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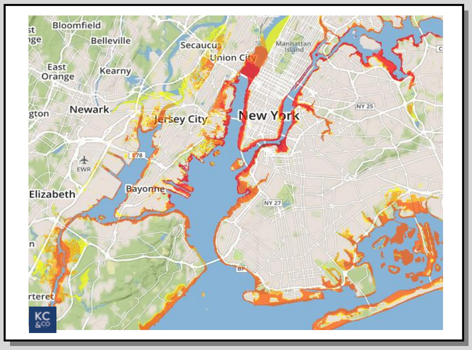

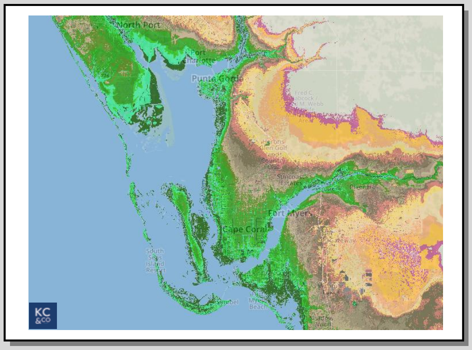

Most Vulnerable US Cities to Storm Surge Flooding

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Introduction

Hurricane Katrina was a stark reminder that strong winds are only part of the story when it comes to hurricanes. For most hurricanes, wind is the primary driver of property damage and economic disruption. But for certain storms, like Katrina, the storm surge flooding can cause tremendous devastation and economic loss—in some cases, dwarfing the wind damage.

Why do some storms produce more storm surge than others? Which coastal cities are at highest risk from coastal flooding caused by the 100 year hurricane? What would be the property damage and losses from the 100 year events? These are the questions this study answers.

Political and media attention tend to focus on the most recent events, but this study shows that some of the cities most vulnerable to storm surge flooding have not been impacted for decades. A few have not experienced a direct hit from a major hurricane in the historical record.

This study differs from previous reports in two significant ways.

First, the ranking of the cities is based on the estimated property damage and losses likely to be experienced in specific events. Previous rankings have been based on the population or numbers of properties subject to coastal inundation without estimates of the resulting damage. Insurers and reinsurers require information on losses from extreme events for risk management purposes.

Second, while the entire Gulf and East Coasts are susceptible to storm surge flooding, this is the first study that normalizes the locations based on probability and ranks cities based on damages and losses from an equally likely event. The ten most vulnerable cities were determined based on the magnitude of the property losses resulting from storm surge flooding caused by the 100 year hurricanes. The meteorological characteristics of the 100 year event change along the coastline in accordance with the hurricane hazard. The losses were estimated using the KCC RiskInsight® high resolution coastal flooding model.

The KCC high resolution model provides insurers with unique insights and valuable information on flood risk in the US. It provides fully transparent 30 meter resolution flood footprints for over 2,000 events that can be superimposed on portfolios of properties to estimate losses. Using RiskInsight®, insurers can access detailed hazard maps to ascertain which locations are in the 100 and 250 year flood contours, for example. Insurers can also easily determine how much total value they have at risk by elevation bands and flood depths for different return period events.

Even insurers that don't write flood insurance will be impacted by large surge producing hurricanes. After major events, it can be difficult to determine how much of the loss was caused by wind versus water. Extensive flooding will hamper recovery efforts, thereby likely exacerbating the wind and surge losses.

Executive Summary

This study provides insurers and other organizations with valuable information on potential storm surge losses and the relative risk of US coastal cities. It can be used to focus mitigation efforts, for emergency planning, insurance underwriting, and other risk management purposes.

US cities have not previously been ranked based on the property losses caused by storm surge from a specific event, i.e. an equally likely hurricane along the entire Gulf and East coasts. Using the RiskInsight high resolution coastal flooding model and detailed databases of property exposures, the storm surge impacts were estimated for over 300 events at ten mile spaced landfall points, and cities were then ranked by the estimated property damage, including building, contents, and time element losses.

Highlights of the study include:

- **While every coastal location is subject to storm surge flooding from the 100 year hurricane, the largest losses are concentrated in relatively few places along the coast**
- **Tampa/St Petersburg is the metropolitan area most vulnerable to flooding damage with a loss potential of $175 billion**
- **Four of the top cities are in Florida; the west coast of this state is more vulnerable than the east coast**
- **Three cities—Tampa, New Orleans, and New York—will likely have losses exceeding $100 billion from the 100 year event**
- **Most of the flood damage potential is not currently insured; private flood insurance presents a significant opportunity for insurers that have the right tools for understanding the risk**

Insurance companies have been reluctant to write private flood insurance primarily because it has been difficult to assess the loss potential. Until relatively recently the high resolution data required to model coastal storm surge was expensive and hard to obtain. Catastrophe models covering storm surge flooding have been volatile and opaque—two reasons insurers have had little confidence in the models' ability to provide credible information.

RiskInsight is an advanced catastrophe loss modeling platform, and it's the only catastrophe model that provides full transparency on the model components. This level of transparency is necessary for insurers to understand coastal flood risk well enough to be confident in pricing and underwriting decisions.

What is storm surge?

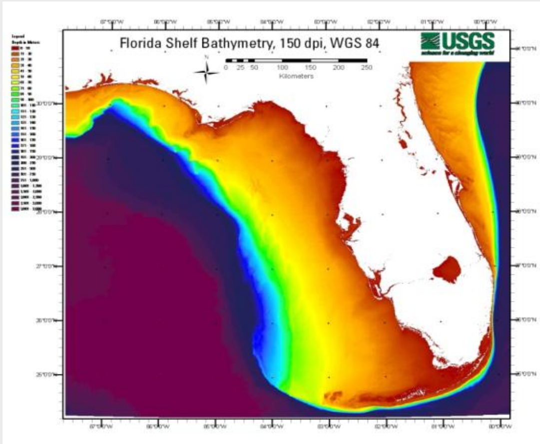
Storm surge is the rise in sea surface along the coast caused by a tropical cyclone. Factors that influence the magnitude of the increase in water level, i.e. the height of the storm surge, include the intensity of the winds, the track angle relative to coastal orientation, and the local bathymetry.

Interestingly, while the intensity of the winds is the strongest meteorological impact on the increase in the sea surface, there is not high correlation between wind speed and the magnitude of the storm surge. For example, Superstorm Sandy and Hurricane Ike were relatively weak storms that resulted in tremendous storm surge; Hurricane Charley was a strong storm that resulted in very little storm surge.

The lack of correlation between storm intensity and storm surge has led the National Hurricane Center to remove the storm surge heights from the well-known Saffir-Simpson hurricane rating scale. Other factors are often just as important as wind speed in determining the magnitude of the storm surge.

For example, the size of the storm and the track angle are very important influences on storm surge. In general, larger storms create more coastal flooding, primarily because longer stretches of coastline are impacted. Storms traveling inland perpendicular to the coast will also create higher peak surge.

The topography of the ocean floor along the coast can significantly impact peak surge heights. The low pressure in the eye of a tropical cyclone that causes the winds to circulate above the ocean surface also creates a vertical circulation of water in the ocean.   While the storm is in deep water, this circulation is uninterrupted, but when a hurricane moves into shallower water closer to shore, the water is pushed up causing the storm surge.



Wider, more gently sloping continental shelves with large shallow water areas will produce larger storm surges. This figure produced by the US Geological Survey illustrates the variability in the continental shelf along the Florida coastline.

The shape of the coastline and the presence of inlets and bays also significantly impact the storm surge by creating a funneling effect. When water is forced into these narrow channels by the power of the strong winds, it has nowhere to go but up. This is one reason why the storm surge potential changes so rapidly along the coastline.

Inland flooding resulting from storm surge is determined by elevation and local topography. Several areas highly prone to storm surge flooding have erected mitigation devices such as sea walls and levees. These devices provide some protection for low lying coastal areas and are assumed to be effective for purposes of this study.

The Fox Point Hurricane Barrier was built in 1960 and includes river gates, pumping stations, and two rock and earth dikes. It has been designed to protect downtown Providence—an area devastated by the Great New England Hurricane of 1938—against a 20 foot storm tide.

Why focus on the 100 year hurricane?

Emergency planners, design engineers and insurers typically peg their decisions to specific "return period" events. The 100 year return period is particularly popular within the insurance industry and is relied on quite heavily for catastrophe risk management decisions.

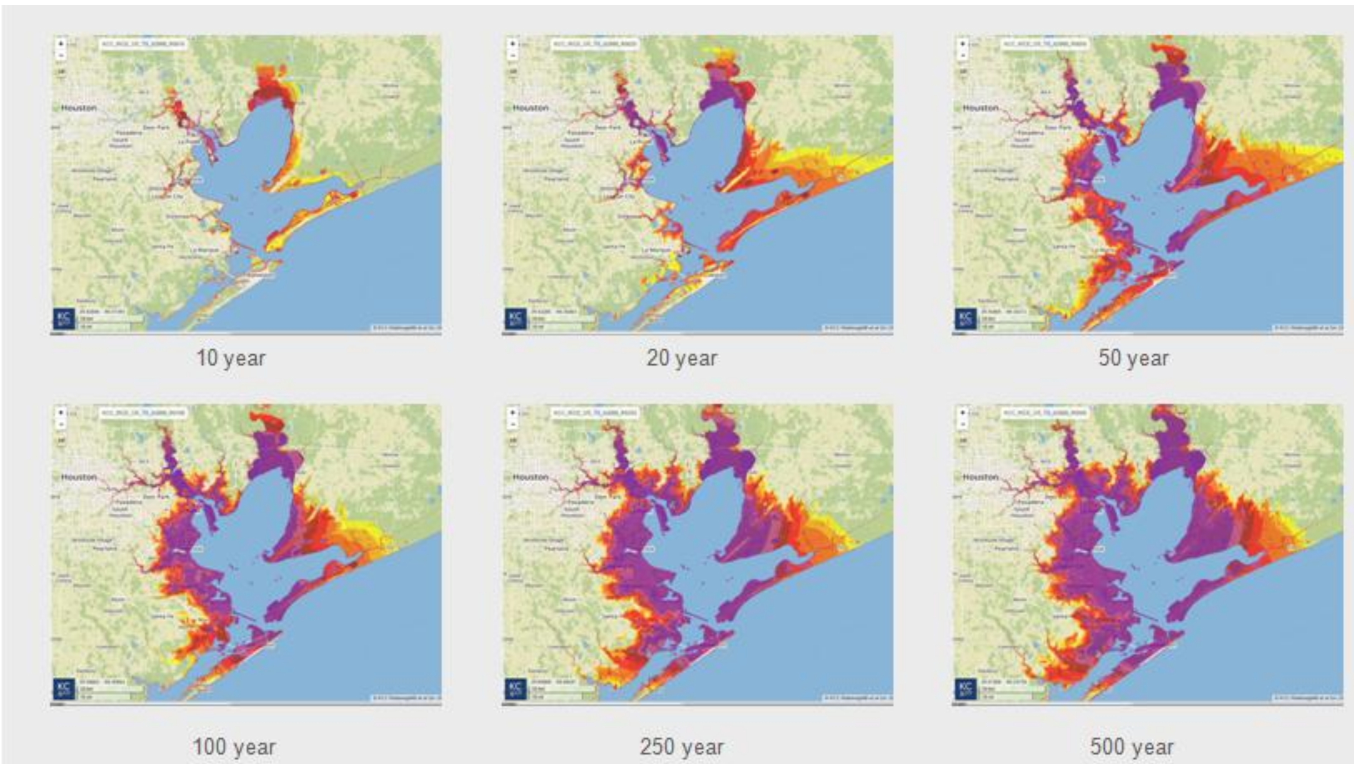
It's important to define the 100 year hurricane because there are frequently misconceptions about what this event represents. The 100 year hurricane is the type of event for which there's a one percent probability of occurrence in any given year. Because the probability is one percent, it's expected to occur once every hundred years on *average*.

This does not mean the 100 year hurricane will occur exactly once every hundred years—it can occur any time—even two years in a row. Over a ten year period, there's an approximately 10 percent chance it will occur.

The 100 year hurricane should be thought of as an infrequent but not unexpected occurrence. The 100 year hurricane is *not* the worst case scenario and larger loss producing events can occur—just with lower expected probabilities.

The 100 year hurricane is defined by its meteorological characteristics and it changes along the US coastline. For example, in the Gulf region, the 100 year event is a strong Category 5 hurricane while in the Northeast, it's a Category 3 event. There are eight regions along the coast and the 100 year event is defined for each of those regions using the historical data and scientific expertise. For more information on the Characteristic Event (CE) methodology refer to the papers listed at the end of this study.

It's important to note that the 100 year wind event may not produce the 100 year flood event because weaker storms that are larger in size can produce equivalent or even more storm surge than stronger, smaller storms. For example, the storm surge footprints for the 50 and 100 year hurricanes at Galveston-Houston, as shown below, can cause similar losses.



While there is not a perfect correlation between the wind and surge, the 100 year hurricane is a good metric for comparing the risk of coastal cities. It provides a robust relative measure for the purposes of this study.

The study results

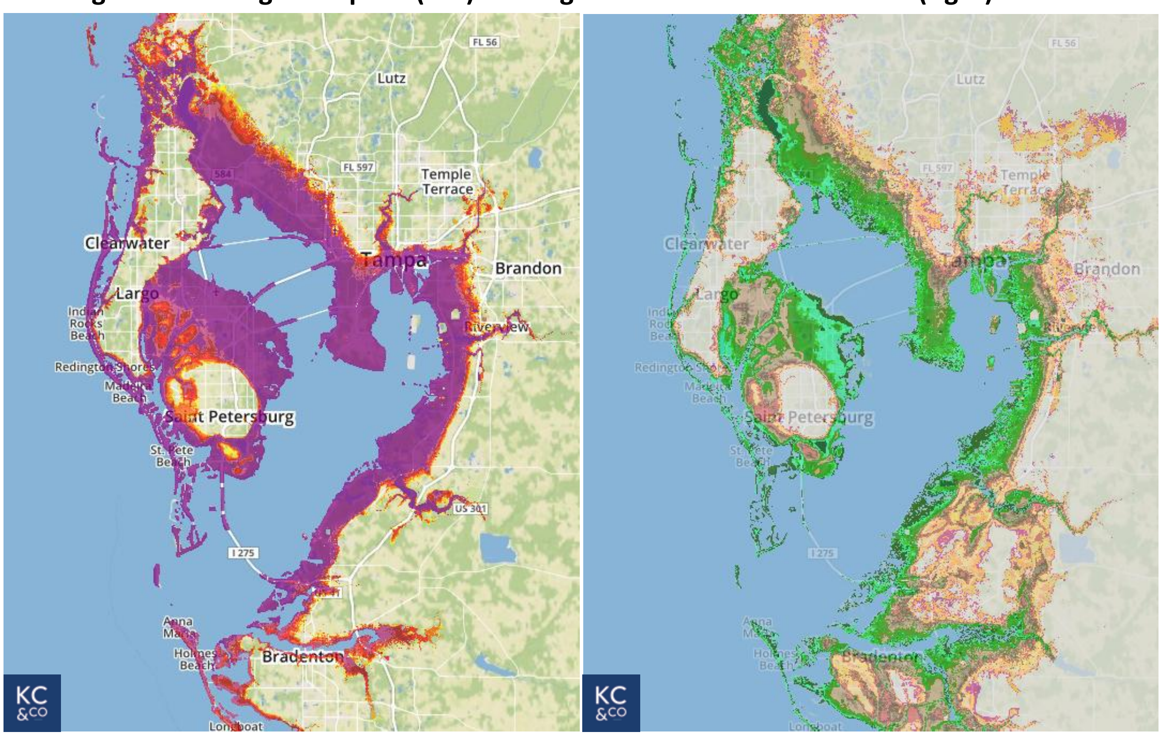
Here are the US cities most vulnerable to storm surge flooding as ranked by losses to residential, commercial and industrial properties from the 100 year hurricane. Loss estimates, including building, contents, and time element (insured and uninsured), have been rounded to the nearest $5 billion. The losses are for the entire event—not just the metropolitan areas highlighted.

#1: Tampa, FL Estimated Loss: $175 Billion

WHY IT'S VULNERABLE

There are several reasons why Tampa is the most vulnerable US city to storm surge. First, the continental shelf is relatively wide off the west coast of Florida which means the local bathymetry will accentuate the rise in sea surface from a major hurricane. Second, Tampa Bay creates a large funnel—particularly for a hurricane with its radius of maximum winds near the mouth of the bay. A severe storm with the right track orientation will cause an enormous buildup of water that will become trapped in the bay and inundate large areas of Tampa and St. Petersburg. Fifty percent of the population lives on ground elevations less than ten feet.

RiskInsight Storm Surge Footprint (left) and High Resolution Elevation Data (right)



The dark purple areas in the RiskInsight storm surge footprint indicate water levels of 10 feet or more; the green areas in the RiskInsight map on the right indicate elevations of 10 feet or less.

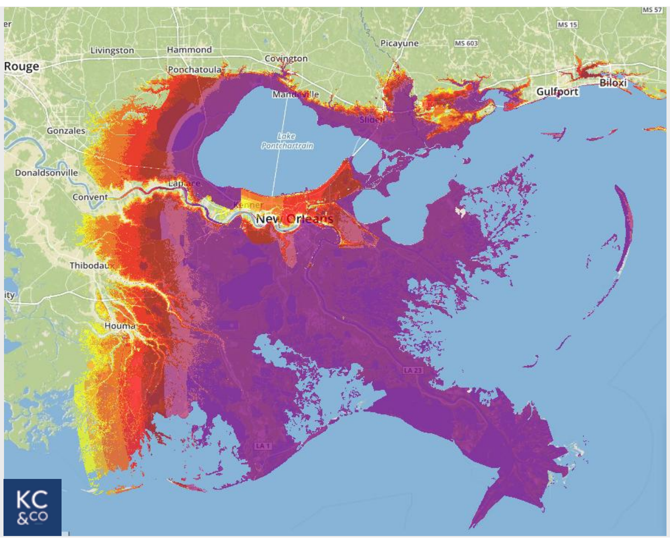
The 100 year hurricane for Tampa is a strong Category 4 storm with peak winds of 150 mph. Tampa has not had a direct hit by a major storm since 1921; that event was barely a Category 3 hurricane. In 2004 Hurricane Charley was headed in this direction but just before landfall made an unexpected turn to the south.

#2: New Orleans, LA   Estimated Loss: $130 Billion

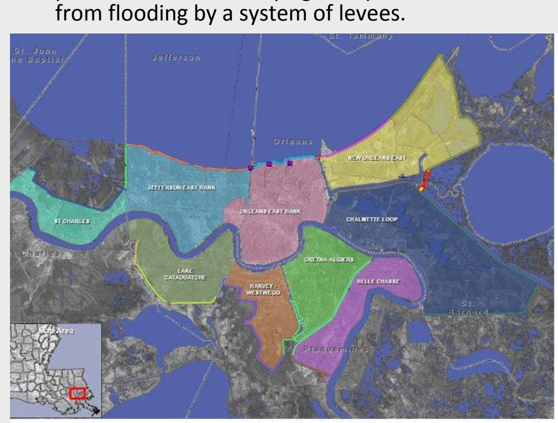
WHY IT'S VULNERABLE

It's not surprising that New Orleans ranks second given that half of the city is at or below sea level. Local bathymetry favors higher storm surges than average, and because of such low elevation and marshy terrain, storm surges can travel tens of miles inland before attenuating. Additional flooding is likely from the overtopping of Lake Ponchartrain as was seen in Katrina. An extensive levee system has been constructed and further strengthened after Katrina. But even if this system is highly effective, there is likely to be some overtopping from a strong Category 5 hurricane.

RiskInsight Storm Surge Footprint Accounts for the Complex System of Levees



Each colored section corresponds to a polder, a tract of low-lying land protected from flooding by a system of levees.



Source: NOLA Environmental

The 100 year hurricane for the Gulf region is a strong Category 5 hurricane similar to Camille in 1969. This is a stronger storm than Katrina, but much smaller in size. Katrina was only a Category 3 storm at landfall but was quite a large hurricane for its intensity. It was Katrina's size that produced the magnitude of storm surge and flooding losses.

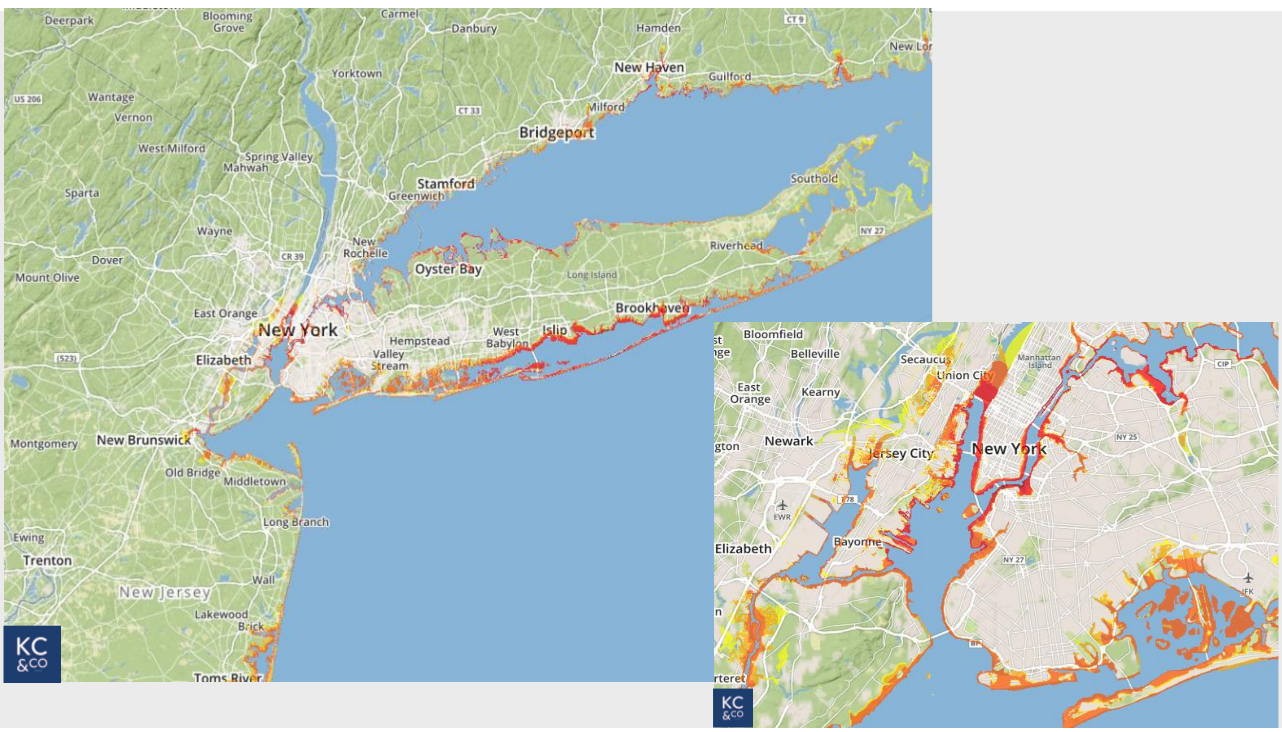
The RiskInsight storm surge footprint shows that the levee system which has been strengthened and reinforced since Katrina will likely afford significant but not complete protection from a strong Category 5 storm.

#3: New York City   Estimated Loss: $100 Billion

WHY IT'S VULNERABLE

The five boroughs of New York City have long coastlines and unique coastal features that make them particularly susceptible to storm surge flooding. Geographical areas likely to experience high surges are Lower Manhattan, Staten Island, and the south shore of Long Island, especially Rockaway Beach and Islip. Because storms will not be as intense in this region and the bathymetry is less favorable to storm surge, peak water heights are not as high as other events—it's the geographic extent of coastal flooding that makes the losses so high. The estimated loss includes damages in New Jersey and along the New England coastline.

RiskInsight Storm Surge Footprint Shows the Extent of Flooding Along the Coast



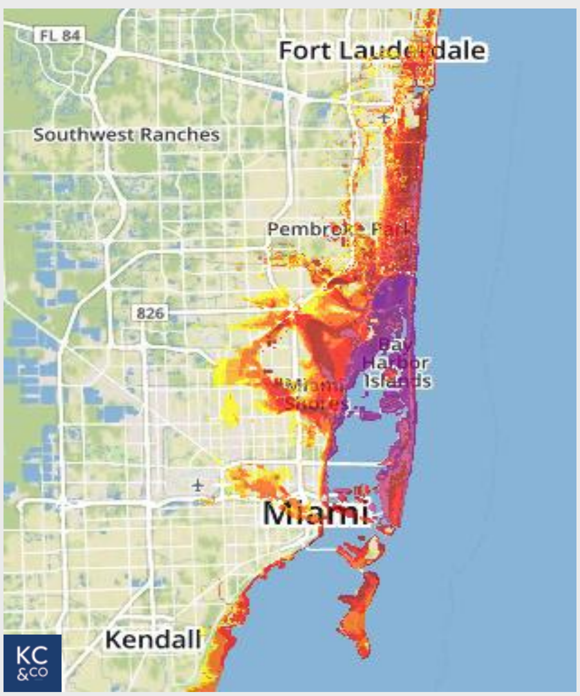
The 100 year hurricane is a Category 3 storm with peak winds of 120 mph. Northeast hurricanes tend to be large storms and the size is what drives the magnitude of the storm surge. The 100 year event has a typical path for the region which is a northerly track parallel to the New Jersey coastline. The westerly track of Superstorm Sandy causing it to make landfall nearly perpendicular to the New Jersey coast is very rare. That type of track for a Category 3 hurricane would lead to storm surge losses higher than $100 billion but would be a much lower probability event.

#4: Miami, FL Estimated Loss: $80 Billion

WHY IT'S VULNERABLE

In general, the coastal features of Miami are less favorable to storm surge than many other areas—the continental shelf falls off very steeply and the coastline is relatively free of significant bays or other features that would create channeling effects. From a physical perspective, storm surge hazard is relatively low in Miami. Its vulnerability stems from the sheer magnitude of property values near the coast along with low coastal elevations. It's also one of the most likely areas for a direct hit from a severe Category 5 storm.

RiskInsight Storm Surge Footprint Relative to Exposed Property Values in Miami



Source: Florida State Archives

Source: Google Earth

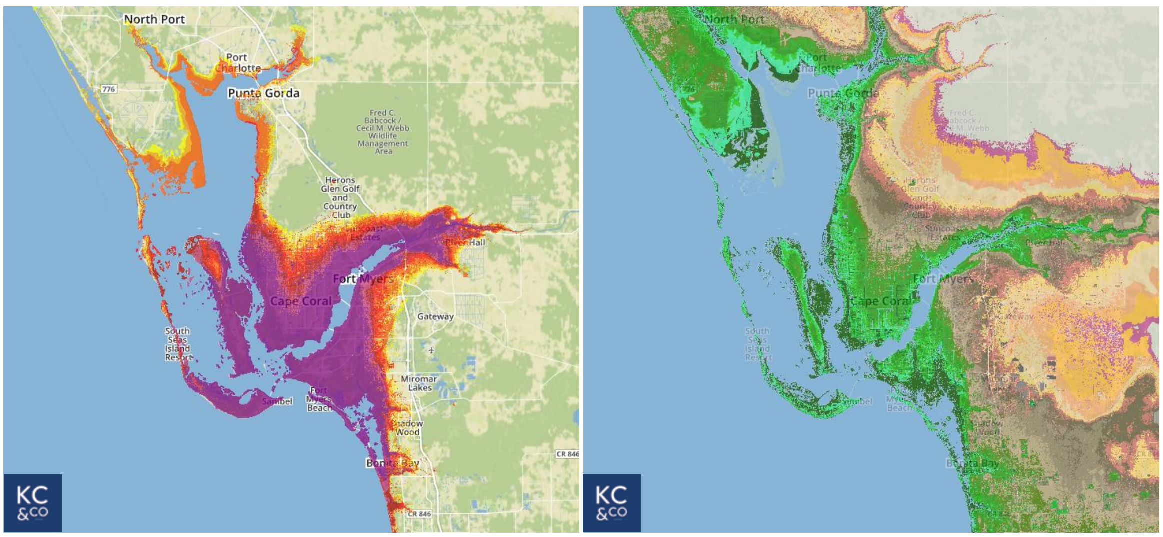
The 100 year hurricane is a strong Category 5 storm with peak winds of 165 mph. Miami hasn't had a direct hit by a major storm since the 1926 Great Miami Hurricane. The photographs above show Miami in 1920 versus today, illustrating how much property value is exposed to storm surge from a major hurricane.

#5: Fort Myers, FL   Estimated Loss: $70 Billion

WHY IT'S VULNERABLE

Its location on the west coast of Florida where the continental shelf is wide means that Fort Myers will likely experience very high surge heights from a major hurricane making landfall north of the city. Most of the population of this city and surrounding towns is below ten feet elevation.

RiskInsight Storm Surge Footprint (left) and High Resolution Elevation Data (right)



The 100 year hurricane is a Category 5 storm with peak winds of 160 mph—more intense than the Tampa event because Fort Myers is further south and in a higher hurricane frequency zone.

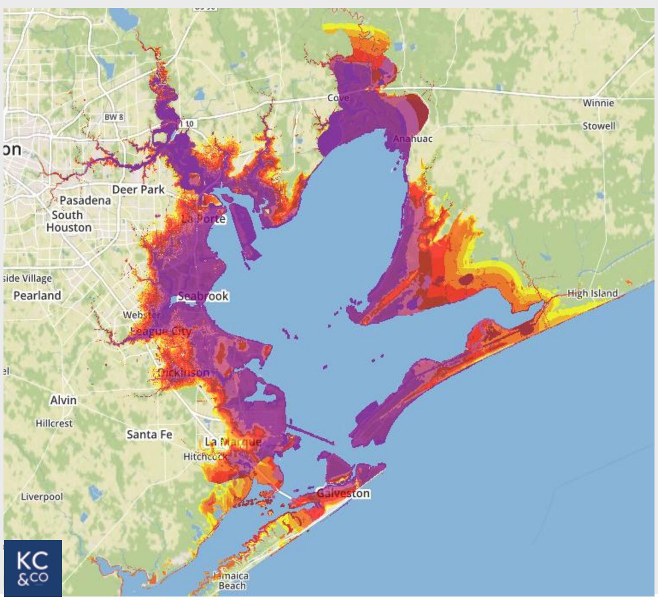
While it did not come ashore at Fort Myers, the Labor Day Hurricane of 1935—still the strongest US landfalling hurricane on record—brushed the southwestern coast of Florida with Category 5 wind speeds. If such an event were to make a direct hit on this part of the Florida coastline, Fort Myers and the surrounding areas would likely be completely inundated by the storm surge.

#6: Galveston-Houston, TX Estimated Loss: $55 Billion

WHY IT'S VULNERABLE

A storm track with the radius of maximum winds positioned at the mouth of Galveston Bay will cause the high waters to be channeled into the bay thereby accentuating the water heights. Hurricane Ike in 2008 was only a Category 2 hurricane when it made landfall causing billions of dollars of flooding damage.

RiskInsight Storm Surge Footprint (below) and damage in Galveston (top right) and Houston (bottom right) from Hurricane Ike

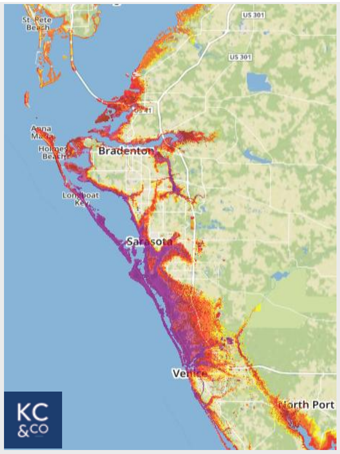


Sources: FEMA, US Navy

The 100 year hurricane for Texas is a strong Category 5 hurricane—similar to the New Orleans event. While Texas has not been hit by a Category 5 hurricane in the past 150 years, four Category 4 hurricanes have made landfall along the Texas coastline since 1900. Two of these—one in 1900 and one in 1915 struck very close to Galveston and caused tremendous storm surge flooding. Thousands of people were killed by the storm surge in the 1900 event which prompted the construction of the Galveston sea wall.

#7: Sarasota, FL

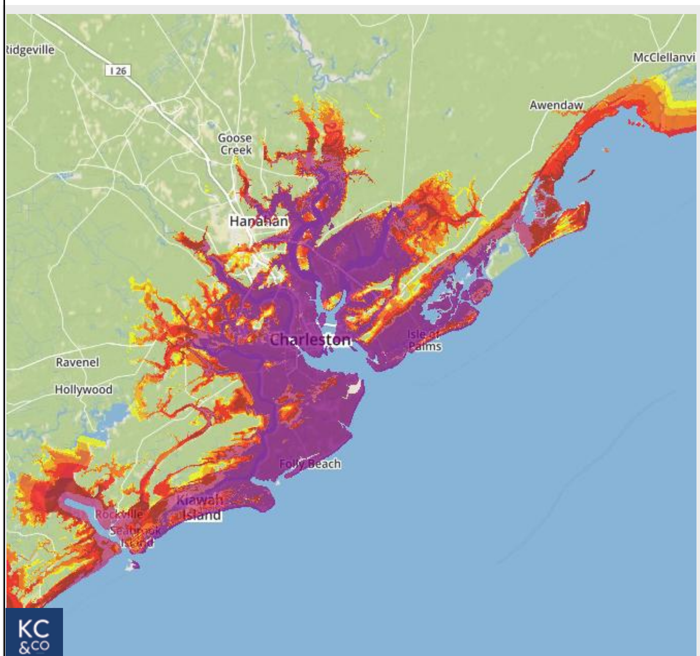
Estimated Loss: $50 Billion



Like the other cities on the west coast of Florida, Sarasota is vulnerable to storm surge losses due to the local bathymetry and the amount of property value at low elevation. The 100 year hurricane is a Category 5 storm.

#8: Charleston, SC

Estimated Loss: $45 Billion



In 1989 Hurricane Hugo caused tremendous storm surge flooding losses on Sullivan's Island, the Isle of Palms, and in Charleston. But because the track of Hugo was to the north of Charleston, the peak winds and storm surge were closer to the small town of McClellanville. A storm like Hugo, but with a track about 30 miles south of Charleston, will cause much worse storm surge flooding in downtown Charleston and therefore much higher losses.

Methodology underlying this study

The ten most vulnerable cities were selected based on the magnitude of the property losses resulting from storm surge flooding caused by the 100 year hurricane. The losses were estimated using the KCC RiskInsight® high resolution coastal flooding model.

Modeling storm surge is a complicated process because many factors influence how much storm surge will be experienced at individual locations, and all data must be at high resolution. Storm surge is caused by tropical cyclones so the first step is generating a catalog of events. This study focuses on the likely flooding and damage from the 100 year hurricanes, and the 100 year event was defined for over 300 ten-mile spaced landfall points from Texas to the Northeast. (Other return periods are available in RiskInsight.)

Because wind is the primary meteorological variable driving storm surge, the model next generates the wind footprints for each of the events. The KCC coastal flooding model is a dynamic time-stepping model—the intensity of the winds and storm surge heights are estimated every five minutes on a high resolution grid for the duration of the storm.

The peak storm surge will be located near the peak winds in a hurricane, also called the radius of maximum winds, or Rmax. The model then accounts for the other influences on peak surge, including bathymetry, bay effects, and tides, to calculate the height of the storm tide along the entire coastline impacted by the storm.

The dynamic time-stepping model estimates how far the storm tide will move inland accounting for terrain and elevation. The KCC model uses 30 meter horizontal resolution elevation data which is the highest resolution dataset complete and robust enough for modeling. The model also accounts for mitigation devices, such as seawalls and levees.

For loss estimation, a database of property values is required, and for the purposes of this study, exposure data at census block resolution was used. KCC develops, maintains, and updates detailed exposure databases for estimating total and insured losses and for market share calculations.

Conclusions

While much attention has been focused on New York and New Orleans, the Tampa/St. Petersburg metropolitan area is the most vulnerable to large losses from storm surge flooding. This is due to unique coastline features, local bathymetry, and the low coastal elevations.

Florida has not experienced a major storm surge event for decades even though this state is home to four of the top eight cities. The past two Category 4 storms to make landfall in Florida—Andrew and Charley—did not produce significant storm surge.

The storm surge loss potential is concentrated in relatively few coastal locations—after Charleston, SC, the next largest losses are produced by storms impacting several smaller metropolitan areas along the East Coast. For example, as was seen in Superstorm Sandy, even a weak storm making landfall along the Mid-Atlantic coast can cover a large area and produce large storm surge losses.

Because major hurricanes are rare events, historical storms do not provide a complete guide for future storm surge losses. This study, which subjects every area with an equally likely event, provides a robust methodology for measuring the relative storm surge risk along the Gulf and East Coasts of the US.

Insurers can use the RiskInsight open loss modeling platform to estimate their own portfolio losses and the losses on individual accounts for the 100 year hurricane and other return period events. All of the storm footprints are visible to model users and can be superimposed on individual locations and books of business. RiskInsight is the only modeling platform offering complete transparency and consistent and robust event sets for catastrophe risk management.

References

KCC White Paper – The 100 Year Hurricane, June 2014

KCC White Paper – Managing Hurricane Risk with Characteristic Events (CEs), May 2014

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