CEDIM Forensic Disaster Analysis Group (FDA)

Hurricane / Tropical Storm Harvey

Information as of 29 August 2017 – Report No. 1

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SUMMARY

Official Disaster Name	Date	Landfall UTC	Local	Duration
Hurricane 09L Harvey	**26-08**	**03 UTC**	**-5**	
Tropical Depression, Tropical Storm, Hurricane Cat 1 - Cat 4	**13-08 – present**			**16+ days**

Preferred Hazard Information:

Location	Movement	Definition (Saffir-Simpson Scale)	Min Sea Level Pressure	Wind Gusts	Time	Wind Sustained
500 km SW of Cape Verde		**Tropical Depression**	**1010 hPa**		**13-08 12 UTC**	**25 kt 46 kph**
500 km E of Barbados	**W 30 kt**	**Tropical Storm**	**1006 hPa**		**17-08 18 UTC**	**35 kt 65 kph**
530 km SE Corpus Christi (TX)	**NW 9 kt**	**Category 1**	**979 hPa**	**90 kt 167 kph**	**24-08 18 UTC**	**75 kt 139 kph**
330 km SE Corpus Christi (TX)	**NW 8 kt**	**Category 2**	**967 hPa**	**110 kt 204 kph**	**25-08 06 UTC**	**90 kt 167 kph**
130 km SE Corpus Christi (TX)	**NNW 9 kt**	**Category 3**	**941 hPa**	**135 kt 250 kph**	**25-08 18 UTC**	**105 kt 194 kph**
25 km E Port Aransas (TX)	**NNW 6 kt**	**Category 4**	**938 hPa**	**140 kt 259 kph**	**26-08 00 UTC**	**115 kt 213 kph**

Location Information:

Country	ISO	Dev. Region	Most Impact	Building PF	HDI (2015)	GDP (2015)	Pop. (2015)
USA	**US**	**Texas (Houston)**	**Houston (FL)**	**Above Avg**	**0.885**	**$503 bn**	**6.66 mill.**

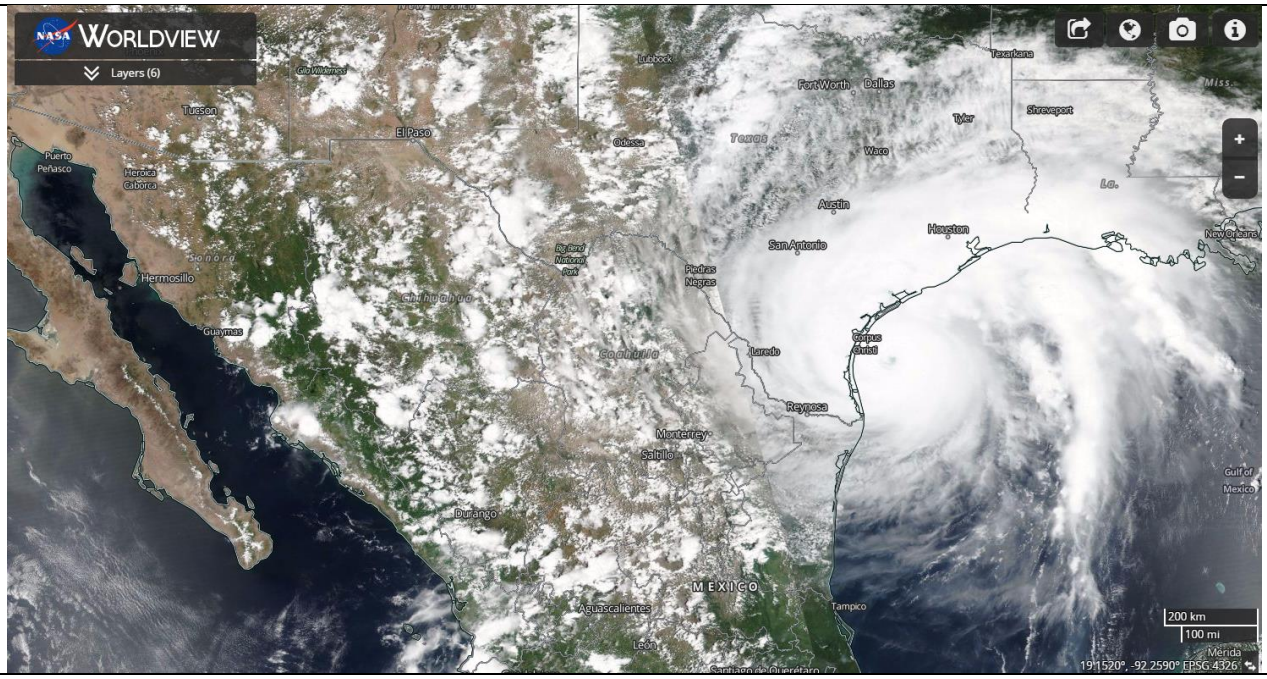
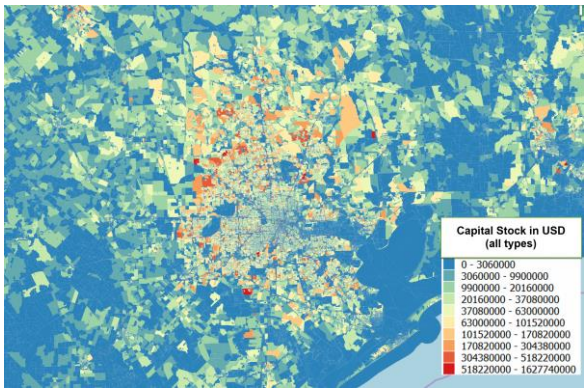


Figure 1: Satellite image showing Harvey shortly before landfall on 26 August 2017 (Image credit: worldview.earthdata.nasa.gov).

Vulnerability and Exposure Metrics (Population, Infrastructure, Economic)



Capital stock per block in Houston Area (CATDAT)

Texas has a gross capital stock totalling around $4.54 trillion, and thus a very high exposure which can be affected by disasters. Of this about $1.5 trillion is residential, and similar amount in non-residential, and the rest made up of government buildings and infrastructure as well as equipment and other goods. There is a large disparity in wealth across the nation as well as GDP in certain regions given the large amount of oil (18% of GDP in Houston is derived from oil vs. 3.6% of workers). In addition, like every metropolis there are richer and poorer neighbourhoods which have very different unit costs. The metropolitan area of Houston has been growing very fast and is the 4th largest metro area GDP in USA.

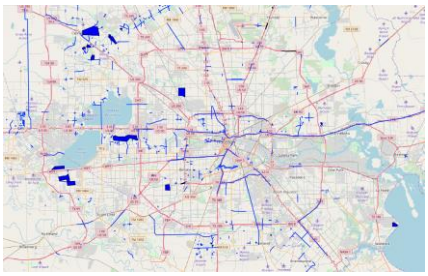
What have been the 2 largest comparable damaging events in the past?

Date - Name	Impact Type	Damage Locations	Social % or Insured %	Economic Loss
2001 Allison	Mainly flooding	TX (Houston), Lousiana	43 deaths, $5 bn insured	$12 bn (2017)
2005 Katrina	Storm Surge, Wind, Flooding	New Orleans, Louisiana, oil rigs.	Ca. 1800 deaths, $82 bn insured losses (Sigma)	$160 bn (2017)

Preferred Building Damage Information: (Damage states will be filled in later when more info available)

Description: *Widespread damage and destruction surrounding the Houston metropolitan area.*

Flooding has occurred in many places around Houston, but also on other river reaches outside of the city causing damage to buildings in Lafayette. 2 dams and a few levees have been breached, but much damage will be to infrastructure, government equipment, cars, commercial and industrial facilities and of course private homes. Around $267 bn in stock is assumed to be damaged to some degree. Around 700 roads are currently blocked.



Current flooded roads – M. Dempsey, Chron.

Effect Information: For weather impacts see *http://www.wettergefahren-fruehwarnung.de*

Type	Impact	Damage %	Social %	Economic %
Wind	Many roads blocked, infrastructure damage, buildings near Rockport, Corpus Christi	Confined to landfall area but likely 50,000 claims	At least 2 deaths	<10%
Flood	Widespread flooding, highest rainfall on record causing flash and riverine flooding of properties, industry, govt.	At this point, claims are unknown but as many as 250,000 properties possible	At least 28 deaths	>90%

Preferred Social Impact Information:

Type	Median	Accepted Range	Description	Source
Deaths	30+	May rise		News reports
Injuries	unknown	May rise	Still counting	News
Rescued	3,500	Up to 13,000	Still counting	News
Homeless/Displaced	50,000	May rise	Estimated 2 million affected	**

Preferred Current Economic Impact Information for Texas: $billion int. event-day dollars

Type	Median	Accepted Range	Description	Source
Replacement Cost	$57.9 bn	$41.6 bn – $80.2 bn	Replacement Cost including structures, equipment for all types (residential, non-residential, govt.) for Texas (using rapid loss model)	CATDAT / CEDIM / Daniell
Total Loss	$40 bn	$25.4 bn – $54.9 bn	Total estimate (using rapid loss model) and depreciated stock	CATDAT/ Daniell
Insured Loss	$10 – 20 bn	unknown	This will become concrete in the coming days. NFIP has a 16% takeout in Harris County, but commercial higher	Industry Estimates

Direct Economic Damage (Total) - Summary

- The rapid loss estimation of CEDIM/CATDAT/James Daniell gives a total damage value coming out to between $38.4 and $82.3 bn with a replacement cost (>$59.8 bn) totalling around 3.5% of GDP in Texas.
- The exposed stock with some damage to floods was calculated to be $267 bn.
- Indirect losses and total macroeconomic effects are expected to increase this estimate, as well as damage in neighbouring Louisiana and further inland as rainfall-induced flooding occurs.

Where does this compare to historical events within CATDAT?

Rank	Year	Month	Day	Country	Location	Type	Killed	Direct Economic Costs ($USDbn 2017)
1	2011	3	11	Japan	Earthquake	Tohoku	18618	218
2	2008	5	12	China	Earthquake	Sichuan	88287	162
3	2005	8	29	United States	Hurricane	Katrina	1833	160
4	1995	1	16	Japan	Earthquake	Kobe	6433	97
5	1994	1	17	United States	Earthquake	Northridge	72	93
6	2012	10	30	United States	Hurricane	Sandy	159	70
7	1980	11	23	Italy	Earthquake	Irpinia	2900	67
8	2010	5	29	China	Flood	Fujian	1691	62
9	**2017**	**8**	**26**	**United States**	**Hurricane (Flood)**	**Harvey**	**30+**	**58**
10	1923	9	1	Japan	Earthquake	Great Kanto	105385	51
10	1998	7	1	China	Flood	Hubei	3656	51

1. Meteorological Information

1.1. Evolution of Hurricane Harvey

Harvey arose from a tropical wave west of West Africa on 13 August 2017 and quickly travelled westwards across the tropical Atlantic Ocean. Before entering the Caribbean Sea, Harvey was classified as a tropical storm for the first time on 17 August 2017. While crossing the Lesser Antilles and moving over the Caribbean Sea Harvey decreased and nearly dissipated; he was neither classified as tropical storm nor a tropical depression any more. The remnants moved into a northwesterly direction across the Mexican peninsula of Yucatan towards the southwestern Gulf of Mexico until 22 August 2017. Due to very favourable conditions – sea surface temperatures of 30–31°C and low windshear – Harvey reawoke, warm and moist air near the surface began to circle around a center and finally intensified into a category 1 hurricane in the evening of 24 August 2017. Unlike most forecast models suggested, Harvey strengthened into a category 4 hurricane in just over 24 hours and immediately before arriving at the shoreline of Texas (Figure 2).

Harvey crossed San Jose Island and Aransas Bay and came ashore on 26 August 2017 around 03 UTC close to the city of Rockport with about 10.000 residents. With landfall the hurricane became quasi stationary south west of Victoria. As large parts of the hurricane were still over sea, enormous amounts of energy were released by moist and warm airmasses that came directly from the Gulf of Mexico and continued to feed the system. Radar and satellite images images showed a well pronounced eye until 10 UTC and Harvey lost his hurricane status not before 18 UTC.

Figure 2: Track and intensity of Harvey (shown: 21–29 August 2017; data source: National Hurricane Center).

On 27 August 2017, propagation speeds were as little as 3 kph. Over several days, the entire troposphere was characterized by very little wind speeds at all levels, and there was no steering of Harvey. The jetstream was located far to the north and over the north-western and eastern parts of the USA blocking high pressure systems were present. Harvey became a rain producer releasing rain amounts of biblical extent across south eastern Texas and particularly affecting the greater Houston area.

1.2. Precipitation and Wind

Well before Harvey came ashore the worst had to be assumed concerning rain due to the predicted environmental atmospheric conditions after landfall. Additionally to lingering Harvey a quasi-stationary front was present across the south eastern USA and oriented parallel to the Gulf coast. Converging low level northerly and south easterly winds along the frontal system siginificantly enhanced precipitation processes. Not surprisingly, some long-term rain records were pulverised.

The outer rain bands of Harvey captured the Texas coast in the morning hours of 25 August 2017. They intensified particularly at the eastern edge of the approaching storm and until evening they extended to western Louisiana.

After landfall heaviest precipitation concentrated over the area between Houston, San Antonio and Austin.In the course of the afternoon the gap between the inner and outer spiral rain bands increased indicating Harvey's weakening. At midnight rain areas stretched to Shreveport, some 500 km away from the storm center. During the morning hours on 27 August 2017 rain areas moved away from the storm's center into northerly and easterly directions. An elongated band of rain affected Houston; like a string of pearls embedded convectively enhanced rain areas were responsible for extreme rain rates and were supplied by a steady flow of warm and moist air from the Guld of Mexico. Thus also some regions in Louisiana received heavy rainfall. A similar scenario occurred on 28 August 2017.

Rain Amounts

On 27 August 2017, 100–200 mm per hour were observed (25–50 mm would be an extreme event already). 6 hourly rain amounts between 300 and 350 mm correspond to a return period of 500 years according to Harris County Flood Control District.

Rainfall totals in Harris County were as high as around 1000 mm within 4 – 5 days (Table 1). For example, the station Clear Creek @ I-45 recorded 326 mm within 6 hours (27 August 2017) and accumulated storm rain amount (25–29 August 2017) was 1199 mm.

Table 1: Selection of storm total rain amounts (25 August 2017, 01 UTC – 29 August 2017, 14 UTC; Data source: NWS Weather Prediction Center).

Texas	Marys Creek at Winding Road	1250 mm
Texas	Cedar Bayou at FM 1942	1235 mm
Texas	Clear Creek at I-45	1199 mm
Texas	Dayton	1170 mm
Texas	Santa Fe	1144 mm
Louisiana	Iowa	378 mm
Louisiana	Lake Charles	337 mm

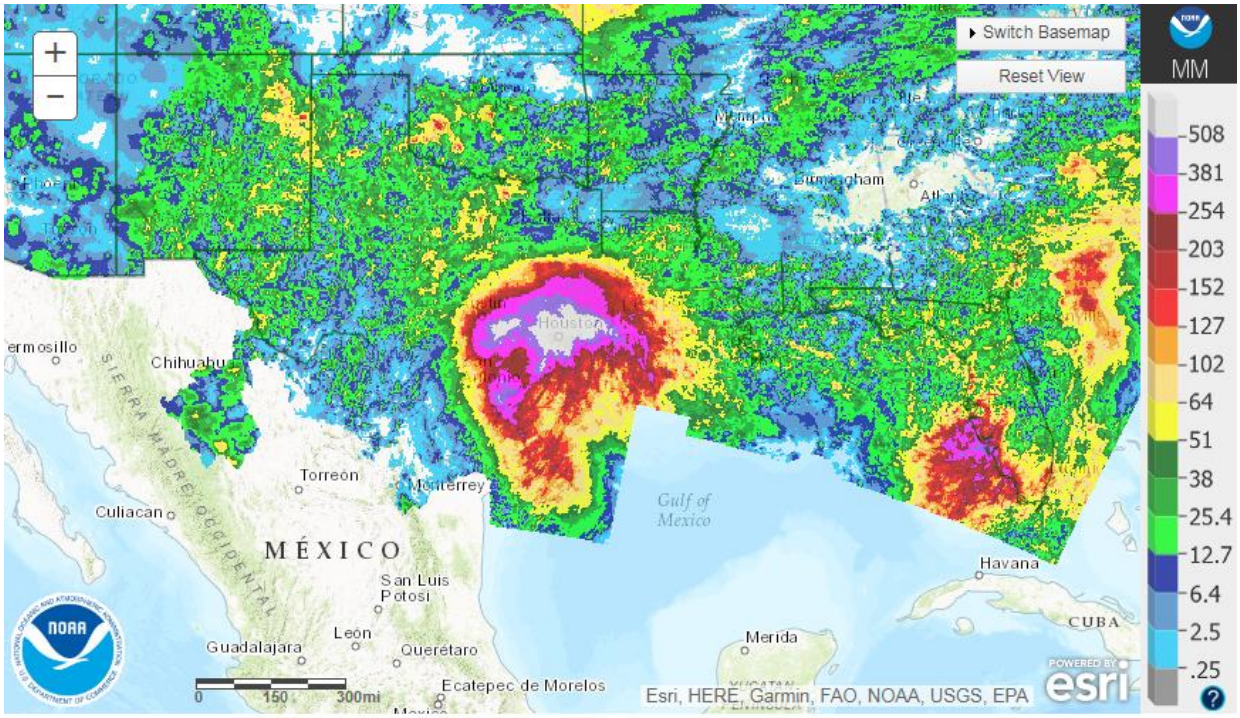


Figure 3: 7-Day Observed Precipitation prior to 29 August 2017, 12 UTC (Image credit: water.weather.gov/precip).

Wind

With making landfall close to peak storm intensity Harvey led to hurricane force winds in the coastal areas of Texas between Corpus Christi and Port Lavaca. Recorded maximum wind gusts were 212 kph in Port Aransas (Table 2).

Table 1: Selected peak wind gusts in Texas related to Harvey

Texas	Port Aransas	212 kph
Texas	Copano Village	201 kph
Texas	Lamar	177 kph
Texas	Rockport	174 kph
Texas	Taft	145 kph

1.3. Some meteorological facts about Harvey

Harvey had a minimum central pressure of 938 hPa on 26 August 2017. It was a category 4 hurricane with 1 min-sustained winds of 215 kph and gusts of 260 kph. Landfall was near Rockport (Texas) around 03 UTC on 26 August 2017. Harvey was responsible for enormous rain amounts of more than 1200 mm within 4 days that have never been recorded before in many places. Houston International Airport got “only” 771 mm; for comparison: Long term precipitation average (1981–2010) at this location is 96 mm for the entire month of August. 771 mm represents 61% of average year rain per year.

Harvey was the strongest hurricane to hit the mainland USA since Charley on 13 August 2004. The last major hurricane (category 3 or above) to cross the US coastline was Hurricane Wilma on 25 October 2005. Harvey brought the longest period without a major hurricane hitting the US – 4323 days – to an end. Harvey is the first hurricane after hurricane Ike (2008) to affect Texas.

Sources:

weather.unisys.com; NRL Tropical Cyclone Page; National Hurricane Center; tropicalatlantic.com; NWS, Weather Prediction Center; weather.rap.ucar.edu; wunderground.com; water.weather.gov; CIMSS Tropical Cyclone Group; Tropical Rainfall Measuring Mission (TRMM); NASA Earth Observatory; Harris County Flood Control District; https://www.texmesonet.org; https://www.washingtonpost.com

2. Flood Situation in the Texas Gulf Region

Actually 74 gauges (from total 446) in the Texas-Gulf-Region are in flood. Major flooding is observed at 42 gauges, moderate flooding at 17 gauges, minor flooding at 15 gauges and 11 gauges are in a near flood stage. At 22 gauges the historic record has been exceeded, the maximum at San Bernard River near Sweeny with a observed water level 11 ft. higher than the former record. The peak is expected at September 3rd .

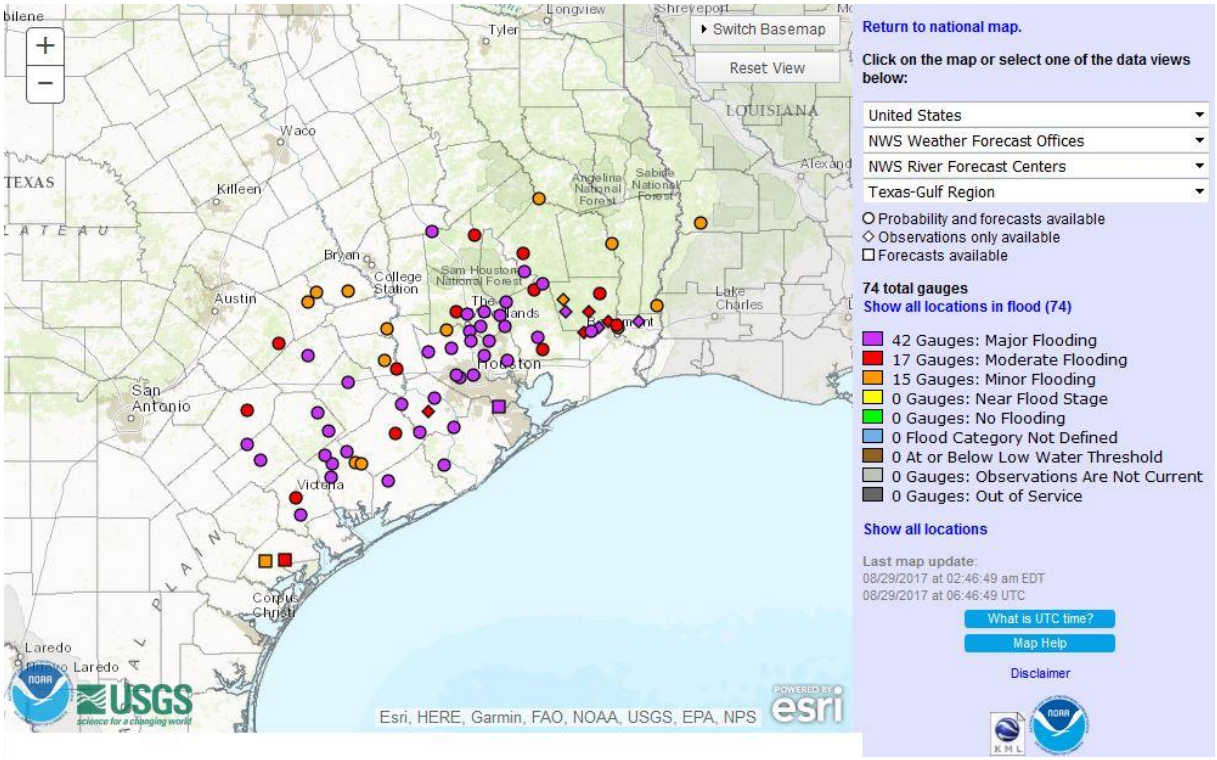


Figure 5: Flood gauges situation in Texas-Gulf-Region (last updated at 29 August 2017; image credit: National Weather Service, National Oceanic and Atmospheric Administrations, NOAA, https://water.weather.gov).

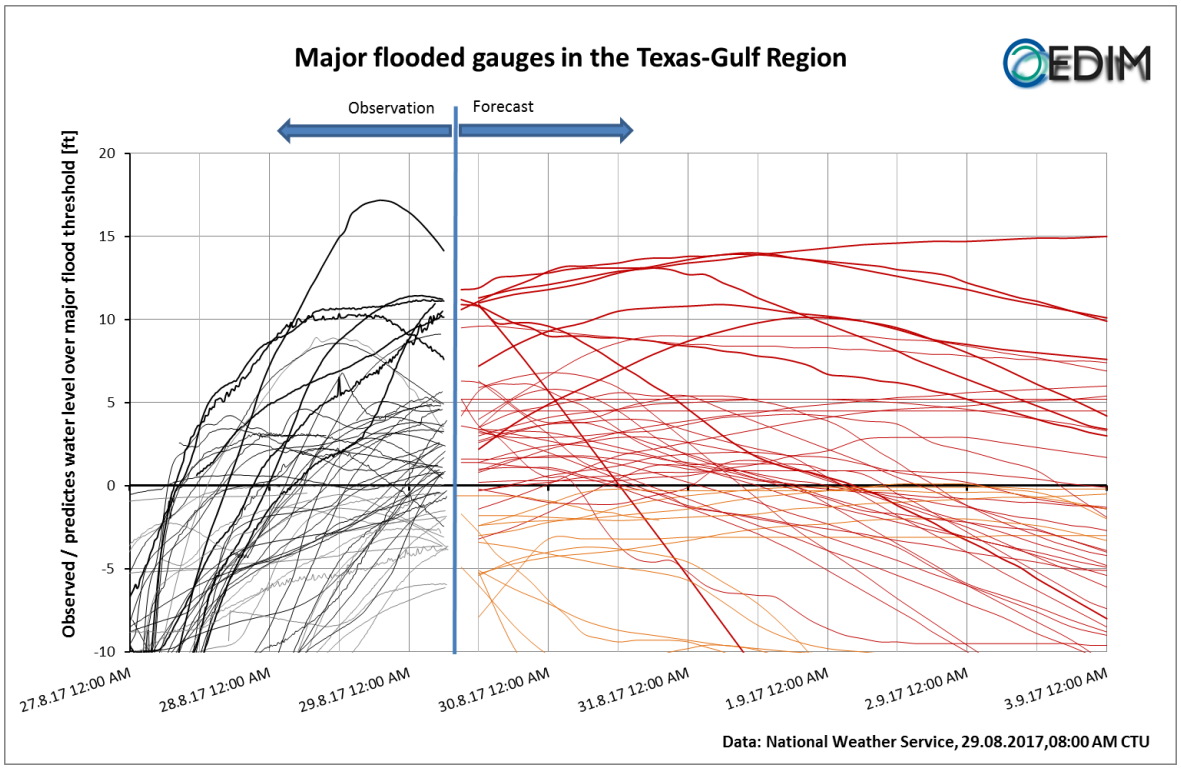


Figure 6: Observed / Predicted water level over major flood threshold at major flood gauges in the Texas-Gulf-Region (Data source: National Weather Service, 29.08.2017,08:00 AM CTU)

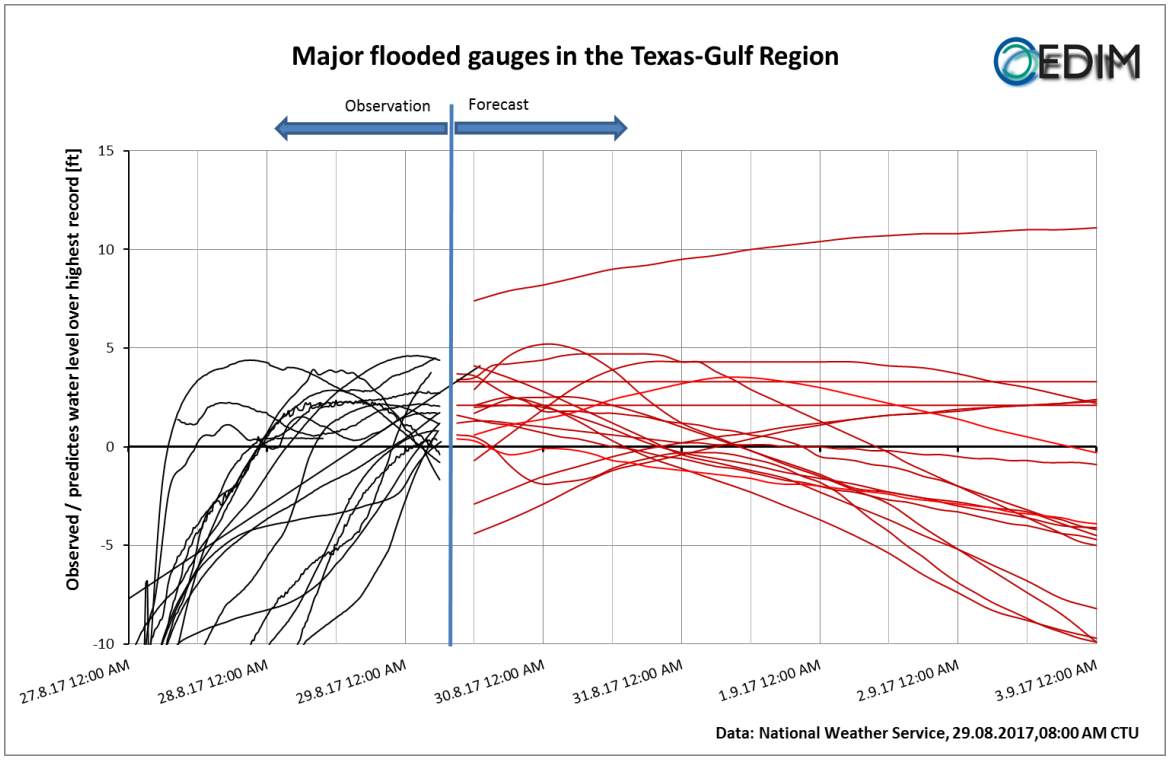


Figure 7: Observed / Predicted water level over highest records in the Texas-Gulf-Region (Data source: National Weather Service, 29.08.2017,08:00 AM CTU)

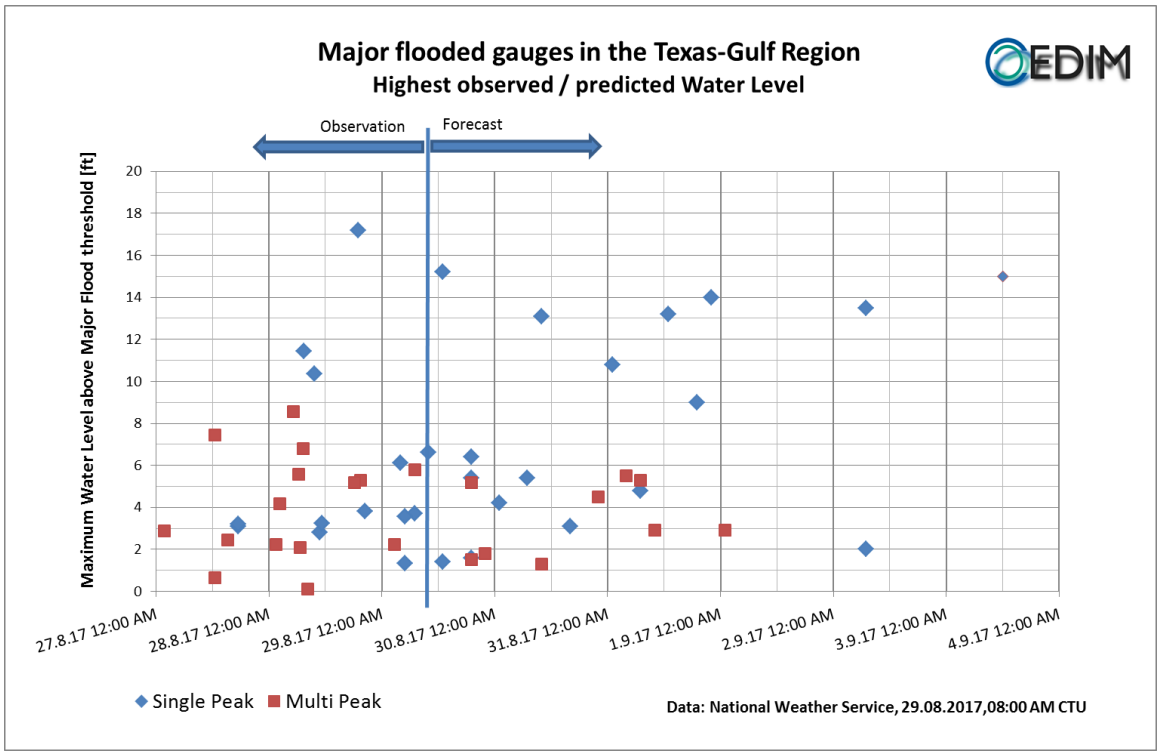


Figure 8: Observed / Predicted maximum water level over major flood threshold at major flood gauges in the Texas-Gulf-Region (Data source: National Weather Service, 29.08.2017,08:00 AM CTU)

Based on the actual forecast, the severe situation will last at the least the next three days. In some rivers, the major flood threshold will be exceeded even more than 10 to 15 ft. Due to the ongoing heavy rainfalls at some rivers multiple peaks in maximum water level occurred or will occur the next days. It is expected that the flood situation in the Texas-Gulf-Region will relax after September 3rd.

3. Overfilled reservoirs

In an effort to limit the scope of the disaster, the US Army Corps of Engineers decided to release water from two overfilled reservoirs, Addicks and Barker, although this put downstream areas at further risk.

Since their construction around half a century ago, Addicks and Barker dams with a total storage capacity of about 410,000 acre feet (510,000,000 m3) have reduced flood damages downstream Buffalo Bayou and in the City of Houston. However, after the 2009 storms, these two dams were tagged by their owner, Corps, with an "extremely high risk of catastrophic failure" label.

Some media reported this failure potential as an explanation for water releasing during Hurricane Harvey, since water level was rising rapidly (Figure 9), increasing the risk of collapse. Corps on the other hand explained the action of water releasing as an attempt to control flood levels at surroundings. “It’s going to be better to release the water through the gates directly into Buffalo Bayou as opposed to letting it go around the end and through additional neighborhoods and ultimately into the bayou,” said Zetterstrom, Galveston District commander.

Sources:

https://waterdata.usgs.gov/tx/nwis/uv/?site_no=08072500
https://waterdata.usgs.gov/usa/nwis/uv?site_no=08073000
http://www.swg.usace.army.mil/Media/News-Releases
https://en.wikipedia.org/wiki/Addicks_Reservoir
http://www.houstonpress.com/news/if-the-addicks-and-barker-dams-fail-6594886
https://www.usatoday.com/story/news/nation-now/2017/08/28/controlled-release-water-houston-reservoirs/607594001/

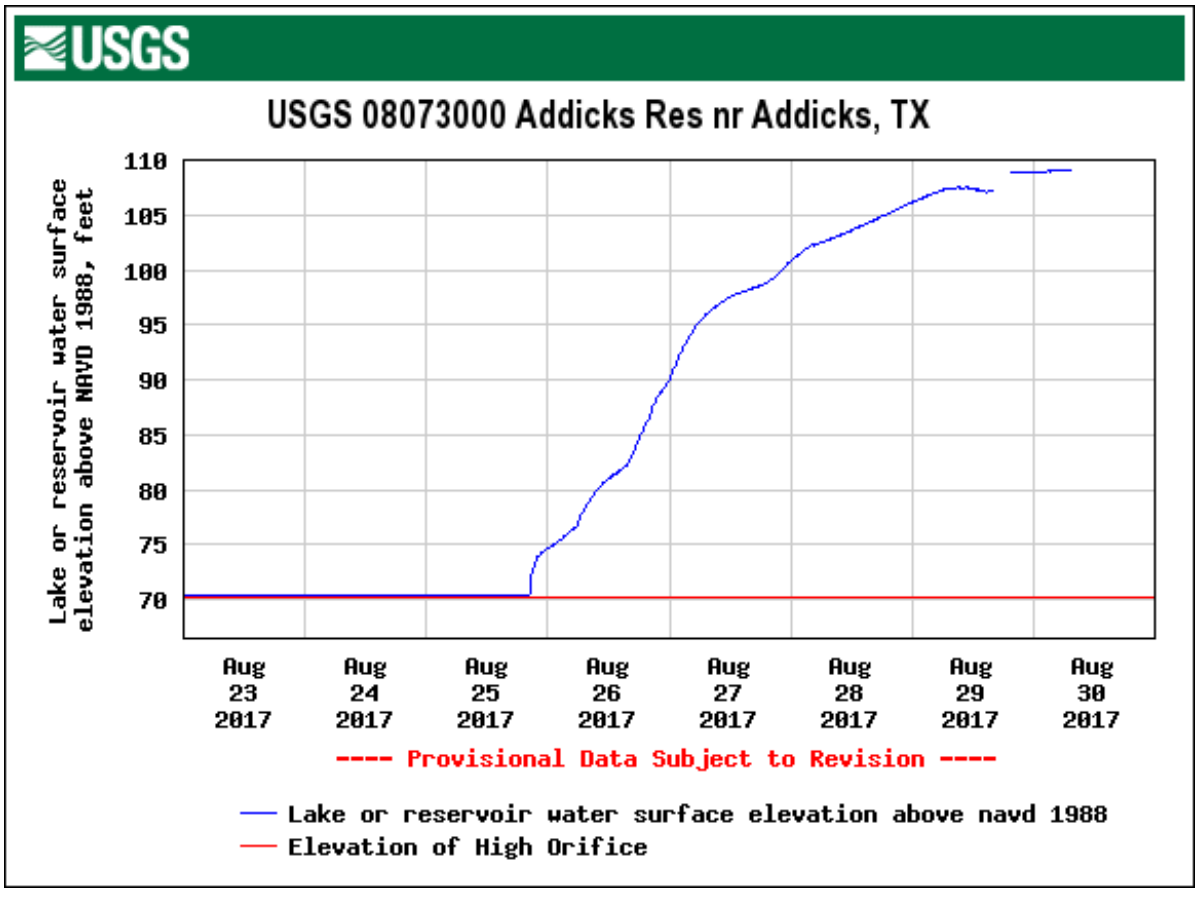


Figure 9: Rising water levels at Addicks reservoirs during Hurricane Harvey (source: USGS National Water Information System).

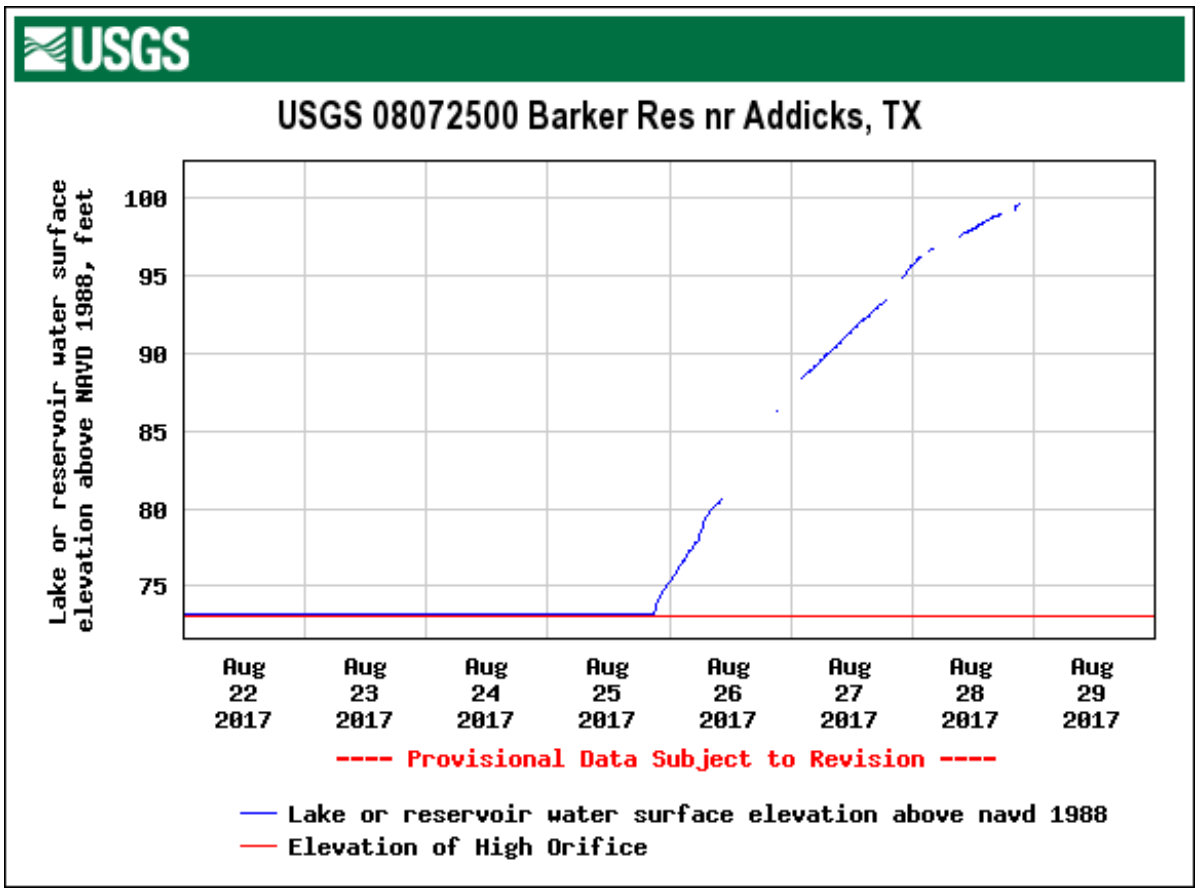


Figure 10: As Figure 9 for rising water levels at Barker reservoirs (source: USGS National Water Information System).

4. CEDIM Loss Modelling

Loss modelling has been undertaken using various datasets to create a loss estimate. The hazard data was derived from rainfall data as above, and similarly flow data was used to calibrate a return period in each subcatchment which was then used to derive the losses from the National Flood Hazard Map layers depending on which zonation and river flow data were used.

The derived flood maps were then plotted on block census data, which had been converted with residential and non-residential capital stock estimates. In addition, government capital stock has been derived and various portions in transportation networks, buildings and other components have been examined. A total exposed value to flood waters and high winds upwards of $267 bn has been estimated out of a total of $4.54 tn.

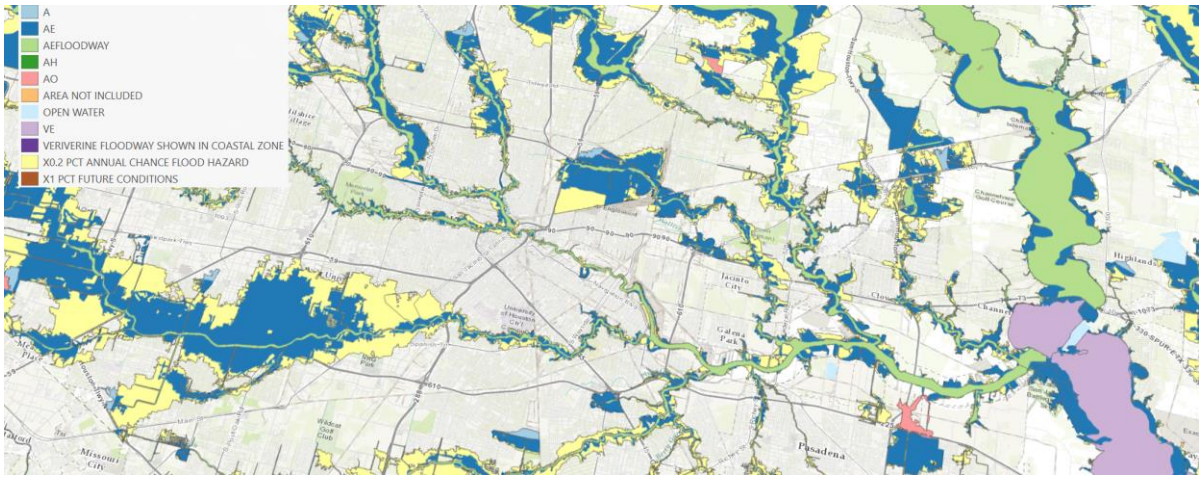


Figure 11: Possible flood extents derived from flood hazard maps (NFHL, Texas) as well as Q3 flood maps.

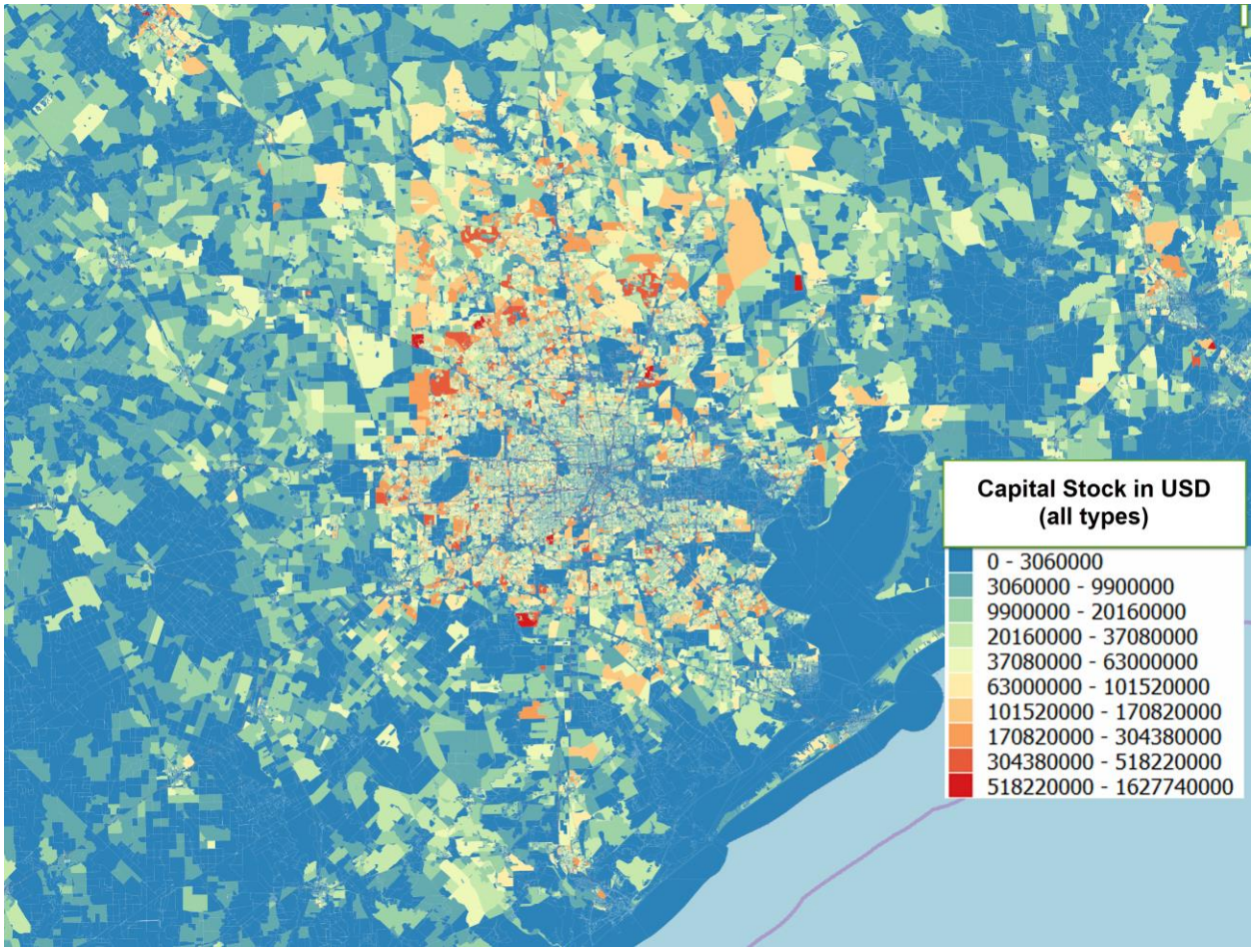


Figure 12: Example of capital stock per census unit for the loss analysis in Houston (CATDAT).

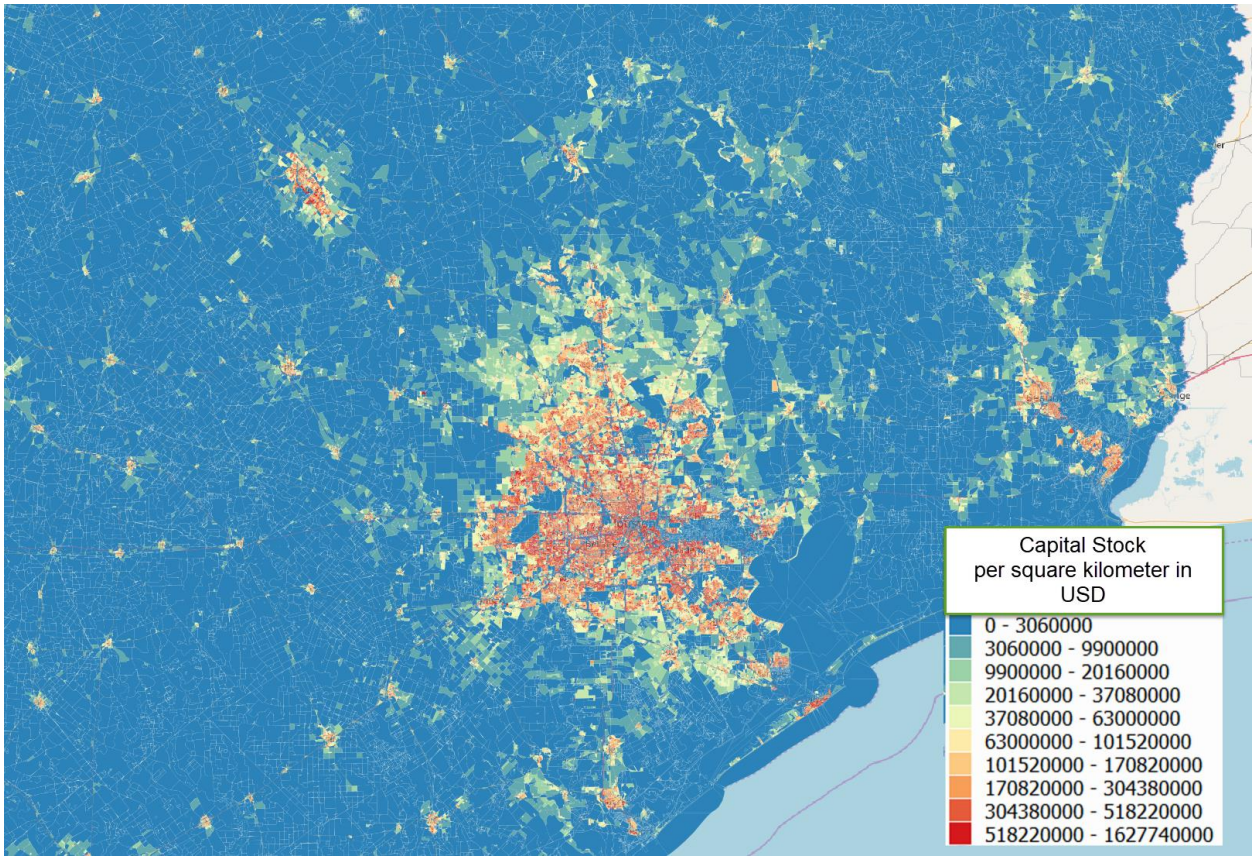


Figure 13: Example of capital stock normalised by area for the loss analysis in Houston (CATDAT).

The flood vulnerability functions have been derived on the basis of HAZUS and other datasets such as Huizinga et al. (2017) in order to create robust flood vulnerability functions. The hurricane vulnerability functions have been derived with respect to Pita et al. (2014) and HAZUS.

A loss estimation was undertaken for flood as well as wind from the hurricane in order to get an understanding of the magnitude of the event, as well as the possible range of losses. The wind modelling gave a loss between $3.55 bn and $4.94 bn, and thus compared to the flood losses is reasonably small. The flood losses however, were significant giving a value between $38 bn and $75.3 bn for the event.

Table 3: Losses resulting from the analysis in billion USD in each sector.

	Residential	Non-Residential	Government	Goods (Automobiles etc.)	Total
Minimum	13.7	11.5	12.7	3.7	41.6
Maximum	26.7	22.3	24.1	7.1	80.2
Median	19.1	16.1	17.5	5.2	57.9

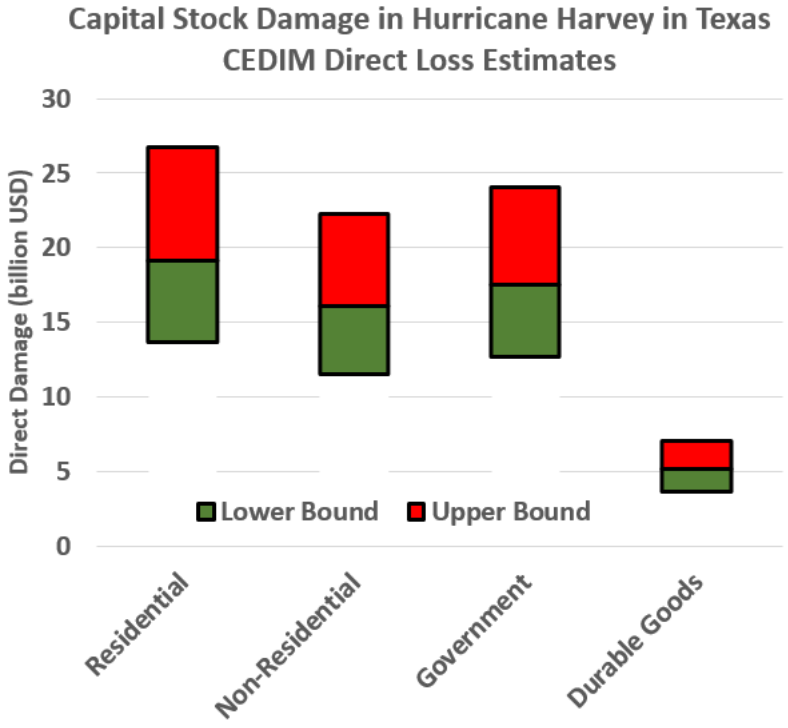


Figure 14: Direct loss estimates for Hurricane Harvey for Texas showing error bounds for the median estimate as of 29th August 2017.

This was also compared to historic losses within CATDAT in order to provide a reasonable loss estimate such as for the events of Allison in 2001 and Katrina in 2005.

The downtime within the oil industry as mentioned below, will have some impact, however compared to capital losses will not exceed them. Similarly the power outage to 300,000 customers will have an effect depending on the length of outages. As more information comes to light, these estimates as well as the indirect losses associated with the event will become possible to calculate. It is important to note the Gross domestic product (GDP) compared to the percentage of employed, as it is likely that tourism outages and other issues for downtime in terms of health care could cause more losses than lost earnings from the mining/oil sector.

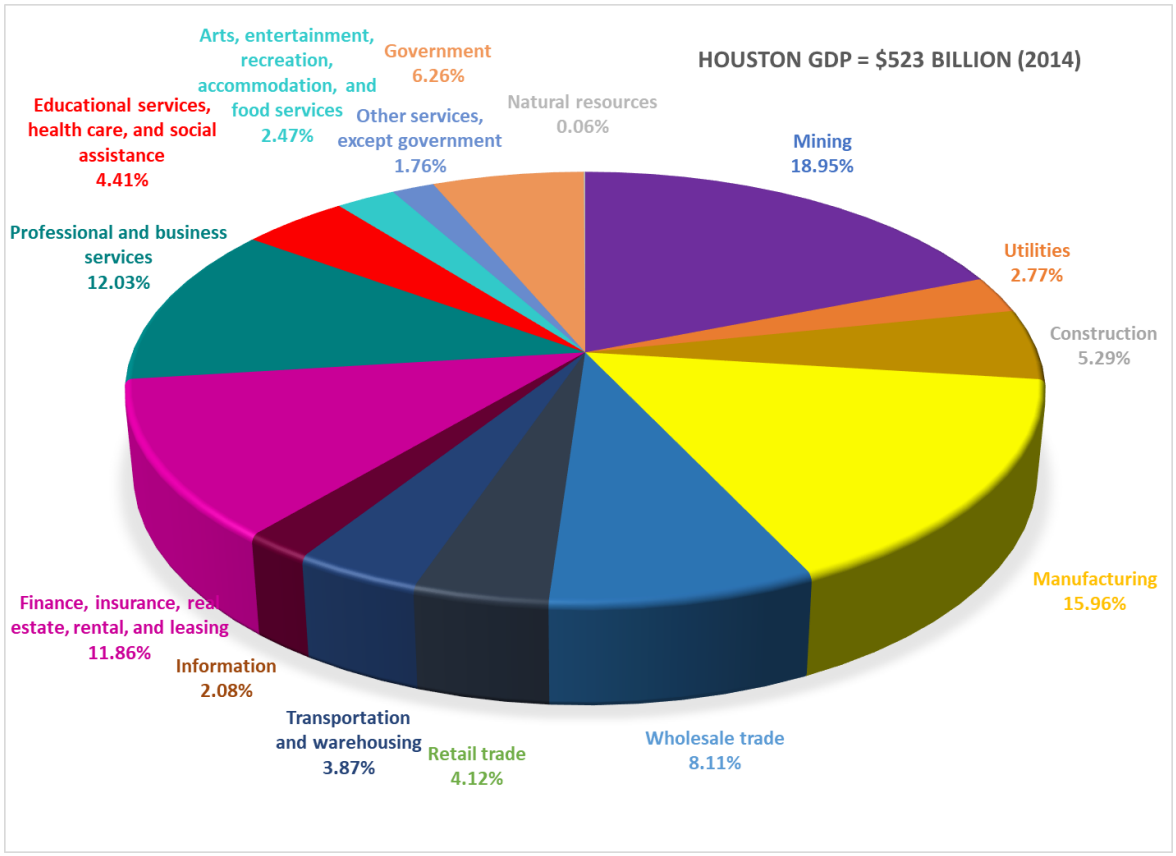


Figure 15: GDP estimates for Houston MSA including breakdown of sectors (Data aggregated from Bureau of Economic Analysis).

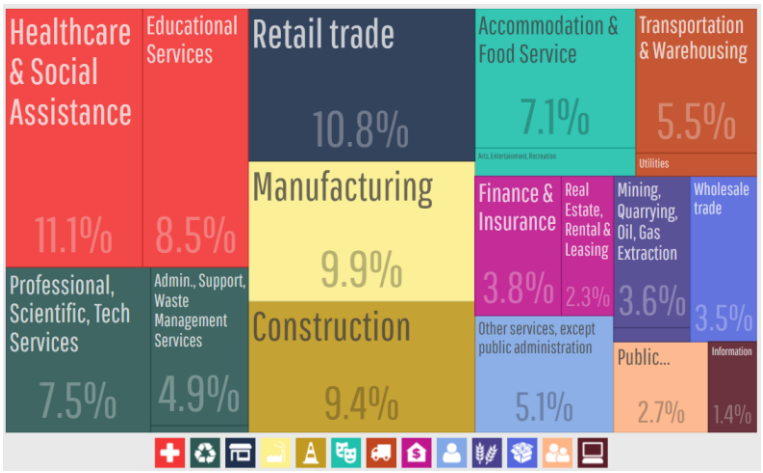


Figure 16: Employment in key sectors. It can be seen that Mining and oil produce about 5 times the GDP comparative to the number of employed people in the sector. (DataUSA diagram - GNU Affero General Public License v3.0 (GPLv3), www.datausa.io).

5. Critical Infrastructure and Production affected by Harvey

Power grid

US DOE reported about the power outages across Texas and Louisiana. On Saturday morning, 258,137 customer power outages across Texas (about 2% of total customers) and no significant power outages in Louisiana were reported. The number increased to 306,058 (about 2.6%) and 5,381 (< 1%) in Texas and Louisiana on Sunday but was slightly reduced to 274,086 (2.3%) and 1,031 (<0.2%) on Monday August 29.

Oil & Gas Production

Starting on Thursday afternoon, 21.5% of the oil production and 23.2% of the natural gas production in Gulf of Mexico were shut-in as a precaution in anticipation of the storm. The number increased on Saturday to 22% of the oil production and 25.7% of the natural gas production in Gulf of Mexico. By Monday, 43.2% of total Texas Gulf Coast refining capacity and 11.8% of total US. refining capacity were shut-down. If refineries are affected by salt, damage can be crucial. So far this region delivers about 27% of natural gas consumption of the US (NZZ, 28 August 17). Port Arthur refinery has been greatly affected by flooding with capacity reduced to 40%.

Harbour and Ship Channels

Ports in that area are partly closed or open with restriction. It is expected that this will last as long as Harvey is travelling in that area. The Galveston Ship Channel (which is the busiest in the country) was closed on Friday (25 August 2017). Several cruise ships stucked in the Gulf of Mexico.

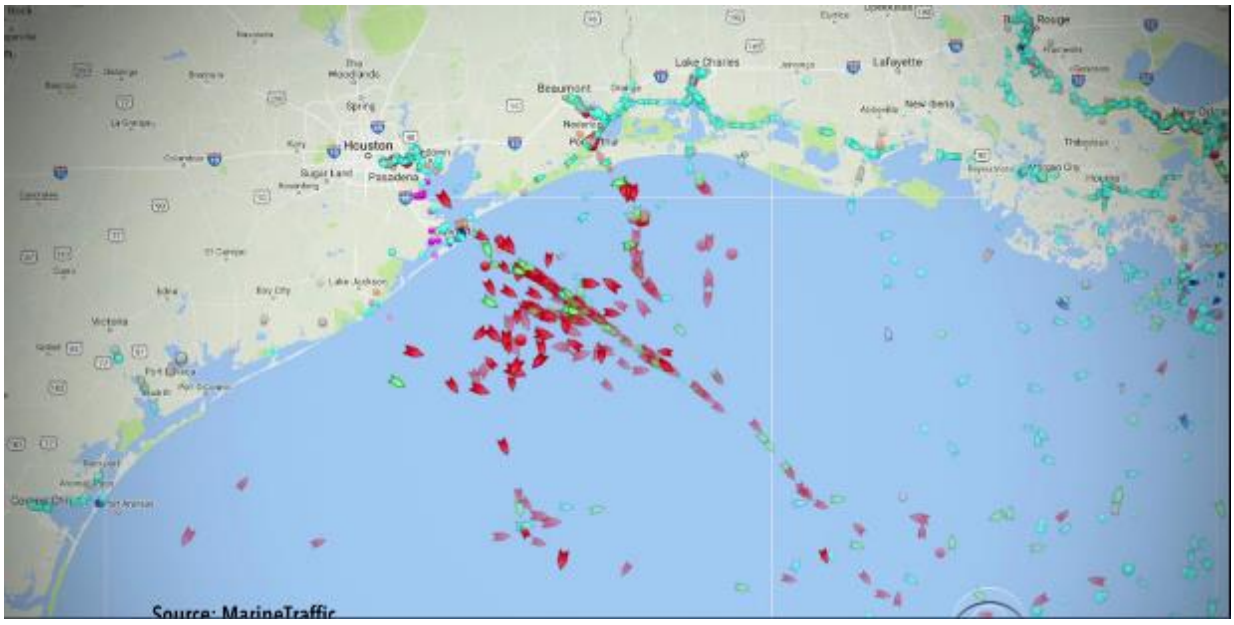


Figure 17: Vessels waiting offshore for Galveston Ship Channel to be re-opened (source: http://www.marinetraffic.com/en/ais/details/ports/8822/USA_port:GALVESTON).

Traffic

Up to 700 roads in the Houston area are closed and flooded according to the crowd sourced map of Marc Dempsey from the Houston Chronicle, the list includes much of I-10, I-45, 290, 288, Beltway 8, the Westpark tollway, and Sam Houston Tollway. On a two-lane Texas highway a massive sinkhole had formed and finally collapse making the highway impassable.

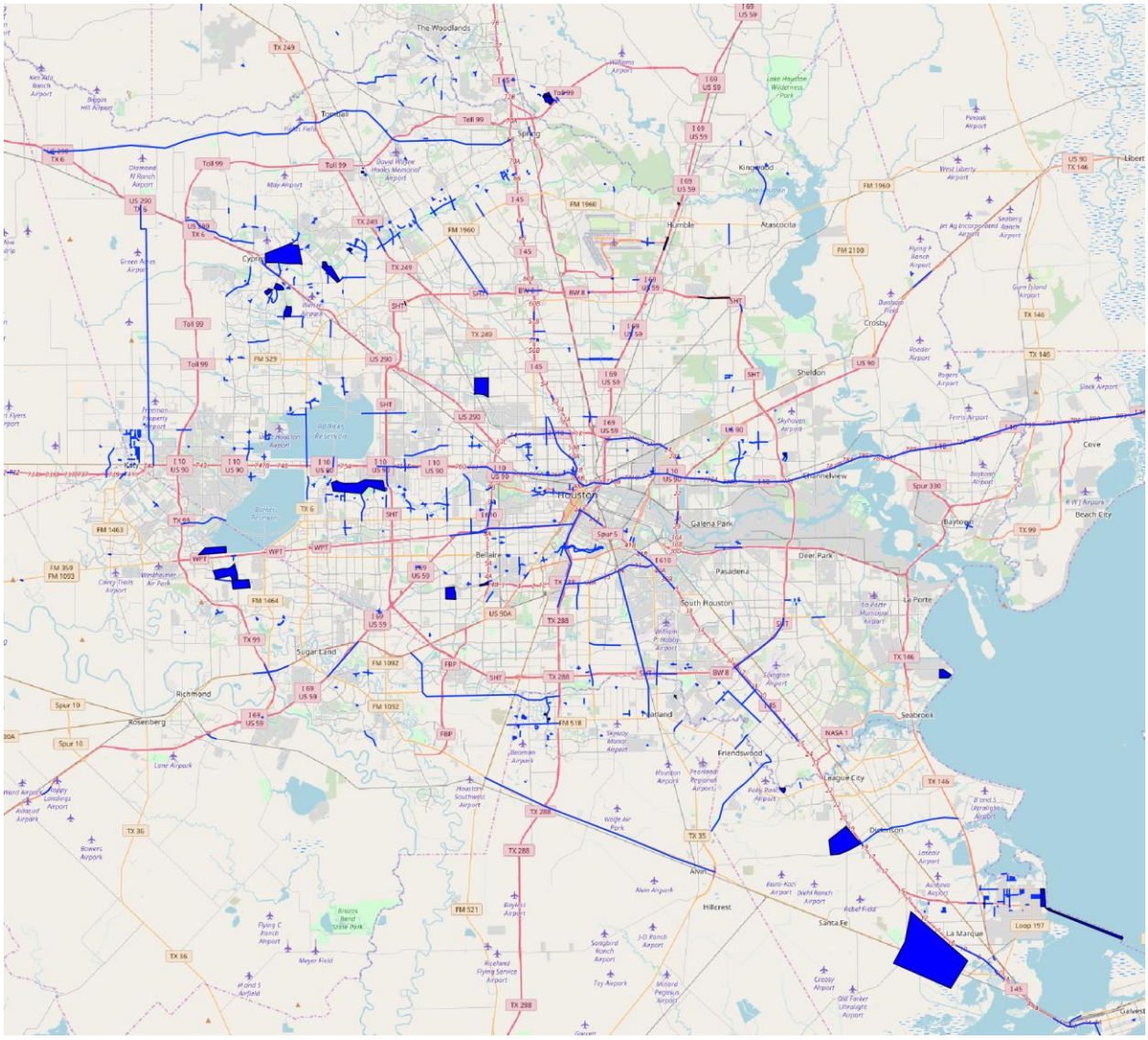


Figure 18: Flooded Roadways picture of Greater Houston made via data from crowd sourcing care of M. Dempsey, Chron and Google; and also OpenStreetMap.

Airports

Both of Houston's major airports have closed — along with six others in the area, including Corpus Christi (CRP). Houston's George Bush Intercontinental (IAH) is closed to all flights except for military and relief flights. Nearly 4000 flights were cancelled in total. Harvey has caused major disruptions across the US.

Other infrastructure

One hospital in Houston was evacuated and evacuation of one is ongoing (27 August 2017). On Monday, 28 August 2017, a further hospital in Sugar Land was closed. Elderly care centres were also evacuated in case of flooding. Houston University is closed till 30 August 2017 Wednesday and used as accommodation; several school districts are closed, also parks. Many stores, restaurants and theaters were closed.

Sources:

https://www.energy.gov/oe/downloads/hurricane-harvey-situation-reports-august-2017
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6. Further Reading

Previous CEDIM FDA activities on US-hurricanes:

Sandy 2012: http://www.cedim.de/download/CEDIMFDAreportSandy_2012_no2.pdf

Matthew 2016: http://www.cedim.de/download/FDA_matthew_2016_report1_update2.pdf

Loss Database and Modelling:

CATDAT: https://www.kit.edu/kit/english/pi_2016_058_natural-disasters-since-1900-over-8-million-deaths-and-7-trillion-us-dollars-damage.php

Further detailed meteorological information to relevant hurricanes [in German]:

Harvey 2017: http://www.wettergefahren-fruehwarnung.de/Ereignis/20170825_e.html

Charley 2004: http://www.wettergefahren-fruehwarnung.de/Ereignis/20040820b_e.html

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