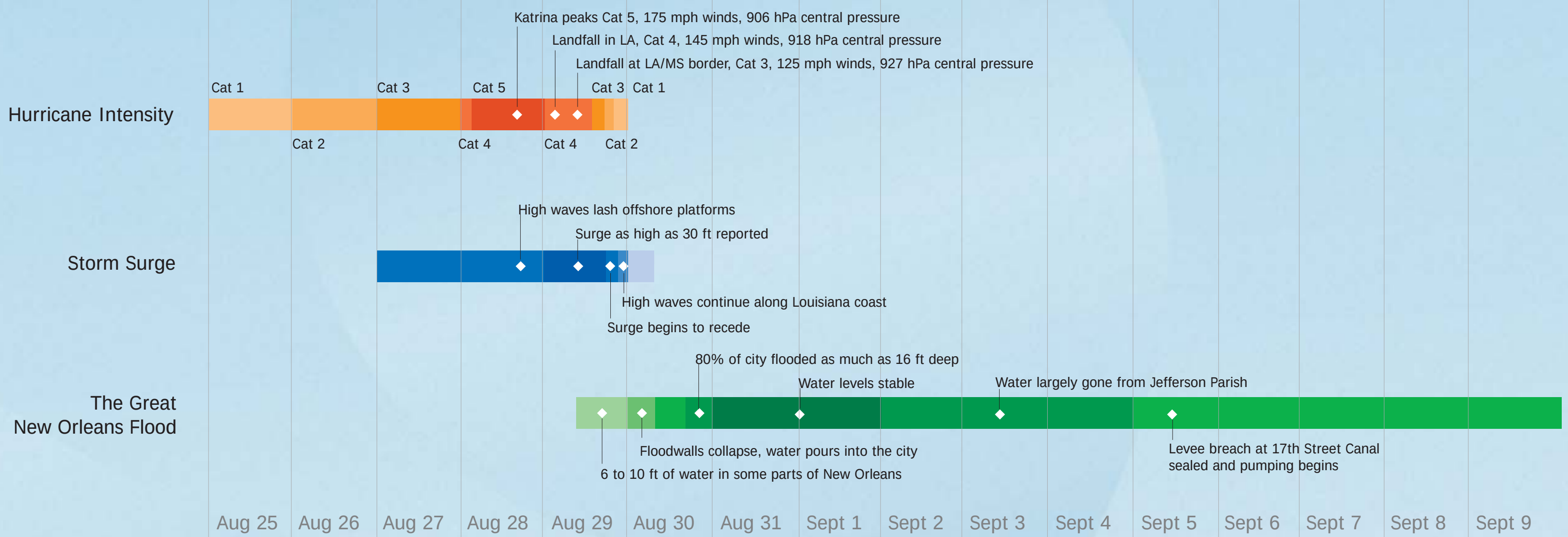
Sept 5 Troops arrive in New Orleans. The levees at the 17th Street Canal are sealed and pumping begins. Casualty searches proceed, and helicopters continue search-and-rescue operations for survivors. By the end of the effort, more than 22,000 stranded people are rescued.

Sept 6 The mayor of New Orleans reiterates fears of 10,000 dead. Forced evacuation of the entire city begins as there are concerns about safety and pollution.

Sept 7 Evacuation complete.

Sept 8 House-to-house search initiated throughout New Orleans. FEMA operations and management of disaster assessed.

Sept 9 Casualty recovery continues. FEMA director removed from directing relief efforts.



Modeling Losses from Hurricane Katrina

RMS estimates of insured losses from Hurricane Katrina are driven by several components of the loss, as summarized in Table 3.

The RMS insurance industry loss range consists of total expected gross industry losses in Louisiana, Mississippi, Alabama, Florida, and for the offshore oil and gas industry. This range results from detailed modeling and analysis of the wind, surge, flood, and socio-economic and infrastructure impacts on insurance loss, including the development of a model for the specific assessment of flooding in New Orleans. Since Hurricane Katrina's hazards and the insurance losses that they will ultimately cause, have significant uncertainty, these losses are given as ranges.

It is important to note that while RMS has estimated the direct physical effects of the wind and surge separately from the flooding, we are not taking a position on how insurance and reinsurance claims should be handled regarding the definition of an event.

The loss range has been developed using the RMS® 2005 U.S. Hurricane Industry Exposure Database (IED), for both onshore and offshore exposures, and supplemented with additional RMS research on private market flood insurance penetration and coverage.

This section describes how these losses occurred and the issues that will determine the resolution of the final loss numbers in these estimates.

Landfall in Florida

The National Hurricane Center initiated advisories on Tropical Depression 12 (TD12) at 5 pm EDT on August 23, 2005 when the storm was located over the Bahamas. During the next 24 hours its convective signature continued to develop steadily, and TD12 became Tropical Storm Katrina at 11 am EDT on August 24. The existence of low-shear and warm sea surface temperatures contributed to the storm's improved cloud banding and upper-level outflow.

Katrina continued to strengthen and became a hurricane just prior to its first landfall in southeastern Florida. It came onshore between Hallandale Beach and North Miami Beach at 7 pm EDT on August 25 with 1-minute sustained winds of 80 mph (category 1 on the Saffir-Simpson scale) and minimum central pressure of 985 hPa. Katrina's landfall was positioned south of earlier forecasts and moved southwest over land at 8 mph as it was steered by a large middle-atmospheric ridge to the northwest of the storm.

The impact of the storm was borne by south Florida residents with weary familiarity after the four hurricanes of 2004. Although not unusually heavy, Katrina's southern outflow generated over 5 inches of rainfall across a large area of southeastern Florida. Localized heavy rainfall of more than 10 inches of rain occurred in south Miami-Dade County and further south, causing flash flooding and 11 deaths.

Loss Component	Gross Industry Loss
First Landfall in Florida	$1 - 2 Billion
Offshore Energy	$2 - 5 billion
Wind and Surge, Second Landfall	$20 - 25 billion
New Orleans Flooding	$15 - 25 billion
Additional Sources of Loss	$2 - 3 billion
Total Estimated Loss	$40 - 60 billion

Table 3. RMS insurance industry loss estimates (published September 9, 2005)

Figure 2. Track forecasts during Katrina's lifetime; after August 27, forecasts consistently predicted landfall close to New Orleans

RMS modeled Katrina's windfield using meteorological data. With an estimated peak gust wind speed of 94 mph, the modeled windfield generated wind-related losses of about $900 million using the RMS 2005 IED. The loss forecast range of $1 to $2 billion accounts for potential variability in actual wind speeds and potential losses that may be exacerbated by high localized rainfall and pre-existing demand surge in Florida following the 2004 hurricane season.

Impact on Offshore Energy

At 3 am EDT on August 26, Katrina emerged from the southwestern coast of Florida into the Gulf of Mexico as a tropical storm with sustained winds of 70 mph. It quickly strengthened to a category 1 hurricane with 75 mph sustained winds. The National Hurricane Center forecasted that with extreme warm waters ahead of it, Katrina would be a "dangerous hurricane in the northeastern Gulf of Mexico in about three days."

Once in the Gulf of Mexico, Katrina moved southwest and intensified rapidly. By midday on August 26, Air Force reconnaissance reports indicated that the storm had strengthened to a category 2 hurricane (sustained winds at 100 mph) with a central pressure of 971 hPa. As Katrina moved west and north-northwest it passed over some of the Gulf's warmest waters, which re-energized the hurricane. Normally at this time of the year, sea surface temperatures are near 29 to 30°C, but on August 26 these parts of the Gulf were 31 to 32°C.

By August 27, Katrina's windfield had expanded and maximum sustained winds reached 115 mph, making it the third major hurricane of the 2005 season. With hurricane watches in place for the coastlines of Alabama, Mississippi, and southeastern Louisiana, observers noted Katrina's windfield strengthening and expanding as it moved northwest toward the central Gulf of Mexico coastline. The radius to maximum winds (Rmax), an indication of the size of the windfield, varied between 15 and 19 miles. During a series of rapid intensification periods, Katrina strengthened to a category 4 hurricane at 2 am EDT on August 28 (145 mph sustained winds)

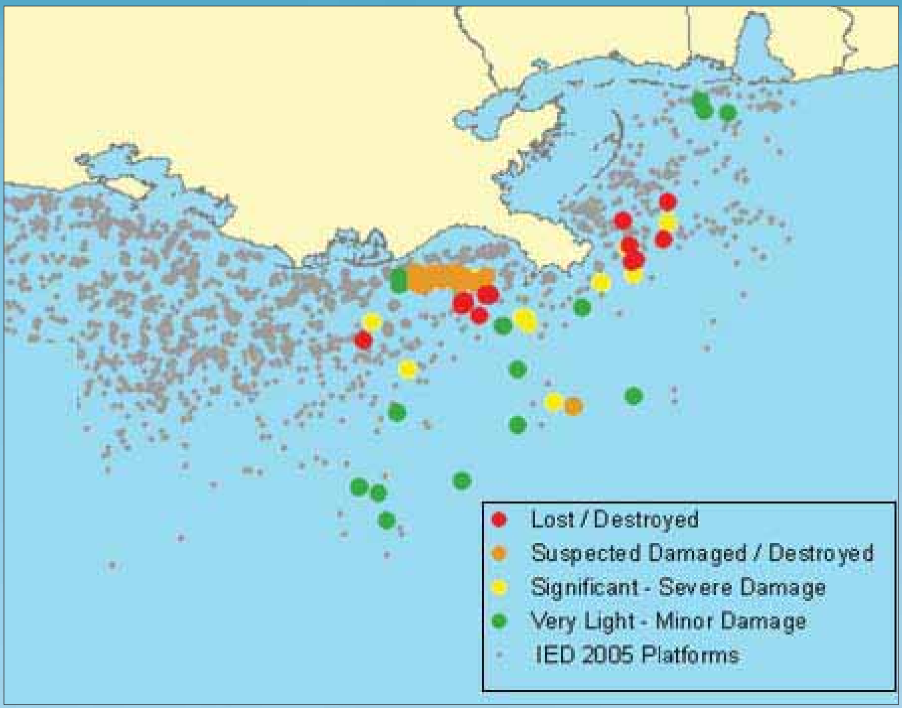


Figure 3. Offshore platforms affected by Hurricane Katrina (reports as of September 19)

and to a category 5 hurricane (160 mph sustained winds) six hours later. Katrina dropped in pressure from 930 to 909 hPa in six hours, a rate of 3.5 hPa per hour.

Katrina's maximum sustained winds occurred at midday on August 28, reaching 175 mph. By 5 pm EDT the minimum central pressure had fallen to 902 hPa. These pressure levels made Katrina the fourth lowest on record in the Atlantic basin, a record it held for 26 days until Hurricane Rita. Making landfall on September 24, Hurricane Rita set a record with an even deeper pressure of 897 hPa.

Hurricane Katrina maintained a category 5 intensity as it crossed the offshore oil and gas fields of the Mississippi Canyon Corridor and South Timbalier. More than $20 billion in platform replacement value (600 platforms) were exposed to winds in excess of 140 mph peak gusts (the peak wind speeds of Hurricane Ivan in 2004). Forty-six shallow water platforms—representing more than 1% of the total production of the Gulf of Mexico—have been reported destroyed. Other platforms sustained damage to varying degrees: four drilling rigs were destroyed, nine rigs were extensively damaged, and six rigs drifted in the storm. Four large deep water platforms suffered extensive damage. A section of a rig that broke apart

Landfall Region	Pressure (hpa)	1-mn Sustained Winds (mph)	Radius to Maximum Wind (miles)	Translational Speed (mph)
South East Florida	985	80	17	6
South of Buras, Louisiana	920	140	19	15
Louisiana-Mississippi Border	927	125	32	16

Table 4. Hurricane Katrina landfall characteristics. Information from the National Hurricane Center/Tropical Prediction Center, National Weather Service and NOAA/AOML Hurricane Research Division

in dry dock drifted and became lodged under the Cochrane road bridge over the Mobile River in Alabama.

Reported damage to pipelines in Mississippi Canyon Corridor and South Timbalier could take months to repair. Some have been inspected, tested, and have re-commenced operations, while others had not yet been inspected over one month after the event.

Lost Oil and Gas Production

With the damage to rigs and refineries, more than 91% of oil and 83% of gas production in the Gulf of Mexico region was initially shut down. Four major refineries were badly damaged. After three weeks, 55% of oil and 34% of gas production was still unavailable. Just prior to Hurricane Rita, the Minerals Management Service estimated three to four months of shutdowns before production would be restored to normal levels. Additional damage to energy facilities caused by Hurricane Rita could considerably extend the time taken to resume normal production in the region. It is likely to take much longer than the restoration time following Hurricane Ivan in 2004, when gas production was back to normal after 45 days and oil after 80 days. Nearly half of the halted oil production was driven by onshore damage to refineries.

Loss Estimation

RMS modeled the offshore windfield based upon meteorological data and buoy measurements. The RMS offshore IED was used to estimate insurance industry losses of between $2 to $5 billion, including $1 to $2 billion of direct damage to platforms. Repair and replacement costs were based on research RMS conducted following Hurricane Ivan in 2004. Losses include estimates of additional impacts to pipeline infrastructure and the expected loss of production. If production takes longer to resume, or damage to pipelines or other parts of the infrastructure is found to be more extensive, the losses will be at the higher end of this range.

Landfall on the Gulf Coast

During the night of Sunday, August 28, just 50 miles before landfall, Katrina's windfield and the convection in its eyewall weakened slightly. Its second landfall on the Gulf Coast actually consisted of crossing two shorelines, weakening and expanding in size as it progressed. Since hurricanes have their strongest winds to the right of the track, Katrina, by veering to the east of the New Orleans rather than passing to the west, spared the metropolitan area of New Orleans and the city of Baton Rouge from even stronger winds than experienced.

Katrina's first touchdown on the Gulf Coast was just south of Buras, Louisiana at 7:10 am EDT on August 29 as a category 4 hurricane, with sustained winds of 140 mph and central pressure of 920 hPa.

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 11 am EDT. By this time, the sustained winds had weakened to 125 mph, making Katrina a category 3 hurricane. However the storm's Rmax had almost doubled, from 19 miles to 32 miles. This radius is unusually large and puts Katrina 1.0 to 1.5 standard deviations from the mean Rmax recorded for hurricanes in the Gulf of Mexico. It was also moving at a forward speed that was faster than normal for Gulf of Mexico hurricanes.

The outer bands of the storm started to affect the Gulf Coast with rain and winds before Katrina made landfall. The landfall region received cumulative rainfall in excess of 10 inches, adding to the damage in many locations.

Wind Damage

RMS modeled the windfield of Katrina's second landfall using meteorological data, recorded wind speed measurements, assessments of damage on the ground, and aerial surveys specially commissioned by RMS. Many monitoring stations went offline or were unable to make recordings due to the severity of the storm, reducing the number of recorded wind speed observations across the affected area. Modeled wind

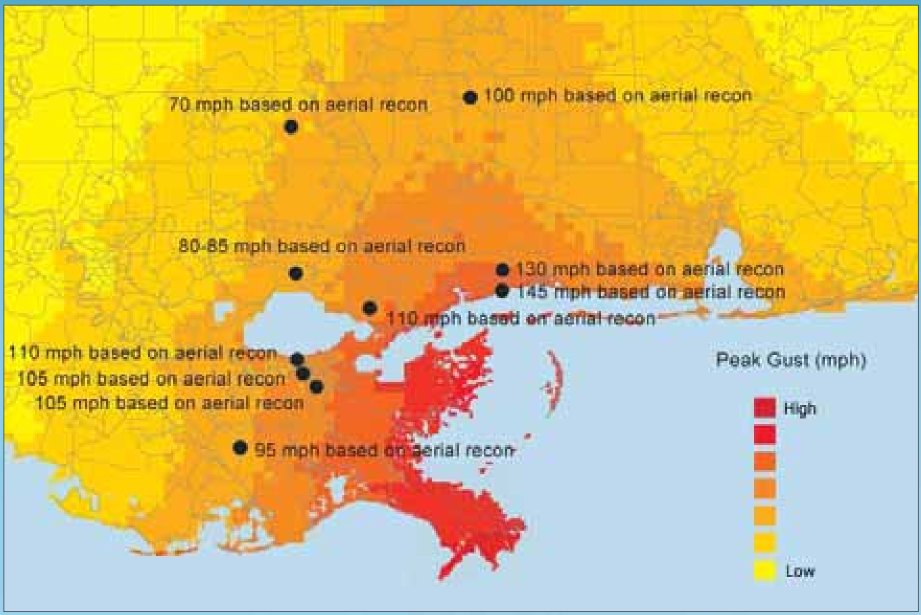


Figure 4. Map of the RMS modeled windfield of the Gulf Coast landfall

speed patterns, however, are in good agreement with measured wind speeds and reconnaissance observations.

RMS dispatched a field survey team to the Gulf Coast region as the hurricane made landfall. The team conducted extensive reconnaissance across the affected region for three days after the storm. They were able to photograph a large number of damaged facilities and make notes on damage observations while traversing the windfield footprint of the storm. RMS also commissioned a three-day aerial photographic survey of most of the affected region.

Figure 5. Damage from the force of the wind to the canopy columns at a gas station in Hattiesburg, MS

Overall the wind speeds across the region were not as severe as originally feared. The last minute reduction in intensity of the hurricane meant that most areas suffered damage consistent with a category 3 hurricane or less. Damage observations suggest that peak gust wind speeds in the immediate coastal landfall area were between 130 and 140 mph.

Wind damage observations in New Orleans were consistent with peak gust wind speeds of around 100 mph across the city. The estimation of wind speeds around New Orleans is critical to loss estimation since it has much of the region's concentration of insured exposure.

The damage observed across the footprint conformed to failure mechanisms in similar hurricanes, including:

- Extensive damage to roofs, windows, and non-structural elements
- Impact damage from trees and other debris
- Some failures of roofs, truss systems, and structural members
- Damage to gas station canopies, metal panel roofing, and light metal buildings
- Damage to older masonry buildings and collapses of unreinforced masonry walls

Detailed claims analyses will likely show that many buildings in the affected region had slightly higher damage levels for a given wind speed than similar buildings in Florida. Previous hurricanes have demonstrated that buildings in Louisiana and Mississippi have higher vulnerability than many other states, reflecting differences in regional construction practices, building code levels and enforcement, and the local architectural styles of structures. RMS assesses these factors with a State Vulnerability Index for all hurricane-prone states; Mississippi is in the most vulnerability category.

Louisiana and Alabama are in the second most vulnerable category. These three states have traditionally enforced the Standard Building Code, which was used in Florida until it adopted its own more stringent Florida Building Code. More recently these states allowed their counties to adopt the International Building Code, leaving adoption decisions to the local jurisdiction levels.

Certain local construction practices observed by the field survey team in the affected region were not as good as building and design practices in more hurricane-prone Florida. For example:

- There is more unreinforced masonry construction, which suffered some of the worst collapses, some of which caused injury
- Some of the structural elements of buildings were poorly reinforced, or occasionally unreinforced, leading to damage, as seen in storm surge damage to structural piers
- Gable construction using vinyl siding applied directly to the gable end trusses rather than a solid substrate were easily stripped by the wind, allowing rain inside the building

Storm Surge

Katrina drove a severe storm surge onshore. The NHC estimated the coastal surge to be 18 to 22 feet, with locally higher surges of up to 28 feet. Estimates from the observations of damage suggest that in some locations the surge reached heights of over 30 feet. The storm surge was commensurate with a category 5 hurricane (defined by the Saffir-Simpson scale as

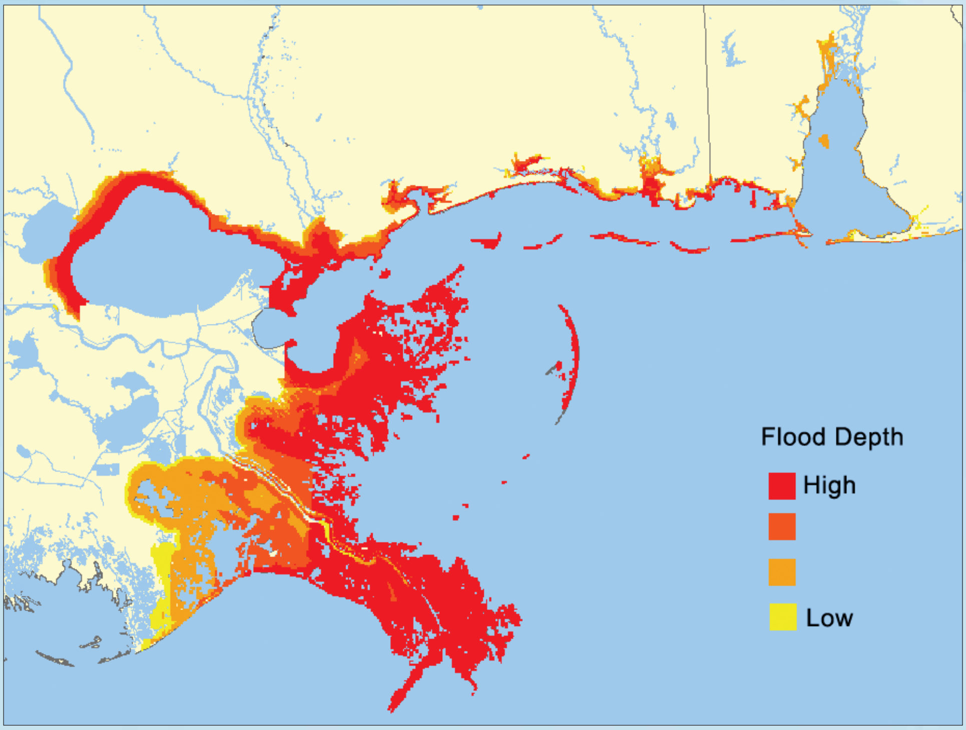


Figure 6. Hurricane Katrina storm surge modeled hazard along the Gulf Coast (excluding the flood in New Orleans, which was modeled separately)

Figure 7. Storm surge damage to the lower stories of a reinforced concrete hotel in Biloxi, MS

Figure 8. The larger of the two Grand Casino barges washed ashore in Biloxi, MS; both of the Grand Casino barges were originally moored to the right of the hotel, which can be seen in the background of this photo

Figure 9. Storm surge damage to Hwy 90 bridge heading east out of Biloxi, MS towards Ocean Springs; in addition to becoming unseated from its piers, the bridge deck was displaced laterally approximately 20 feet

having a storm surge of over 18 feet), while observed winds experienced along the coastline were on the order of 140 mph, those of a category 4 hurricane (131 to 155 mph).

A number of factors appear to have contributed to the extraordinary height of the storm surge as well as the impact of the associated waves. Hurricane Katrina maintained category 5 intensity for nearly 24 hours before landfall, and its deep low pressures helped to build water depths ahead of it. The large radius of maximum winds affected a large area of water, pushing it into the coast. The shallow bathymetry and funneling behavior of the Louisiana-Mississippi embayment caused further surge amplification and increased the run-up of the water onto the shore.

Storm Surge Damage Zones

RMS survey teams classified the extent of inundation into three categories, based on damage to structures and debris lines, and approximate surge heights likely to have impacted those locations. This classification was validated using aerial survey data and mapping digital elevation models against forecast water heights.

- **Total**: An inundation area extending inland on average around 2,000 feet, where the storm surge was deepest (from around 6 feet up to about 30 feet) and causing complete destruction, often washing structures off their foundations
- **Major**: An area where large waves caused structural damage to property, and the water depth was approximately 2 feet to 6 feet deep
- **Moderate**: Areas with shallow flooding and light wave action: water depth up to about 2 feet deep

It is worth noting that in many locations, the observed surge inundations extend inland well in excess of the 500-year return period limits denoted for the National Flood Insurance Program (NFIP).

In Mississippi, the coastal communities of Gulfport and Biloxi were severely damaged by a combination of storm surge and Katrina's winds. Some of the hardest hit areas were in the peninsula in East Biloxi, a four-block stretch of waterfront in Long Beach, and the low-lying areas of Henderson Point on the west side of Pass Christian. Mississippi's Governor, Haley Barbour, estimated that 90% of structures between the beach and the railroad in Biloxi, Gulfport, Long Beach, and Pass Christian were destroyed.

At least five of Biloxi's floating casinos were heavily damaged or destroyed. Casinos constructed on floating barges proved particularly vulnerable to surge. These were significantly more vulnerable than onshore engineered structures, some being washed from their moorings and damaged by waves before beaching further ashore.

Loss Estimation from Wind and Storm Surge

RMS estimates that the industry's wind and storm surge losses for the second landfall will be $20 to $25 billion, based on the RMS hazard footprints (excluding flooding in New Orleans) and the RMS 2005 Industry Exposure Database. This estimate does not include the flood loss in New Orleans or the full costs of the surge. The estimate assumes a high penetration of commercial lines (structure and contents), coverage for flood, and that there would be extended business interruption (BI) claims for large commercial properties affected by surge. The estimate assumes that nearly all (90%) residential lines (structure and contents) losses would be covered by the NFIP or excluded from standard homeowners policies.

The estimate includes a conservative view of likely demand surge (40%), consideration of additional sources of loss (such as aggravated business interruption and off-premises power interruption), and the latest vulnerability estimates. The vulnerability estimates used in this estimation reflect the preliminary conclusions from analysis of claims data sets, which are a part of RMS' ongoing analysis of 2004 hurricane events. When completed, the resulting vulnerability functions will be incorporated in the next release of the U.S. hurricane model. We expect that the most significant conclusions of this effort will be increased vulnerability to commercial lines risks.

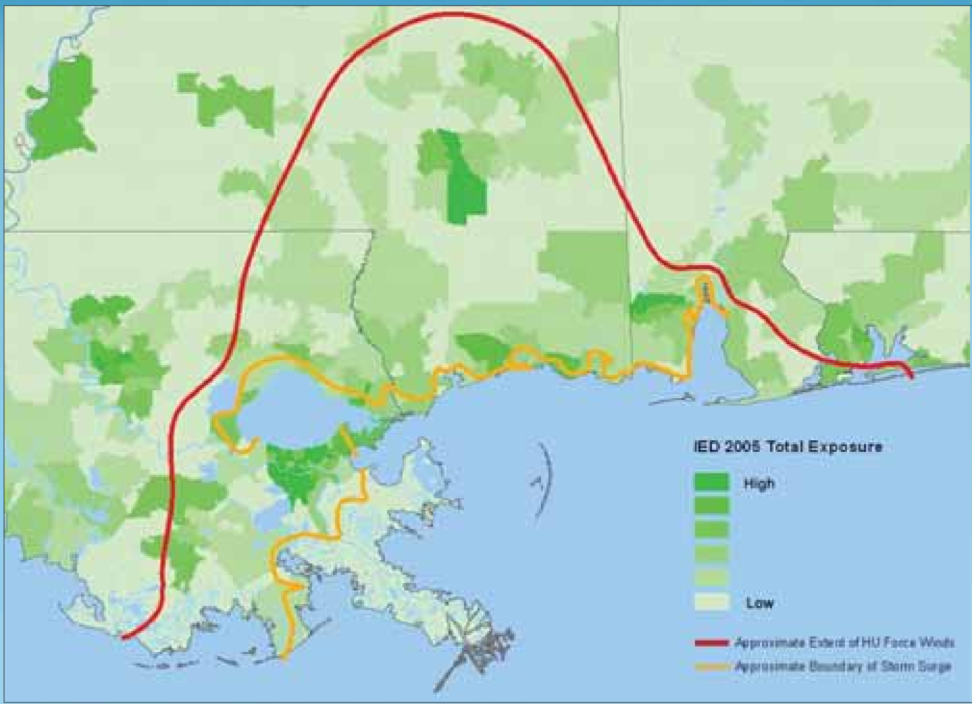


Figure 10. Exposure affected by Hurricane Katrina Gulf Coast landfall

Factors that will determine where in the range the losses will end up include the level of demand surge, the interpretations of the proportion of loss due to wind where there is ambiguity or dual cause, the costs and duration for Additional Living Expenses (ALE), and the extent of business interruption.

In estimating losses resulting from standard insurance policies, RMS recognizes that standard insurance policies do not include the flood peril. Where a building has been damaged both by water and wind, the normal practice is for an insurer to pay the component of the damage estimated to have been caused by wind. In practice, this is a complex estimation, and claims settlement may involve an element of negotiation. Where buildings have been destroyed, the determination of whether wind or surge is the cause can become a forensic exercise. Estimating the amount that insurers will pay for an event where hundreds of thousands of buildings have suffered damage from both wind and surge involves allowing for a range of potential outcomes from those negotiations. The loss range estimated by RMS for wind damage includes a component for some degree of water damage that insurers might cover in their claims settlements.

The loss range does not assume insurers forced to pay for all water damage under windstorm coverages. Various suits have been filed, including one by the Mississippi Attorney General on behalf of the state, to get insurers to pay claims on properties with substantial surge and flood damage. The RMS loss range does not include this possibility; if these suits are successful, losses could be considerably more than the estimated range.

The Flooding of New Orleans

In the two days before Katrina's landfall, officials urged the 1.3 million residents of the New Orleans metropolitan area to evacuate. There was heightened awareness of the city's vulnerability to flooding caused by hurricane-related storm surge and potential levee breaching. More than 350 miles of levees protect the city that is mostly below sea level, and the levee system was only designed to withstand a category 3 hurricane. More intense storms were expected to have the potential to overtop the levees. The Army Corps of Engineers, levee districts, and local emergency managers had carried out exercises around a hypothetical hurricane threatening levee failure in the city as recently as a year ago.

Levees Breached After the Storm Had Passed

The storm surge overtopped several of the New Orleans levees as Katrina made landfall. There were reports of floodwater seeping into several parts of the city on Monday, August 29, but the main levees on the Gulf Coast and along the Mississippi remained intact. One breach on the Industrial Canal in the southeast of the city was reported at 11 am, and water flooded the 9th Ward to the southeast of New Orleans. Another significant entry of water was reported from the floodwall on the 17th Street Canal around 2 pm on the same day. But as the storm passed and moved away on the evening of August 29, city officials expressed some relief that the levees had largely held.

However, the worst was still to come. The storm surge had driven water levels to record heights within Lake Pontchartrain. As the storm was parting it pushed winds from the north, driving a small additional surge onto the south shore of the lake in the middle of the night. The lake levees were able to withstand this, however the floodwalls along the banks of canals coming from the lake were weaker. As water overtopped them, it undermined the foundations causing sudden breaches in several floodwalls. The floodwall on the 17th Street Canal that had been leaking since the previous afternoon failed in the early hours of Tuesday morning, and developed into a major breach 500 feet long allowing water to flow into Orleans Parish. The rate of flow through this breach was impossible to stem, despite several attempts. Entering through the break in the Industrial Canal and another major failure in the northeast of the city, the water flowed from the lake into the city for 36 hours until it was at lake level, covering most of Orleans Parish and portions of the neighboring Jefferson and St. Bernard Parishes. Flood depths reached up to 16 feet in the central city area.

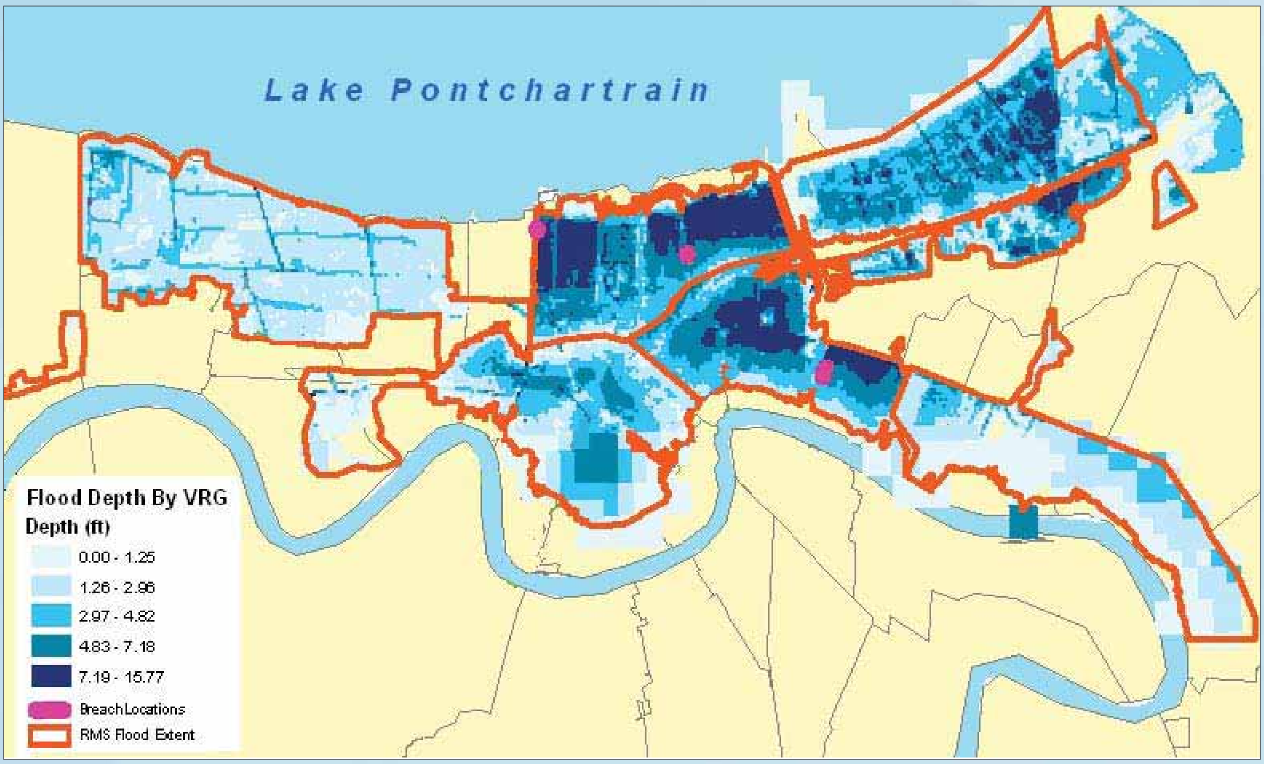


Figure 11. RMS modeled flood depth in New Orleans

Figure 12. London Canal levee break (image curtesy of DigitalGlobe)

Failures in Emergency Response

Despite evacuation pleas, more than 100,000 people were stranded in flooded regions of the city, some unable to leave and some choosing not to evacuate. Some of the evacuation plans, such as providing buses, failed. The failure of the levees caught officials and emergency responders off-guard, and it appears that police, medical, and other means of assistance were inadequate to cope with the scale of the disaster.

Rescue efforts scaled up over several days, but in the meantime those left in New Orleans suffered increasing deprivation and lack of facilities. Civil disorder and looting began. A compulsory evacuation was ordered on September 6, involving an airlift and major logistical resources, and troops went house-to-house helping to ensure a complete evacuation. Much media attention was focused on the lengthy time for emergency response, ultimately leading to the resignation of the head of the Federal Emergency Management Agency (FEMA).

Casualties from the Flood

The flood waters poured into the low-lying parts of the city in the middle of the night. In the lowest lying parts of Orleans Parish, the water may have submerged single story houses within two hours. By daylight the roofs of two-story buildings were just visible. Over 900 bodies were recovered and others were still reported missing by the end of the house-to-house searches. At one point the mayor quoted from a report estimating that 10% of trapped people could have drowned, leading to his estimate of 10,000 dead; however, worst fears of the death toll for the flood did not materialize.

Pollution and Ancillary Damage

During the flood, the water washed out gasoline tanks, oil tanks floated and cracked, and a large amount of oil contaminated the flood waters. Sewage systems were flooded, and two major landfills leached material into the waters. Several other industrial sites, gas stations, and other locations where hazardous materials were stored also flooded. Concern about the health hazards of the polluted flood waters was one of the principal reasons for the compulsory evacuation of the city.

The flood waters prevented fire crews from being able to suppress burning fires, which were possibly caused by ruptured gas pipes, electricity cuts, or arson. Several fires burned for many hours in industrial buildings and residential homes across the city.

Reclaiming New Orleans from the Waters

In the initial days following the flood, Army Corps of Engineers officials estimated that it would take as long as 80 days to remove all the water from the city. In the second week of the disaster, estimates were shortened to 40 days or less. The quicker pace is due to success in getting more pumps working, in closing levee breaches caused by the hurricane, and in intentionally opening other breaches for water to flow out. Water dropped by up to 6 inches a day in some areas, and much of the area was drained within two weeks.

As Hurricane Rita passed near the southeastern coast of Louisiana on Saturday, September 24, locally heavy rainfall and storm surge in Lake Pontchartrain caused a breach in the repaired section of the Industrial Canal. The city's 9^{th} Ward was flooded for the second time, and residents were prohibited from returning until early October when drainage was finally completed. However, this was less serious than it first appeared: the breach from Hurricane Rita is estimated to have set back reclamation efforts by less than a week. By early October the city was declared "90 to 95% dry," but contamination concerns remain for the flood sludge left behind.

The Army Corps of Engineers has formed a Task Force Guardian team of several thousand personnel to restore the levee protection. They hope to create levees of sufficient height to withstand moderate storms during the remaining hurricane season. The Corps estimates that they will restore the levees back to pre-Katrina levels of protection—that is, able to protect the city from a hurricane of up to category 3—by the start of the 2006 hurricane season. Increasing the level of protection to survive future storms as strong as Katrina will require a major budget commitment by Congress and a lengthy project of levee raising and strengthening around the whole city, but the debate about the cost-effectiveness of this has not yet begun.

Modeling the Great New Orleans Flood

RMS estimated the New Orleans flood-related losses by building a digital model of the flood's extent and depth across the three parishes. Using a high-resolution (5-meter horizontal) digital terrain model for ground elevation data, RMS represented the eleven 'catchment basins' with the central New Orleans levee system and generated flood depths on a 100 x 100-meter grid across the greater New Orleans area. The modeled flood extent and associated flood depths were calculated to be consistent with observations from satellite imagery taken on August 31 and September 3, aerial photography taken on August 30, and the FEMA flood extent maps as of August 31, 2005. For some areas where satellite imagery was obscured by cloud cover, the flood extent was modeled by assuming that water levels in the area would equalize with the normal water level of Lake Pontchartrain (1 to 2 feet above sea level). The modeled flood depths were validated using aerial survey data and assessing flood depths relative to surrounding structures, automobiles, and other distinguishable objects.

To estimate the damage to affected properties, a suite of flood damage-depth curves for structure and contents were developed based on Army Corps of Engineers studies and RMS flood modeling work in the U.K., Belgium, and Germany. The curves vary by the height and occupancy type of the building.

Flood Component of Loss Estimation

The RMS IED, originally developed at the ZIP Code level, was assigned to the flood depth grid using high-resolution land use and land cover data. Flood insurance take up assumptions were based on an analysis of the NFIP data, U.S. Census data, and insurance market interviews. The majority of residential structure and contents losses were assumed to be covered by the NFIP, and the remaining losses to these coverages from flooding were assumed to be largely uninsured. For commercial lines, market feedback indicated a high penetration of private-sector flood insurance coverage for structure and contents, but with significantly lower policy limits than for wind coverage.

The overall loss to the insurance industry from flooding in New Orleans is estimated at $15 to $25 billion. A 40% demand surge factor was included in all the loss estimates.

As with estimating storm surge losses, there is considerable uncertainty associated with the settlement of claims from flood-related damage in properties that also have wind damage. The extent of the presence of flood waters will also influence the ultimate losses, as longer duration leads to more structural decay, a greater degree of pollution and required clean-up, an increased possibility of mold, and higher claims for ALE and BI due to the civil exclusion.

The additional rupture of the levees by Hurricane Rita on September 24 is not expected to cause significant additional property loss. Most of the buildings affected had already been flooded, but the additional time for reclamation will extend the ALE and BI costs.

Moving Inland

After landfall on the Gulf Coast, Hurricane Katrina moved inland and dissipated, but tracked across the central U.S. as a moderate storm. The NHC downgraded Katrina to a tropical storm 30 miles northwest of Meridian, Mississippi on Monday, August 29 at 8 pm EDT. Katrina continued to move as a tropical storm toward the northeast. The NHC issued its last advisory on Katrina as it was moving through the Ohio Valley by 11 pm EDT on Tuesday, August 30.

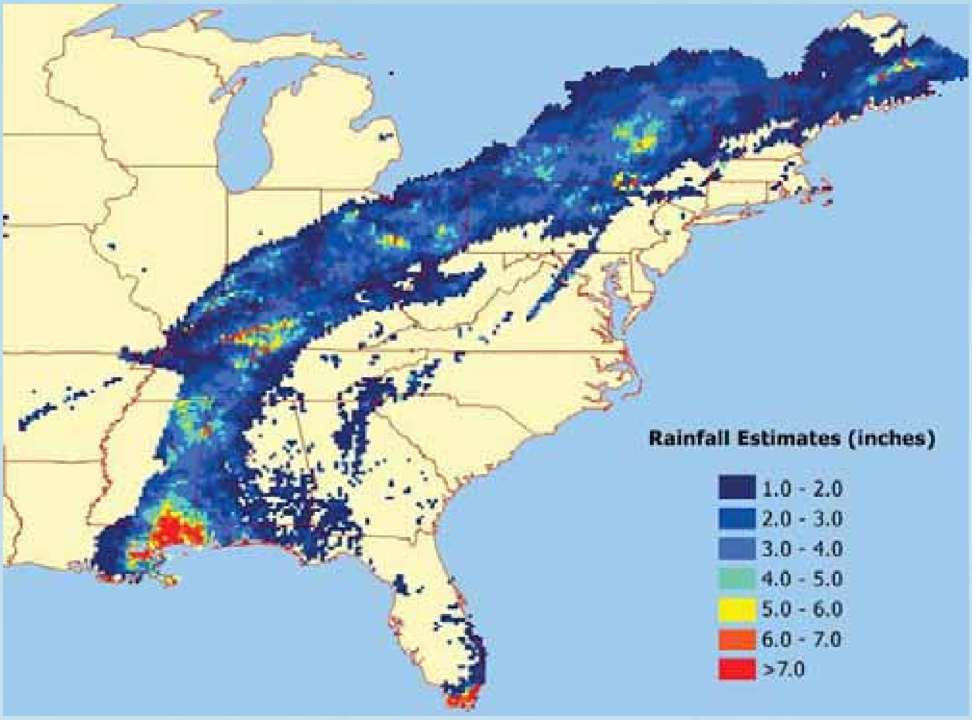


Figure 13. Rainfall footprint of Katrina–cumulative rainfall map from gauge-weighted radar estimates from NOAA/NCEP Environmental Modeling Center

As Katrina moved inland and weakened to a tropical storm, it brought strong winds and heavy rain across a broad swath of the central United States. Two to four inches of cumulative rainfall were recorded along the path of Katrina with localized rainfalls in excess of five inches as far north as New York. No extensive inland flooding was reported outside the landfall areas, but localized areas of heavy rainfall caused road closures in several states. Hurricane Katrina brought much rain to the affected regions, but its cumulative rainfall was not particularly severe.

Additional Losses

Power Outages

As the storm hit on August 31, over 30 power stations across the region were taken out of service either to avoid damaging equipment or due to failures of generator or transmission systems. These included the 1,089-megawatt Waterford 3 nuclear reactor, the 825-megawatt Michoud natural gas and oil-fired station, and the 1,263-megawatt Grand Gulf unit in Mississippi. Entergy's 959-megawatt Michoud station in New Orleans was flooded to more than 8 feet. An estimated 1.3 million residential and commercial premises lost power. While power companies warned customers to expect a long and difficult restoration, electricity was restored to critical facilities such as hospitals within 24 hours, and to about half of those affected within a week. Three weeks after the storm, about a quarter of a million customers were still without power. More than a month after the event, electricity supply still was not restored in some of the hardest-hit areas.

Decontamination and Clean Up

Clean up costs arising from the failure of oil tanks and the leaching of other hazardous materials into the ground and water will add significantly to losses. There were six major oil spillages across southeastern Louisiana, with an estimated 7 million gallons of oil spilled. To put this into context, this is equivalent to two-thirds of the spillage that occurred in the wreckage of the Exxon Valdez, one of the worst environmental disasters to date, with an estimated cost of $1.25 billion for clean up in 1989. Spillage due to Katrina could cost considerably more, as it has occurred across the population centers of the Gulf Coast. In the New Orleans area, some 80% of St. Bernard Parish's properties are estimated polluted with oil spillage in the flood waters. In some parts, where oil has sunk into the earth, officials estimate that as many as 4,000 homes will have to be razed and 2 to 3 feet of soil removed before the area can be inhabited again.

Costs of the clean up are expected to exceed $1.5 billion for waste management alone. The storm surge has also deposited an estimated 40 to 50 million cubic yards of silt and debris, all of which needs to be cleaned up and transported away.

Ports and River Freight

Disruption was severe at the ports in the affected area. The region contains five of the top 12 U.S. ports, including South Louisiana, the country's top port by cargo volume. Imports arriving at Gulf ports include steel, rubber, coffee, and fresh fruit. Freight companies were estimated to be losing $3 to $4 million a day while the ports were closed. Coastal waterways have been badly disrupted, with barges and containers scattered up to a quarter of a mile inland. There is no easy alternative to the Mississippi River as a shipping route, so cargo traveled instead by road and rail, pushing up costs. U.S. corn exports—75% of which normally pass through New Orleans—could be particularly badly hit. The majority of these exports usually ship in the harvest months of August and September.

The agriculture industry was hit by damage to crops in the field: sugar cane, cotton, soybeans, and corn were all impacted by the storm, and prices—particularly for sugar cane—increased significantly. Livestock and poultry losses are also expected to be significant.

Figure 14. Collapse of the front wall and loading bays of a commercial building in Gulfport, MS

Business Interruption

Power outages have caused significant losses for businesses, even those undamaged by the storm itself. Some of this loss will be claimed under business interruption coverages on property insurance.

Businesses that have purchased contingent BI coverage can file claims for losses under special coverages due to hurricane damage that prevents deliveries and services from their critical suppliers. Contingent business interruption to businesses outside the affected areas may contribute additional losses.

Within the city of New Orleans, businesses face losses from the mandatory evacuation order. The extent to which this may be claimed under insurance terms will emerge over time. Business owners began returning to the city after more than three weeks away to find damage from winds, penetration by rain, flood waters, looting, pollution, and a small number of fires.

The re-evacuation of personnel for Hurricane Rita and the failure of certain levees for the second time will add to the BI costs by further delaying the return of businesses to the city.

Energy Production

Katrina caused substantial disruption to production across a region that provides a quarter of U.S. oil and gas production. This led to rises in energy prices, with oil peaking at nearly $70 a barrel in the days immediately following Katrina. Energy prices increased again with the prospect of further damage in Hurricane Rita, but dropped slightly when Rita's impact was less than feared. The resulting increases in gasoline prices are expected to impact consumer demand, but analysts believe the impact will be short-lived and will not force the country into recession. The U.S. economy is still expected to grow at 3.5% to 4% for the year.

Tourism and Airlines

Tourists spent $5 billion in New Orleans last year, which represents half of the state of Louisiana's tourism income. The hurricane will cause tourists to visit other destinations, and business conventions are being moved to other cities that can accommodate the groups. Mississippi's gambling industry has been hardhit, with the state's 13 floating casinos either heavily damaged or destroyed. The collapse of tourism in New Orleans has had some effect on the airline industry, but the biggest financial impact on airlines is likely to be from soaring fuel prices. Production of aviation fuel is down by 13% and the price has gone up by 19%. At a time when many airlines are already struggling, this latest fuel rise is forecast to be very painful for air carriers.

Demand Surge

As the impact of Katrina was recognized by the construction industry, concerns about capacity constraints for labor and materials drove price fluctuations that presage substantial increases for

Figure 15. The Copa Casino barge washed ashore in Gulfport, MS

reconstruction costs. This demand surge has been observed in previous large scale catastrophes but the effects are likely to be considerably larger than previously seen. Hurricane Katrina is estimated to have destroyed over 250,000 properties: an order of magnitude larger than the 28,000 destroyed by Hurricane Andrew.

Early indicators of demand surge have been observed,[1] including steep rises in the prices of construction materials on the market and building cost indicators. Construction costs have been fluctuating significantly over the past two years, and the impacts of hurricanes have been a compounding factor. Prices of steel and lumber reached record highs in 2004, but had declined in the months before Katrina as production had been increased to meet demand. Lumber prices jumped around 15% after Katrina but remain well below levels of a year ago. Steel production is less scalable, and prices could increase more than lumber. Cement shortages have been reported in more than 30 states and will be a key material needed for rebuilding. Consequently, significant pressure on cement prices is expected. There is already talk of lowering tariffs on imported cement to take advantage of supplies available from countries like Mexico.

Forecasts predict additional impact on construction costs may come from higher energy prices, so materials that are energy-intensive to manufacture, such as steel, cement, and roofing, will be affected. Higher gas prices will increase transportation costs, further adding to the cost of bulky materials trucked across land.

Labor costs are expected to be driven upward by significant shortages of manpower combined with widespread upward pressure on wages in the next couple of years.

The Flood of Litigation

In addition to, or perhaps because of the scale of the loss it is also becoming clear that Hurricane Katrina will bring unprecedented levels of legal action against a wide range of potential defendants. Suits have been filed against insurance companies, real estate agents, federal agencies, owners of hospitals, retirement homes, and many others. The U.S. Chamber Institute for Legal Reform has warned that the rash of lawsuits will delay and complicate recovery efforts for hundreds of thousands of the storms' victims.

Several suits are focused on the ambiguity around water damage and insurance coverage. Mississippi Attorney General Jim Hood has filed suit on behalf of the state to get insurers to "pay billions of dollars" to homeowners denied flood claims based on standard flood exclusions. In a separate development, Richard Scruggs, a Mississippi lawyer who helped many states reap multi-billion dollar awards from tobacco companies in the 1990s, said he plans to "file thousands of suits" in state courts, citing a Mississippi statute known as the 'valued policy law.' Other suits are citing negligence as proximate cause for insurance losses, potentially widening the interpretation of causes of loss.

Plaintiff attorneys have also filed a suit arguing that all property and homeowners in the greater New Orleans area have the right to recover insurance proceeds from their home owners insurance company as a result of high water because flooding was caused by man-made neglect and wind damage rather than a so called "Act of God" through rising water.

The wide range of litigation raises real concerns for insurers that legal actions of this type could potentially widen the interpretation of causes of loss and extend claims beyond coverages for which premiums were charged. If such legal actions are successful, the implications for insurance companies and for availability of insurance in the future could be far-reaching.

[1] 'Gulf Coast Hurricanes Will Impact Construction Costs,' *Property & Portfolio Research Inc*, September 27, 2005. Referenced by permission.

Lessons for Vulnerability Assessment

The claims from Hurricane Katrina will add to the ongoing analysis of claims data from the 2004 hurricane season. RMS is already analyzing $13 billion of 2004 claims data from 42 different companies.

The hurricanes of 2004 and 2005 represent around twice as much claims data as all previous hurricanes since 1990. Significant improvements in the quality of data captured during underwriting and claims processing since 2000 make it possible to analyze these claims in far more detail than was possible from earlier hurricane seasons.

RMS analysis of claims from the 2004 hurricanes has identified a number factors contributing to the difference between modeled and incurred losses, as illustrated in Figure 16. These include factors relating to incomplete (or sometime inaccurate) exposure data, demand surge, and differences in vulnerability for particular lines or sub-lines of insured exposure.

The 2004 data continues to be instrumental in assisting with recalibration of vulnerability assessments for a number of different building types, including the manufactured homes vulnerability functions released earlier in 2005, and for commercial property and other asset classes. Detailed wind damage claims data from Katrina is expected to provide further differentiation of risk categories and regionalization of vulnerabilities, as well as reinforce the need to improve the quality control of data entry on property locations, building types, and their characteristics.

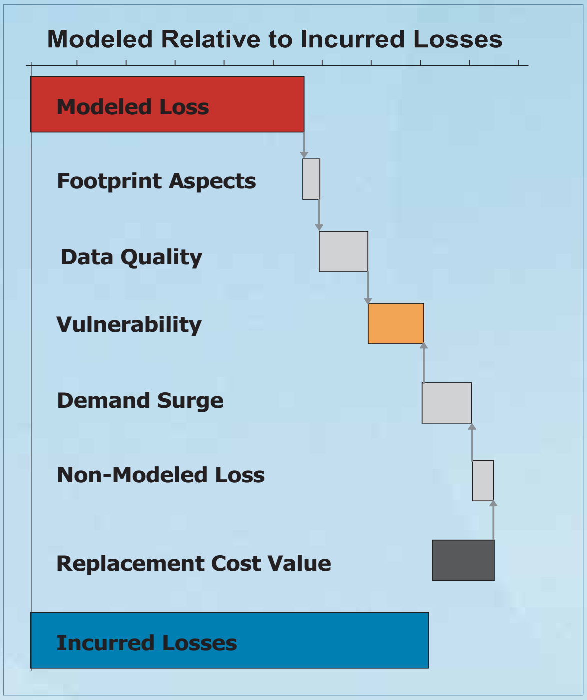


Figure 16. RMS 2004 claims analysis deconstructing modeled versus incurred losses

Flood Claims

Katrina will also generate a very large number of flood claims, both for properties affected by the flooding in New Orleans as well as those impacted by the storm surge along the coast. For many of these properties it will be important to identify the precise address level location so that the damage can be related to the different contributions of passive flooding and wave action. This claims data is also expected to further clarify the degree to which insurers may cover some elements of flood loss when structures have sustained both wind and flood damage.

Katrina is also likely to produce claims for properties that suffered neither flood nor wind damage, but were subject to deterioration damage and claims for time coverage costs as a result of the evacuation of New Orleans.

Claims Analysis Project for Katrina and Rita

Once the claims process is well underway for the 2005 storms, RMS will be making a data call to insurance clients and working with them to understand the relationship between the severity of the hazards at a location, the characteristics of the property, and the ensuing loss.

Extreme Storm Surges

The unusual magnitude of the Katrina surge—larger than that normally associated with the level of winds experienced—suggests the possibility of underestimation of flood risk along this coastline. Going forward it is clear that all sections of the flood

Figure 17. Extensive damage to this building in Biloxi, MS suggests that the storm surge reached as high as 20 feet

risk management community need to resolve the mismatch between the predictions and this experience. Whether current analyses underestimate the risk of extreme surges will need to be reviewed in light of Katrina.

If storm surge risk has been underestimated, it will have important implications for rebuilding. It would also raise important questions about the risk to critical facilities such as oil refineries, many of which were sited and designed during a period of low hurricane activity.

Similarly, the underestimation of storm surge risk could mean that the zoning maps produced in support of the National Flood Insurance Program may need to be updated. There are three flood boundaries employed within the definition of flood risk: the V zone, which is equivalent to the zone expected to be impacted by high energy waves; the 100-year return period inundation flood zone; and the 500-year return period inundation flood zone. Along parts of the coastline, the zone of intense wave damage from Hurricane Katrina extended significantly further inland than the 500-year flood zone.

For the insurance industry there are also more fundamental issues around how the market considers storm surge and flood losses within its hurricane loss scenarios. The ambiguity of what is intended to be covered relative to what actually gets paid reflects the weaknesses of a system in which coverage is provided for only certain agents of the hurricane peril. In this environment, claims payment depends heavily upon trying to determine the agent of damage.

Additional Lines of Business

Significant levels of loss occurred in lines of business and asset classes that have not experienced major losses in past catastrophes. Risk managers may need to re-examine their exposure to these classes in more detail, and modeled losses may need to be expanded to incorporate them more explicitly.

These additional asset classes could include cargo, inland marine and recreational watercraft, floating casinos, onshore energy, automobiles, and possibly human casualty lines such as workers compensation, life, and health.

Contingency

Katrina is expected to have a significant component of its loss from contingency: the disruption of services and flow of goods that causes loss outside of the directly impacted area. Direct contingency can be modeled where the business, facility, or lifeline on which the activity is determined can be specifically identified (and its susceptibility to loss included in the modeling). The larger the event, the greater the amount of contingency that can be anticipated. Once contingency becomes more complex, the analysis needs to consider the overall impacts of the event on the original location more systemically.

Profile of a 'Super Cat'

Recognizing a Super Cat

Hurricane Katrina was an event of greater magnitude and significance than any natural catastrophe in the developed world over the past decade. It displayed a range of processes and phenomena that amplify losses. A number of these, such as demand surge and fire following earthquake, are already incorporated within RMS catastrophe models. Katrina illustrates several different ways that a Super Catastrophe expands losses beyond the direct linkages of hazard, exposure, and vulnerability.

The principles of catastrophe modeling emerged out of the catastrophes of the late 1980s and early 1990s, including the Loma Prieta and Northridge earthquakes, and hurricanes Hugo and Andrew. These catastrophes revealed the importance of detailed information on exposure and vulnerability in calculating loss. The largest of all these losses, from Hurricane Andrew and the Northridge Earthquake, also showed the significance of demand surge, or the way in which shortages of materials and repair crews, as well as consumer pressures over the interpretation of 'replacement value' and 'insured value,' caused increases in the costs of claims. While the insurance costs of the 1995 Kobe Earthquake were modest, it was also a Super Cat event with economic losses in excess of $100 billion, and it provided an important reminder that the consequences of one catastrophe could lead to a second major catastrophe, such as fires that burned unchecked through the dense poorer areas of the city.

What happened in Hurricane Katrina has helped define a new paradigm for understanding Super Cat losses, suggesting a new overarching methodology to connect processes that were previously included as 'exceptions' within catastrophe models. Instead of seeing fire following earthquake and demand surge as add-ons to standard models, these can be integrated as core components of a holistic Super Cat risk assessment methodology.

Loss Amplification

Nonlinear Factors Increase Loss

In Super Catastrophes like Katrina, losses become nonlinear, i.e., the scale of the event itself causes losses to increase further. This can be seen in several processes, for example:

- As buildings disintegrate under wind or flood loads, they create debris that increases the damage to buildings nearby
- Damage to infrastructure prevents pumps from operating, limits water availability for fire hoses, and compromises other vital equipment; failure of telecommunications means that timely information does not reach emergency managers; flooded roads and evacuated personnel means that fires are left to burn
- At low levels of damage people help their neighbors; at high levels of damage the community is overwhelmed, unable to rescue each other, and casualties quickly escalate; similarly, community action to mitigate damage or stabilize and prevent deterioration of damage is lost at higher levels of damage
- Faced with high levels of damage and pollution in the reconstruction process, decisions are made to demolish whole neighborhoods, rather than to repair and save some of the less damaged properties

Demand Surge

Models already recognize an important aspect of the way in which claims costs reflect the total magnitude of the loss through demand surge. Demand surge encompasses all those elements of the costs that are resource constrained. The fact that demand surge is itself a function of the overall economic loss introduces a nonlinear feedback in the estimation of economic loss. Nonlinear behavior of economic shocks is described by Leontief input-output economic models.[2]

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[2] Leontief, Wassily W. *The Structure of American Economy, 1919-1929; An Empirical Application of Equilibrium Analysis*, Cambridge, Mass.: Harvard University Press, 1941.

Longer Delays

Larger scale losses take longer to repair and resolve. This increases the likelihood of properties sustaining further damage or deteriorating, and information becoming lost. Time-element costs of claims increase. Additional Living Expenses depend on how long it takes to allow people to return to their homes, which may be affected by the availability of claims assessors and repairers. Businesses, such as hotels, may prolong their reopening to wait for customers to return, increasing business interruption costs.

Claims Exaggeration

With larger numbers of claims, insurers are unable to monitor them as rigorously, leading to the potential for fraud and claims exaggeration. It is likely that there will be more than 1.6 million claims from Hurricane Katrina, and while the focus will be on the most costly claims, the checking process for many of the smaller claims may have to be relaxed.

Coverage Expansion

The question as to how much of all of the expenses, lost revenues, and damages will be covered by insurance remains unresolved. Insurers will want to stick tightly to their interpretation of policy coverages, but are under pressure to pay for a broader range of losses. Litigation is mounting to expand the interpretation of policy coverages.

In future Super Cats, major litigation is probably inevitable: where there are large numbers of potential claimants and significant potential settlement costs, the leading members of the plaintiff's bar will consider it worth mounting suits.

It is also possible that from a commercial point of view, some insurers may conclude that generous claims settlements are good for future business, something which occurred for example after another Super Cat: the 1906 San Francisco Earthquake.

Increased Correlation of Loss

These inflationary factors are not independent of one another, and their interdependence adds to the complexity of estimating Super Cat losses. There is increased correlation in loss outcomes across different locations, lines of business, and insurance coverages.

Existing models allow for correlation of loss between sites, associated with secondary uncertainty in hazard and building vulnerability. In earthquake modeling, higher correlation has traditionally been incorporated to capture this effect, but in hurricane modeling, the smaller historical events have suggested that loss correlation is less pronounced. However, it is clear that for extreme hurricane loss correlation also rises.

For flood losses, there is an increased level of correlation among different properties that share the same flood defense or among different coverages for the same property. Certain lines of business, such as oil refineries or casinos, are situated in similar coastal locations with high levels of surge damage. The degree of correlation of losses across a series of locations within the same policy may therefore be much higher than for an average assumption around multi-location hazard and damage levels.

Loss Interaction

In modeling terms, a high degree of correlation is known as 'loss interaction' in which loss is no longer a 'random' local process, but becomes highly correlated and regionally ordered. The loss distribution is no longer scattered around an expected mean value extrapolated from lower values, but is highly skewed towards upper percentiles. Correlation occurs across different lines of business, and between ancillary perils, in ways that would be unexpected if a random process is assumed.

At some level, there could even be a 'phase transition' in the claims environment, where what happens at one location depends intrinsically on its neighbors. Such a transition could mark a change in the status of a catastrophe—a tipping point where the system switches from the usual 'random process' of damage distributions, to exhibiting high correlation and order. Enforced evacuation could be considered one example of such a phase transition, where the level of infrastructure damage reaches a level at which a city is no longer considered inhabitable.

Additional Sources of Loss

A Super Cat not only increases the losses from expected damage agents like wind and storm surge, it also increases the number of damage agents and the lines of business and asset classes damaged, adding to the losses an insurer suffers in an event. Hurricane Katrina has revealed a number of examples of additional sources of loss to an insurer.

Pollution

Pollution has been extensive in Hurricane Katrina, principally from the floodwaters leaching contaminating agents. The main damage agents of the wind and the flood waters caused tanks to crack and spill, sewage systems to leak, and other hazardous chemicals to be washed through inhabited areas. Pollution clean up greatly increases the costs of repair and lengthens the time it will take to start repairs and re-occupy undamaged properties. The unsanitary waters were one of the main reasons given for the mandatory evacuation of the city of New Orleans. Pollution is likely to be a primary area of litigation and could cause additional liability claims for insurers covering many industrial facilities.

Evacuation Causing Loss

The mandatory evacuation of the population of New Orleans after the flooding of the city has become a major source of consequential economic and physical damages. Most obviously, the evacuation caused significant additional living expenses among those evacuated, which may potentially be claimable from insurers under standard policies. Evacuation has also caused significant disruption to many businesses, not only those located in the evacuation area, but all those dependent on a labor force coming from New Orleans, including oil and gas facilities, refineries, and the New Orleans port.

The evacuation of key personnel also led to the collapse of critical facilities within New Orleans itself. This includes the pumping systems to prevent flooding, the fire department, and as has now become apparent, emergency response personnel and law enforcement officers.

The evacuation also led to fire outbreaks, both accidental as a result of gas leaks and reportedly arson. Fires uncontrollably burned without fire fighters, access to fire pumps and hoses, and pressure in the city's water system. It was fortunate that the strong winds had subsided by the time of these fire outbreaks, or many blocks of the city could have been lost to fire.

Abandonment due to evacuation means that damaged properties will deteriorate further before they can be repaired, accumulating mold, fungal agents, rust, plaster expansion, and other deterioration. Even undamaged properties exposed to high temperatures and humidity for several weeks without being cleaned or aired are likely to suffer mold or deterioration, potentially leading to insurance claims.

The evacuation of New Orleans was an inevitable response to the fact that the principal functions of the city had collapsed, and there was a serious public health problem. A major civil exclusion zone was also created across a large area of central Manhattan following the collapse of the World Trade Center, and some similar elements of loss expansion were observed in that evacuation. Future Super Cats are likely to result in the mandatory evacuation of major urban areas, particularly if they involve widespread contamination such as a toxic release, or where the primary functions of a city are significantly disrupted.

Multi-line Losses

The exceptional storm surge and flooding in New Orleans will cause significant losses across many lines of insurance business, in addition to the standard property lines including cargo, inland marine, onshore energy and many others. Future Super Cats are likely to see similar expansion of loss impacts across multiple lines of business. For some insurers, this was a particularly punishing feature of the World Trade Center loss in 2001.

Asset-liability Correlation

The size of catastrophe from Hurricane Katrina was large enough to have economic impacts that extended far beyond the region of storm damage and out into the wider economy. The most obvious of these consequences concerned the prices for refined gasoline as well as for crude oil and natural gas. The shortage of refined petroleum even led to increases in the cost of gasoline worldwide as producers sought to divert supplies. Two already distressed U.S. airlines chose to seek bankruptcy protection in the aftermath of the storm, in consequence of the rise in jet fuel prices. Katrina also affected (both up and down) the share prices of insurers, reinsurers, and reinsurance brokers as investors digested the likely implications of the event both in terms of the costs to income and capital as well as the opportunities for future market hardening. Such impacts into the wider economy are anticipated to increase with the size of a Super Cat loss, and Katrina will be an important point of reference for stress testing and dynamic financial analysis to explore correlations between the asset and liability sides of an insurer's balance sheet.

Cat Following Cat

Katrina has demonstrated the scale of loss that can occur when the principal damage agent in a catastrophe triggers another sizeable follow-on disaster: Cat following Cat. One of the lessons from Katrina is that risk managers need to anticipate a greater range of potential catastrophes that might be caused by the principal damage agents of a natural catastrophe.

One of the most significant potential follow-on catastrophes is fire following earthquake. Earthquakes have historically demonstrated the potential to cause casualty figures and property destruction even higher than those caused by the shock damage alone. RMS currently models fire following earthquake in the U.S., Canada, and Japan. Dam failures are another example of Cat following Cat events that could cause locally severe losses.

What happened in Katrina has reinforced the potential for technological failures triggered by natural catastrophes. The spillage of oil and hazardous materials has caused costly pollution over a wide area. It is possible that future catastrophes could spill more dangerous chemicals and trigger toxic clouds that could kill or pollute on a larger scale. Nuclear power stations are designed to withstand most likely natural catastrophe forces, but they can fail, and certain combinations of circumstances could lead to radiological releases that would be hugely disruptive and costly to remedy.

The flooding of New Orleans also emphasizes a key facet of Super Cats—the increased role of correlation among events that might have been considered independent. In the RMS® U.S. Hurricane Model, extreme surges are modeled extending into New Orleans (for hurricanes of Category 3 and above), but there was an assumption that there would not be significant breaching and flood depths would be limited by the pumping capacity in the city. The loss of pumping capacity was directly linked with the occurrence of the hurricane for two key reasons. First, the personnel who ran the pumps were evacuated because it was considered that pump house buildings might not survive extreme hurricane winds. Second, the hurricane winds caused a loss of electrical power. Once flooding had followed the evacuation, it was not possible for the pump operators to return to their stations.

Therefore all those factors that led to the failure of the pumps turned out to be highly correlated with the catastrophe event and its flood consequences. This has important lessons for risk assessment at other active flood defense systems protecting major cities, such as the Thames Barrier protecting central London from catastrophic wind driven storm surge floods.

Given these lessons, Hurricane Katrina will expand the scale of risk management for Cat following Cat events in the future.

Consequences for Risk Management

In previous major catastrophes, it took several years to complete the consolidation of claims. Given that Hurricane Katrina is likely to be larger and more drawn out than anything seen previously, it will be a long time before final loss numbers are known with any certainty. Nevertheless, the scale of loss is readily apparent, and its consequences are likely to ripple through the insurance and reinsurance industry for many years to come. Events of lesser magnitude have, in the past, caused significant changes in the insurance industry, so we can expect Katrina to have profound consequences for the industry itself, and specifically on the insurance industry's catastrophe risk management agenda.

Changes to the Insurance Industry

Major catastrophes result in changes to the insurance landscape—companies seek new capital, some companies may fail, others are downgraded, mergers and consolidations occur. The losses tend to harden prices, which makes underwriting attractive and provides opportunities for some, possibly leading to new capital or innovation in the market.

Change could even be more radical. Katrina has prompted discussion of whether hurricane risk is even insurable by the private market—floating ideas of natural catastrophe pools or government backstops. The debate about the capital adequacy of the industry to cover extreme losses, raised by the Terrorism Risk Insurance Act, could broaden in a post-Katrina environment. These radical changes may be unlikely, but the fact that they are being openly discussed shows the extent of the loss ramifications.

Improved Catastrophe Risk Management

Most certainly of all, the event will lead to increased focus on controlling exposure to potential losses on this scale, and successful companies of the future will be those who best manage their catastrophe risk. Leading companies will develop an agenda of important actions and priorities, which will include several of the following:

Multi-line Accumulation Management

Increasing efforts will be made to identify, track, and manage multi-line accumulations of exposure at all resolutions, from individual four-wall structures to entire metropolitan regions. Accumulation management has been a priority throughout the industry since the terrorism events of September 11, 2001, and Katrina has reinforced the importance of gathering detailed data on insured exposures and managing accumulations of these exposures on a timely basis.

Improved Accuracy of Exposure Data

The accuracy and resolution of information held by insurers on their individual insured exposures will be considerably improved. Perhaps more acutely than in any previous catastrophe, Katrina has highlighted the influence of data quality on the industry's ability to accurately understand accumulations and to reliably use catastrophe models to evaluate risk. Achieving material and lasting improvements in data quality will require collaboration throughout the industry as well as increasingly explicit pricing and capacity penalties for inferior data.

More Differentiated Analysis of Individual Risks

Underwriting and portfolio management practices will incorporate more differentiated analysis and underwriting of individual risks. The hazard and loss experience of Katrina and other recent hurricanes will be incorporated into future catastrophe risk models of increased precision and differentiation. The unprecedented amount and quality of loss data from these events provides a wealth of information for detailed model calibration and expansion.

A Strategic View of Hurricane Activity

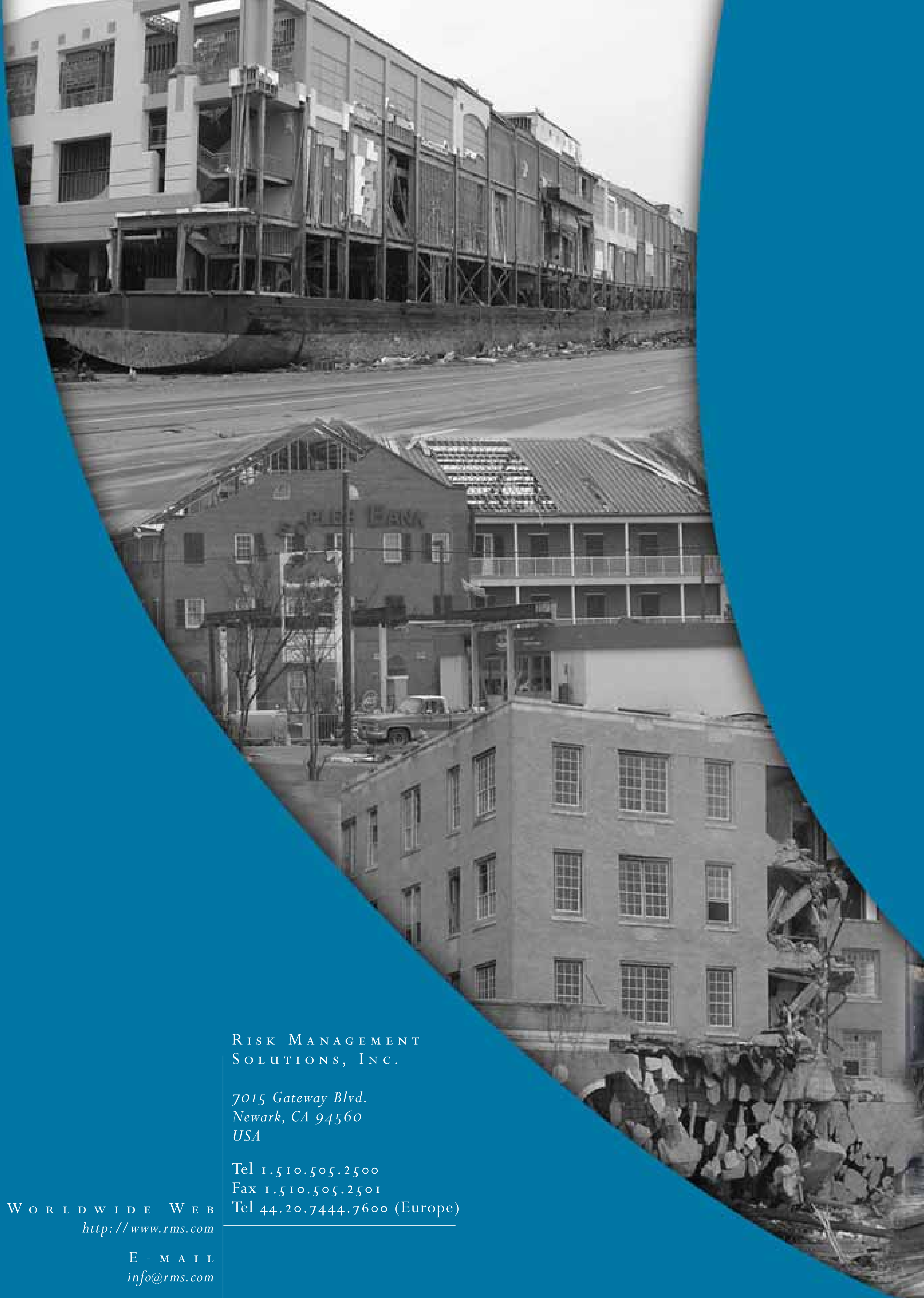
Insurers will incorporate strategic views of hurricane frequency and severity into their assessments of risk, appropriate to reflect potential effects of climate variability on the frequency, severity, and geography of future hurricane activity. Scientific research into climate effects on landfalling hurricane activity will provide deeper understanding of the drivers of the unprecedented losses in recent seasons. Over time, the industry will adapt to managing risk recognizing that climate activity can vary significantly away from the long-term baseline.

More Holistic Analysis of Extreme Events

Insurers will build a more holistic assessment of their portfolio exposure to Super Cat events into their risk management processes. Experiences such as the 2001 World Trade Center loss, the 1995 Kobe Earthquake, and now Hurricane Katrina have demonstrated the potential consequences of extreme catastrophe events. Models will be increasingly important, enabling insurers to analyze more of their exposure and helping them capture the correlations of loss across different lines of business to these extreme events. Leading insurers will stress test their risk management decisions using, for example, scenarios of extreme events to explore the potential impacts of Super Cats not just on insured exposures but also on assets and operational risks.

Managing the Super Catastrophes of the Future

These and other changes to the insurance industry's catastrophe risk management processes will emerge over the months and years following Hurricane Katrina. RMS has always worked with clients to help them meet the challenges posed by the ever-changing landscape in catastrophe risk management. As each new event has revealed additional aspects and insights, RMS has provided support, tools and models to assist clients in responding to them. Hurricane Katrina has been an event of unprecedented severity and complexity. RMS is committed to investigating, researching, and absorbing the lessons of Hurricane Katrina to help clients successfully manage the Super Catastrophes of the future.



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