Aon Benfield
Analytics | Impact Forecasting

Hurricane Harvey

Event Recap Report

March 2018

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Executive Summary

Hurricane Harvey, which made its first landfall in Texas on August 25, 2017 became the second costliest natural disaster in United States history. Unprecedented amounts of rainfall, which were recorded across broad sections of southeast Texas and southwest Louisiana, caused catastrophic flooding with far-reaching impacts on several sectors of the economy. Total economic losses were in the vicinity of USD100 billion, while public and private insurers bore 30 percent of the cost.

Hurricane Harvey developed from a weak tropical storm that crossed the Atlantic Ocean without causing any major damage. Before tracking through the Yucatan Peninsula, Harvey's structure degenerated to such extent that it was degraded to an "open wave" and the National Hurricane Center (NHC) ceased to issue advisories for the storm. However, after emerging in the Gulf of Mexico, rapid intensification allowed Harvey to attain major hurricane status (Category 3+) while nearing the Texas coast. During this time, forecasts continued to call for massive rainfall accumulations in Texas and Louisiana as the storm was poised to stall for several days.

Harvey made its first landfall as a Category 4 hurricane late on August 25 near Rockport, TX, with sustained winds of 130 mph. This was the first major hurricane landfall on the U.S. mainland since Hurricane Wilma in October 2005. For the next few days, Harvey stayed close to the Texas coast, while releasing unprecedented amounts of rainfall. Harvey made its final landfall in Louisiana on August 30, maintaining tropical storm status and later dissipated over the U.S. mainland.

Harvey broke the historical record for the maximum rainfall total caused by a tropical cyclone over the U.S. mainland: an unprecedented total of 60.58 inches (1,539 millimeters) was measured in Nederland, TX. The totals widely exceeded 45 inches in coastal Texas. Beside the exceptional rainfall, Harvey caused notable storm surge and wind gusts along the coastline. The brunt of the damage caused by Harvey's winds was borne by Rockport and the surrounding region.

The vast majority of the historic losses caused by Harvey resulted from the catastrophic flooding in the Houston metro area and the Beaumont/Port Arthur, TX region as multiple rivers crested at record levels and reservoirs overflowed. Devastating impacts of property, businesses, vehicles, infrastructure and agriculture followed.

Nearly 370,000 customers lost power, the majority of which were located in Texas and energy providers cited widespread damage on the electricity grid. A substantial reduction in refining capacities was recorded in refineries in the Houston and Corpus Christi areas.

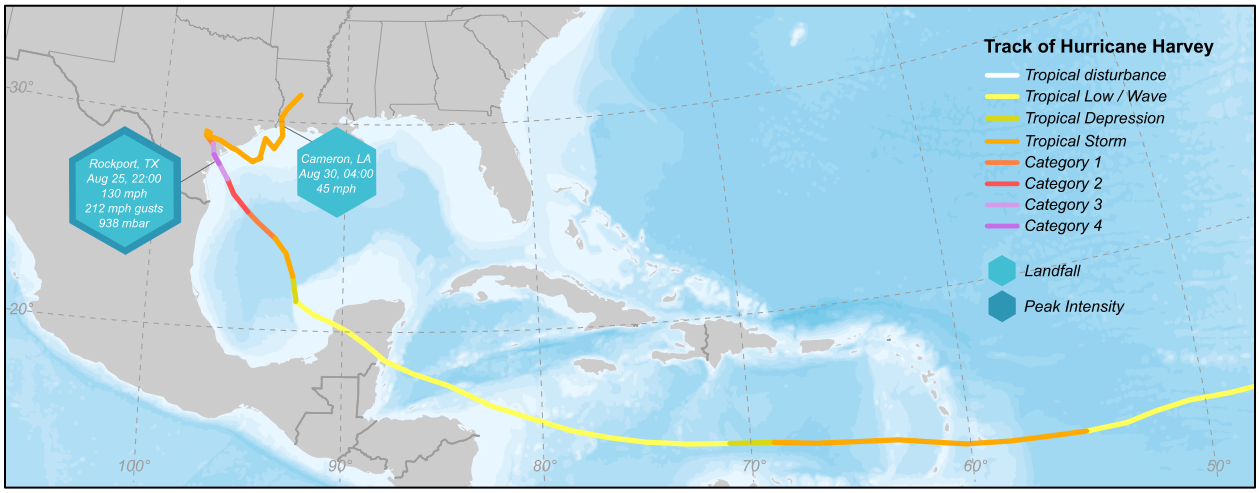
Harvey's impacts on transportation and infrastructure included widespread closure of ports, at least 12,000 cancelled flights and numerous road and railway closures. A significant number of boats and marinas were damaged or destroyed.

Hurricane Harvey generated major economic losses, which are estimated in the ballpark of USD100 billion. This includes physical damage to residential and commercial properties, automobiles, infrastructure, agriculture, offshore & onshore energy, and marine interests. It also assumes a high cost resulting from business interruption to many sectors.

Harvey became the second costliest natural disaster ever recorded in the United States, second only to Hurricane Katrina. Approximately 30 percent of the economic cost was covered by public and private insurance entities, with the majority under claims filed via the National Flood Insurance Program (NFIP).

Meteorological Recap

Note: The National Hurricane Center, Weather Prediction Center, Storm Prediction Center and National Weather Service each provided well-verified forecasts for the lifespan of Hurricane Harvey. This is particularly impressive given the complexities involved in determining the track, forward speed, and intensity of Harvey in addition to the challenging atmospheric set-up.



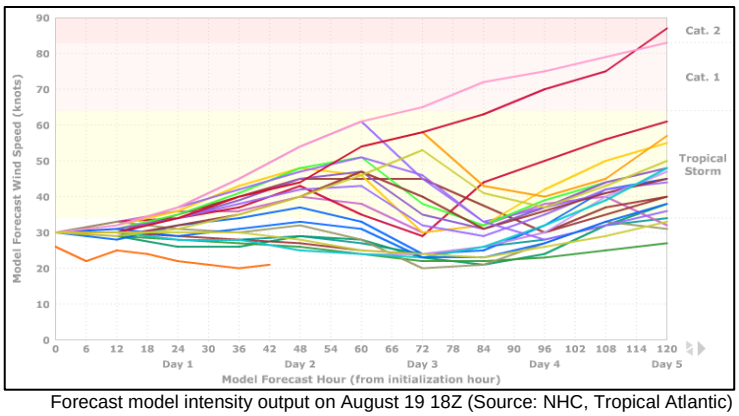
Data: NOAA, NASA

Hurricane Harvey was first identified by the National Hurricane Center (NHC) as a tropical wave, just off the East Coast of Africa on August 13. The NHC continued to monitor the wave through the next four to five days as it tracked westward across the Atlantic Ocean. Sufficient thunderstorm activity associated with the wave slowly organized and a low level circulation center was identified on satellite imagery on August 17 prompting the NHC to begin issuing advisories on a potential tropical cyclone.

Later on August 17, an Air Force Reserve Hurricane Hunter reconnaissance mission found a well-defined circulation with strong convection and maximum sustained wind speeds of 40 mph (65 kph) prompting the NHC to name the disturbance Tropical Storm Harvey. Atmospheric conditions for further development of the storm were marginal as warm sea surface temperatures were offset by moderate vertical wind shear. However, Harvey continued to track in a general westward direction as it moved through the Lesser Antilles, including directly across Barbados and St. Vincent on August 18 at tropical storm strength.

Harvey on August 19 (Source: NASA)

The following day, NHC meteorologists noted that the structure of Harvey had deteriorated based on a ragged-looking storm evident in satellite imagery (see image on the right) while a Hurricane Hunter mission found a much weakened system with a closed circulation only evident at very low levels in the atmosphere. Through August 19, wind shear continued to tear apart the storm and by the late afternoon it had been downgraded to a tropical depression. The track motion continued in a general west-northwestward direction across the Caribbean Sea toward Belize and Mexico.

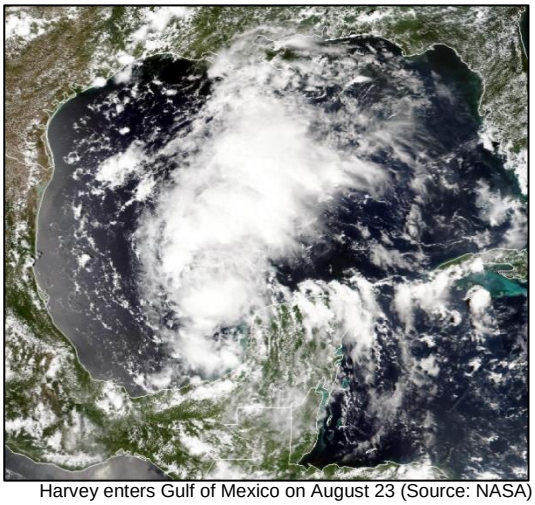


Forecast model intensity output on August 19 18Z (Source: NHC, Tropical Atlantic)

At this time, the forecast computer models showed significant bifurcation: one set of models predicted that wind shear would subside in 24 hours allowing major re-intensification of Harvey prior to it making landfall over Belize or Mexico's Yucatan Peninsula; the other set of models showed that the structure of the storm had decayed so severely that it would not be able to regenerate itself, despite atmospheric conditions becoming significantly more favorable.

Late on August 19, the NHC reported that Harvey had degenerated to such an extent that it was now considered an "open wave" and as a result they ceased issuing advisories on the system. The wave continued to track over the open waters of the western Caribbean Sea before later crossing the Yucatan Peninsula on August 22.

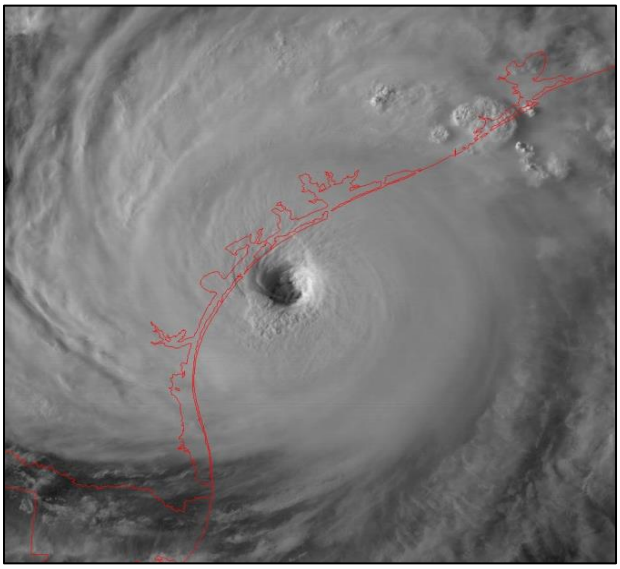
The NHC continued to monitor the wave as it emerged in the Bay of Campeche and Harvey's remnants almost immediately began to re-intensify over very warm sea surface temperatures. The agency began issuing advisories once again on August 23 as a Hurricane Hunter mission found a closed low-level circulation center. The system remained disorganized with an asymmetric pattern evident in satellite imagery despite atmospheric conditions over the western Gulf of Mexico being very favorable. The warm sea surface temperatures combined with low levels of vertical wind shear to allow Harvey to regain its structure and rapidly intensify. In their first advisory on August 23, the NHC first noted the potential for Harvey to make landfall as a hurricane-strength system over the U.S. state of Texas.


Harvey enters Gulf of Mexico on August 23 (Source: NASA)

As Harvey moved over the western Gulf of Mexico it turned and took a more northerly track for roughly 24 hours through August 24-25 as the system began to strengthen its inner core given the very favorable atmospheric and oceanic conditions. Early on August 24 it was once again upgraded as Tropical Storm Harvey for the second time. Intensification of the system occurred more quickly than forecast and just 12 hours later Hurricane Harvey was named with maximum sustained wind speeds of 85 mph (140 kph) based on data measured by a Hurricane Hunter.

As Harvey attained hurricane intensity its track once again changed direction and it turned to the north-northwest and toward the Texas coast as the steering currents altered. The intensification rate of the system slowed slightly through the late hours of August 24, but aircraft reconnaissance missions on August 25 continued to find a more powerful cyclone. In fact, the aircraft data found that the system had intensified into a Category 2 storm with 105 mph (165 kph) winds. This strengthening was clearly evident given an improved satellite signature. A deep, strong ring of convection around an intermittent eye feature indicated that the storm was responding to a very favorable atmosphere.

By the late morning of August 25, local National Weather Service (NWS) offices in Brownsville and Corpus Christi began observing Harvey via Doppler radar scans. It was determined that the hurricane had developed a pair of concentric eyewalls. The NHC noted that the concentric eyewalls were proving problematic for their intensity forecasts due to the potential for an eyewall replacement cycle to occur. (*During an eyewall replacement cycle the intensity of a hurricane generally decreases or stays stable while the extent of the wind field increases.*) The agency continued to warn of the prodigious amount of rainfall expected to fall across a broad swath of east Texas and western Louisiana given the size of Harvey regardless of how intense the storm may be at landfall. At this point, the Weather Prediction Center (WPC) was warning of the possibility of up to 30 inches (762 millimeters) of rain falling in a five-day span.

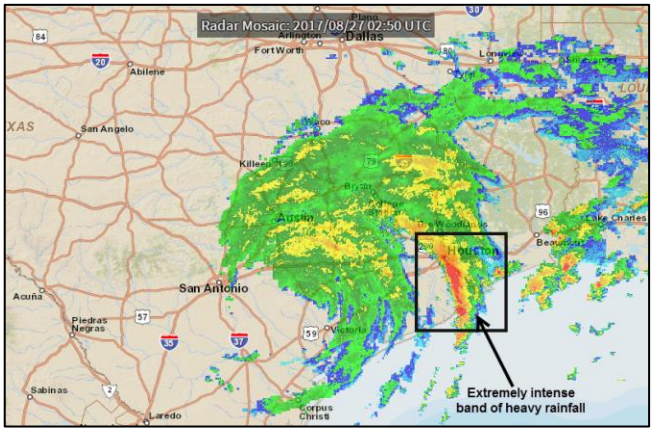


Harvey just prior to landfall on August 25 (Source: NASA)

Despite the presence of the concentric eyewalls, Harvey continued to intensify through August 25 as its wind speeds increased and central pressure plummeted. During this time, Harvey was traversing over a deep and warm eddy of water. These conditions helped the cyclone become a major hurricane during the afternoon of August 25. In another flight, the Hurricane Hunters measured wind speeds that corresponded to maximum sustained surface winds of 125 mph (205 kph); strong Category 3. Harvey continued to intensify all the way up until its initial landfall into Texas at approximately 10:00 PM CDT local time (03:00 UTC, August 26) as a 130 mph (215 kph) Category 4 strength hurricane. Landfall location was near the town of Rockport, Texas, which is located between Port Aransas and Port O'Connor.

The storm would continue to slow its forward progress after its initial landfall while tracking directly over Rockport and causing extensive wind, storm surge and flood damage across numerous neighboring towns and cities. The NHC would later confirm a second landfall at 01:00 AM CDT August 26 (06:00 UTC) at Copano Bay, Texas as a 125 mph (205 kph) Category 3 system.

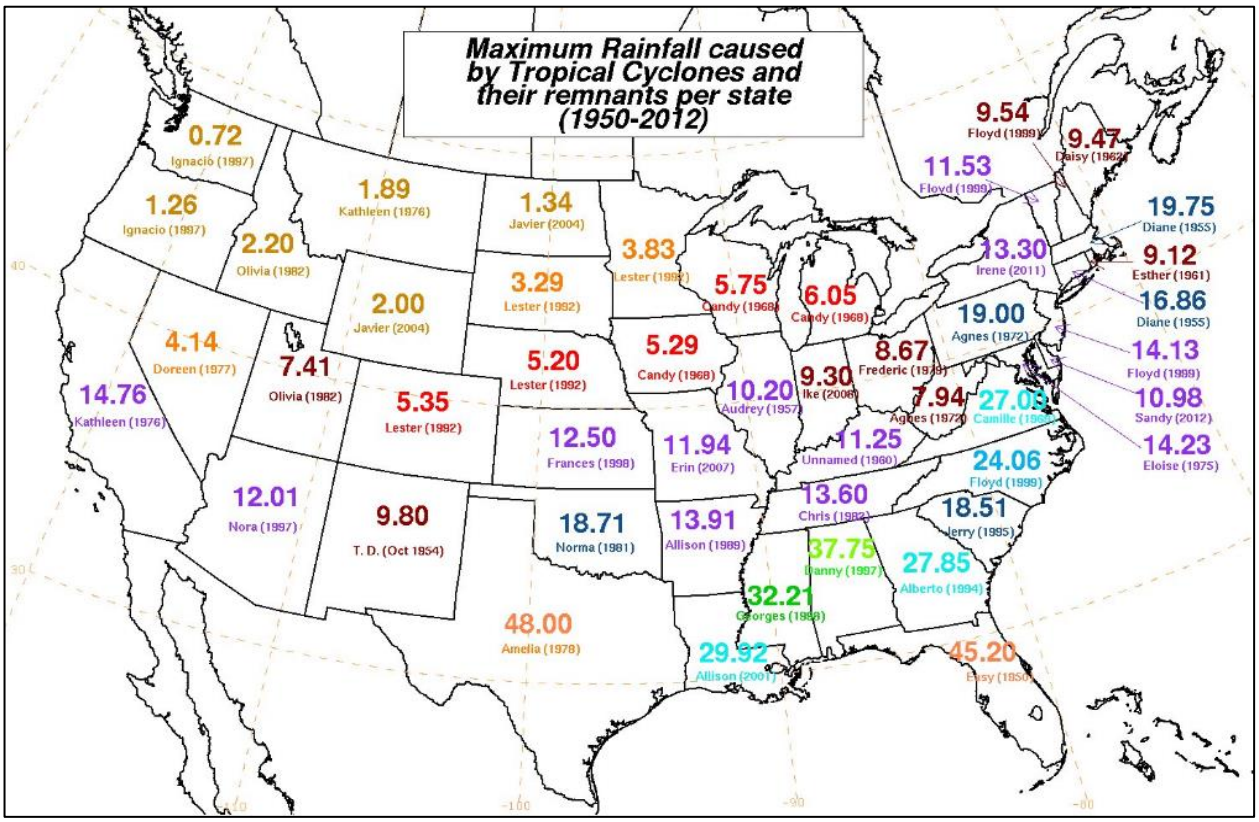
Throughout the day on August 26, Harvey very gradually began to weaken and lose its wind speed intensity. The storm ceased to contain hurricane-force winds during the afternoon, but maintained an impressive appearance on satellite. Numerous incredibly intense bands of heavy rain and isolated tornadoes accompanied the bands of rain that led to multiple Flash Flood Emergencies – including in the greater Houston metro region. The slow-moving nature of the system prompted the WPC to indicate that isolated areas of Texas could see upwards of 50 inches (1,270 millimeters). This did occur.



Radar image on August 26 (Source: NASA)

Harvey maintained minimal tropical storm-force winds while meandering back into the Gulf of Mexico. The NHC only expected minimal (if any) intensification, primarily due to sea surface temperatures being much cooler given recent upwelling and the intrusion of dry air into Harvey's core. The storm eventually made its final landfall near Cameron, Louisiana on August 30 around 3:00 AM (8:00 UTC) with 45 mph (75 kph) winds. Despite the lack of strong intensification, the storm continued to bring relentless heavy rainfall to parts of Texas and Louisiana. Harvey was expected to finally lose its tropical characteristics by September 2 while its remnants tracked into the Ohio Valley and Northeast. Despite future dissipation, it will take at least a week for flood waters and river levels to recede to normal.

Below is a graphic that shows maximum rainfall totals caused by tropical cyclones – and their remnants – for each Lower 48 state dating to 1950. Harvey broke the continental US record for rainfall by a tropical cyclone: a total of 60.58 inches (1,538.7 millimeters) of rain was recorded at Nederland, Texas.

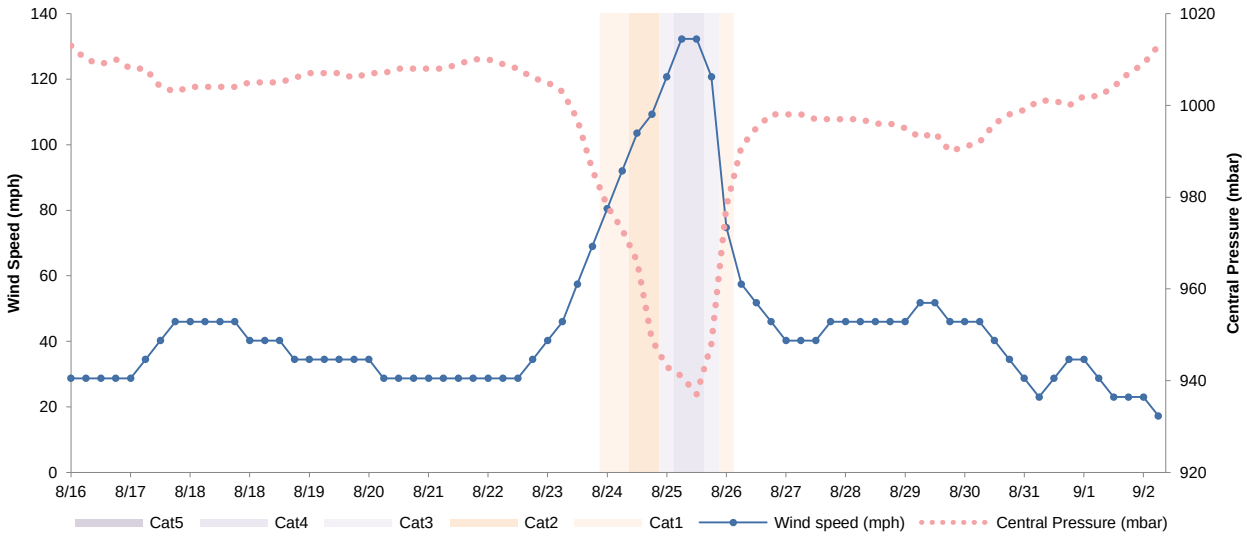


Source: NOAA

Storm Data

Below is official storm data from the National Weather Service, Weather Prediction Center, and National Hurricane Center.

Wind & Central Pressure



Source: Aon Benfield & NOAA

Wind Gusts

Location	Wind Gust (mph)	Location	Wind Gust (mph)
Port Aransas, TX	132	Austwell, TX	80
Copano Village, TX	125	Magnolia Beach, TX	79
Lamar, TX	110	Edna, TX	73
Aransas Pass, TX	109	Chapman Ranch, TX	71
Rockport, TX	108	Brazos, TX	70
Aransas, TX	106	Palacios (Airport), TX	69
Taft, TX	90	Seadrift, TX	67
Victoria, TX	83	Ganado, TX	64
Fulton, TX	83	La Ward, TX	64
Flour Bluff, TX	81	Portland, TX	63

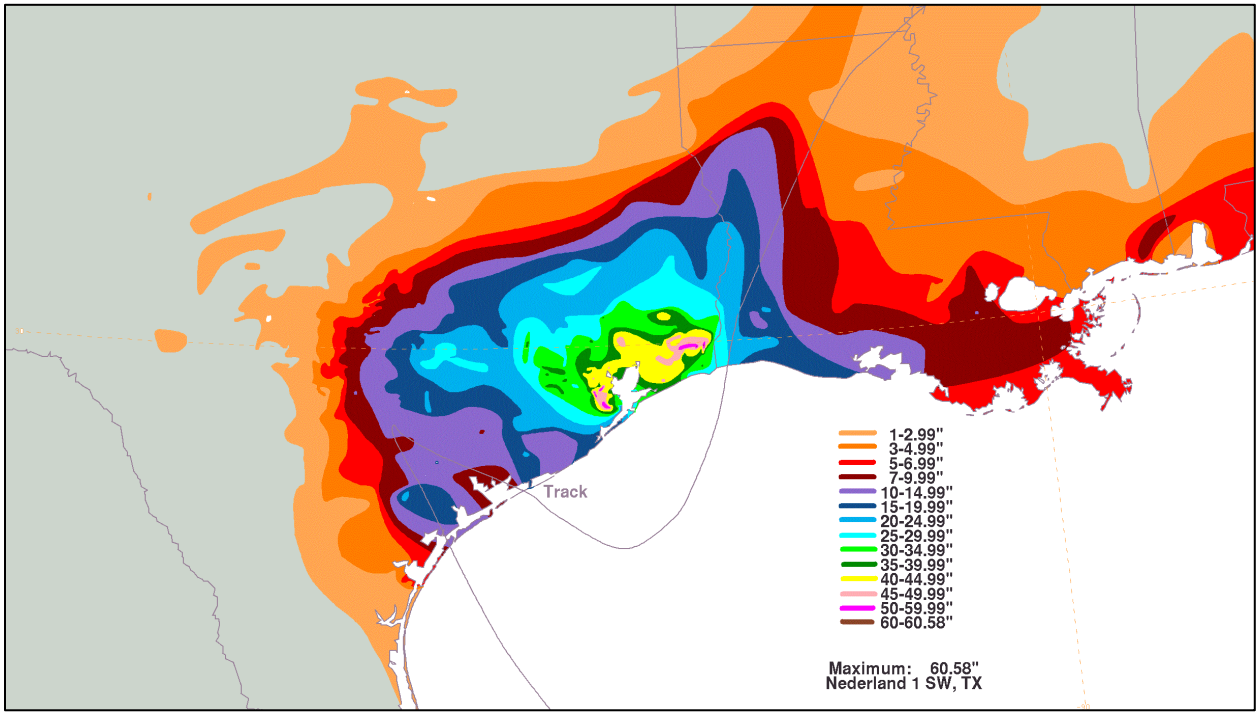
Source: NOAA

Rainfall Totals

Location, County	Total Rainfall (in)	Location	Total Rainfall (in)
Nederland, TX	60.6	Port Arthur, TX	48.0
Groves, TX	60.5	Nassau Bay, TX	47.9
Friendswood, TX	56.0	Mayhaw Bayou, TX	47.5
Santa Fe, TX	54.8	China, TX	47.4
La Belle, TX	53.8	Skillern Tract, TX	47.4
League City, TX	52.9	Bevil Oaks, TX	47.3
Webster, TX	52.3	Amelia, TX	46.6
Ellington Field, TX	52.0	Zummo, TX	46.5
Liberty, TX	49.4	Central Gardens, TX	46.4
Dayton, TX	49.3	Willow Marsch Bayou, TX	46.4
Fannett, TX	49.3	Hamshire, TX	45.8
Hillebrant Bayou, TX	49.1	Pasadena, TX	45.7
Beaumont, TX	49.1	Horsepen Creek, TX	45.7
Clear Creek, TX	48.2	Rush Ditch, TX	45.2
Webster, TX	48.2	Pipkin Ranch, TX	45.1
Clear Lake, TX	48.1	Highlands, TX	45.1
Taylors Bayou, TX	48.0	Pine Tree Ditch, TX	45.0

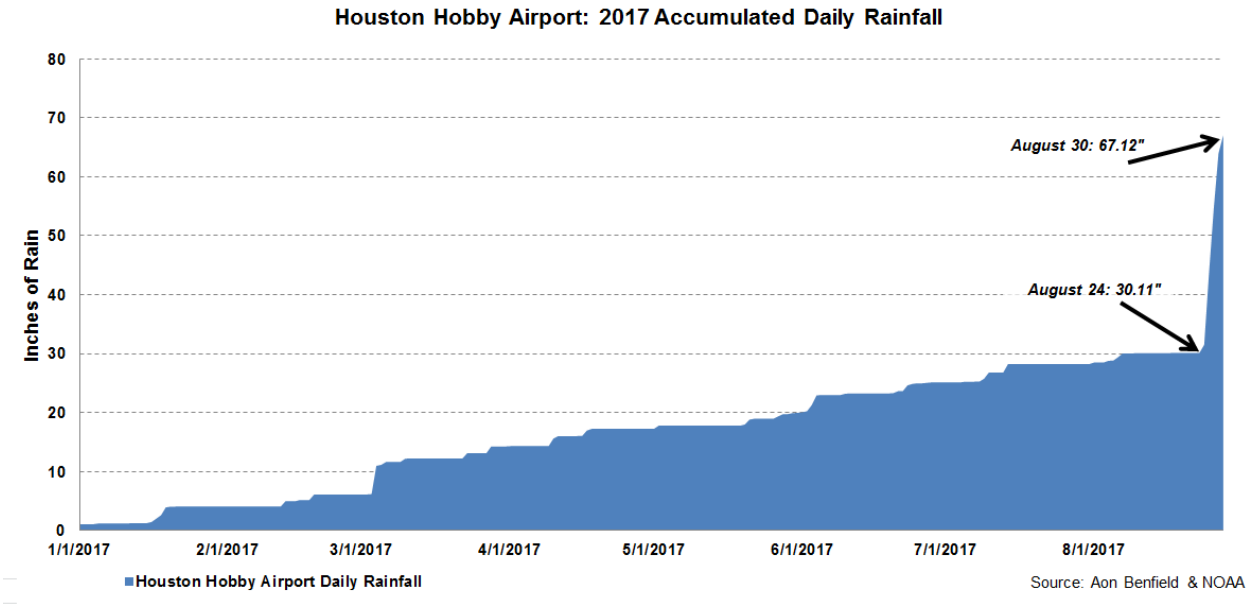
Source: NOAA

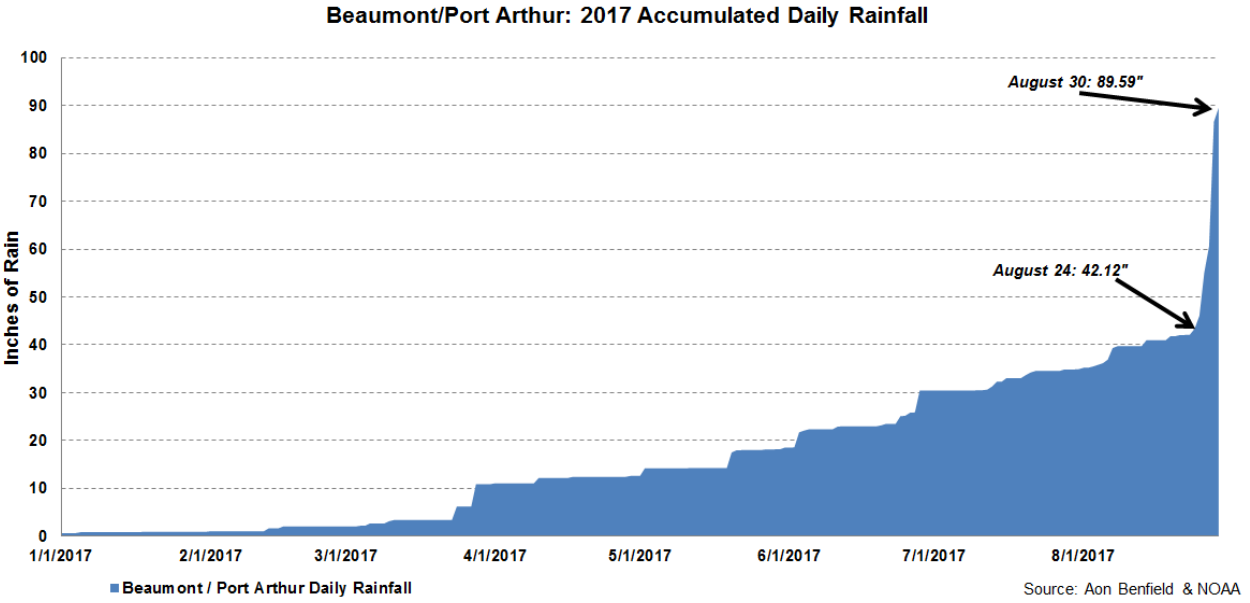
Rainfall Map



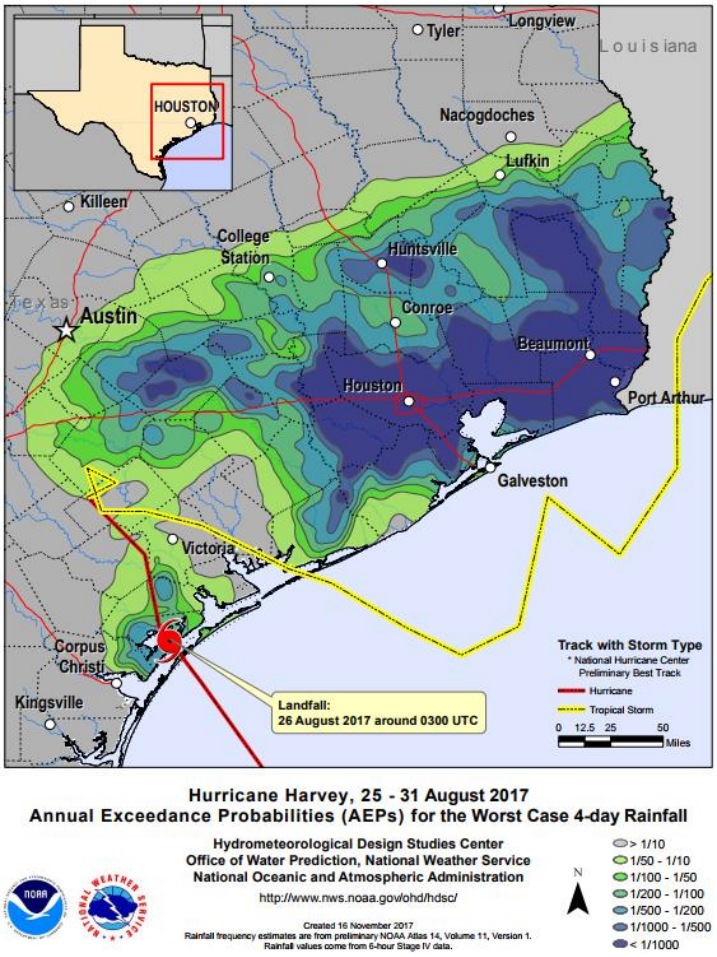
Source: NOAA

Select Rainfall Gauges





Rainfall Return Period



There is no simple way to provide a blanket rainfall return period (RP) for Hurricane Harvey. Based on typical rainfall patterns, there are some specific locations that end up receiving much higher – or lower – rainfall amounts. For Harvey, the extent of extreme rainfall was substantial. An unusually large and remarkable swath of minimal 40-inch (1,016-millimeter) rainfall extended from west of Houston to the Texas/Louisiana border. Due to this fact, preliminary rainfall return period analysis by NOAA's Hydrometeorological Design Studies Center indicates that an abnormally large swath of southeast Texas incurred rainfall RP rates minimally ranging from 500 to 1,000 years.

Given the volume of water, local infrastructure across southeast Texas was simply unable to handle such an enormous amount of rainfall in a short amount of time. This led to major water run-off that quickly accumulated across a very large area. With so much residential and commercial growth throughout this part of the state – combined with abundant concrete and poor absorbing clay soil – this only worsened the flood impact.

It is worth noting that Texas has incurred numerous extreme rainfall events during the past decade. In fact, Harvey became the sixth event to bring rainfall at a return period of at least 1,000 years since 2010 alone. The other events occurred around the metro areas of San Antonio (May 2013 & May 2015), Austin (October 2015 – twice), and Houston (April 2016).

Please note that rainfall return periods can be determined based on many different time intervals, which can range from 5 minutes to 60 days. Hurricane Harvey's rainfall reached the 1,000-year rainfall return period based on many time intervals during the course of a number of hours and days. To put this return period into better context, a 1,000-year event means that there is a 0.1 percent chance of any such event occurring in any given year. It does not mean that it will be another 1,000 years until the next event of similar size will occur in this location. Another important point is that rainfall return periods do not automatically translate to an equally sized flood return period.

Storm Surge & Inundation

Storm Surge Heights

Storm Surge*

Location	Storm Surge (ft)	Location	Storm Surge (ft)
Manchester, TX	9.67	Eagle Point, TX	3.60
Port Lavaca, TX	6.90	Bob Hill Pier, TX	3.59
Seadrift, TX	5.77	San Luis Pass, TX	3.46
Port Aransas, TX	5.52	Matagorda Bay, TX	3.40
Aransas Wildlife Reserve, TX	4.80	Matagorda City, TX	3.30
Packery Channel, TX	4.73	Port O'Connor, TX	3.13
Copano Bay, TX	4.11	Sargent, TX	2.49
Morgan's Point, TX	3.88	Rockport, TX	1.97

**Water height recorded above Mean Sea Level (MSL)*

Source: NOAA

Storm Surge: *The observed storm tide minus the normal or astronomical high tide.*

Record River Gauge Data[#]

Location	Maximum Gauge Height	Major Flood Level	Previous Record
Lake Creek above the Woodlands, TX	150.96	154.00	147.75 (05/2016)
Brazos River above San Felipe, TX	129.00	129.30	128.50 (05/2016)
Cypress Creek near Cypress, TX	128.11	125.00	127.60 (10/1994)
West Fork San Jacinto River near Conroe, TX	126.97	117.80	126.10 (10/1994)
Cypress Creek near Westfield, TX	97.10	85.90	94.34 (10/1949)
East Fork San Jacinto River near New Caney, TX	79.99	69.00	76.20 (10/1994)
Buffalo Bayou at West Belt Drive, TX	71.18	65.30	68.37 (08/1983)
West Fork San Jacinto River near Humble, TX	69.10	52.30	67.30 (10/1994)
Buffalo Bayou at Piney Point Village, TX	67.46	60.00	61.23 (03/1992)
Black Creek at Highway 326, TX	55.09	54.00	52.72 (06/2016)
San Bernard River near Boling, TX	43.24	32.00	42.41 (06/1960)
Pine Island Bayou near Sour Lake, TX	39.42	32.00	37.50 (10/1994)
Navidad River at Sublime, TX	36.35	26.00	34.00 (11/2004)
Menard Creek near Rye, TX	35.97	28.00	31.13 (10/1994)
Navidad River near Morales, TX	35.83	34.00	33.00 (11/2004)
Navidad River near Speaks, TX	32.82	29.00	28.20 (04/2009)
Trinity River at Liberty, TX	32.14	29.00	31.00 (10/1994)
San Bernard River at East Bernard, TX	31.98	28.00	28.45 (04/2016)
Navidad River at Strane Park, TX	31.27	29.00	29.60 (11/2004)
San Bernard River near Sweeny, TX	28.00	20.00	23.90 (10/1998)
East Fork San Jacinto River at Cleveland, TX	27.17	23.00	24.97 (10/1994)
Cow Bayou near Mauriceville, TX	26.52	20.00	22.53 (10/2006)
Peach Creek near Splendora, TX	25.57	17.00	22.73 (10/1949)
Clear Creek at Friendswood, TX	24.08	21.00	20.46 (06/2001)
Davidson Creek near Lyon, TX	19.47	20.00	19.33 (10/1994)
Trinity River near Moss Bluff, TX	17.52	17.20	15.15 (06/2016)
Neches River at Beaumont, TX	15.83	10.00	13.00 (10/1994)

Source: NOAA

[#] *Data thru August 30, 2017*

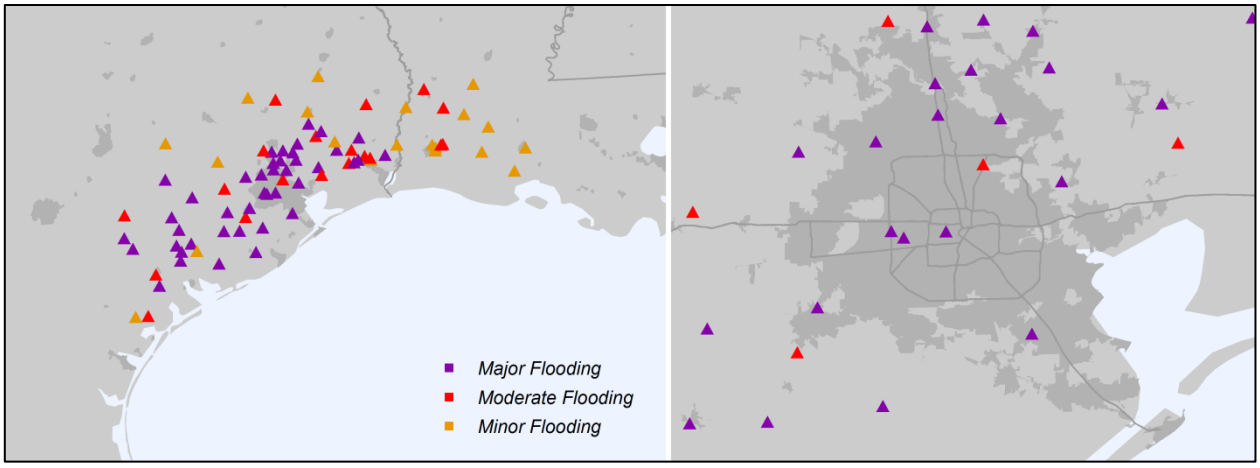
River Gauge Data for Stations at Major Flood Stage[#]

Location	Maximum Gauge Height	Flood Level	% of Full Capacity
San Jacinto River near Sheldon, TX	28.50	10.00	285%
Calcasieu River near Old Town Bay, LA	9.90	4.00	248%
Colorado River above La Grange, TX	54.18	26.00	208%
Guadalupe River near Cuero, TX	44.36	24.00	185%
Lavaca River near Edna, TX	32.53	21.00	155%
Guadalupe River at Victoria, TX	31.22	21.00	149%
Bayou Anacoco near Rosepine, LA	25.37	17.00	149%
Caney Creek near Splendora, TX	26.58	18.00	148%
Sandy Creek near Cordele, TX	25.84	18.00	144%
Colorado River at Columbus, TX	47.91	36.00	141%
Buffalo Bayou at Shepherd Drive, TX	38.78	28.00	139%
Guadalupe River near Bloomington, TX	27.69	20.00	138%
Bedias Creek near Madisonville, TX	25.87	19.00	136%
Trinity River near Goodrich, TX	48.39	36.00	134%
Sandies Creek near Westhoff, TX	27.24	21.00	130%
Colorado River at Wharton, TX	50.42	39.00	129%
Tres Palacios River near Midfield, TX	29.85	24.00	124%
Sabine River near Bon Wier, TX	36.84	30.00	123%
Brazos River near Rosharon, TX	52.67	43.00	122%
Garcitas Creek near Inez, TX	24.38	20.00	122%
Spring Creek near Spring, TX	111.45	91.50	122%
Brazos River at Richmond, TX	54.46	45.00	121%
Greens Bayou at Houston, TX	62.69	55.00	114%
Trinity River near Romayor, TX	42.74	40.00	107%
Cypress Creek near Hockley, TX	162.84	157.30	104%
Bundick Creek at Bundick Lake, LA	100.24	97.00	103%

Source: NOAA

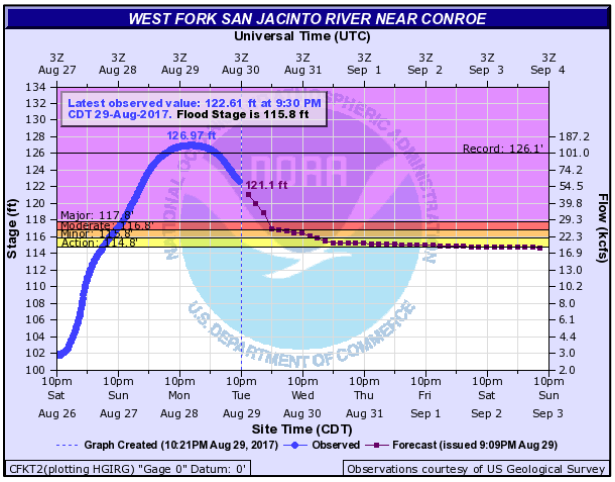
[#] *Data thru August 30, 2017*

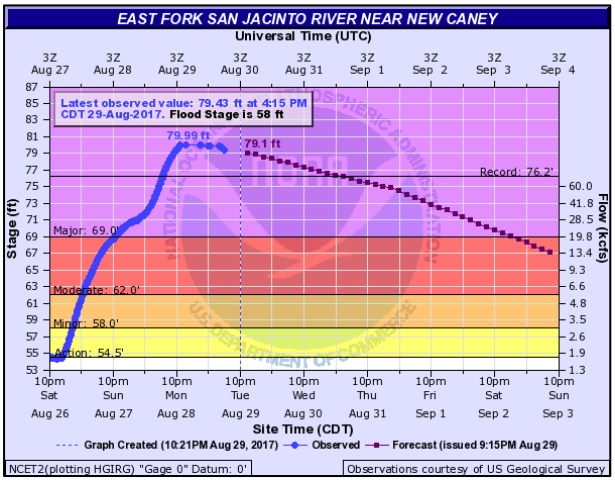
River Gauge Height Map

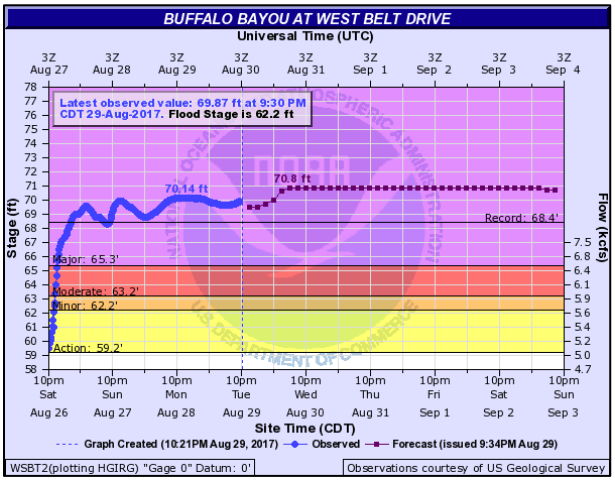


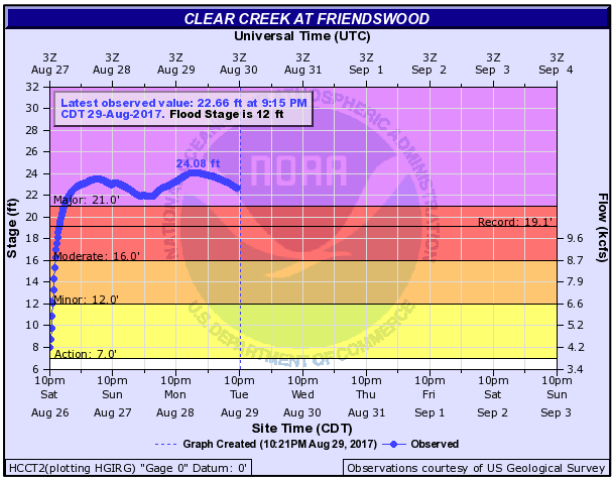
Flooding stages across SE Texas and Houston area as of August 29, 11:00AM CDT (Data: NOAA, Background: OpenStreetMap)

Selected River Gauge Locations



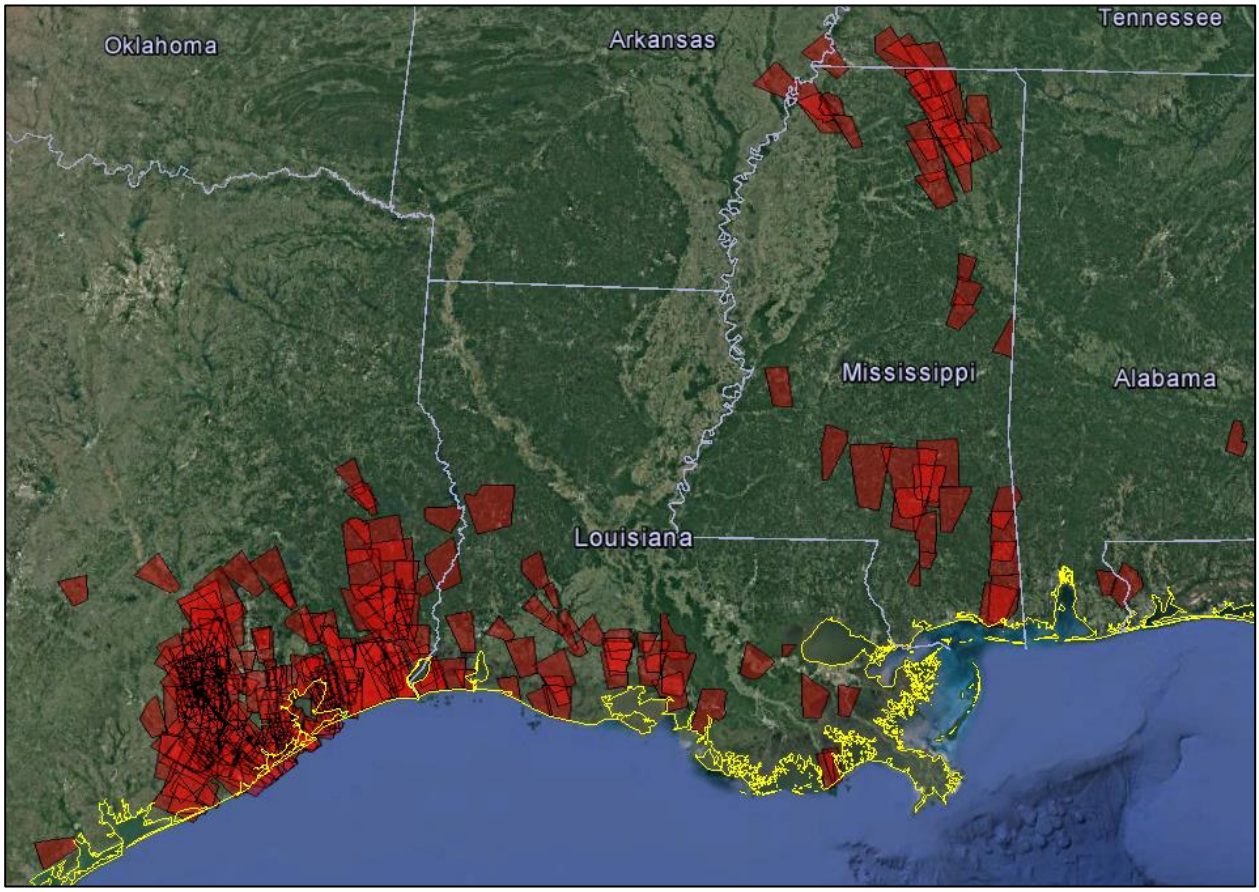






Hydrographs for selected river gauges in Harris County (Source: NOAA)

Severe Weather



Map showing all tornado warnings associated with Harvey from August 24-31 (Source: NOAA & Iowa State University)

Spin-up tornado activity is a common expectation during landfalling tropical cyclone events, and this was especially evident with Harvey. At least 327 individual tornado warnings were issued during Harvey's lifecycle as a tropical cyclone and its post-tropical remnants. Most of these tornado warnings were based on atmospheric rotation detected by Doppler radar. However, the majority of these warnings were likely false alarms as the final number of confirmed twisters during the event was less than 50.

Greatest Number of Tornadoes by U.S. Tropical Cyclone Event

Tropical Cyclone	Year	Number of Tornadoes
Hurricane Ivan	2004	118
Hurricane Beaulah	1967	115
Hurricane Frances	2004	103
Hurricane Rita	2005	98
Hurricane Katrina	2005	59
Hurricane Andrew	1992	56
Tropical Storm Fay	2008	50
Hurricane Gustav	2008	49
Hurricane Cindy	2005	48
Hurricane Georges	1998	48

Source: Roger Edwards (Storm Prediction Center)

Impacted Areas and Effects

Texas

Reported death tolls varied, though it is believed that at least 88 people were killed; almost all of who were in the greater Houston metro area and as a result of the catastrophic flooding. This total includes those killed directly and indirectly by the event. Dozens of other people were also injured. More than 40,000 people were forced into shelters, and as many as 450,000 people in Texas alone would eventually need assistance. One of the major shelters was established in the George Brown Convention Center in downtown Houston which had an estimated capacity of 5,000. However, more than 9,000 people ended up arriving at the facility. A further 2,000 people sought refuge at the Mo Campbell Education Center in Houston.

Wind Damage

Among the hardest hit areas by Harvey's winds was the town of Rockport which bore the brunt of the hurricane's landfall. The local mayor reported "widespread destruction" on the morning of August 26. The town was under a mandatory evacuation order prior to the arrival of Harvey which included the evacuation of inmates from the local jail. At least one person was killed and 12 others were injured in Rockport. Local media reports indicated that as many as nine others were still missing. Images on local media showed trailers and mobile homes which had been tossed about, toppled and snapped power poles and trees, roofs torn from homes and other buildings, properties that had been impaled by trees and extensive debris strewn across roads, sidewalks, yards, car parks, and other open spaces.

Rockport Airport, TX (Source: Agence France Presse)

Portions of the town's high school were also destroyed as was an emergency medical post. Severe damage was also reported to the library and other public facilities. Officials struggled to coordinate a rescue response due to extensive outages in power supplies and telecommunications while local media speculated that some residents may be trapped inside collapsed buildings.

Numerous towns and cities to the south of Rockport, including Corpus Christi, also fared badly as reports indicated that hundreds of mobile homes were destroyed. Officials in Port Aransas reported early on August 28 that most structures in the city had been "compromised to some level". They also noted that although a mandatory evacuation order was in place for the town's 3,800 residents, as many as 100 people stayed behind. They were all accounted for by late on August 26. Following extensive searches of the town there was only one confirmed fatality there.

To the north of Rockport, extensive damage was noted in the town of Refugio as trees and power poles were strewn across streets and impaled in buildings. Multiple homes lost their roofs while at least two mobile homes were destroyed. The town's high school also lost its roof. Extensive damage was also reported from Port Lavaca and Victoria.

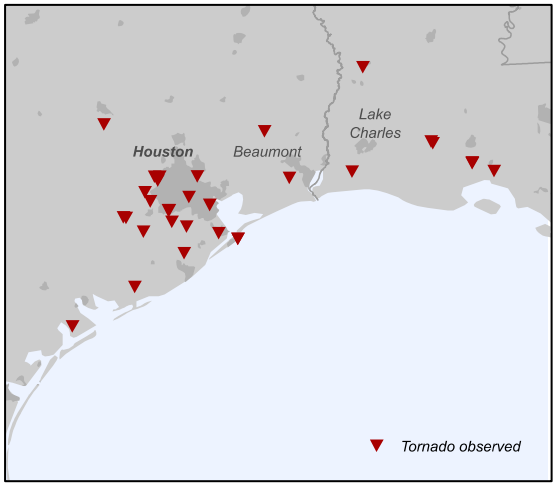
The Gulf of Mexico's oil and gas industry was also impacted as refinery shut-downs extended along the coast. Among those to close was Exxon Mobil's Baytown refinery - the second largest in the country. Multiple platforms in the Gulf of Mexico were also evacuated through August 27. A total of 105 production platforms were closed of the 737 in the Gulf. Five rigs were also evacuated while one more was moved from Harvey's path. Ahead of Harvey's arrival, three refineries and two petrochemical plants were closed causing many gas stations to run out of gasoline and pushing prices to their highest levels in four months. Disruption to the supply caused by Harvey is likely to push prices even higher in coming months according to analysts.

Storm damage in Corpus Christi, TX (Source: US Coast Guard)

Along the Texas coast it was reported that 313,000 customers were left without power in the aftermath of Harvey's landfall. A major portion of those outages were in the Corpus Christi area

Severe Weather

Additionally Harvey spawned multiple tornadoes when it came ashore. The Storm Prediction Center received 33 reports of tornadoes from August 25-30. These reports were filtered to remove duplicates. The reported twisters were all in Texas (22) and Louisiana (11).



Tornadoes observed on August 25-28 (Source: NOAA)

Tornado touchdowns were reported from Brazoria, Brazos, Calhoun, Fort Bend, Galveston, Hardin, Harris, Jefferson, Matagorda, Waller, and Wharton Counties, Texas, and from Acadia, Cameron, Forrest, Iberia, Lafayette, Vermilion, and Vernon Parishes, Louisiana. One tornado touched down in Hackberry, Louisiana early on Saturday (August 26) afternoon but early reports indicated that damage due to the twister was minimal.

Another tornado made at least four touchdowns in the Cypress area of Houston, TX. At least one vehicle was flipped while local emergency responders noted that extensive damage to roofs had occurred. Tornadic damage to homes, vehicles, businesses, and other buildings was also noted around Matagorda.

One oil spill was noted as the result of severe weather generated by Harvey: a bolt of lightning struck a fiberglass storage container prompting it to ignite on August 27. An estimated 210 gallons (795 liters) of oil was released at a facility operated by Karbuhn Oil Company.

Flood Damage

The majority of the damage inflicted by Harvey was as a result of catastrophic flooding inflicted by the combination of a large storm surge and prodigious amounts of rainfall as the storm pulled warm, moist air from the Gulf of Mexico over the Texas coast for days following its landfall. The NWS reported that conditions were “unprecedented” and issued a flash flood emergency for the entire Houston metro area.

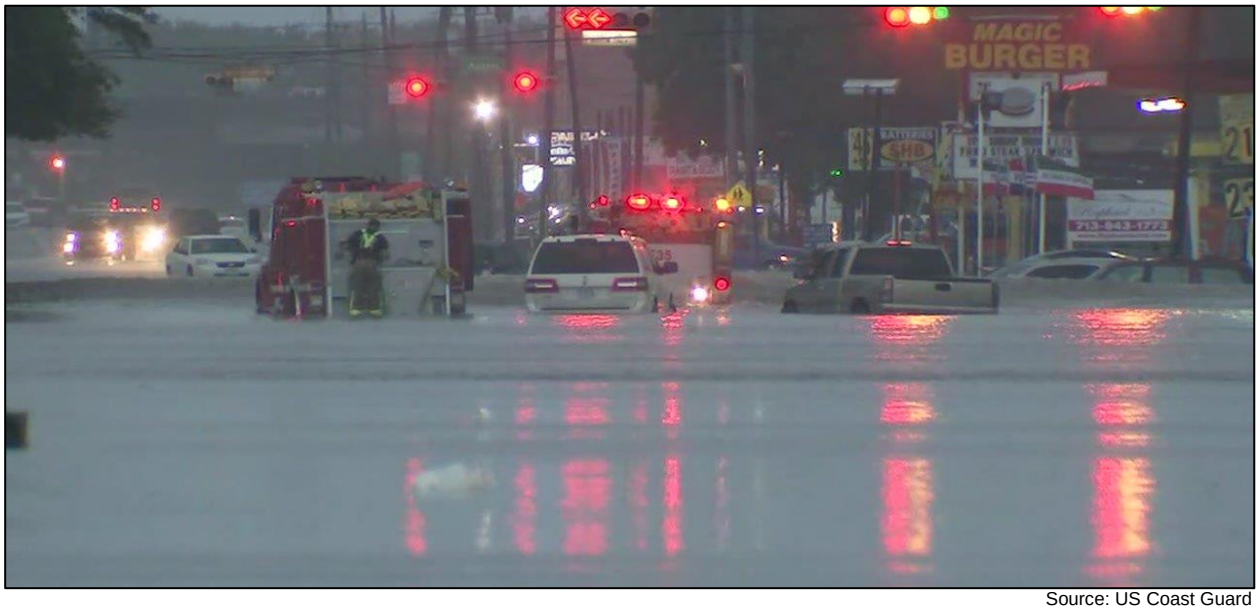
River levels rose rapidly prompting widespread and devastating floods. Among the worst affected areas was Harris County, including the Houston metro area. By early on August 27, NWS meteorologists were already describing the floods as the “worst Houston had ever experienced” and official guidance from emergency management teams to people whose homes became inundated was to “get on the roof”. Another NWS official described the situation as “catastrophic”, “historic”, and “epic”.

Aerial view of flooding in Houston, TX (Source: US Coast Guard)

In a Civil Emergency Message released at 6:10 AM CT August 27 (12:10 UTC), the following message was transmitted at the request of the city of Houston:

“Emergency management officials have requested that people escaping flood waters as a last resort do not stay in the attic. If highest floor of your home becomes dangerous… get on the roof.”

Controlled releases of water from two dams (Addicks and Barker) in the western part of Harris County began on August 28. Both dams were designed to withstand 1-in-1,000 year flood events. The release worsened flooding in several neighborhoods but was deemed necessary to avoid bigger, uncontrolled flows from occurring later. Despite the increased outflow from the dams, the spillway of Addicks Reservoir was overtopped by rising water level at approximately 07:19AM CDT on August 29.



Source: US Coast Guard


Aerial view of flooding in Houston, TX (Source: Houston Chronicle)

By August 31, record-breaking river gauge levels were recorded in the Brazos River, Navidad River, San Bernard River, San Jacinto River, Trinity River, Clear Creek, Cypress Creek, Davidson Creek, Lake Creek, Menard Creek, Peach Creek, and Buffalo Bayou while the Colorado River, Guadalupe River, Lavaca River, Tres Palacios River, Bedias Creek, Caney Creek, Garcitas Creek, Sandies Creek, Sandy Creek, Spring Creek, Brays Bayou, White Oak Bayou, and Greens Bayou all reached major flood stage. Multiple other rivers, creeks, and bayous were in moderate or minor flood stages and many were still rising.

Emergency services were inundated by tens of thousands of calls for help and carried out thousands of rescues through August 26-29.FEMA alone estimated 30,000 water rescues. From the time of Harvey's landfall through midday on August 28, officials reported that Houston's 911 system had received and processed some 75,000 calls. The fire department alone had received some 15,000 calls through August 30. Almost 20 helicopters were utilized in rescue operations as well as dozens of boats.

The Coast Guard reported they were receiving more than 1,000 calls per hour for assistance at the peak of the event. Several reports circulated in local media of boat-owners in the Houston area undertaking unofficial rescue missions as emergency services were overwhelmed. By August 28, the entire Texas National Guard, comprised of 12,000 members, was activated, while FEMA deployed 1,800 staff. By August 30, a further 10,000 National Guard troops from across the U.S. had been deployed to Texas taking the total number deployed there to approximately 24,000.

Houston's George Bush International Airport and William P. Hobby Airports were closed due to flooded runways affecting thousands of flights. Multiple ports were also closed, through Monday, August 28 at the earliest, including those at Houston, Galveston, Texas City, Freeport, and Corpus Christi. Lists of road closures throughout Houston and the surrounding areas were endless and grew by the hour. At one point, more than 250 roads, highways, and interstates were shut. On August 28, around 220,000 customers were left without power in the Houston area alone.

While most of the focus remained on Houston, the flooding disaster in Beaumont and Port Arthur, Texas was also substantial. Exceptional flooding left both cities reeling. In Beaumont alone, the flooding was so severe that both water pumps had failed; leaving the city of nearly 120,000 entirely without running water. The pumps were not fixed until the water fully receded. The flooding was also blamed on causing the Arkema plant to have multiple chemical explosions in the nearby town of Crosby. The twin blasts on August 31 occurred after organic peroxides overheated. The chemicals require being kept cool, but Arkema lost power on August 27 and that caused temperatures to rise in the storage facility; prompting containers to pop and catch fire.


Aerial view of flooding in Houston, TX (Source: Alertnet.org)

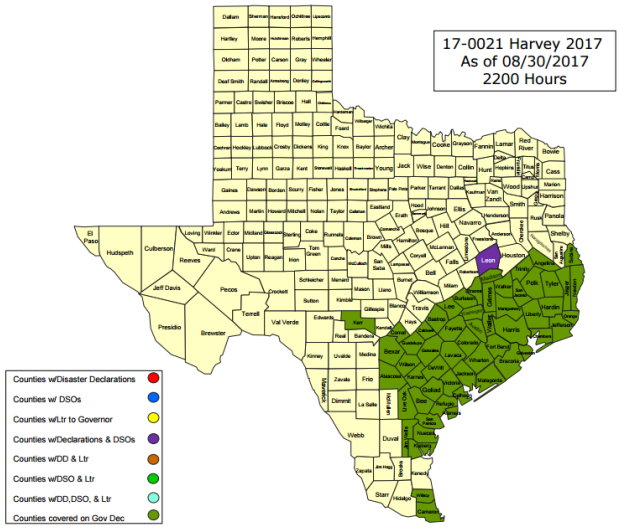
On August 30, the Motiva Enterprises plant in Port Arthur, Texas began a complete shutdown. The plant is the biggest oil refinery in the country and had already been running at half-speed prior to the full closure. In total more than one-fifth of U.S. refining capacity had been shuttered by August 30 prompting a rise in gasoline prices. Analysts estimated that it may take up to two weeks or longer before normal operations could resume.

An oil spill occurred at Kinder Morgan's Pasadena Terminal on August 26 as a result of a storage tank being tilted due to large volumes of floodwaters. The amount of oil spilled was not confirmed but the tank had a capacity of 6.3 million gallons (24 million liters). Officials reported that they believed the spill was contained. Two further oil spills were reported on August 30 by Burlington Resources Oil and Gas in DeWitt County. One of the spills was a 16,170 gallon (61,210 liter) spill near Westhoff and the other was a 13,272 gallon (50,240 liter) spill near Hochheim. In addition, an 8,500 gallon (32,175 liter) barrel of wastewater was also spilled.

Beyond structural damage, there was substantial impact to a high volume of automobiles, infrastructure and agriculture. Those damage costs were well into the billions of dollars.

To provide greater context to automobiles specifically, reports from multiple automotive industry groups indicate that as many as 500,000 (or more) vehicles were damaged by Harvey. This was much higher than the 250,000 damaged during Hurricane Sandy and the 200,000 during Hurricane Katrina. A quote from Cox automotive indicated that vehicle ownership rates are about 1.8 vehicles per household in Houston. This is higher than what was seen in New York during Hurricane Sandy (1.3) and in New Orleans during Hurricane Katrina (1.6).

Texas Disaster Declarations



A federal disaster proclamation was signed on August 25. This came in addition to the 58 counties declared by the state as disaster areas. The 58 affected counties were Angelina, Aransas, Atascosa, Austin, Bastrop, Bee, Bexar, Brazoria, Brazos, Burleson, Caldwell, Calhoun, Cameron, Chambers, Colorado, Comal, DeWitt, Fayette, Fort Bend, Galveston, Goliad, Gonzales, Grimes, Guadalupe, Hardin, Harris, Jackson, Jasper, Jefferson, Jim Wells, Karnes, Kerr, Kleberg, Lavaca, Lee, Leon, Liberty, Live Oak, Madison, Matagorda, Montgomery, Newton, Nueces, Orange, Polk, Refugio, Sabine, San Jacinto, San Patricio, Trinity, Tyler, Victoria, Walker, Waller, Washington, Wharton, Willacy and Wilson Counties.

Summary of Property Damage in Texas

Single Family Homes & Businesses

County	Single Family Homes				Businesses	
	Affected	Minor Damage	Major Damage	Destroyed	Major Damage	Destroyed
Harris	51,011	38,640	24,790	845	359	0
Jefferson	30,193	15,405	16,131	5,006	2,180	0
San Patricio	7,873	2,842	227	29	72	0
Orange	5,328	0	0	0	0	0
Galveston	4,540	8,719	6,652	1,266	96	0
Fort Bend	4,076	3,022	1,384	54	32	0
Aransas	3,264	4,380	2,658	867	174	0
Brazoria	3,131	2,859	1,930	503	21	0
Calhoun	1,319	1,611	931	109	72	0
Matagorda	1,144	178	487	13	524	0
Liberty	1,062	5,030	532	100	15	0
Tyler	1,005	101	80	80	0	0
Hardin	980	426	536	629	30	0
Wharton	920	270	271	32	24	0
Montgomery	400	301	350	40	10	0
Cameron	343	0	0	0	0	0
Jasper	300	130	150	20	35	0
San Jacinto	300	50	100	150	0	0
Polk	250	100	100	50	15	0
Refugio	238	661	880	321	66	0
Nueces	230	800	3,630	526	457	0
Waller	150	100	30	30	5	0
San Augustine	150	75	75	0	10	0
Fayette	135	30	18	107	28	0
Caldwell	46	65	18	4	0	0
Bastrop	43	61	33	1	0	0
Austin	35	4	10	21	0	0
Goliad	18	3	1	3	0	0
Grimes	16	3	18	3	4	0
Guadalupe	12	5	4	0	0	0
Kleberg	8	8	0	0	0	0
Walker	4	9	4	0	0	0
Madison	4	1	0	0	0	0
Bee	0	8	0	0	0	0
Lee	0	1	3	1	0	0
DeWitt	0	0	40	4	0	0
Jackson	0	0	0	20	0	0
TOTAL	**118,530**	**85,899**	**62,074**	**10,816**	**4,229**	**0**

Mobile Homes & Multi-Family Homes

County	Mobile Homes				Multi-Family Homes			
	Affected	Minor Damage	Major Damage	Destroyed	Destroyed	Minor Damage	Major Damage	Destroyed
Jefferson	3,001	2,011	623	502	240	585	636	0
Matagorda	807	191	59	14	2	1	1	0
San Patricio	710	410	185	125	104	56	13	1
Galveston	657	446	824	27	242	482	244	572
Aransas	560	778	753	514	252	200	381	103
Tyler	500	20	0	0	0	0	0	0
Fayette	350	5	10	335	0	0	0	0
Wharton	199	37	49	80	41	7	9	0
Calhoun	167	170	1,171	312	88	84	13	0
Harris	128	20	121	0	737	185	472	0
Brazoria	117	104	100	29	136	10	136	5
Hardin	109	59	59	80	1	0	0	0
Nueces	100	300	500	500	10	10	40	10
San Jacinto	100	50	25	2,540	0	0	0	0
Polk	100	10	40	50	0	0	0	0
San Augustine	50	25	25	0	10	5	5	0
Fort Bend	48	4	3	0	0	0	0	0
Refugio	36	77	124	109	36	3	50	12
Waller	30	30	40	50	3	6	2	2
Jasper	30	15	5	10	0	0	0	0
Orange	28	0	0	0	120	0	0	0
Austin	25	6	10	9	0	0	0	0
Caldwell	21	27	20	3	0	0	0	0
Montgomery	20	25	10	50	1	12	41	10
Bastrop	15	7	3	2	7	2	3	0
Goliad	9	0	0	0	0	6	0	0
Guadalupe	6	3	7	1	0	0	1	0
Liberty	3	100	53	25	65	42	23	0
Bee	3	0	0	3	0	0	0	0
Grimes	1	1	5	2	0	0	0	0
Lee	0	5	3	25	0	0	0	0
Walker	0	0	0	2	0	0	0	0
TOTAL	**7,933**	**4,936**	**4,830**	**5,399**	**2,095**	**1,696**	**2,070**	**715**

Public Buildings & Facilities

County	Debris Removal	Police/EMS	Roads & Bridges	Water Facilities	Buildings	Public Utility Systems	Other	TOTAL
Harris	44,399,500	34,024,504	301,200	18,500	35,308,047	72,115,500	1,756,000	188,102,733
Galveston	19,716,500	3,907,595	49,832,500	100,000	10,755,300	3,050,000	24,577,614	111,939,510
Jefferson	26,800,000	7,800,000	30,000,000	0	458,600	2,010,000	10,942,866	78,011,466
Nueces	10,000,000	510,000	1,000,000	0	20,500,000	1,200,000	7,026,000	40,236,000
Aransas	81,050	0	11,991,476	8,393	2,156,166	1,752,000	20,413,333	36,402,418
Fort Bend	1,893,600	3,779,146	6,471,265	20,000	2,873,692	186,000	21,149,256	36,372,959
Refugio	12,512,600	50,400	28,328	0	13,362,445	15,700	25,000	25,994,373
Hardin	370,000	50,000	17,107,660	230,000	4,150,000	203,000	865,000	22,975,660
San Patricio	5,505,975	840,363	0	0	7,051,535	5,930,000	800,000	20,127,873
Brazoria	7,355,000	4,614,590	1,350,000	500,000	5,459,400	47,001	760,000	20,085,991
Jasper	1,250,222	1,500,000	14,250,000	0	450,000	245,000	1,634,390	19,329,612
Liberty	4,000,000	500,000	5,300,000	250,000	0	1,600,000	0	11,650,000
Caldwell	125,000	527,500	4,133,201	0	120,000	2,000	4,583,400	9,491,101
Matagorda	88,840	215,840	1,232,120	750,000	2,622,000	1,402,000	152,000	6,462,800
Calhoun	1,270,000	0	3,178,000	0	910,000	0	990,000	6,348,000
San Augustine	0	0	1,400,000	0	0	0	2,275,000	4,675,000
Walker	40,000	153,000	2,365,000	0	100,000	2,000	18,373	2,678,373
Montgomery	154,500	506,164	1,000,000	0	104,000	80,000	0	1,844,664
Waller	100,000	50,000	1,500,000	0	20,000	0	0	1,670,000
San Jacinto	0	90,000	1,500,000	0	70,000	0	0	1,660,000
Polk	0	1,000	1,000,000	0	1,000	30,000	350,000	1,382,000
DeWitt	199,280	216,873	700,000	0	28,000	175,000	7,000	1,326,153
Colorado	45,000	0	150,000	0	110,000	1,000,000	0	1,305,000
Guadalupe	300,000	197,669	6,001	0	500,142	0	177,229	1,181,040
Bastrop	0	0	924,500	0	225,000	0	0	1,149,500
Wharton	25,000	150,000	850,000	0	0	0	25,000	1,050,000
Bexar	0	999,929	0	0	0	0	0	999,929
Orange	0	0	0	50,000	0	250,000	365,000	935,000
Washington	7,500	6,000	600,000	0	4,000	1,000	125,000	743,500
Sabine	30,000	75,000	600,000	0	0	0	20,000	725,000
Tyler	50,000	50,000	500,000	0	0	20,000	20,000	640,000
Bee	146,725	16,150	4,260	457,400	15,000	0	0	639,535
Gonzales	118,504	134,262	250,000	0	0	52,017	19,600	574,383
Austin	25,000	10,000	500,000	0	20,000	0	0	555,000
Comal	12,059	254,477	0	0	0	168,511	0	435,046
Webb	0	0	0	0	0	0	411,478	411,478
Madison	1,000	0	300,000	0	75,000	0	0	375,000
Victoria	0	355,000	0	0	0	0	0	355,000
Jim Wells	3,534	310,007	2,172	0	0	11,000	0	326,713
Milam	0	25,000	300,000	0	0	0	0	325,000
Cameron	3,933	279,861	0	0	2,000	7,000	500	293,294
Goliad	47,000	0	0	0	0	0	244,490	291,490
Lee	5,250	6,898	59,400	0	0	0	135,000	206,548
Nacogdoches	0	144,219	0	0	0	0	0	144,219
Lavaca	51,620	78,235	0	0	6,500	0	0	136,355
Burleson	3,500	13,000	97,050	0	0	0	0	113,550
Kleberg	0	71,014	0	0	0	0	4,180	75,194
Brazos	0	0	62,524	0	0	0	0	62,524
Jackson	0	60,000	0	0	0	0	0	60,000
Kerr	0	26,035	0	0	0	0	0	26,035
Robertson	0	0	0	0	500	6,675	0	7,175
TOTAL	**137,237,691**	**63,614,331**	**162,820,258**	**4,384,293**	**105,822,684**	**92,961,404**	**100,455,209**	**669,252,262**

Louisiana

As Harvey edged northward through August 28-29, a federal disaster was declared for five “at-risk” Louisiana parishes including Beauregard, Calcasieu, Cameron, Jefferson Davis, and Vermillion in the southwest of the state. The Louisiana governor sought the addition of Allen, Acadia, Iberia, Natchitoches, Rapides, Sabine, and Vernon to the declaration on August 30. With rainfall topping 20 inches (508 millimeters) across southwestern sections of the state, this caused several rivers and streams to swell well above flood stage.

Of particular interest was in Beauregard Parish, where all residents along the Sabine River were requested by local officials to evacuate their homes. Hundreds of roads throughout the hardest-hit parishes were closed given high water levels. As of August 31, river levels were continuing to rise as smaller creeks and streams were draining into the larger watershed.

The governor of the state would later comment on August 30 that assessments indicated that the scope of damage was less than initially feared.

Energy Impacts

Electricity

The United States Department of Energy's Office of Electricity Delivery and Energy Reliability reported that approximately 367,474 customers lost power in Texas (312,698), Louisiana (19,350), and Tennessee (35,426) due to Hurricane Harvey. CenterPoint separately reported that 878,000 of their customers experienced outages. The peak of reported outages by the DoE in Texas came on August 29 and in Louisiana on August 30. Tennessee's power outages peaked on September 1. The vast majority of outages in Texas were reported in Harris (88,237), Nueces (35,489), Orange (27,704), Aransas (19,016), and Tyler (12,367) counties. Numerous energy suppliers were impacted by the outages including AEP Texas, CenterPoint Energy, Entergy, Texas-New Mexico Power, Oncor Electric Delivery, Beauregard Electric Coop, CLECO Power Inc., and Southwestern Electric Power Co.

AEP Texas restoration effort (Source: Altec Inc.)

AEP Texas, the largest energy provider affected by Hurricane Harvey, sustained significant damage to its network and infrastructure and more than 220,000 AEP Texas customers experienced outages. Additionally, one member of the company's restoration crew lost their life undertaking work to restore power supplies: approximately 5,600 personnel in total were involved in the company's restoration effort. AEP Texas reported that more than 5,000 distribution poles had to be replaced due to damage inflicted by the hurricane; approximately 300 transmission structures were knocked down and required to be replaced or repaired; and a further 200 transmission structures were damaged by the storm. They noted that Harvey inflicted the most severe damage to their network in 44 years.

CenterPoint Energy also sustained significant damage to their network causing outages for some 878,000 of their customers in total. CenterPoint's outages peaked at 120,000 at once on August 28. The estimated rebuilding cost of their Memorial substation which was inundated when the Buffalo Bayou overflowed was USD15 million. The substation served approximately 12,500 customers and was submerged by four feet (1.2 meters) of floodwater. A further five of the company's substations were also flooded in the Houston area.

CenterPoint Energy's Memorial substation (Source: CenterPoint Energy)

Natural Gas

On September 1, CenterPoint Energy notified authorities of a natural gas leak from an 18-inch (0.5-meter) diameter underwater pipe in the Neches River, Beaumont, TX which was quickly and successfully isolated by dive teams. Woodsboro Natural Gas also reported six leaks, all of which had been repaired by September 2.

Offshore Energy Platforms

Despite Harvey tracking through a region of the Gulf of Mexico full of offshore oil and gas platforms, there was not widespread damage to these facilities. However, in advance of Harvey's arrival, the U.S. Bureau of Safety and Environmental Enforcement (BSEE) reported that 105 production platforms – or 14 percent of the 737 manned platforms in the Gulf of Mexico – had been evacuated.

Offshore Production

From August 26-27, the peak of disruption to oil and gas production in the Gulf of Mexico was noted with 24.5 percent of oil production (428,568 barrels per day) and 25.9 percent of natural gas production (835 million cubic feet per day) shut-in according to estimates by the Bureau of Safety and Environmental Enforcement. These figures slowly and steadily dropped through the end of August and into September as detailed in the table below.

U.S. Gulf of Mexico Oil & Gas Production Status

		Shut-In										
Production	**Pre-Event**	**08/25**	**08/26**	**08/27**	**08/28**	**08/29**	**08/30**	**08/31**	**09/01**	**09/02**	**09/03**	**09/04**
Crude Oil (barrels per day)	1,750,000	377,177	428,568	378,633	331,370	319,526	323,760	236,115	152,989	106,813	96,260	121,484
Natural Gas (million cubic feet per day)	3,220	748	835	827	583.39	615.09	611.09	568.09	405.99	337.2	271.39	259.19
		Evacuated										
Infrastructure	**Pre-Event Count**	**08/25**	**08/26**	**08/27**	**08/28**	**08/29**	**08/30**	**08/31**	**09/01**	**09/02**	**09/03**	**09/04**
Manned Platforms	737	86	112	105	98	102	102	94	75	43	No data	14
Rigs	31	5	6	6	5	5	5	5	0	0	0	0

Onshore Production

The Texas Railroad Commission estimated on August 26 that approximately 300,000 to 500,000 barrels per day of crude oil production had been shut-in in the Eagle Ford region. That was down from a pre-Harvey production estimate of 870,000 barrels per day. Additionally they noted that 3.0 billion cubic feet per day of natural gas production was shut-in which was approximately half of the pre-Harvey production capacity.

Petroleum Refineries

Multiple refineries were also shut down throughout Texas due to Harvey. In the Corpus Christi area, six refineries with a combined refining capacity of 924,720 barrels per day (equivalent to 18.4 percent of the total Gulf Coast refining capacity) were closed. Four refineries in the Houston/Galveston area were operating at reduced capacities as of August 26, two of which began the process of shutting down on August 27 taking the combined refining capacity of the closed facilities to 1,810,920 barrels per day; equivalent to 36.0 percent of the total Texas Gulf Coast refining capacity. The following day a further two refineries in Houston/Galveston began shutting down taking the total capacity of closed or closing refineries to 2,170,149 barrels per day or equivalent to 43.2 percent of total Texas Gulf Coast refining capacity. This figure was also equivalent to 11.8 percent of the total U.S. refining capacity. Additionally, as of August 28, three more refineries in Houston/Galveston and one in Beaumont/Port Arthur were operating at reduced levels.

As of August 29, six refineries in the Corpus Christi area, seven in Houston/Galveston, and one in Beaumont/Port Arthur were shutdown. The combined capacity of these refineries was 3,268,449 barrels per day, equal to 33.7 percent of Gulf Coast refining capacity and 17.6 percent of total U.S. capacity. Furthermore, one refinery in Houston/Galveston, two in Beaumont/Port Arthur, and two in Lake Charles were operating at reduced rates. The following day, another Beaumont/Port Arthur refinery was added to the list of closures taking the affected capacity to 3,871,449 barrels per day or 39.9 percent of total Gulf Coast capacity: 20.9 percent of total U.S. capacity.

August 28, saw the first Corpus Christi refinery begin startup operations. Further startups were initiated on August 30 when six refineries with a capacity of 1,269,720 barrels per day (or 13.1 percent of Gulf Coast refining capacity) began the process. As of September 1, four refineries were operating at reduced capacities, six had initiated the startup process, and 10 remained shut down.

By September 4, eight refineries remained shut down with a combined capacity of 2,110,229 barrels per day - equal to 21.8 percent of the total Gulf Coast refining capacity or 11.4 percent of the total U.S. refining capacity. A further eight refineries had begun the process of restarting while four refineries remained operational at reduced levels.

The numbers of refineries operating at reduced capacities or shut down decreased gradually through September 11 as restart operations continued. At that time just four remained closed while seven were restarting. A further four were operating at reduced rates. By the end of September, one refinery with a capacity of 225,000 barrels per day (equal to just 2.3 percent of the total Gulf Coast capacity or 1.2 percent of the total U.S. capacity) was in the process of restarting and a further eight were operating at reduced rate. The combined capacity of the eight was 2,661,470 barrels per day or 27.5 percent of the total Gulf Coast refining capacity or 14.4 percent of the total U.S. refining capacity.

At the peak, 15 oil refinery plants in the Houston area and Corpus Christi were shut down that led to a 50 percent greater reduction in refining capacity than was lost during Hurricane Katrina in 2005.

Ports

From August 25-26, the U.S. Coast Guard closed all ports in the Corpus Christi and Houston & Galveston sectors. This included Brownsville, Corpus Christi, Freeport, Galveston, Houston, and Texas City. Additionally, ports in Port Arthur and Lake Charles sector were open but with operational restrictions in place. These included Beaumont, Lake Charles, Orange, Port Arthur, and Sabine Pass. By August 28, all Port Arthur and Lake Charles sector ports were closed.

Also on August 28, it was reported that 22 oil tankers with a cargo of 15.3 million barrels of imported crude oil were unable to offload due to the extensive port closures along the Texas coast. This number increased to 25 the following day and to 55 by September 4. The affected vessels remained in anchorage off the Texan ports of Corpus Christi, Houston, Galveston, Freeport, Texas City, Beaumont, Nederland, Port Arthur, Port Neches and Sabine Pass and the Louisiana port of Lake Charles.

Brownsville was the first port to reopen on August 26. By August 31, Freeport, Galveston, Houston, and Texas City ports were open with restrictions. Corpus Christi reopened with restrictions on September 1 while Freeport fully reopened on September 2. At the same time Beaumont, Lake Charles, Nederland, Orange, Port Arthur, Port Neches, and Sabine Pass reopened with restrictions. Texas City Port fully reopened on September 6. The final update issued by the DoE on September 27 indicated that Brownsville port was open while the remaining aforementioned ports were open with some restrictions.

Transportation Impacts

Airports & Airlines

The impact to the airline industry was substantial as more than 12,000 flights ended up being cancelled nationwide due to Harvey. Most of those flights came in and out of Houston's two main airports (George Bush Intercontinental Airport and Hobby Airport) as the airports were closed for nearly five days. Hobby Airport's runways were flooded during the peak of the event; while roads leading to George Bush Airport were inundated. Other affected Texas airports were in San Antonio and Austin.

Numerous airlines cited significant financial impacts from Harvey due to lost business. United Airlines reportedly lost up to USD265 million alone. Other airlines lost less, such as Southwest (USD77 million) and Spirit (USD11 million), though impacts were costly.

Roadways

Flooded roads in Houston, August 29 (Source: Texas Department of Transport)

At the peak of the flooding that was spawned by Hurricane Harvey, the Texas Department of Transport noted that more 500 roads were closed throughout the state. As of October 16, only one road remained closed due to damage: Park Road 1C in Buescher State Park, Bastrop County. Also at this time, the department noted that more than 4,300 bridges had been inspected following Harvey of which 13 required repairs. The federal government diverted USD25 million of funds to the Department of Transport to aid with the response to Hurricane Harvey.

The Department of Transport additionally carried out extensive debris removal work across multiple counties and cities. As of October 16, they had collected more than 10 million cubic feet (283,000 cubic meters) of debris from just four of the worst affected districts.

Railways

Kansas City Southern Railway declared force majeure (*defined as unforeseeable circumstances that prevent from fulfilling a contract*) and an embargo on shipments through Laredo and Brownsville-Matamoros going to Houston and Corpus Christi on August 25. Three days later they declared force majeure and an embargo on the remainder of its Texas network that was affected by Hurricane Harvey.

Union Pacific reported on August 30 that sections of its track were out of service in 18 of its 28 Houston subdivisions and it was diverting traffic along alternate routes through Longview and Dallas. Part of Union Pacific's Englewood Yard was flooded.

BNSF reported on August 29 that normal train flows in the Harvey-affected region were unlikely to resume for “an extended period” while CSX Corp. noted that it was closing monitoring its network throughout Louisiana. YRC Freight’s Houston terminal was closed from August 29. From September 1 ABF Freight noted that there were disruptions to its services in Houston, Dallas, Little Rock, and San Antonio due to Harvey.

Marine Industry

Boats

The impact from Harvey on recreational boats was significant, though not as catastrophic as initially feared. A study by BoatUS – a recreational boat industry organization – found that roughly 13,500 boats were damaged or destroyed in Texas and Louisiana. This equaled an economic cost of USD155 million. For context, this was much less than the 65,000 boats and loss of more than USD650 million during 2012’s Hurricane Sandy in the US Northeast.

Marinas

Cove Harbor Marina and Drystack, near Rockport, Texas (Source: DDP USA)

Cove Harbor Marina and Drystack, just south of Rockport, TX reported that they took a direct hit from Harvey and as such, sustained significant damage. More than 400 boat tenants were affected although it was not known exactly how many vessels were damaged or destroyed. Significant damage to the marina’s infrastructure was noted and the drystack building was tagged for demolition due to the extent of damage sustained. Damage was estimated at USD10 million.

Further damage was cited around Port Lavaca, where officials counted 77 sunken boats in the region. This was a fraction of the 676 boats which sank in Texas waters as Harvey slowly traversed the state. Rockport Harbor also took a direct hit from Harvey and sustained significant damage. Additionally, the neighboring Rockport Aquarium was all but destroyed, and ultimately had to be demolished.

Key Allegro Marina in Rockport also endured severe damage: at least two of their docks were destroyed. It was noted that serious damage was also sustained to buildings at the facility.

Other marina and moorings facilities that are known to have sustained damage include the Island Moorings Yacht Club and Marina, Port Aransas Municipal Boat Harbor, and Island Moorings Marina, all of which are in or around Rockport and Port Aransas.

Source: The Aquarium at Rockport Harbor

Environmental Impacts

Coastal Erosion

Harvey was responsible for severe erosion all along the central and northern Texas coastline. Impacts from storm surge and prolonged elevated water levels led to major dune overwash, breaching, and erosion. However, it is worth noting that the Texas General Land Office has cited that 64 percent of the Texas coast was previously eroding at an average rate of 6.0 feet (1.8 meters) per year. Some locations in the state are losing more than 30 feet (9.1 meters) per year, which is accelerated due to continued coastal growth, sea level rise and other natural factors.

Flora & Fauna

Harvey caused damage of USD104 million to the University of Texas' Marine Science Institute at Port Aransas and killed hundreds of study animals (mainly fish) and displaced 14 researchers. Damaged facilities included the loss of one of five water quality monitoring stations, heavy damage to a rehabilitation keep for injured wildlife, and the loss of part of the roof of the headquarters building which allowed for significant water damage to occur as heavy rain poured into the building.

Damage at the Marine Science Institute (Source: University of Texas)

The Marine Science Institute additionally carried out post-Harvey research on the impact the hurricane had on seagrass communities in the Gulf of Mexico in an area extending from Galveston to Port Isabel. Their immediate studies focused on areas that had been exposed to hurricane-force winds including the Upper Laguna Madre to Aransas and Copano Bay. When compared to baseline data that the team had collected for years prior to Harvey they found that about half of the Coastal Bend's seagrass meadows were impacted to a greater or lesser degree.

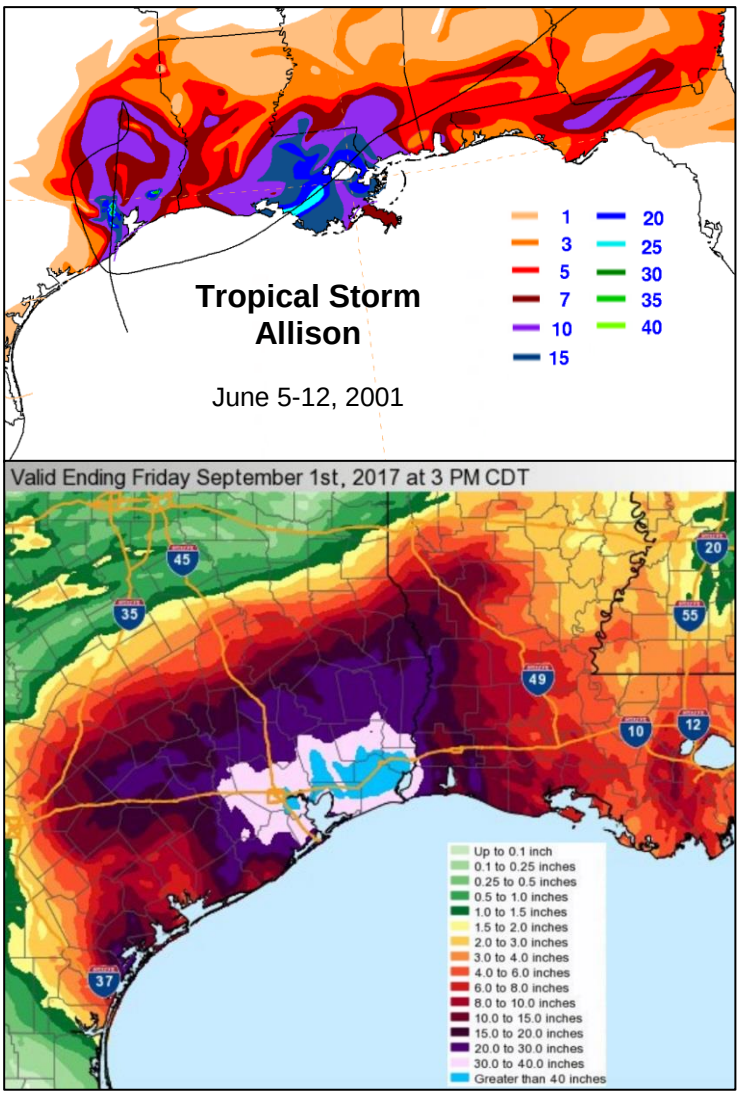
They noted that some stations were largely unscathed while others had been striped to their roots and rhizomes. They also added that Harvey had significantly reduced the salinity of the water in coastal regions from approximately 30-35 parts per thousand to 9-13 parts per thousand. Seagrass does not thrive when salinity levels are below 15 parts per thousand for prolonged periods. Further studies by the team are expected to concentrate on the recovery of the established seagrass meadows.

Comparison: HU Harvey vs. TS Allison (2001)

The impact of Hurricane Harvey raises the question of comparison to 2001's Tropical Storm Allison. Both systems were similar in their slow-motion across the western Gulf of Mexico and prompted substantial rainfall over the course of several days.

The primary difference is that Harvey made landfall as a Category 4 hurricane; while Allison came ashore with 50 mph (85 kph) winds. Almost all of Allison's damage was on account of extreme flooding that affected the greater Houston, TX metro region and areas eastward in southern Louisiana. With Harvey, while the inland flood portion will be the predominant driver of financial losses, there was a notable wind damage component as well.

What is perhaps most striking about the catastrophic damage impact from Harvey, is that the city of Houston made many major upgrades to infrastructure in the aftermath of Allison – and Harvey still over whelmed. One of the most major changes was in the city's Medical Center, where the UT Health Medical School endured hundreds of millions of dollars in damage. As an example of a Post-Allison initiative, hospitals moved their generators to higher floors and installed submarine doors to keep water from entering. Additionally, officials built berms around facilities.



Allison rainfall (top) versus Harvey (bottom) – Source: NOAA

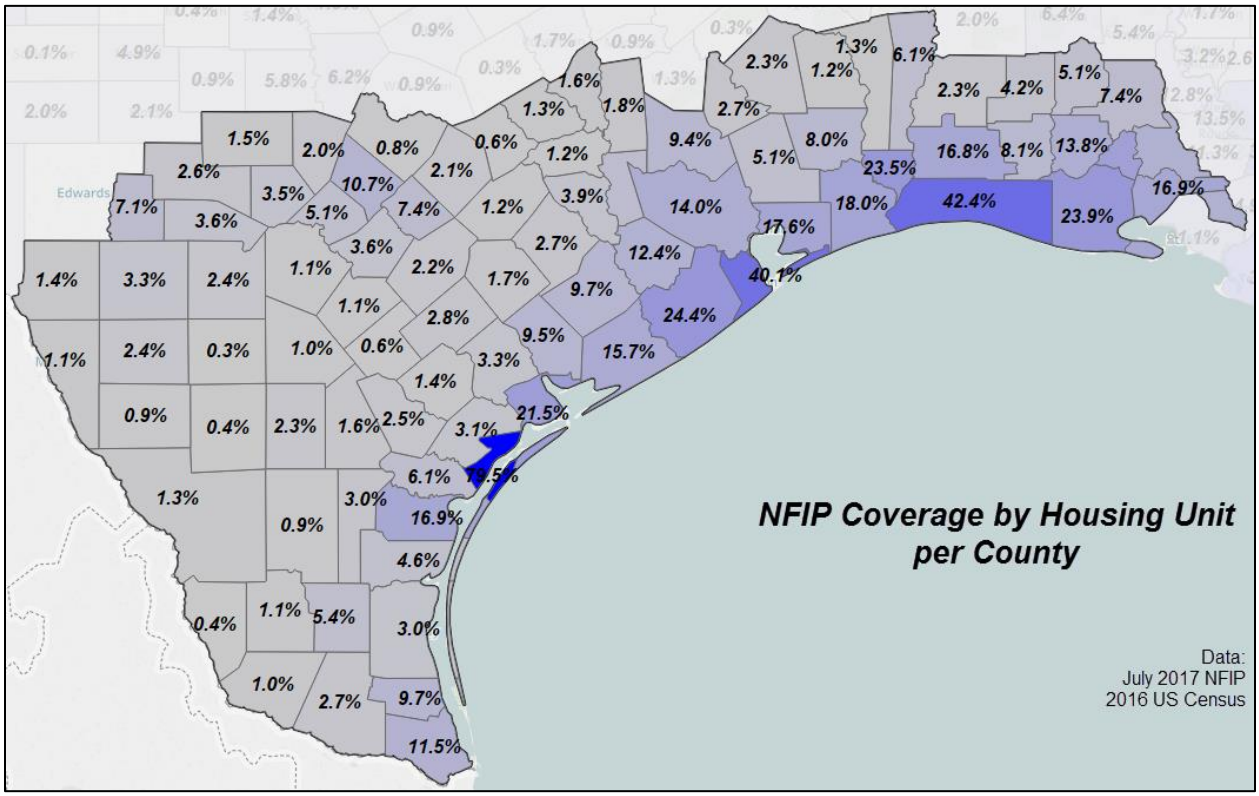
Harris County also worked closely with the U.S. Army Corp of Engineers to substantially upgrade and enlarge the county's system of rainwater-draining bayous. In all, more than USD900 million was spent on upgrading Sims Bayou in South Houston, Brays Bayou in western and central Houston, and White Oak Bayou in northwest Houston. In the 16 years since Allison, there have been numerous flash flooding events – in addition to Hurricane Ike in 2008 – which tested these new initiatives. For the most part, the new storm plans and infrastructure improvements had worked well.

Perhaps the biggest difference in the Houston metro area since Allison has been the explosive boom in population and exposure.

Miscellaneous

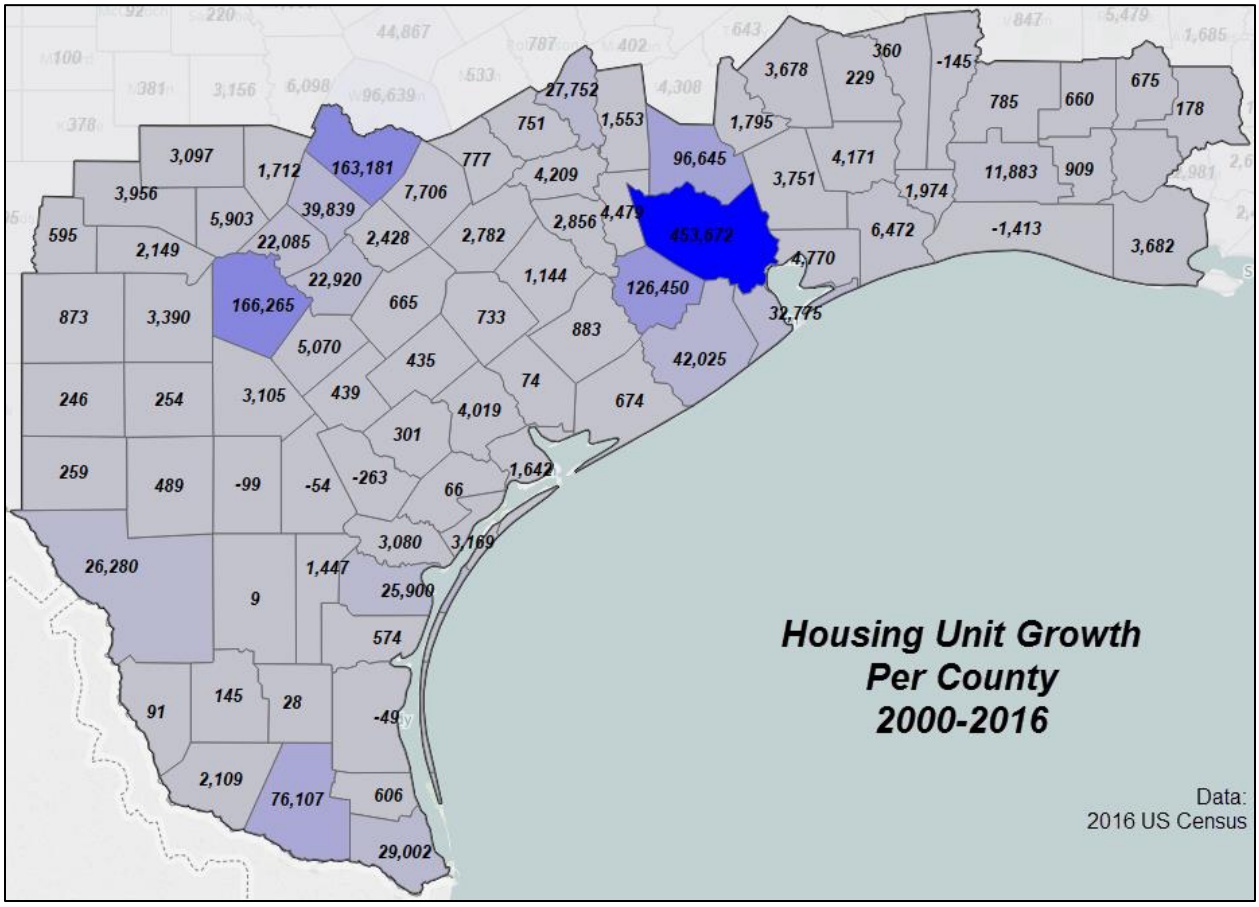
NFIP Coverage

The graphic below shows NFIP coverage by county across the hardest-hit areas by Harvey. The data is based on statistics from NFIP and the U.S. Census Bureau at the time of landfall. In Harris County, TX – home to the city of Houston – just one out of six homes currently had active NFIP policies in place. The rates of coverage are most pronounced immediately along the coastline, but decline into the single-digits once getting further inland.



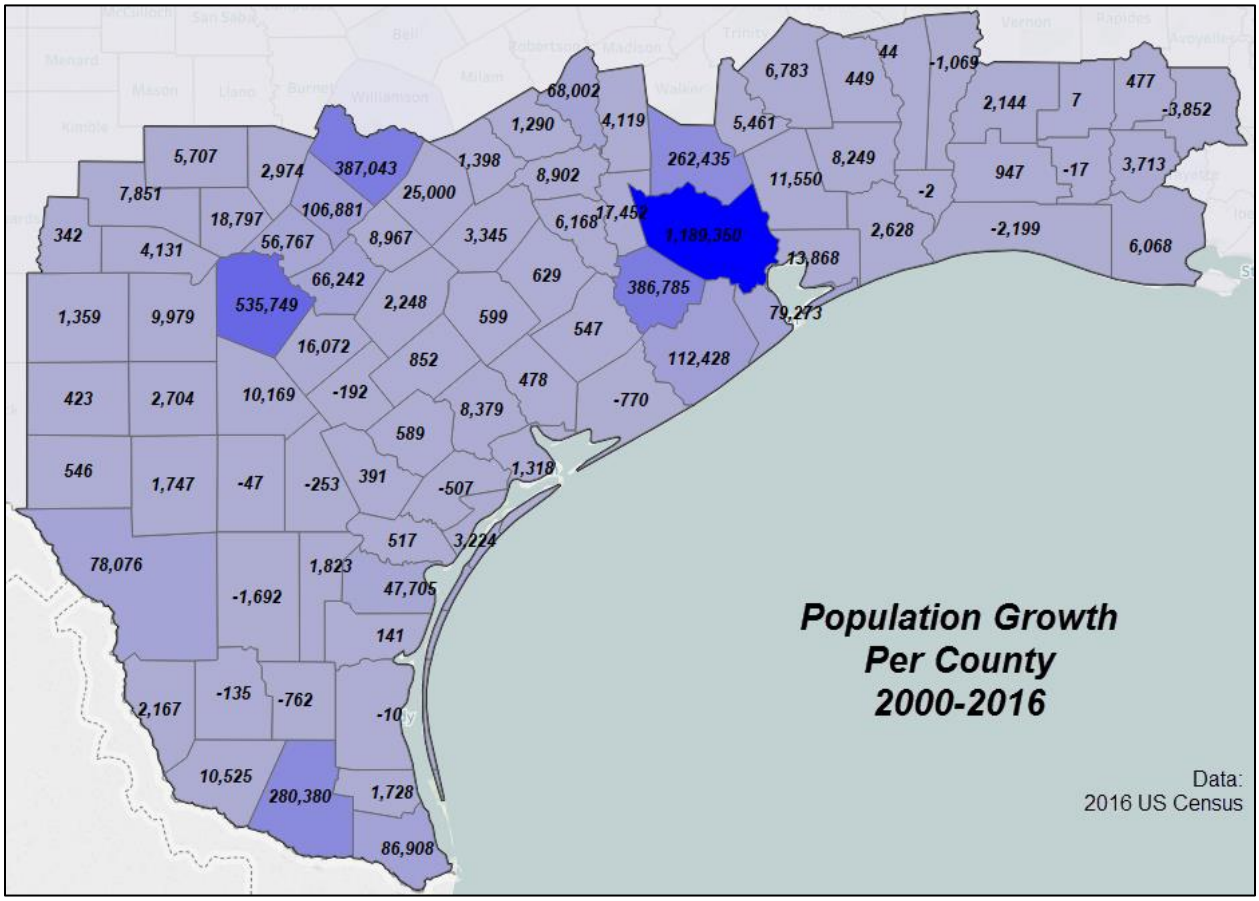
Housing Unit Growth

The graphic below shows an absolute increase in number of housing units per county since 2000 across the affected area. The highest increase of exposure in the last 16 years can be detected in Harris County (city of Houston) and across surrounding counties of greater Houston. Second highest increase can be observed further inland in a cluster of counties around Bexar (San Antonio) and Travis (Austin).



Population Growth

The spatial distribution of recent population growth in the affected area correlates with focal points of housing development and is concentrated in large cities of Houston, San Antonio and Austin and across their metropolitan areas.



Impact Forecasting Reconnaissance Trip

Members of Aon Benfield's Catastrophe Management and Impact Forecasting teams traveled to Houston, Texas from September 19-21, 2017 for a three-day damage assessment following Hurricane Harvey's landfall in late August. Several neighborhoods and parts of the metro region were visited: Bellaire, Dickinson, Pearland, Meyerland, South Houston, Katy (Cinco Ranch), Buffalo Bayou reservoir (Nottingham Forest neighborhood), and Sienna Plantation.

Among the most notable findings:

1) There was a significant difference in areas with a mixture of homes built Pre-FIRM (Flood Insurance Rate Map) and those with newer construction in modern FEMA map zones. Homes which were elevated to meet current mandates often escaped without major damage. However, Pre-FIRM homes that were grandfathered with previous code standards often incurred entire loss to their first floor contents.

Home without any foundation elevation (Source: Impact Forecasting)

Home built with 12-18" elevation (Source: Impact Forecasting)

2) The height and longevity of flood waters across many neighborhoods and commercial regions led to significant molding and weakening of dry wall. The combination of tropical heat and humidity in Houston additionally worsened structures that did not have much external circulation. This often led to a loss of contents on the second story.

First floor remnants following 2' of water (Source: Impact Forecasting)

Molding on walls (Source: Impact Forecasting)

3) Significant flooding occurred in areas even where local officials had properly planned for at least a 100-year flood event. Given the extensive volume of new construction and concrete throughout Houston metro, the current infrastructure was not prepared to handle more than 60 inches of rainfall. This led to major flash flooding and inundation. The dominant soil type (clay) and excessive amount of concrete additionally provided further risk for flash flooding.

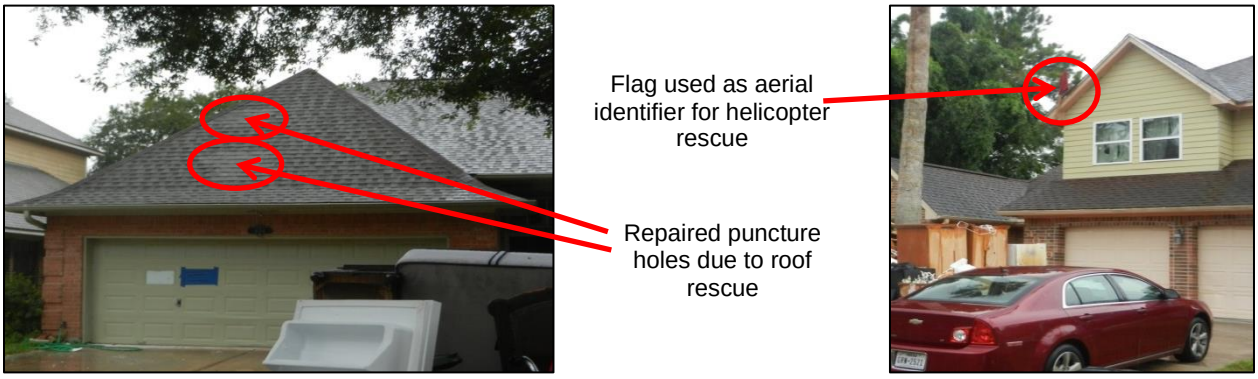
Infrastructure development in Houston (Source: Impact Forecasting)

Heavy rain causes flash flood on Sept. 20 (Source: Impact Forecasting)

4) Dozens of tornado touchdowns during Hurricane Harvey led to roof damage in multiple neighborhoods. In some instances, roof damage was severe enough to allow for indoor water intrusion that led to an entire loss of indoor contents.

Tornado and indoor water damage (Source: Impact Forecasting)

5) Water heights reached up to 8 feet in numerous neighborhoods, making ground rescue impossible. This led to some residents needing to be rescued from their roofs via helicopter after holes were punctured through attics.



Impact Forecasting: Modeled U.S. Results

Storm Surge

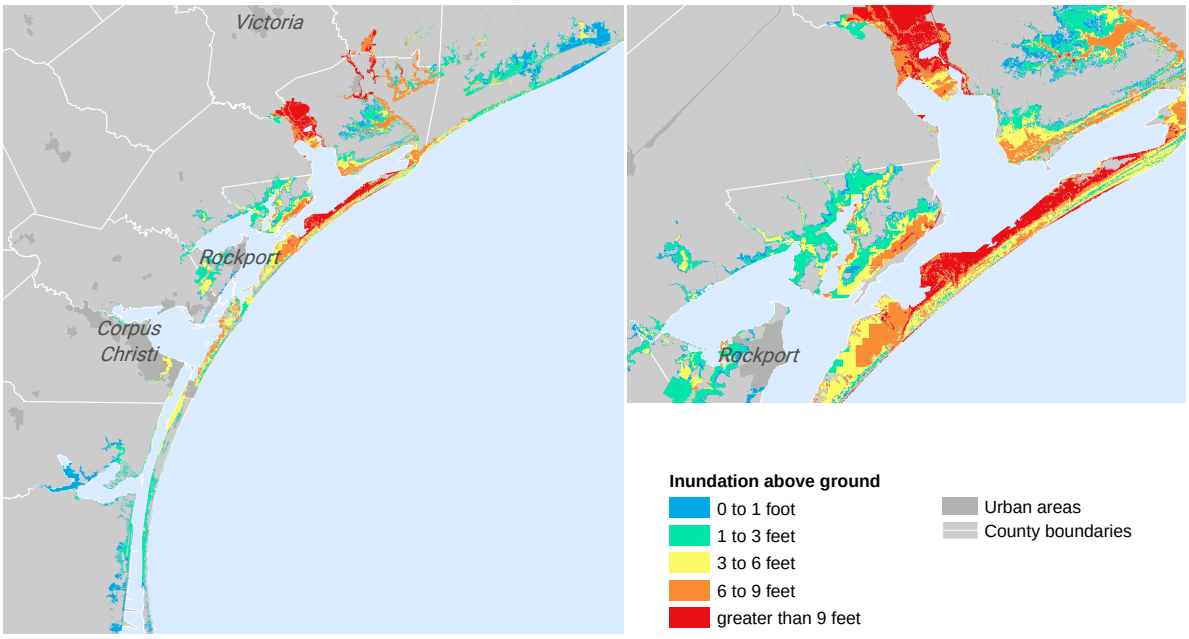
The importance of coastal and inland flood driving a larger portion of loss than wind from Harvey highlights the need to be able to effectively model storm surge - both for post-loss risk assessment and as part of a pre-loss stochastic evaluation of portfolio risk. In order to do this, Impact Forecasting has implemented the SLOSH methodology into its loss calculation platform, ELEMENTS.

What is SLOSH?

According to the National Hurricane Center, the **S**ea, **L**ake and **O**verland **S**urges from **H**urricanes (SLOSH) model is a computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field which drives the storm surge. The SLOSH model consists of a set of physics equations which are applied to a specific locale's shoreline, incorporating unique bay and river configurations, water depths, bridges, roads, levees, and other physical features.

Impact Forecasting Storm Tide Heights Using SLOSH

Impact Forecasting has a suite of catastrophe models that analyze the financial implications of catastrophic events so that our clients achieve a greater understanding of their risks. To estimate the potential “insurable losses” for Hurricane Harvey, presented in the next section of this report, Impact Forecasting used this implementation of SLOSH, as well as its hurricane wind model and riverine and pluvial inland flood model, through its in-house ELEMENTS platform. The following maps show predicted inundation along the Texas and Louisiana coastlines. The estimates are based on actual parameters from Harvey, including official height data as measured by the National Oceanic and Atmospheric Administration (NOAA) and the USGS.



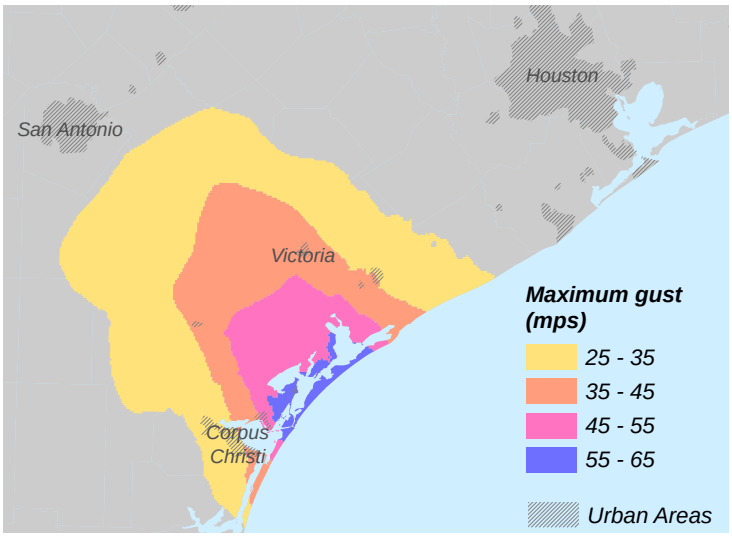
As a reminder, data used for storm tide is water height above the North American Vertical Datum of 1988 (NAVD88). Note that this is different from inundation, which is the measured water height above ground level after high tide that occurs as a result of the storm tide. To see a full glossary of tropical cyclone-related terms see Appendix D.

Wind

The full track of Hurricane Harvey was reconstructed using the preliminary best-track data from the National Hurricane Center's Automated Tropical Cyclone Forecasting system (ATCF). The ATCF, developed by the US Naval Research Laboratory, is a computer based application designed to automate and optimize the forecasting process of tropical cyclones. The NHC and the Joint Typhoon Warning Center (JTWC), among other institutes, are the operational users of the ATCF.

The parameters utilized in the reconstruction included the position of hurricane eye (latitude and longitude), minimum central pressure, forward speed, heading angle, and radius of maximum winds that were reported in 6-hour increments. These hurricane parameters were imported into the wind field and the storm surge models to calculate wind speeds and surge heights. These wind speeds and surge heights were next used in Impact Forecasting's ELEMENTS program to estimate the potential insurable losses caused by the hurricane.

The Impact Forecasting wind field model is a spectral-based parametric model that solves equations of motion by using the finite difference method. The wind field model has been calibrated, both spatially and temporally, to the surface winds. The wind speed footprint, as modeled by Impact Forecasting, for Hurricane Harvey is presented on the right. This footprint has general agreements with the wind speed swath from the NHC.

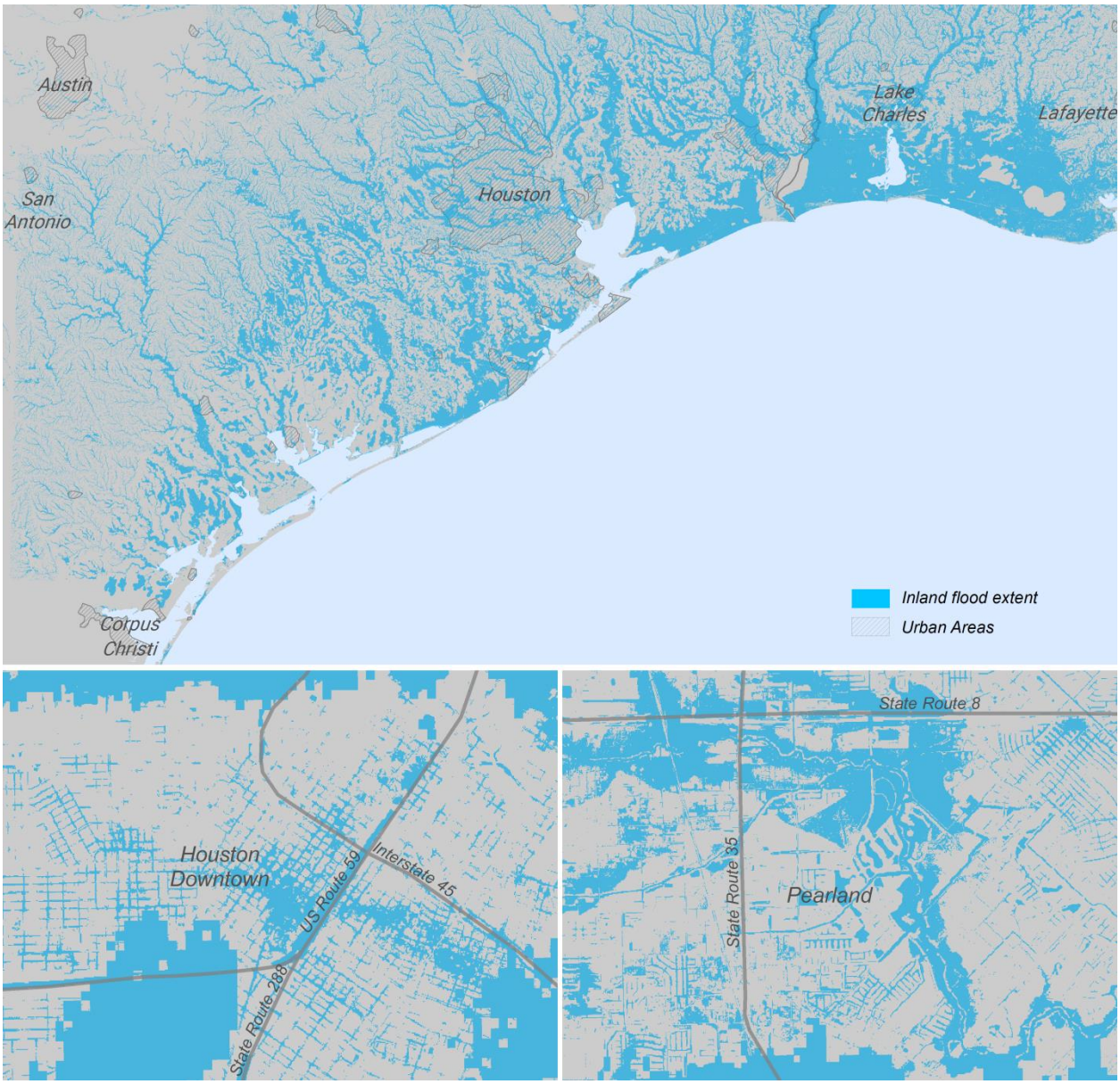


Source: Impact Forecasting

Inland Flood (Riverine & Flash Flood)

Given the substantial rainfall associated with Hurricane Harvey, Impact Forecasting additionally ran its inland flood model. The inland flood results show areas impacted by both pluvial (flash flood) and fluvial (riverine) flooding and were constructed using Impact Forecasting's 1D riverine and 2D hydrodynamic rainfall-runoff model. In order to run the model, real-time stream gauge discharge observations were collected for the impacted regions. Due to a number of stream gauges failing during the peak of the event, corrections were made in order to include them in the calibration process.

Some areas recorded rainfall rates with an estimated return period in excess of 1,000 years. This means that there was a 0.1 percent chance (1/1,000 probability) that the recorded rainfall would occur at any given location in any year. Given the rainfall rates, Impact Forecasting used pre-calculated return period flash flood events to construct the Harvey rainfall extent. The final inland flood extents are shown on the next page.



Source: Impact Forecasting

Impact Forecasting Modeled Loss Results

Based on the modeled results of Impact Forecasting's wind, storm surge, and inland flood models from its initial near real-time runs in September 2017, it was determined that "insurable losses" resulting from Hurricane Harvey in the United States would range between **USD52 and 69 billion**. *Please note that "insurable losses" does not indicate the total economic loss estimate, nor the insured loss estimate. This only includes the value of properties (homes, businesses, vehicles) that are potentially insured by the private market. It does not include additional damage to such things as infrastructure.*

The specific breakout is as follows:

Wind & Storm Surge:	**USD2 to 4 billion**
Inland Flood:	**USD50 to 65 billion**

Financial Impact

Hurricane Harvey left a catastrophic path of devastation across a wide swath of southeast Texas and portions of extreme southwest Louisiana and is expected to have an overall economic impact in the vicinity of USD100 billion. This includes physical damage to residential and commercial properties, automobiles, infrastructure, agriculture, offshore & onshore energy, and marine. It also assumes a significant cost resulting from business interruption to many sectors.

From an insurance point of view, as mentioned previously, the relative lack of NFIP coverage in some of the hardest-hit areas meant that an abnormally high portion of economic damage caused by flooding was not covered by insurance. Hurricanes have historically shown a roughly 50 percent ratio of insured-to-economic loss damage. However, hurricane losses that are primarily driven by coastal or inland flood tend to show lower percentages of coverage. Hurricane Matthew in 2016 only had roughly 40 percent of the overall economic cost covered by public and private insurance entities as most of the damage resulted from considerable inland flooding in North Carolina and South Carolina.

Aerial view of flooding in Houston (Source: NOAA)

Insured losses resulting from Harvey were thus also significantly less than the overall economic cost. At roughly USD30 billion, this meant that only 30 percent of the financial cost was covered by public and private insurers. This was almost entirely due to most of the damage resulting from extreme flooding in the Houston metro area, as opposed to wind. A statement from FEMA's National Flood Insurance Program cited that claims payouts were well into the billions, and could reach as high as USD11 billion. Additional losses were incurred by the onshore and offshore energy industry.

Harvey was the costliest hurricane to strike the state of Texas. It surpassed Hurricane Ike in September 2008. Ike cost the United States at least USD35 billion in economic damage; while public and private insurers paid more than USD20 billion (2017 USD). It also far surpassed losses from 2001's Tropical Storm Allison – which was previously considered the worst flood event in Houston's recorded history. In fact, Harvey's rainfall surpassed Allison in nearly half the time (2-3 days compared to five days). Allison cost an estimated USD12 billion in economic damage (2017 USD). Less than half of that cost (USD5.0 billion, 2017 USD) was covered by insurance.

Bottom line: Hurricane Harvey was one of the costliest natural disasters in United States history, second only to 2005's Hurricane Katrina. The full scope and magnitude of the damage and humanitarian impact was enormous and the economic impact was substantial.

Harvey Name Retirement

The World Meteorological Organization (WMO) is responsible for determining the official names for tropical cyclones around the world. In the rare case in which a tropical cyclone is particularly significant from a casualty and/or cost perspective, the WMO will retire the storm name. Below is the official list of retired hurricane names in the Atlantic Ocean. It is expected that Harvey will join this list.

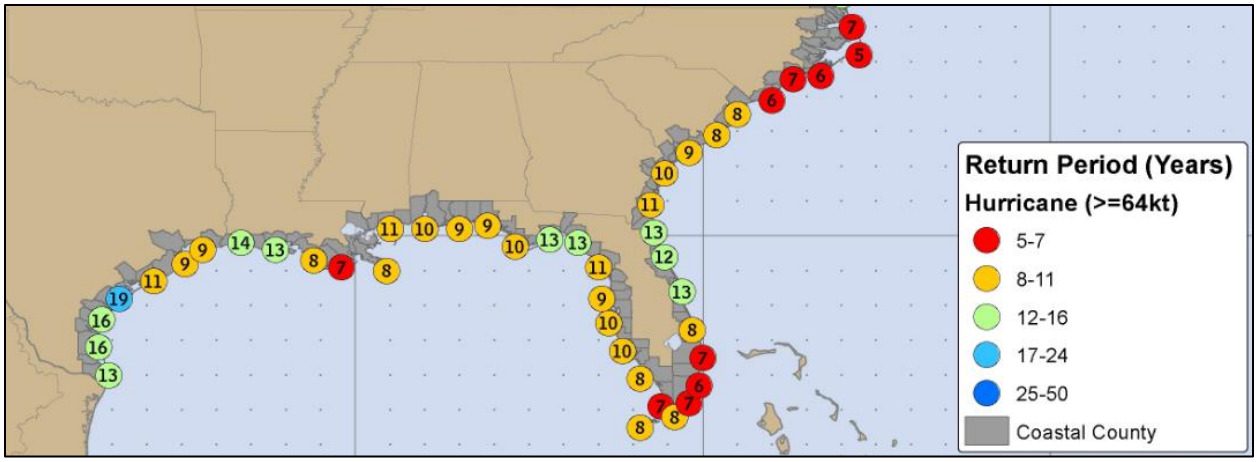
				1954 *Carol* *Hazel*	**1955** *Connie* *Diane* *Ione* *Janet*	**1956**	**1957** *Audrey*	**1958**	**1959**
1960 *Donna*	**1961** *Carla* *Hattie*	**1962**	**1963** *Flora*	**1964** *Cleo* *Dora* *Hilda*	**1965** *Betsy*	**1966** *Inez*	**1967** *Beulah*	**1968** *Edna*	**1969** *Camille*
1970 *Celia*	**1971**	**1972** *Agnes*	**1973**	**1974** *Carmen* *Fifi*	**1975** *Eloise*	**1976**	**1977** *Anita*	**1978**	**1979** *David* *Frederic*
1980 *Allen*	**1981**	**1982**	**1983** *Alicia*	**1984**	**1985** *Elena* *Gloria*	**1986**	**1987**	**1988** *Gilbert* *Joan*	**1989** *Hugo*
1990 *Diana* *Klaus*	**1991** *Bob*	**1992** *Andrew*	**1993**	**1994**	**1995** *Luis* *Marilyn* *Opal* *Roxanne*	**1996** *Cesar* *Fran* *Hortense*	**1997**	**1998** *Georges* *Mitch*	**1999** *Floyd* *Lenny*
2000 *Keith*	**2001** *Allison* *Iris* *Michelle*	**2002** *Isidore* *Lili*	**2003** *Fabian* *Isabel* *Juan*	**2004** *Charley* *Frances* *Ivan* *Jeanne*	**2005** *Dennis* *Katrina* *Rita* *Stan* *Wilma*	**2006**	**2007** *Dean* *Felix* *Noel*	**2008** *Gustav* *Ike* *Paloma*	**2009**
2010 *Igor* *Thomas*	**2011** *Irene*	**2012** *Sandy*	**2013** *Ingrid*	**2014**	**2015** *Erika* *Joaquin*	**2016** *Matthew* *Otto*			

Appendix A

United States Hurricane Landfall Return Periods

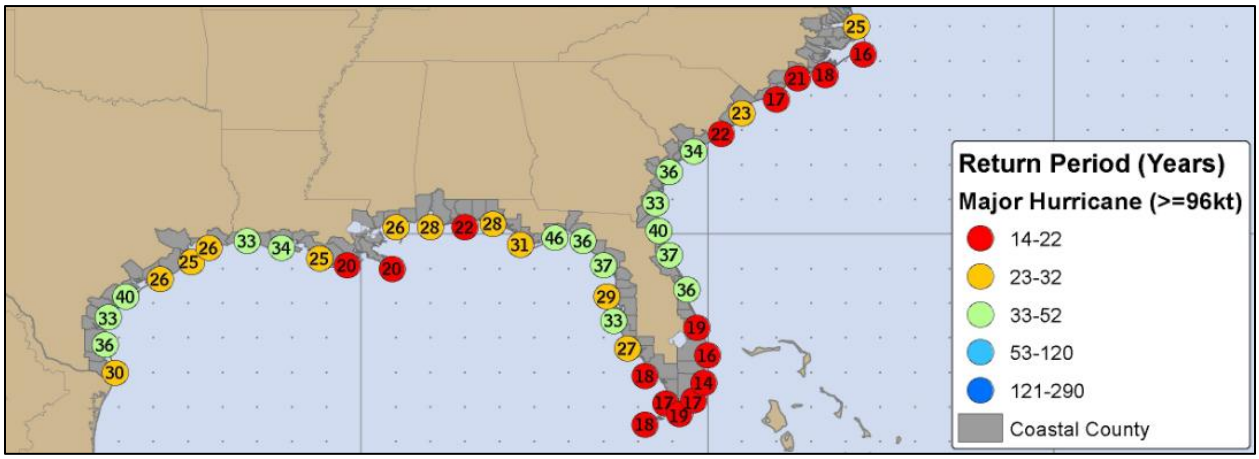
Below are maps from the National Hurricane Center (NHC) that provide tropical cyclone return periods for areas along the United States coastline located south of the North Carolina border.

The first map shows regions at greatest risk of hurricanes tracking within 50 nautical miles (57 miles (93 kilometers)) of a particular location along the coastline. Historical data shows that the southern tip of Florida, Louisiana, and the outer banks of North Carolina are areas that typically record a hurricane every five to seven years.



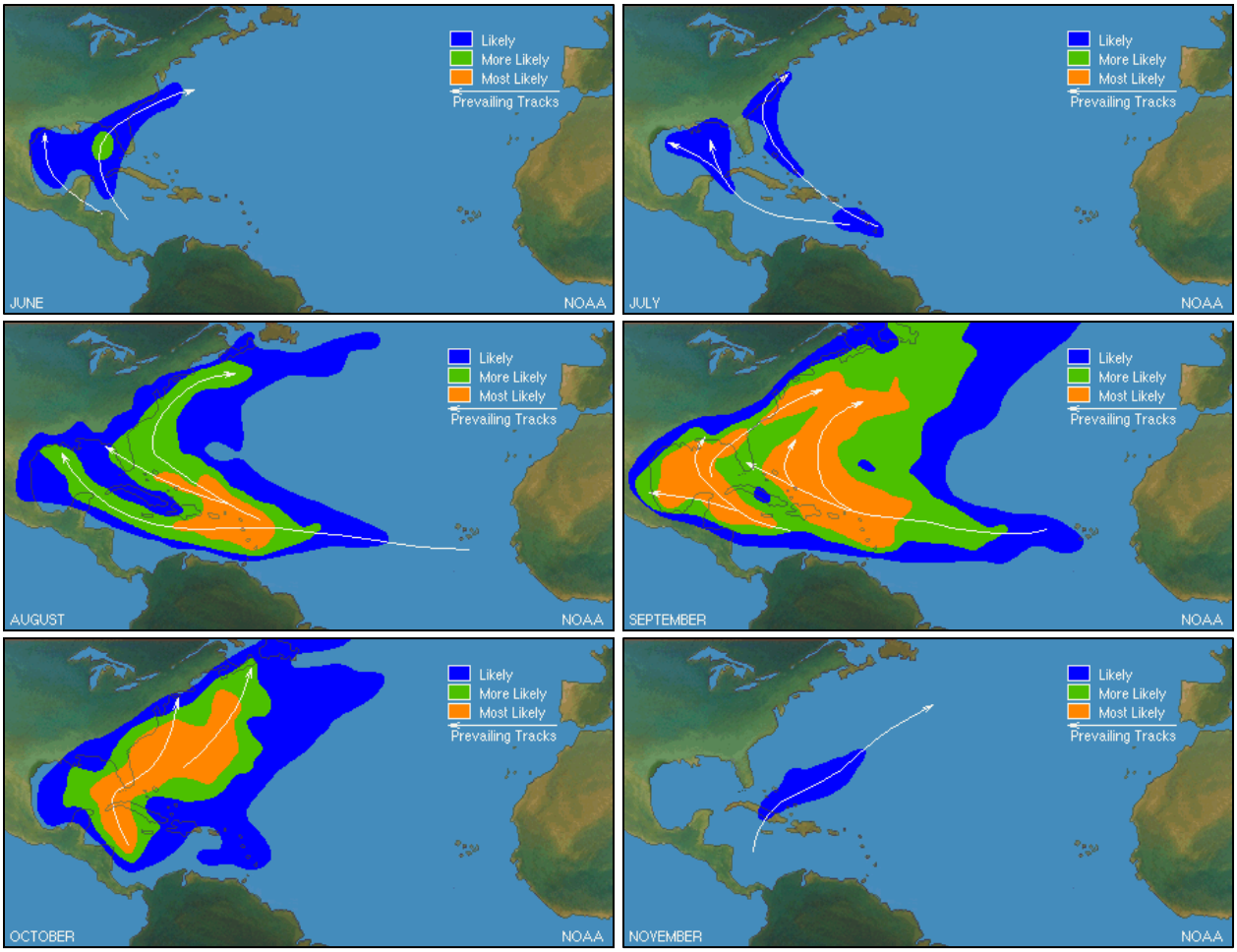
Hurricane landfall return period (Source: NHC)

The second map shows regions at greatest risk of major hurricanes within 50 nautical miles (57 miles (93 kilometers)) of a particular location along the coastline. Historical data shows, unsurprisingly, that there are longer return periods for stronger storms. Areas with greatest historical frequency include south Florida, the Florida panhandle, Louisiana, South Carolina, and North Carolina Harvey's first official landfall came in Aransas County, Texas, which has a return period for such an event every 33 - 40 years.



Major hurricane landfall return period (Source: NHC)

In terms of tropical cyclone development, the official Atlantic Hurricane season runs from June 1 to November 30 – though tropical cyclones have been known to develop during any month. As seen in the graphics below, the most likely months for cyclogenesis are during the peak months of August, September, and October. During these months, atmospheric and oceanic conditions are climatologically the most conducive for cyclones being influenced and/or steered by a strong Atlantic ridge of high pressure and/or by the advancement of strong troughs that dig into the central and eastern United States.



The caveat to cyclogenesis is, of course, the eventual track of storms that do develop. While greater frequency of storms increases the chance of US landfall, the reality is that it only takes one landfalling storm to entirely change the perception of how active a season is to the general public – regardless of how many storms actually make landfall in a single season.

Appendix B

Costliest Atlantic Basin and United States Hurricanes

Atlantic Basin

Rank	Storm Name	Affected Locations	Economic Loss[1] (2018 USD)	Insured Loss[2] (2018 USD)
1	Hurricane Katrina (2005)	United States	156 billion	81 billion
2	Hurricane Harvey (2017)	United States	100 billion	30 billion
3	Hurricane Sandy (2012)	U.S., Cuba, Jamaica, Hispaniola	81 billion	32 billion
4	Hurricane Maria (2017)	Puerto Rico, Caribbean	65 billion	27 billion
5	Hurricane Irma (2017)	U.S., Cuba, Caribbean	55 billion	23 billion
6	Hurricane Andrew (1992)	U.S., Bahamas	47 billion	28 billion
7	Hurricane Ike (2008)	U.S., Jamaica, Hispaniola, Cuba	43 billion	21 billion
8	Hurricane Wilma (2005)	U.S., Jamaica, Haiti, Mexico, Cuba	34 billion	15 billion
9	Hurricane Ivan (2004)	U.S., Hispaniola, Caribbean, Bahamas	32 billion	12 billion
10	Hurricane Rita (2005)	U.S., Caribbean	23 billion	11 billion

United States (Mainland)

Rank	Storm Name	Affected Locations	Economic Loss[1] (2018 USD)	Insured Loss[2] (2018 USD)
1	Hurricane Katrina (2005)	Gulf Coast, Southeast	156 billion	81 billion
2	Hurricane Harvey (2017)	Gulf Coast	100 billion	30 billion
3	Hurricane Sandy (2012)	Northeast, Mid-Atlantic, Ohio Valley, Midwest	72 billion	32 billion
4	Hurricane Andrew (1992)	Southeast	46 billion	27 billion
5	Hurricane Ike (2008)	Texas, Midwest, Northeast	34 billion	20 billion
6	Hurricane Ivan (2004)	Southeast, Mid-Atlantic, Northeast	27 billion	11 billion
7	Hurricane Irma (2017)	Southeast	25 billion	15 billion
8	Hurricane Wilma (2005)	Florida	23 billion	13 billion
9	Hurricane Rita (2005)	Southeast, Plains	23 billion	11 billion
10	Hurricane Charley (2004)	Southeast	21 billion	10 billion

[1] Economic losses included those sustained to residential and commercial properties, automobiles, infrastructure, electrical grids, public buildings, business interruption, etc.

[2] Insured losses include those sustained by private industry and government entities such as the US National Flood Insurance Program.

Appendix C

United States Emergency Declarations

Texas

Emergency Declaration made on 08/23/2017.

Counties:

Aransas, Austin, Bastrop, Bee, Bexar, Brazoria, Burleson, Calhoun, Chambers, Colorado, Comal, Dallas, DeWitt, Fayette, Fort Bend, Galveston, Goliad, Gonzales, Grimes, Guadalupe, Hardin, Harris, Jackson, Jasper, Jefferson, Jim Wells, Karnes, Kleberg, Lavaca, Lee, Liberty, Madison, Matagorda, Milam, Montgomery, Newton, Nueces, Orange, Polk, Refugio, Sabine, San Augustine, San Jacinto, San Patricio, Tarrant, Travis, Tyler, Victoria, Walker, Waller, Washington, Wharton

Louisiana

Emergency Declaration made on 08/28/2017.

Parishes: Acadia, Allen, Ascension, Assumption, Avoyelles, Beauregard, Bienville, Bossier, Caddo, Calcasieu, Caldwell, Cameron, Catahoula, Claiborne, Concordia, DeSoto, East Baton Rouge, East Carroll, East Feliciana, Evangeline, Franklin, Grant, Iberia, Iberville, Jackson, Jefferson, Jefferson Davis, La Salle, Lafayette, Lafourche, Lincoln, Livingston, Madison, Morehouse, Natchitoches, Orleans, Ouachita, Plaquemines, Pointe Coupee, Rapides, Red River, Richland, Sabine, St. Bernard, St. Charles, St. Helena, St. James, St. John the Baptist, St. Landry, St. Martin, St. Mary, St. Tammany, Tangipahoa, Tensas, Terrebonne, Union, Vermilion, Vernon, Washington, Webster, West Baton Rouge, West Carroll, West Feliciana, and Winn.

United States Major Disaster Declarations

Texas

Major Disaster Declaration made on 08/25/2017.

Counties: Aransas, Austin, Bastrop, Bee, Brazoria, Calhoun, Chambers, Colorado, DeWitt, Fayette, Fort Bend, Galveston, Goliad, Gonzales, Grimes, Hardin, Harris, Jackson, Jasper, Jefferson, Karnes, Kleberg, Lavaca, Lee, Liberty, Matagorda, Montgomery, Newton, Nueces, Orange, Polk, Refugio, Sabine, San Jacinto, San Patricio, Tyler, Victoria, Walker, Waller, and Wharton.

Appendix D

Glossary: Terms as defined by the National Hurricane Center

Advisory:
Official information issued by tropical cyclone warning centers describing all tropical cyclone watches and warnings in effect along with details concerning tropical cyclone locations, intensity and movement, and precautions that should be taken.

Best Track:
A subjectively-smoothed representation of a tropical cyclone's location and intensity over its lifetime. The best track contains the cyclone's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at 6-hourly intervals. Best track positions and intensities, which are based on a post-storm assessment of all available data, may differ from values contained in storm advisories.

Direct Hit:
A close approach of a tropical cyclone to a particular location. For locations on the left-hand side of a tropical cyclone's track, a direct hit occurs when the cyclone passes to within a distance equal to the cyclone's radius of maximum wind. For locations on the right-hand side of the track, a direct hit occurs when the cyclone passes to within a distance equal to twice the radius of maximum wind.

Eye:
The roughly circular area of comparatively light winds that encompasses the center of a severe tropical cyclone. The eye is either completely or partially surrounded by the eyewall cloud.

Eyewall:
An organized band or ring of cumulonimbus clouds that surround the eye, or light-wind center of a tropical cyclone.

Extratropical:
A term used in advisories and tropical summaries to indicate that a cyclone has lost its "tropical" characteristics. The term implies both northward displacement of the cyclone and the conversion of the cyclone's primary energy source from the release of latent heat of condensation to baroclinic (the temperature contrast between warm and cold air masses) processes. Cyclones can become extratropical and still retain winds of hurricane or tropical storm force.

Extratropical Cyclone:
A cyclone of any intensity for which the primary energy source is baroclinic, that is, results from the temperature contrast between warm and cold air masses.

Gale Warning:
A warning of 1-minute sustained surface winds in the range 34 knots (39 mph (63 kph)) to 47 knots (54 mph (87 kph)) inclusive, either predicted or occurring and not directly associated with tropical cyclones.

High Wind Warning:
A high wind warning is defined as 1-minute average surface winds of 35 knots (40 mph (64 kph)) or greater lasting for 1 hour or longer, or winds gusting to 50 knots (58 mph (93 kph)) or greater regardless of duration that are either expected or observed over land.

Hurricane:
A tropical cyclone in which the maximum sustained surface wind (using the US 1-minute average) is 64 knots (74 mph (119 kph) or more.

Hurricane Warning:
An announcement that hurricane conditions (sustained winds of 74 mph (119 kph) or higher) are *expected* somewhere within the specified area of a tropical, subtropical or post-tropical cyclone. The warning can remain in effect when high water or a combination of high water and waves continue, even though winds may be less than hurricane-force.

Hurricane Watch:
An announcement that hurricane conditions (sustained winds of 74 mph (119 kph) or higher) are *possible* within the specified area of a tropical, subtropical or post-tropical cyclone.

Indirect Hit:
Generally refers to locations that do not experience a direct hit from a tropical cyclone, but do experience hurricane force winds (either sustained or gusts) or tides of at least 4.0 feet above normal.

Inundation:
The total water level that occurs on normally dry ground as a result of the storm tide, and is expressed in terms of height above ground level.

Invest:
A weather system for which a tropical cyclone forecast center is interested in collecting specialized data sets and/or running model guidance. The designation of a system as an invest does not correspond to any particular likelihood of development of the system into a tropical cyclone.

Landfall:
The intersection of the surface center of a tropical cyclone with a coastline. Because the strongest winds in a tropical cyclone are not located precisely at the center, it is possible for a cyclone's strongest winds to be experienced over land even if landfall does not occur. Similarly, it is possible for a tropical cyclone to make landfall and have its strongest winds remain over the water.

Major Hurricane:
A hurricane that is classified as Category 3 or higher on the Saffir-Simpson Hurricane Wind Scale.

Post-Tropical Cyclone:
This term describes a cyclone that no longer possesses sufficient tropical characteristics to be considered a tropical cyclone. Post-tropical cyclones can continue carrying heavy rains and high winds. Former tropical cyclones that have become fully extratropical or remnant lows are two classes of post-tropical cyclones.

Radius of Maximum Winds:
The distance from the center of a tropical cyclone to the location of the cyclone's maximum winds. In well-developed hurricanes, the radius of maximum winds is generally found at the inner edge of the eyewall.

Rapid Intensification:
An increase in the maximum sustained winds of a tropical cyclone of at least 30 knots (35 mph (55 kph)) in a 24-hour period.

Remnant Low:
A post-tropical cyclone that no longer possesses the convective organization required of a tropical cyclone, and has maximum sustained winds of less than 34 knots (39 mph (63 kph)).

Storm Surge:
An abnormal rise in sea level accompanying a hurricane or other intense storm, and whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge is usually estimated by subtracting the normal or astronomic high tide from the observed storm tide.

Storm Tide:
The actual level of sea water resulting from the astronomic tide combined with the storm surge.

Storm Warning:
A warning of 1-minute sustained surface winds of 48 knots (55 mph (88 kph)) or greater, predicted or occurring, not directly associated with tropical cyclones.

Subtropical Cyclone:
A non-frontal low-pressure system that has characteristics of both tropical and extratropical cyclones. Like tropical cyclones, they are non-frontal, synoptic-scale cyclones that originate over tropical or subtropical waters, and have a closed surface wind circulation with a well-defined center. Unlike tropical cyclones, subtropical cyclones derive a significant proportion of their energy from baroclinic sources, and are generally cold-core in the upper troposphere, often being associated with an upper-level low or trough. In comparison to tropical cyclones, these systems generally have a radius of maximum winds occurring relatively far from the center and generally have a less symmetric wind field and distribution of convection.

Subtropical Depression:
A subtropical cyclone in which the maximum sustained surface wind speed (using the US 1-minute average) is 33 knots (38 mph (62 kph)) or less.

Subtropical Storm:
A subtropical cyclone in which the maximum sustained surface wind speed (using the US 1-minute average) is 34 knots (39 mph (63 kph)) or more.

Tropical Cyclone:
A warm-core non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere.

Tropical Depression:
A tropical cyclone in which the maximum sustained surface wind speed (using the US 1-minute average) is 33 knots (38 mph (62 kph)) or less.

Tropical Disturbance:
A discrete tropical weather system of apparently organized convection originating in the tropics or subtropics, having a non-frontal migratory character, and maintaining its identity for 24 hours or more.

Tropical Storm:
A tropical cyclone in which the maximum sustained surface wind speed (using the US 1-minute average) ranges from 34 knots (39 mph (63 kph)) to 63 knots (73 mph (118 kph)).

Tropical Storm Warning:
An announcement that tropical storm conditions (sustained winds of 39 to 73 mph) are *expected* somewhere within the specified area within 36 hours in association with a tropical, subtropical or post-tropical cyclone.

Tropical Storm Watch:
An announcement that tropical storm conditions (sustained winds of 39 to 73 mph) are *possible* within the specified area within 48 hours in association with a tropical, subtropical or post-tropical cyclone.

Tropical Wave:
A trough or cyclonic curvature maximum in the trade-wind easterlies. The wave may reach maximum amplitude in the lower middle troposphere.

Contact Information

Adam Podlaha
Head of Impact Forecasting
Aon Benfield Analytics
Impact Forecasting
+44.20.7522.3820
adam.podlaha@aonbenfield.com

Steve Bowen
Director / Meteorologist
Aon Benfield Analytics
Impact Forecasting
+1.312.381.5883
steven.bowen@aonbenfield.com

Siamak Daneshvaran
Head of Research & Development
Aon Benfield Analytics
Impact Forecasting
+1.312.381.5886
siamak.daneshvaran@aonbenfield.com

Michal Lörinc
Catastrophe Analyst
Aon Benfield Analytics
Impact Forecasting
+420.234.618.358
michal.lorinc@aonbenfield.com

Anwesha Bhattacharya
Senior Analyst
Aon Benfield Analytics
Impact Forecasting
+ 91.080.6621.8575
anwesha.bhattacharya@aonbenfield.com

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