# HURRICANE HARVEY SURVEY ASSESSMENT AND LESSONS LEARNED

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**Abstract**

Historically United States had its worst hurricane season in year 2017 with two category 4 hurricanes within two weeks. Hurricane Harvey ranked as category 4, made landfall on August 25, 2017 on San Jose Island east of Rockport, Texas. It moved back to Gulf of Mexico on August 28 and moved along the Texas coast with strong wind shear making it the worst destruction in the Texas History with inland flooding. Based on the losses caused by Hurricane Harvey, it is ranked as the second worst hurricane in the history of the United States, next to hurricane Katrina (category 3) which made landfall on August 29, 2005 in Louisiana. Hurricane Harvey affected a total of over 13 million people in many states and about 9 million in Texas alone. Hurricane Harvey was the eighth named storm, first major hurricane of the 2017 Atlantic hurricane season and within two weeks followed by hurricane Irma (category 4), land fall on September 9, 2017 and was the worst hurricane in the history of Florida and has been ranked as the third worst hurricane in the history of the United States. Based on past data, reliability based model to predict the hurricane frequency along Texas coast and Gulf coast have been developed. Since there was no hurricane in Texas for the past 8 years, based on 9-year cycle there was 92% probability for hurricane in Year 2017. Hurricane Harvey was blamed for at least 88 total deaths and in Texas alone affected 50 counties and 600 zip codes. Immediately after Hurricane Harvey a survey (web based (http://hurricane.egr.uh.edu/news/hurricane-harvey-survey-2017) and phone based (Hurricane HARVEY Assessment)) was undertaken by the Texas Hurricane Center for Innovative Technology (THC-IT) to determine the damages to residential structures and utilities in Texas based on zip codes. The survey is ongoing and responses have been received from over 100 most affected counties. In this survey location (city, county), home ownership, type of residential structures (categorized as wood, brick or concrete), type of insurance, preparedness, utilities (water and power) issues. Also data on cost of damages and type of government assistance received were collected. The survey also included issues related to rapid recovery, transportation, work place/educational institution and debris removal and were grouped into three classes (no problem, problem and major problem) for analyses. The preliminary analyses are based on the data collected from the survey and information available in the literature, especially from FEMA. Harvey survey results have identified the problems related hurricane flooding, insurance, damages, debris issues and rapid recovery. The hurricane Harvey survey results related to losses was also comparable to the FEMA data. Also factors affecting the inland flooding caused by hurricane Harvey have been identified to develop enhanced inland flooding models for built-in environment with the lessons learned on preparedness, losses, raid recovery and debris from the hurricane Harvey.

## Introduction

Hurricanes are the worst natural disaster affecting the United States. One hurricane can cause enormous economic losses, human deaths and place tremendous burden on the local, state and federal governments and insurance industry. In year 2017, United States had the worst hurricane season based on the total losses. In the Gulf of Mexico, there were three hurricanes in the year 2017 with hurricane Harvey (category 4) being the worst hurricane in the State of Texas history and hurricane Irma (category 4) being the worst hurricane in the State of Florida history. Uniqueness about this is that for the first time two hurricanes rated as category 4 happened in the Gulf of Mexico within two weeks originating from the Atlantic Ocean.

The earliest hurricane report came from Christopher Columbus, who encountered a tropical storm near Hispaniola, on one of his voyages to the New World. According to statistics windstorms and hurricanes are the causes of major losses. The main form of losses will be the structural damages, utilities or lifelines lost or business interruptions. The prediction of the impact of a hurricane on economic losses is not only beneficial to the public, but it could also be used by the insurance companies as the reference to decide their policies (Huang et al. 2001). Also it is very important to develop building codes to design appropriate building structures based on these information at different locations. The government could also make regulations for buildings to include not only wind withstanding design but control indoor flooding.

Despite significant improvements in predicting, tracking and warning the public about hurricanes, there has been relatively little progress in predicting inland flooding and estimating the expected hurricane losses in the built-in environments and industrial facilities with debris accumulation. These losses can be in the form of flooding of houses, structural damages to critical infrastructures, damage to utilities, power loss and interruptions to businesses and educational activities. After hurricane Harvey, a survey was initiated by the Texas Hurricane Center for Innovative Technology (THC-IT) on August 31, 2017 to determine the preparedness, rapid recovery with damages to residential structures, transportation infrastructure and utilities in the region based on the zip codes. The ongoing responses to the survey have been very good.

### (a) Hurricanes

Hurricanes begin as tropical storms over the moist warm waters in the Atlantic and Pacific Oceans near the equator. As the moisture evaporates it rises until enormous amounts of heated moist air are twisted high in the atmosphere. The winds begin to circle counterclockwise north of the equator or clockwise south of the equator. The relatively peaceful center of the hurricane is called the eye. Around this center, winds move at speeds between 74 and 200 miles per hour. As long as the hurricane remains over waters of 79$^{o}$F or warmer, it continues to pull moisture from the surface and grow in size and force. When a hurricane crosses land or cooler waters, it loses its source of power and its wind gradually slow until they are no longer of hurricane force--less than 74 miles per hour.

Hurricanes over the Atlantic often begin near Africa, drift west on the Trade Winds, and veer north as they meet the prevailing winds coming eastward across North America. Hurricanes over the Eastern Pacific begin in the warm waters off the Central American and Mexican coasts. Eastern and Central Pacific storms are called "hurricanes." Storms to the west of the International Date Line are called "typhoons."

The two NASA-GOES satellites keep their eyes on hurricanes from 22,300 miles above Earth's surface. These satellites were built by NASA and operated by the National Oceanic and Atmospheric Administration (NOAA). It helps with the weather forecasting and warning people when and where these severe storms will hit the land.

**Texas**

Texas has 254 counties, 2595 zip codes with an area of 268,581 square miles. There are 15 coastal counties along the Texas Coast with adjoining populated counties such as Harris County, Fort bend County and Orange County that are frequently affected by the hurricanes reaching Texas. Texas population in year 2017 was 28,704,000 and the coastal population was 7,509,500 which represented over 25% of the population.

**Objectives**

The objective was to investigate the impact of hurricane Harvey on the Texas communities by conducting a survey and also identify the parameters that need to be considered for predictions of inland flooding. The specific objectives are as follows:

(a) Analyze the hurricane Harvey survey data collected to reflect the preparedness, damages, recovery and other issues and compare it to the FEMA data;

(b) Identify the important issues/factors that needs to be integrated with the future predictions of inland flooding and damages caused by hurricanes; and

(c) Lessons learned from hurricane Harvey.

In this study, the Hurricane Harvey Assessment survey prepared by the THC-IT included questions on housing, preparedness, evacuation, insurance, recovery and problems with debris. The data was collected based on the zip codes but the initial analyses are based on the overall responses by the affected communities. Also included in the study are analyses of the data provided by FEMA based on zip codes.

**1. Analyses of hurricane Harvey**

**Hurricane Predictions**

Five coastal states (including west side of Florida) along Gulf of Mexico (GOM) have had the largest number of hurricane landfalls in the history of the United States. From 1851 to 2017, representing 167 years, there have been 173 hurricane landfalls in the five coastal states. During this period the east coast had 89 hurricane landfalls compared to only 7 along the west coast of the U.S. It must be noted that there were also hurricanes without landfall but affecting the coastal states.

By analyzing the data from NOAA for all the five GOM states, the hurricane frequency has been parametrically modeled using the Poisson distribution (Texas Hurricane Center for Innovative Technology Website: http://hurricane.egr.uh.edu) as follows:

$$f(h)=\exp(-\lambda)*\lambda^h/h!; \qquad (h=0,1,2,\ldots), \qquad (1)$$

where, h is the number of hurricane per year, $\lambda$ is the expected number of hurricanes during a year.

**Table 1. Actual and Predicted Frequency of Hurricanes**

| Number of Hurricanes in a year (h) | Count | Hurricane Frequency (Real date) | Predicted Hurricane Frequency (Poisson distribution) |
|---|---|---|---|
| 0 | 59 | 59.00% | 58.29% |
| 1 | 36 | 36.00% | 31.46% |
| 2 | 5 | 5.00% | 8.49% |
| Total | 100 | 100.00% | 98.24% |

Hence based on 100 data from NOAA for one-year cycle, the parameter $\lambda$ for Texas was 0.54 (Table 1) (Liu and Vipulanandan, 2009). Interpreting the data, especially the $\lambda$ value showed that Texas can expect one hurricane every two years.

The prediction models were developed for one-year cycle, two-year cycle to up to 10 year cycle. For eight years from 2009 to 2016 there was no hurricane in Texas. Hence using the 9-year cycle, it predicted 92% possibility of hurricane in year 2017 (Fig. 1) compared to 30% possibility of hurricane based on 1-year cycle.

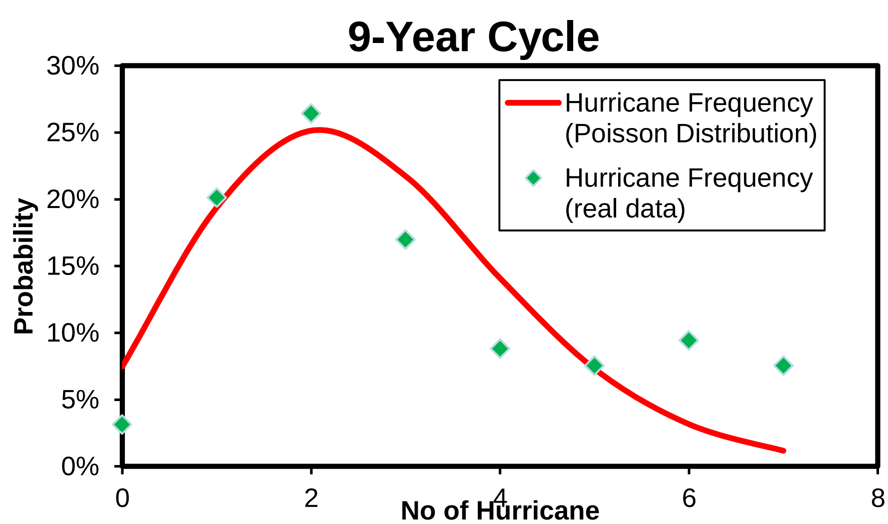


**Figure 1. Probability distribution for 9-year cycle hurricanes in Texas**

**FEMA Data**

The published data from FEMA in December 2017, top 20 zip codes have been identified for both individual assistance and house hold assistance. Combining the two assistances represented total of 24 different zip codes from 8 counties. The total population in the eight counties was 6,573,067. Total of 280,797 were listed in the FEMA application data (individual and housing), which represented 4.3% of the population (Table 2). Analyses and discussions are based on the total affected people and percentage affected based on the county population. Also counties are ranked based on the population in year 2017.

**Harris County (Population 4,652,980, Rank #1)**

The population growth from 2012 to 2017 was 9.4%. It had the largest number of applications from total of 8 zip codes. The highest number of applications was 18,402 from Addick/Bear Creek area and the zip code was 77084. Total number of applications from Harris county was over 98,700 representing over 2.1% of the total population.

**Orange County (Population 85,047, Rank #45)**

The population growth from 2012 to 2017 was 2.5%. It had the second largest number of applications from total of 3 zip codes. The highest number of applications was 16,662 from Vidor and the zip code was 77662. Total number of applications from Orange county was over 44,740 representing over 52.6% of the total population.

**Table 2. Top 20 Zip Codes Applied for Individual and Housing Assistance from FEMA**

| Zip Code | Number of Claims | | | City | County | % Population Affected |
|---|---|---|---|---|---|---|
| | **Individual** | **House** | **Total** | | | |
| 77642 | 13,654 | 6,425 | 20,079 | Port Arthur Area | Jefferson | 7.8 |
| 77084 | 12,770 | 5,632 | 18,402 | Houston-Addick/ Bear Creek Area | Harris | 0.4 |
| 78382 | 11,333 | 7919 | 19,252 | Rock Port | Aransas | 75.3 |
| 77539 | 11,328 | 6,648 | 17,976 | Dickenson | Galveston | 5.4 |
| 77901 | 10,373 | 4,755 | 15,128 | Victoria | Victoria | 16.4 |
| 77662 | 9,782 | 6,840 | 16,622 | Vidor | Orange | 19.5 |
| 77630 | 9,686 | 5,151 | 14,837 | Orange | Orange | 17.4 |
| 77089 | 9,090 | 4,876 | 13,966 | Houston-South Belt/ Ellington Area | Harris | 0.3 |
| 77044 | 8,354 | 4,776 | 13,130 | Lake Houston | Harris | 0.3 |
| 77705 | 8,269 | 3,878 | 12,147 | Beaumont | Jefferson | 4.7 |
| 77090 | 8,141 | | 8,141 | Cypress | Harris | 0.2 |
| 77449 | 7,951 | 4,026 | 11,977 | Katy | Harris | 0.3 |
| 77459 | 7,885 | 5,853 | 13,738 | Missouri City | Fort Bend | 1.8 |
| 77632 | 7,702 | 5,581 | 13,283 | Crange/Mauriceville | Orange | 15.6 |
| 77521 | 7,516 | 3803 | 11,319 | Baytown | Harris | 0.2 |
| 77088 | 7,468 | | 7,468 | Acres Home/Inwood Pines | Harris | 0.2 |
| 77077 | 7,390 | | 7,390 | Briar Forest | Harris | 0.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 77640 | 7,345 | 4,047 | 11,392 | Port Arthur | Jefferson | 4.4 |
| 78415 | 7,198 | 3,543 | 10,741 | Corpus Christi | Nucess | 3.0 |
| 77016 | 6,960 | | 6,960 | Trinity garden | Harris | 0.1 |
| 77450 | | 4,533 | 4,533 | Cinco Ranch | Fort Bend | 0.6 |
| 77479 | | 4,251 | 4,251 | Sugar Land /New Territory | Fort Bend | 0.6 |
| 77407 | | 4,054 | 4,054 | Richmond | Fort Bend | 0.5 |
| 77573 | | 4,011 | 4,011 | League City | Galveston | 1.2 |
| Total | 180,195 | 100,602 | 280,797 | 17 Cities | 8 counties | 4.27 |

**Fort Bend County (Population 764,828, Rank #10)**

The population growth from 2012 to 2017 was 22.2%. It had the third largest number of applications from total of 4 zip codes. The highest number of applications was 13,738 from Missouri City and the zip code was 77459. Total number of applications from Fort Bend County was over 26,570 representing 3.5% of the total population.

**Galveston County (Population 335,036, Rank #17)**

The population growth from 2012 to 2017 was 11.0%. It had the fourth largest number of applications from total of 2 zip codes. The highest number of applications was 17,976 from Dickenson and the zip code was 77539. Total number of applications from Galveston County was over 21,980 representing 6.6% of the total population.

**Jefferson County (Population 251,306, Rank #20)**

The population growth from 2012 to 2017 was 2.0%. It had the largest number of applications one zip code of 20,079 and total of 2 zip codes. The highest number of applications was from Port Arthur area and the zip code was 77642. Total number of applications from Jefferson County was over 32,220 representing over 12.9% of the total population.

**Aransas County (Population 25,572, Rank #101)**

The population growth from 2012 to 2017 was 7.2%. It had only applications from one to zip code but had the third highest number of applications for a zip code. The total number of applications was 19,252 from Rock Port and the zip code was 77382. The hurricane Harvey land fall was here and it affected over 75% of the total population.

**Victoria County (Population 92,081, Rank #43)**

The population growth from 2012 to 2017 was 2.5%. It had the fifth highest number of applications for one zip code. The number of applications was 15,128 from Victoria and the zip code was 77901. It affected over 16.4% of the total population.

**Nucess County (361,221, Rank #15)**

The population growth from 2012 to 2017 was 3.9%. It had the nineteenth highest number of applications from one zip code. The number of applications was 10,741 from Corpus Christi and the zip code was 78415, south of the hurricane Harvey landfall. It affected over 3% of the total population.

**Summary**

The overall percentage affected was 4.27% based on the total population of the affected counties. The data analyses showed large variation in the amounts (total and percentage) of the population affected by the hurricane Harvey. It is important to identify and investigate the many factors that influenced these losses. This will help for future planning for hurricane related disasters.

## Hurricane Harvey Assessment Survey

One week after the hurricane passed through Texas, an assessment survey was initiated by the Texas Hurricane Center for Innovative Technology (THC-IT). The survey was web based (http://hurricane.egr.uh.edu/news/hurricane-harvey-survey-2017) and phone based (Hurricane HARVEY Assessment) to determine the home ownership, preparedness, damages to residential structures, power loss, recovery and debris issues in Texas based on zip codes. The survey is ongoing and responses have been received from 14 counties, over 100 zip codes and 30 cities. Also data on the cost of damages and type of government assistance received are being collected. The survey also included issues related to rapid recovery, transportation, work place/educational institutions and debris removal and are grouped into three classes (no problem, problem and major problem) for analyses. The preliminary analyses are based on the total data collected from the hurricane Harvey survey.

### a. Home Ownership

Over 80% of the survey respondents owned their homes and hence the data collected will help identify the losses encountered during hurricane Harvey. Also 18% of the respondents were in rented houses and apartments. Also 0.4% of the respondents were in living in facility and others include institutional housing. The results of the survey on the types of living homes are compared in Fig. 2.

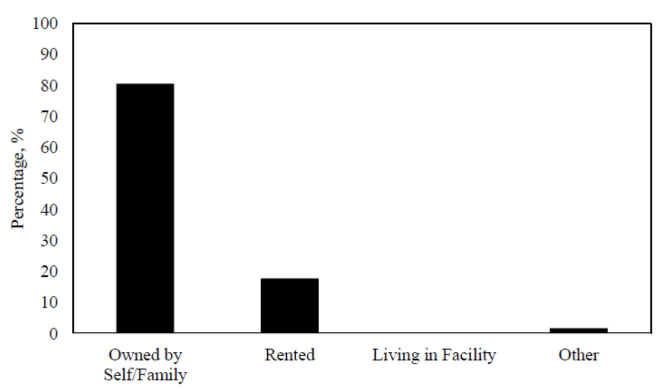


**Figure 2. Percentage of Home ownership compared to rented homes and others**

**b. Type of Insurance**

In order to have faster recovery having relevant insurances are important. During hurricane Harvey over 1 million cars were lost or damaged. Over 86% of the survey respondents had homeowners insurance indicating that some of the rented homes also had Homeowners insurance. About 37% had flood insurance and 15% had wind insurance. The results of the survey on the types of insurances are compared in Fig. 2. The trends observed will require more detailed study and educating of the communities on the benefits of having some of these insurances.

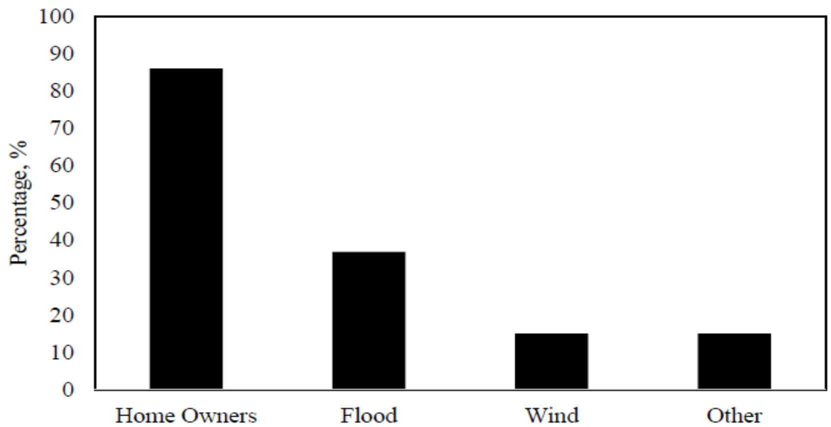


**Figure 3. Percentage of Various types of insurances owned by the respondents**

**c. Flooding area**

Inland flooding was the most damaging event during hurricane Harvey. Flooding areas are identified based on the total rain fall. During hurricane Harvey the maximum rainfall reported was about 60 inches. Based on the survey 27% of the respondents were in the 100 year flooding area and 28% were in the 500 year flooding areas. Also 16% of the respondents were in the 1000 year area. The results of the flooding area types are compared in Fig. 4. Using this data more detailed study is needed based on the rain fall and wind speed distribution, ground elevation, built-in-environment and drainage conditions to identify the worst flooded areas. Also models have to be developed to quantify the flooding.

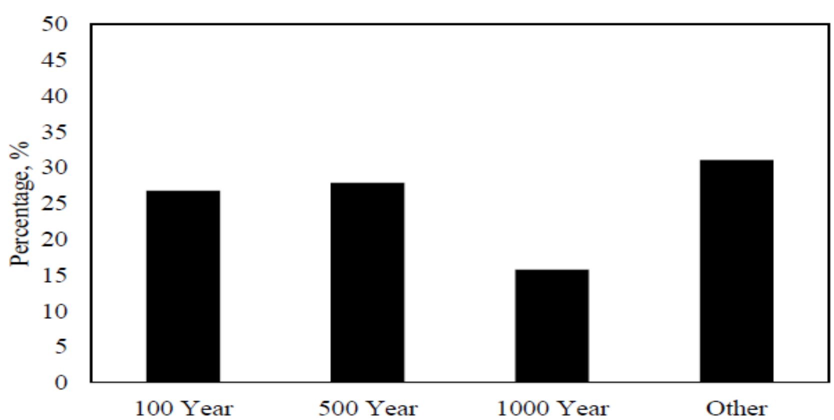


**Figure 4. Percentages of respondents in different areas of flooding.**

**d. Evacuation**

Based on the survey respond, 16% of the population was evacuated (Fig. 5). More detailed study is needed to identify the causes of evacuation. Also models have to be developed to quantify the evacuations and will help with future planning.

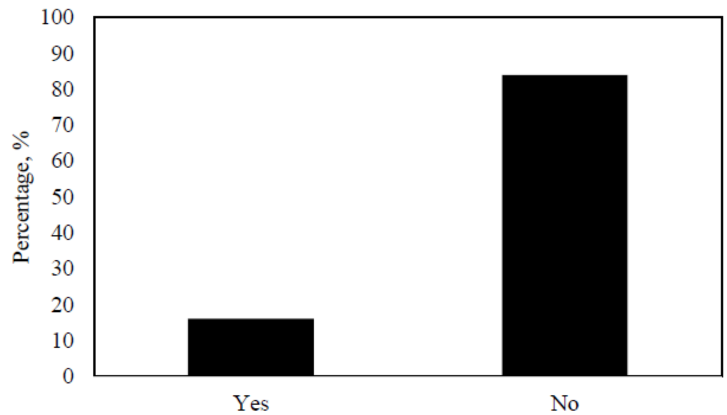


**Figure 5. Percentages of respondents evacuated during hurricane Harvey.**

**e. Government Assistant**

Based on the data collected 2.8% received city assistance and 2.8% received county support. Also 0.9% received state assistance and 10.1% received federal assistance. Also 81.6% of the respondents didn't receive any government assistance (Table 3). More detailed analyses are needed to quantify these trends.

**Table 3. Summary of government assistance received by the respondents**

| Governmental Assistance | Percentage, % |
|---|---|
| City | 2.8 |
| County | 2.8 |
| State | 0.9 |
| Federal | 10.1 |
| Other | 1.8 |
| None | 81.6 |

**f. Drinking Water**

House drinking water system was totally damage for 4% of the respondents. Also it was partially damaged for 6.7% of the respondents (Table 4). More detailed analyses are needed to quantify these trends and identify the major causes of this problem. Since drinking water is the most essential item, methods to solve the problem must be identified.

**Table 4. Summary of drinking water problems based on the survey**

| House Drinking Water Damage | Percentage, % |
|---|---|
| None or Minor Loss | 89.3 |
| Partly Damaged/ Usable | 6.7 |
| Totally Damaged/ Unusable | 4 |

**g. Garbage Pickup**

Based on the survey, 6.6% respondents had total damage to the garbage pickup system. Also 20.3% had partial damage to the garbage pickup system (Fig. 6). More detailed analyses are needed to identify the major causes of this problem. Also garbage pickup is important to keep the neighborhood clean.

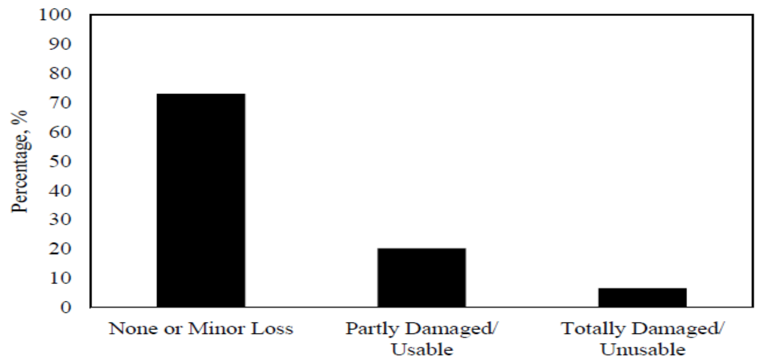


**Figure 6. Garbage Pickup problem during hurricane Harvey.**

**h. Power Loss**

Based on the survey, 6.5% had total power failure and 7.5% partial power failure (Fig. 7). More detailed analyses are needed to quantify these trends and identify the major causes of this problem since power failure will have impact on many activates.

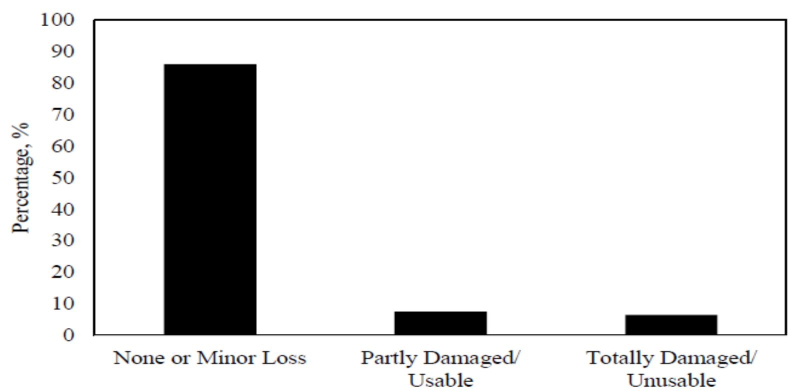


**Figure 7. Power failure problem during hurricane Harvey.**

**i. Structural Damage**

Based on the survey, 4.9% had total damage and 6.7% partial damage to the houses (Table 5). More detailed analyses are needed to quantify these trends and identify the major causes of this problem and will be compared to the data provided by FEMA. The highest housing assistance request was from Rockport, the location of the hurricane Harvey landfall.

**Table 5. Summary of structural damages to houses**

| House Structural Damage | Percentage, % |
|---|---|
| None or Minor Loss | 88.8 |
| Partly Damaged/ Usable | 6.7 |
| Totally Damaged/ Unusable | 4.9 |

**j. Total Loss**

Based on the survey, 5.4% of the respondents had over $100,000 in total loss and the total applications received by FEMA were 4.23%, the numbers are comparable (Table 6). More detailed analyses are needed to quantify these trends and identify the major losses and the causes (wind, flooding, others).

**Table 6. Distribution of the total loss**

| Total Loss | Percentage, % |
|---|---|
| <$1000 | 84.2 |
| <$10,000 | 4.6 |
| <$100,000 | 5.8 |
| >$100,000 | 5.4 |

**k. Debris**

Debris was caused by flood waters carrying various types of waste materials and fallen trees. Also flooding of houses resulted in large volumes of debris in various neighborhoods. Removal of debris was a major problem after hurricane Harvey and the survey data also indicates that over 50% of the respondents had debris removal problem (> 7 days). More detailed analyses are needed to quantify these trends and identify the major causes (wind, flooding, others).

| Number of Days | % Percentage |
|---|---|
| 1 Day | 21.5 |
| < 7 days | 28.2 |
| >7 days | 37.3 |
| Others | 12.9 |

**2. Important Issues**

There is an urgent need for better quantification of inland flooding and potential damages to houses and other infrastructures. This is important for preparedness and rapid recovery. Inland flooding due hurricane is totally different from rain fall flooding currently used 1D and 2D models. Current models also do not take into account the built in environment, wind effects and floating debris. Hence 3D inland flooding model have to be developed taking into account all the important variable.

**Other Models**

In order to quantify the inland flooding, losses, debris and damages, models will be developed taking into account variables such as total rainfall (R), maximum rate of rain fall (r) wind speed (V), ground elevation (E), distance from the coast (D), area of the zip code (A), number of bayous and rivers (C), built-in-environment (B), Tree Distribution (T) and population (P). As need the damaged models developed after hurricane IKE (DM-THC) will be used and/or modified for the hurricane Harvey applications (Vipulanandan et al. 2009).

### 3. Lessons Learned

Based on the experiences from the worst hurricane in the State of Texas history the lessons learned are as follows:

a. Better prediction models are need for hurricane path after landfall and size of the hurricane.
b. Educate the communities regarding preparedness, minimize losses and rapid recovery.
c. Minimize the drinking water infrastructure damages. Build redundancy in in power grids to minimize losses.
d. Improve debris removal and minimize the delay.

## CONCLUSIONS

Based on the data collected from the Hurricane Harvey survey, FEMA report and NOAA data following conclusions are advanced:

(1) Frequency of hurricanes reaching the Gulf of Mexico coast can be represented by the Poisson's distribution. Gulf coast has had 173 hurricanes in the past 167 years.

(2) Year 2017 was a historic year in the U.S. history where there was two category 4 hurricanes in two weeks in the Gulf of Mexico. Hurricane Harvey was the worst hurricane the State of Texas history.

(3) Hurricane Harvey survey indicated varying degree of structural and utility damages. Several factors other than just the rainfall caused the damages.

(4) Damage models (DM-THC) developed after hurricane IKE will be modified to predict the structural, power and utility damages, debris issues due to a hurricane Harvey. Hurricane Harvey survey data will be used with the FEMA data to support the analyses.

## ACKNOWLEDGEMENT

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