The Hazard Mitigation Plan for the City of Houston, Texas

PUAD 5322 Weather and Climate Risks and Hazards

Dr. Katharine Hayhoe

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Kushal Adhikari

Rafael Gatto

Derrick Holland

Stephanie Mendoza

Jon Vue

Introduction

The region selected to design a model plan of action for weather and climate hazards is Houston, Texas in Harris County. Houston is the fourth largest city in the United States and is home to major chemical, naval, and industrial hugs. The size and economy of Houston makes it a major economic area in the United States.

It is important to prepare for and mitigate the weather and climate hazards of Houston in order to reduce the economic losses and human lives lost during these events. Houston is quite vulnerable to weather hazards because of its placement along the coast and increasing population. Some of these hazards include hurricanes, flooding, sea level rising, lighting, tornadoes, drought, extreme heat, wildfires, winter storms, and hail. In addition to recommending mitigation measures we also plan to implement a yearly music festival to educate the public about weather and climate hazards and to create awareness.

Introduction to Harris Country in Houston, Texas

Harris County Characteristics

Harris County is in Southeast Texas on the upper Gulf Coast with an area of 1,778 square miles according to US Census Bureau, 2009. Central Harris County is 55 feet above sea level and rises gradually to around 200 feet on the northern borders, and descends to sea level in direction to Galveston Bay (The Handbook of Texas Online). Figure 1 shows the map of Harris County and the city of Houston.

According to the United States Census Bureau the estimated population of the Harris County in 2016 was 4,589,928 and 98% of the population is urban and only 2% is rural (Harris County Community Wildfire Protection Plan, 2011). If compared with the 2000 Census population of 3,400,578 we can observe an increase of 34.97% in the population. The Texas State Data Center population projections indicate that by Year 2040, approximately 5,842,290 people will be residing in Harris County and its 29 incorporated communities. The 2000 census found that no racial or ethnic group constituted most the metro area population; by 2030, under reasonable scenarios, Hispanics could become a majority. Asians—nearly 5 percent of the population in 2000—are projected to climb to 10 percent within the next two decades (US Census Bureau, 2009).

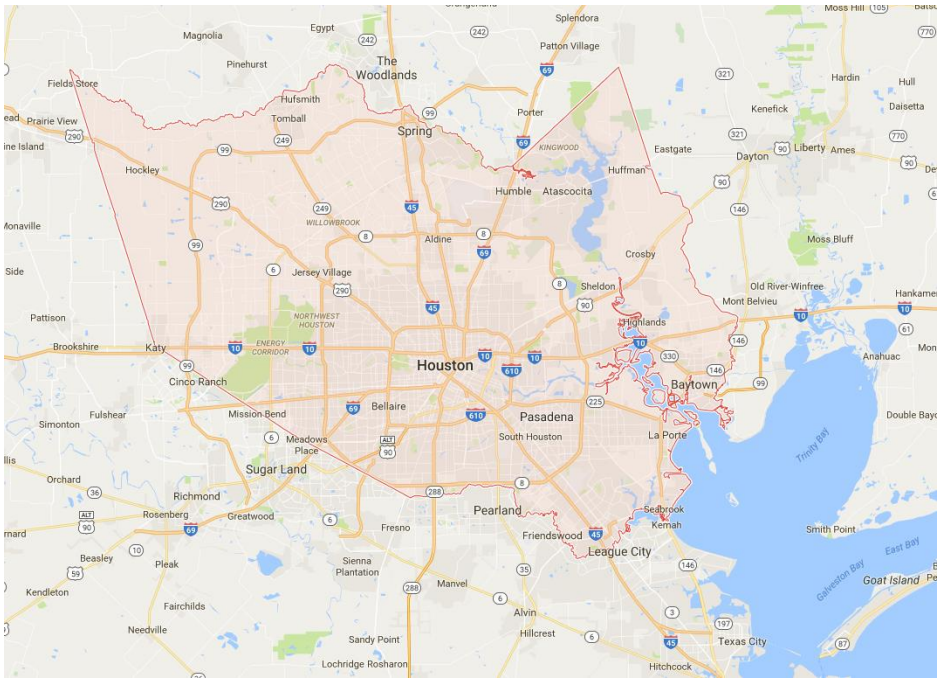

Figure 1: Harris County

It is a highly-industrialized county with the energy sector as the largest contributor accounting for just over 50% of the local economy. The 2006 per capita income in Harris County was $ 45,961, substantially above the $ 35,166 level for Texas (FedStats, 2009). Although the major land use is urbanized there are 50,000 irrigated acres planted in rice, soybeans, grains, hay, corn, and vegetables (The Handbook of Texas Online). The United States Department of Agriculture, 2007 estimate 2210 farms with total land area of 1,106,551, acres. About 18% (197,018 acres) of Harris County land area is forested. The County's predominant ecological region is Western Gulf Coastal Plain, characterized by relatively flat coastal plain topography and mainly grassland natural vegetation (Community Wildfire Protection Plan, 2011).

Harris County Climate

Harris County lies in the semi-tropical humid region of Texas. Summers are hot, with high relative humidity, while winters are generally dry. Using NOAA's tool Climate at a Glance is possible to obtain plots showing how temperature and precipitation has changed in Harris county from 1935 until now. For this was used the Houston city as reference. In figure 2 we can observe the annual average temperature since 1935 with an average of 69.4 °F and an increase rate of + 0.3 °F per decade. In the last 25 years, just one year had average temperatures below the 1931-2000 mean. According to the Harris County Community Wildfire Protection Plan, 2011 the highest average temperature (96°F) occurs in July, with the average low (45°F) occurring in January, the earliest frost usually occurs mid-December, and the latest in mid-March and the temperatures may vary from more than 100° to less than 20° through the seasons.

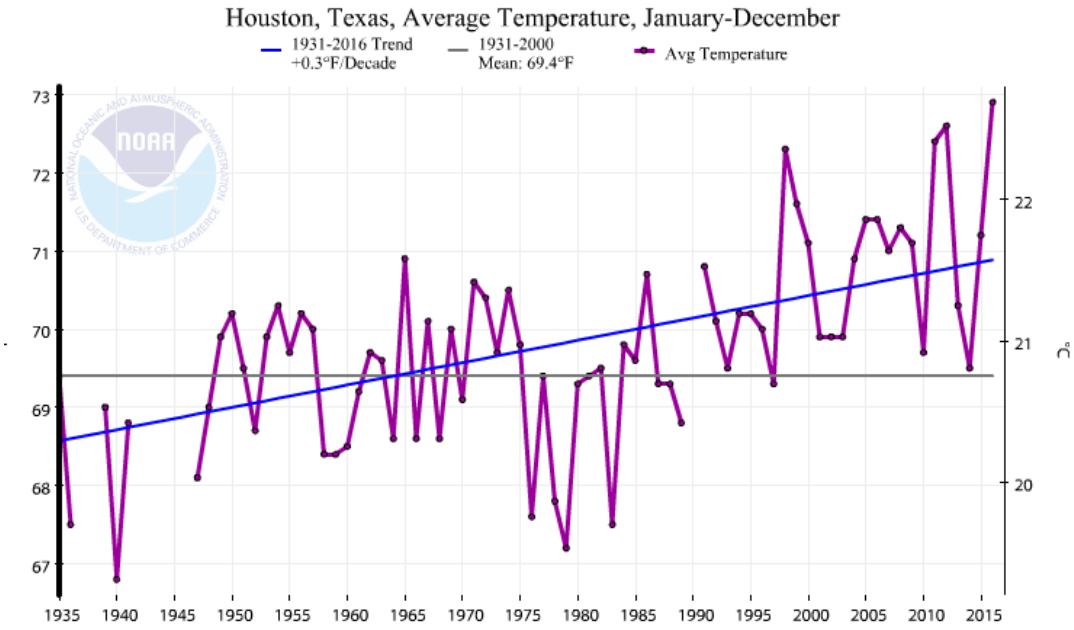

Figure 2: Annual average temperature from 1935-2016 and the calculated trend of increase

In figure 3 we can observe the annual average precipitation since 1940 with an average of 50.64 inches and an increase rate of + 1.27 inches per decade. The monthly average is 3-6 inches with May and June are usually the wettest months; tropical storms and hurricanes are most common in late August and September, but can occur can occur anytime from June to November.

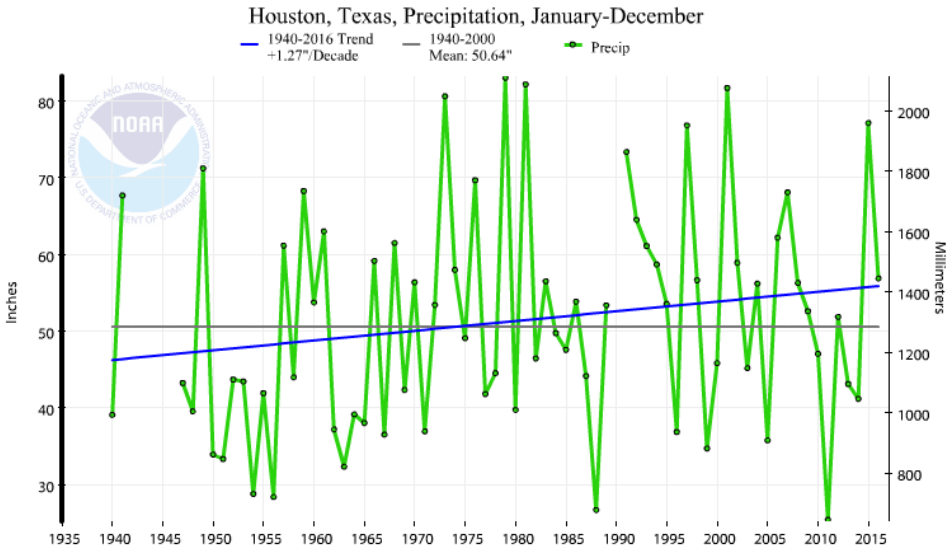

Figure 3: Annual precipitation from 1940- 2015 and calculated trend of increase

Hurricane and Tropical Storms

Introduction/ Past Events

Houston, Texas is approximately 50 miles from the Gulf Coast, which puts the United States' fourth largest city in the path of many hurricanes and tropical storms. The first major hurricane to impact the region, and still one of the deadliest hurricanes on record, is the hurricane that devastated Galveston, Texas. Galveston is directly on the coast of the gulf, and although Houston was not the major area that was impacted, it is important to detail this massive hurricane. According to a comprehensive history of hurricanes in Texas by David Roth (National Weather Service, 2010) this hurricane is the deadliest hurricane on record with an estimated 8,000 people losing their lives. Although this event occurred in the early 1900's, the wireless telegraph allowed for communication between the Caribbean Islands and the Galveston area. People from the Houston area travelled by train down to Galveston, and although there was ample warning by telegraph, people did not heed these warning. In the 1900's, the weather station raised a "Hurricane Flag," which was in essence their modern day hurricane warning (Roth, 2010). The town of Galveston was all but destroyed by the hurricane, but the town did enact changes to protect against such a large storm. Most of the housing at the time was made of wood, and because of this many of the homes were destroyed. The city of Galveston then devised plans and strategies to raise the elevation as well as build a large 17-foot sea wall. According to Roth in 2010, the city never flowered as a port city due to the large storm and the construction of the ship channel in Houston.

In 1943, a tropical storm crossed over the Galveston and Houston area reaching winds of 100 miles per hour. This storm caused considerable damage to Houston. In the Houston Ship Channel mentioned above, two utility towers were destroyed. Most of the damage that Houston withstood in this storm was due to wind. In 1989, Hurricane Chantal caused up to 20 inches of rainfall in the Houston area. This caused power lines to be downed, businesses and homes to flood, as well as damage to some infrastructure. The Houston Ship Channel again suffered damage with the landfall of Hurricane Jerry in 1989. Tropical Storm Frances in 1998 also caused major flooding in Houston, resulting in Interstate 10 completely covered in water. At the start of the 20th century, hurricanes and tropical storms continued to impact the city of Houston. Tropical storm Allison in 2001 caused extreme flooding in the Houston area, as well as many other counties and areas in Texas. A total of $5 billion in damages occurred in Texas, as well as 22 people dying (Roth, 2010). One of the more present day hurricanes to impact Houston is Hurricane Rita in 2005. Hurricane Rita caused a total of $12 billion in damages across the United States. Houston escaped a majority of damage due to Hurricane Rita, except for some structural damage and other minor damage. However, the city did issue an evacuation order, and as a result, 31 people died in the process of evacuating.

The last major hurricane to impact Houston was Hurricane Ike. The state prepared for the hurricane by issuing decrees that certain counties and cities were in the disaster zone, and parts of Houston were under a mandatory evacuation order. Houston was negatively impacted by this hurricane in most part due to loss of electricity and other transportation means (Associated Press). The Chase Tower skyscraper in downtown Houston as well as the Reliant Stadium was damaged due to large winds and heavy rain (Associated Press). Again, all 8 deaths attributed to Hurricane Ike were indirect and occurred during the clean up or evacuation. The major airports in Houston shut down, and transportation was almost stopped to a halt because of the lack of electricity. Although the Houston Theatre District did experience flooding, a majority of the city did not because the storm did not hover over Houston for very long. A major impact on the city was in regards to gasoline. Because the city is so close to the coast, gasoline prices rose exponentially and then when the supply ran out the city could not replenish.

Current Mitigation Plan and Vulnerability

Although Houston has dodged a major hurricane since Hurricane Ike in 2008, many officials and citizens are expressing concern over the lack of action regarding preparation and protection against a large hurricane or tropical storm. According to Climatecentral.org, Hurricane Ike caused over $27 billion in damage and killed 20 people in the Houston and Galveston areas combined (Climate Central, 2012). The organization also ranks the Houston-Galveston area as fifth in terms of vulnerability of hurricane and tropical storm damage (Climate Central, 2012). According to Patrick Jankowski, VP of research for Greater Houston Partnership, a large hurricane can have huge impacts on the Houston Ship Channel as well as impact the United States economy as a whole (Grist, 2016). Other proposals have suggested building flood gates in Galveston to protect Houston from the impacts of large hurricanes, as well as building a flood gate close to the Houston Ship Channel and other industrial spots around Houston (Grist, 2016). These proposals; however, have not reached fruition. Phil Bedient, codirector of Storm Surge Prediction, Education, and Evacuation from Disasters in Houston believes that the city is in for a big hurricane soon, and the under preparation on part of the city will spell doom for its industry and residents (Grist, 2016).

Climate Change/Mitigation Plan & Recommendations

Coupled with the fact that Houston is not amply preparing for another large hurricane, climate scientists have emerged with data that shows hurricanes will only become stronger due to a warmer planet. A warmer planet means warmer ocean water, which is a main agitator for stronger hurricanes. According to an article published by Nam-Young Kang and Jim Elsner in *Nature Climate Change*, there are fewer tropical storms and hurricanes in the future projections, but these storms will be stronger because of the increase in oceanic temperatures (Kang & Elsner, 2015). The study also found that hurricane winds increased by 3 miles per hour between 1984 and 2012, and the number of storms each year decreased by an average of 6.1. Based on these future projections, the city of Houston should take precautions and measures in order to prepare for less storms, but at the same time storms that will be much stronger. These precautions include building floodgates near the Houston Ship Channel, as well as installing flood gates in Galveston to lessen the impact that Houston will feel when there is a big tropical storm. Also, most deaths that occur in Harris County seem to be attributed to evacuation and clean up. These measures should be reevaluated in order to preserve life. The increasing magnitude of hurricanes in projected data should be cause for alarm, but the loss of life after the storm should also be addressed. Houston should take a more hands on approach to protecting people as they evacuate.

Flooding “Death & More Rain to Come” “Turn Around, Don’t Drown!”

Introduction/ Past Events

In the United States, approximately 10,000 deaths have occurred due to flooding since the 1900s. The most frequent and costly natural hazard that occurs in the city of Houston is flooding. In more recent years, between 1994 and 2013 there was a recorded 23 flood events in the city of Houston. The data below traces back to the 1960s. It shows variation of cost for the damages that rose from flooding in the Houston area. The table also shows the US population and how it is substantially growing along with the increase of floods.

Table 1: Flood Occurrence Characteristics between 1960 to 2003

Fiscal Year	Damage (Thousands of Current Dollars)	Implicit Price Deflator	Damage (Millions of 1995 Dollars)	U.S. Population (Millions)	Damage Per Capita (1995 Dollars)
1960	111,168	0.22620	491	180.671	2.72
1961	147,680	0.22875	646	183.691	3.51
1962	86,574	0.23180	373	186.538	2.00
1963	179,496	0.23445	766	189.242	4.05
1964	194,512	0.23792	818	191.889	4.26
1965	1,221,903	0.24241	5041	194.303	25.94
1966	116,645	0.24934	468	196.560	2.38
1967	291,823	0.25698	1136	198.712	5.71
1968	443,251	0.26809	1653	200.706	8.24
1969	889,135	0.28124	3161	202.677	15.60
1970	173,803	0.29623	587	205.052	2.86
1971	323,427	0.31111	1040	207.661	5.01
1972	4,442,992	0.32436	13698	209.896	65.26
1973	1,805,284	0.34251	5271	211.909	24.87
1974	692,832	0.37329	1856	213.854	8.68
1975	1,348,834	0.40805	3306	215.973	15.31
1976	1,054,790	0.43119	2446	218.035	11.22
1977	988,350	0.45892	2154	220.239	9.78
1978	1,028,970	0.49164	2093	222.585	9.40
1979	3,626,030	0.53262	6808	225.055	30.25
1980	No data	0.58145	0	227.225	0.00
1981	No data	0.63578	0	229.466	0.00
1982	No data	0.67533	0	231.664	0.00
1983	3,693,572	0.70214	5260	233.792	22.50
1984	3,540,770	0.72824	4862	235.825	20.62
1985	379,303	0.75117	505	237.924	2.12
1986	5,939,994	0.76769	7737	240.133	32.22
1987	1,442,349	0.79083	1824	242.289	7.53
1988	214,297	0.81764	262	244.499	1.07
1989	1,080,814	0.84883	1273	246.819	5.16
1990	1,636,366	0.88186	1856	249.464	7.44
1991	1,698,765	0.91397	1859	252.153	7.37
1992	672,635	0.93619	718	255.030	2.82
1993	16,364,710	0.95872	17069	257.783	66.22
1994	1,120,149	0.97870	1145	260.327	4.40
1995	5,110,714	1.00000	5111	262.803	19.45
1996	6,121,753	1.01937	6005	265.229	22.64
1997	8,934,923	1.03925	8597	267.784	32.11
1998	2,465,048	1.05199	2343	270.248	8.67
1999	5,450,375	1.06718	5107	272.691	18.73
2000	1,336,744	1.08960	1227	282.125	4.35
2001	7,158,700	1.11539	6418	284.797	22.54
2002	1,116,959	1.12854	990	287.974	3.44
2003	2,405,685	1.14730	2097	290.810	7.21

Aside from the damages flooding can cost and population increase, the number of fatalities during a flooding event is shown in the figure below during the year 2013.

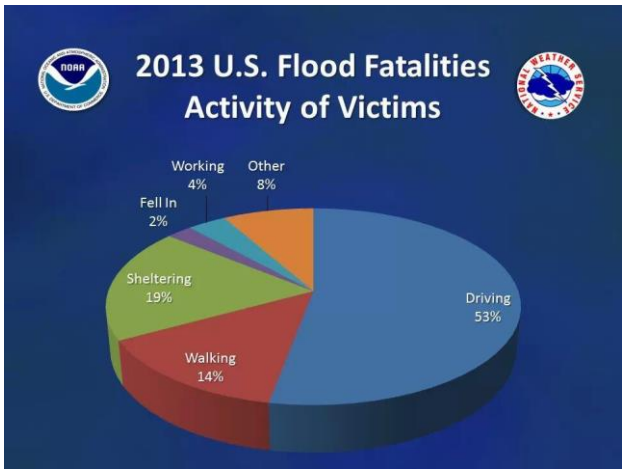

Figure 4: 2013 Flood Fatalities

Driving is the number one cause of death during a flooding event. Over half of the fatalities all over the United States were due to people being in their vehicles during an event. It can be difficult to see how deep a floodplain area is when people are in their cars trying to get to higher elevations. With moderate to high floods, the vehicles can be lifted completely off the pavement and be redirected somewhere.

Climate Change

Climate change has an enormous effect on the Mitigation plan for Houston, Texas. To understand the risk and danger that Houston will encounter in the near future, we must understand how annual precipitation has increased due to anthropogenic causes and how it will continue to increase with time. The previous figure 5 shows precipitation from the years 1940 to 2015 in Houston. The two tread lines show the average from the specified years. It is very clear that the average annual precipitation will continues to increase.

Additionally, another contributing factor to the flooding natural hazard occurrence in Houston, Texas is the increase in floodplain areas around Harris County. The area that is effected by flooding is over 50% of the Houston area. This is due to floodplain data that takes account into Houston's ground elevations throughout the city itself. Some areas are more prone to flooding because of the certain elevations at those certain points. The figure below shows the current estimated 100 and 500-year floodplain of the city of Houston.

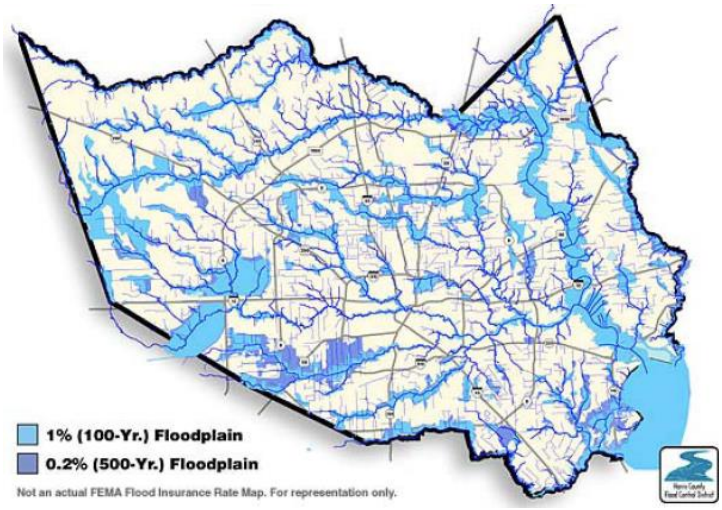

Figure 5: Floodplain of Houston, Texas

The floodplain consideration is very important to the mitigation plan of Houston. As seen in the figure above, the floodplain area covers almost every part of Houston. As population is subjected to drastically increase, the area that is impacted during a flood will change relatively as much, but what will change will have a devastating impact when these continuous floods do occur. As population increase, the floodplain area will still manage to cover at least 50% of the city of Houston. What will change is this, the amount of individuals that are affected during a flooding occurrence will drastically increase in relation to the increased population. Thus, drastically increasing the exposure level of the city of Houston.

Mitigation Plan Recommendations

As recent floods have occurred, the City of Houston does currently have mitigation plans for flooding in the following subcategories:

- Floodplain Management Plan: been in place since 2003 (updated in 2008). Provides framework corrective and preventative measures in place to reduce impacts.
- Stormwater Management Plan: addresses flooding caused by storm water. Focuses on construction and design factors to lessen flooding events in urban areas.
- Tropical Storm Allison Recovery Project: between FEMA and Harris County created new flood hazards information to residents and how to prepare for next floods

These mitigation plans are a great way to reduce the vulnerability of Houston. Additional suggestions to reduce how vulnerable the City of Houston is during flooding events would be to implement flood gates around the city to further reduce the amount of water and to allow the redirection of the water elsewhere. This will also reduce contamination of water sources when a flooding event occurs. Reducing the contamination of water sources will further reduce the spread of diseases that occurs after a flood has occurred. Also, there has been research to adjust the type of pavement material that can be used in the roadways of the city. Typical concrete pavement material typically tends to cause hydroplaning that then also causes horrible accidents to occur on the roads and highways. Different pavement material can have the ability to absorb the precipitate rainfall through its different permeability characteristics. Once absorbed, the water can also be redirected elsewhere to lower negative flooding effects. Implementing different pavement material will help in a small way, for the long run.

Sea Level Rise "Today's Storm is tomorrow's High Tide…"

Introduction/ Past Events

Sea level rise is not currently considered a high priority natural hazard in the City of Houston. The neighboring City of Galveston, Texas has seen its drastic affects by the seal level changes. The image below shows the current coastal region of Galveston and how the sea level rise caught up to their residential area, literally. The effects that Galveston has come across is a projection of Houston's very near future.

Figure 6: Coastal region of Galveston, Texas

The City of Houston is extremely vulnerable and impacted by the effects of subsidence. The extraction of large amounts of groundwater is the main cause of subsidence in the area. This extraction has been recorded to cause the loss of 10 feet in elevation change around the country. The City of Houston has although tried to reduce this effect by switching its source of water to surface water rather than

groundwater. The figure below shows how subsided the City of Houston has developed from the early 1900s to 2000s.

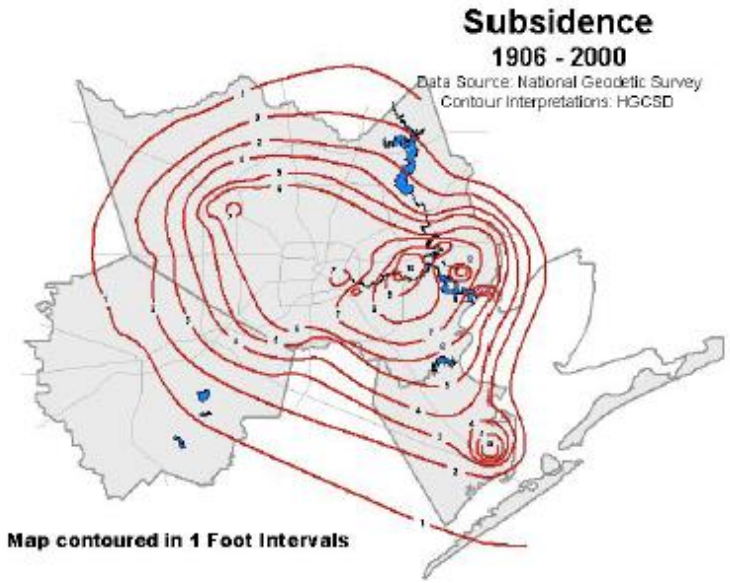

Figure 7: Subsidence in Houston from 1906 to 2000

Climate Change

Additionally to past subsidence effects, greenhouse emissions have increased and effected the ozone, thus causing melting of the north and south poles that therefore increases the sea level rise all over the globe. The following graph shows an estimated sea level projection in the next 100 years.

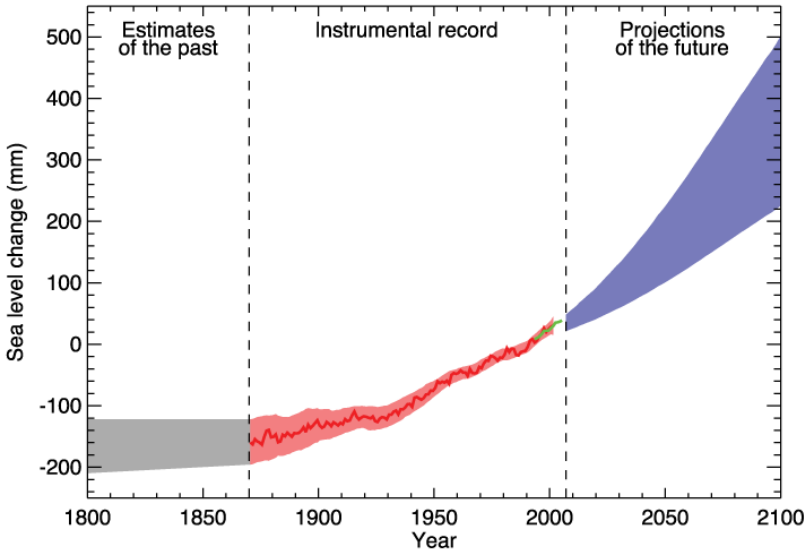

Figure 8: Sea Level Rise Projections of the near Future

Houston is not currently in danger of being affected by the sea level increases. In the future, the dangerous rise will catch up to Houston as it has moderately caught up to Galveston. As sea level rises

up to 25 feet, the image below shows the current waterways (in dark blue) and the future projected water ways (in a lighter blue).

Figure 9: Sea Level Rise Projections of the near Future in Galveston and Houston

The image shows all 100% of the City of Galveston submerged in sea level. Houston being submerged by 5% of the city. When comparing this analysis to Galveston it does not seem drastic at first. Consideration of how many communities and families live in that 5% of Houston is the most important factor that needs to be considered. As the exposure of Houston is increasing, the vulnerability of within the area is the only adjustment or change that the City of Houston can make. The sea level changes that are to come will occur in the far future, but the time is now to make those adjustments so that the City of Houston is ready. Sea level rise is inevitable, whether the City of Houston is prepared or not.

Mitigation Plan & Recommendations

The City of Houston does not currently have any serious measurements to try to reduce the vulnerability of the city. They are although, attempting to make efforts to improve the hazard identification of subsidence and its effects that it has on flood plain areas. Officials are also looking for ways to improve the public on education about how subsidence occurs and potential hazards can arise. Ultimately, the mitigation plans the City of Houston has for possible sea level rise are the same as those for the flooding hazards. Additional recommendations that could lower the vulnerability of Houston is to adapt the city to eventually implement house lifts to those houses that are in a dangerous flood plain area. Sea level rise is an effect from anthropogenic greenhouse gas emissions. To attempt to reduce the sea level rise potential, the City of Houston could lower its emissions to the atmosphere that can lower its effects in the long run.

Lightning “For every 2 lightning strikes in 2000, there will be 3 in 2100”

Introduction/ Past Events

For the City of Houston, lightning is not a natural hazard that has much concern or attention. Although, the past events that have occurred have damaged properties and increased cost repairs. Lightning has

negative effects financially due to property damage. The table shows a total property damage record cost per year from 1994 to 2008.

Table 2: Lightning Activity from 1994-2008

Year	Number of Recorded Lightning Events	Total Property Damage Recorded	Total Crop Damage Recorded	Deaths	Injuries
1994	1	$0	$0	0	3
1996	2	$75,000	$0	0	0
1997	6	$5,550,000	$0	0	12
1998	0	$0	$0	0	0
1998	0	$0	$0	0	0
1999	0	$0	$0	0	0
2000	2	$0	$0	1	17
2001	0	$0	$0	0	0
2002	0	$0	$0	0	0
2003	0	$0	$0	0	0
2004	4	$20,000	$0	2	2
2005	6	$210,000	$0	1	5
2006	2	$25,000	$0	0	0
2007	2	$0	$0	0	5
2008	4	$100,000	$0	0	1
Total		$6,080,000	$0	4	45

Lightning can not only be a hazard financially, but it can also be a hazard that results in fatalities. The following figure shows the number of lightning fatalities that occurred in the last 10 years in the United States.

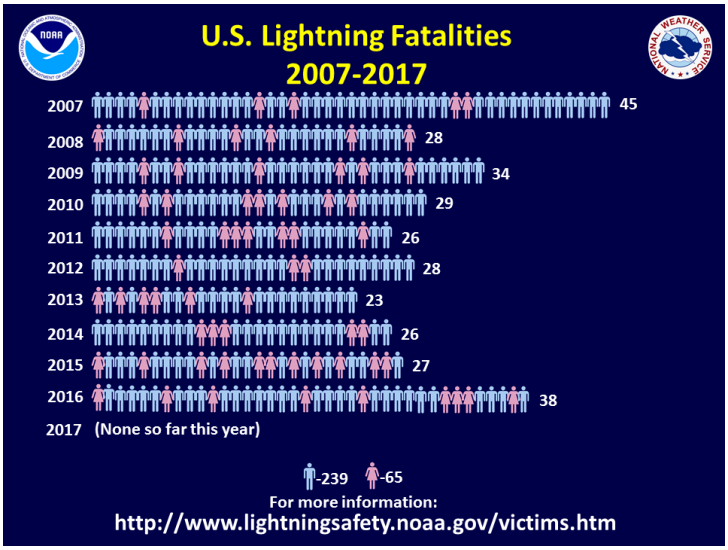

Figure 10: US Lightning Fatalities from the last 10 years

In comparison to other natural hazards that occur in the City of Houston, lightning may not seem to be as crucial as the others. But analyzing previous data from past years, it is clear that lightning is a hazard the city of Houston needs to draw its attention to.

Climate Change

Lightning is a powerful electrical discharge that produces greenhouse gases, more specially the nitrogen oxides in the atmosphere. They are the dominant source in the middle and upper troposphere that can contribute to the temperature changes in the ozone. According to Prof David Romps and his colleagues in 2014, they calculated that every 1C rise in global temperature would lead to an increase in the frequency of lightning strikes by 12%. Not only will global warming affect all natural hazards and increase their intensity, but it will also affect lightning and it effects.

Mitigation Plan & Recommendations

Harris County currently does not have many measurements to address the lightning specifically that occur in the City of Houston. Lightning is natural hazard that can arise during a thunderstorm and tornado. Wildfires are very commonly caused from lightning. Therefore, the natural hazard is a factor that needs to be taken serious when addressing the mitigation plans for Houston. Listed are some of the mitigation actions they have addressed in terms of lightning hazards:

- Lightning Safety Public Outreach Program
- Installation of lightning surge protection measures for clinical infrastructure
- Lightning Alert System

The Lightning Safety Public outreach program that will educate the public on what to do and what not to do when lightning is a possible hazard in the area. It also includes educating the public on self-preparedness and safety precautions to do when a thunderstorm is in the area. The lightning alert system goes hand in hand with the weather alert system. It will send out alerts when a certain natural hazard is said to occur.

Lightning is inevitable, and all we can do is to be properly prepared for when these hazards occur to lessen the vulnerability of the city. Additional changes that could be made to lessen the vulnerability effects of lightning are to alter roofing of properties to lesser conductor material that will not attract lightning.

Extreme Heat

Introduction/ Past Events

Extreme heat can be defined as temperatures that hover 10 degrees or more above the average high temperature for the region, last for prolonged periods of time, and are often accompanied by high humidity and can pose a significant risk to humans. According to CDC, 2004 extreme heat events are the most prominent cause of weather-related human mortality in the United States responsible for more deaths annually than hurricanes, lightning, tornadoes, floods, and earthquakes combined.

Under normal conditions, the human body's internal thermostat produces perspiration that evaporates and cools the body. However, in extreme heat and high humidity, evaporation is slowed and the body must work much harder to maintain a normal temperature. Luber,& McGeehin affirms that prolonged exposure to high temperatures can cause heat-related illnesses, including heat cramps, heat syncope, heat exhaustion, heat stroke, and death

To help the general populous quantify values for identifying this problem, the Heat Index was developed by NOAA's (National Oceanic and Atmospheric Administration). The Heat Index, shown in figure 11, is the combination of air temperature and relative humidity to determine an apparent temperature; "how hot it feels". The Heat Index value is calculated as if standing in a ventilated, shady place.

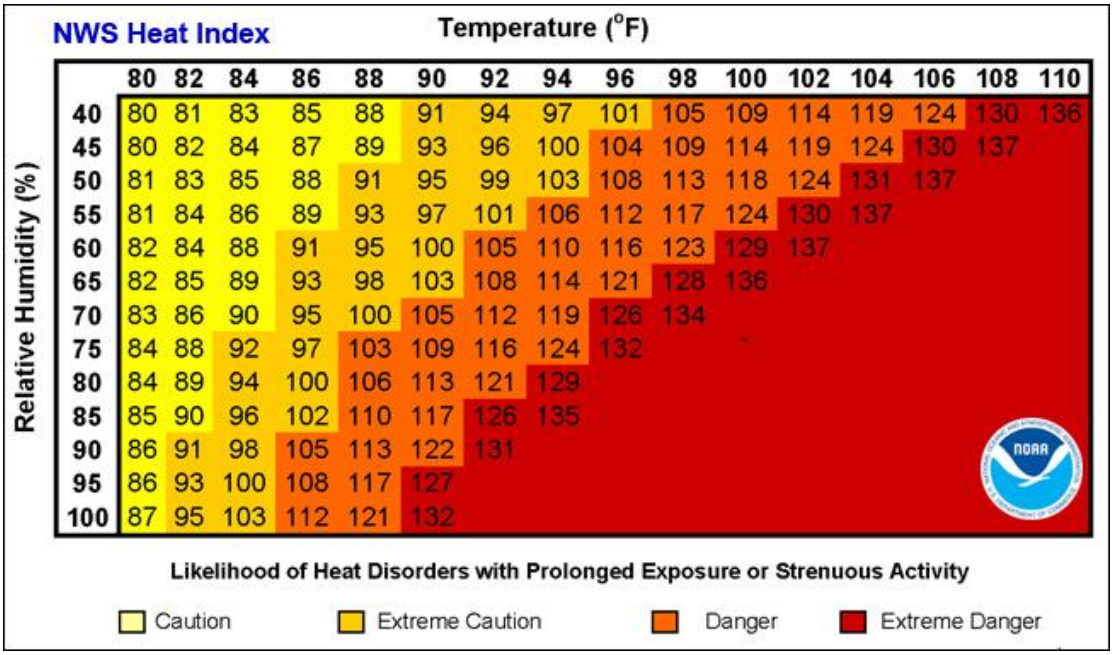

Figure 11 : Heat index.

According to the National Climatic Data Center, Harris County experienced 54 reported extreme heat events from 1950 through May of 2009 causing a total of 142 deaths, 200 injuries and no documented property damage. The year with most deaths was 2005 with 49 deaths because of extreme heat. All the

deadly events happened between May and September. Based on the historical data provided by the National Climatic Data Center (NCDC), the probability of Harris County being affected by an extreme heat event is once every 1.09 years.

Vulnerability

The weather of Harris County makes it very vulnerable because during the summer months, it is normal for the City of Houston to experience high humidity levels combined with elevated temperatures producing a heat index of above 100 degrees.

Harris County due to the high urbanization also suffers from the urban heat island effect. This phenomenon occurs in areas where large amounts of asphalt and concrete are located. Asphalt and concrete store heat for extended periods and slowly release heat at night, which can produce higher nighttime temperatures. The stagnant atmospheric conditions of the heat wave also trap pollutants in urban areas and add the stresses of severe pollution to the already dangerous stresses of hot weather, creating a health problem of undiscovered dimensions.

According to the Texas Division of Emergency Management, 2008 elderly persons, young children, persons with respiratory difficulties, and those who are sick or overweight, poor people that cannot afford air conditioners are more likely to become victims of extreme heat. Due to all these factors, extreme heat is considerate a moderate risk for the Harris County.

Climate Change

Using the Climate Wizard website is possible to obtain annual and seasonal median projected change in temperature for Harris County using two different CO2 emission scenarios for the future: a higher (A2) and a lower (B1). It was analyzed the projections for the years of 2050 and 2080. In table 3 we can observe the projected changes in temperature, as expected we observe an increasing in temperature for both scenarios and more change is expected to happen in summer and fall. Even with the decrease of the greenhouse gases emissions in the future we can still expect an increase in temperature due to the delay that the Earth feels the change in greenhouse gases concentration.

Table 3: Annual and seasonal median projected change in temperature for Llano Estacado Region-TX using a higher (A2) and a lower (B1) CO2 emission scenario for 2050 and 2080.

Median projected change in temperature Llano Estacado Region TX (°F)				
Scenario	Higher A2		Lower B1	
Year	2050	2080	2050	2080
Annual	3.5	6.5	2.5	4.0
Winter (Dec-Feb)	3.0	5.0	2.0	3.5
Spring (Mar-May)	3.5	5.0	2.5	3.5
Summer (June-Aug)	3.5	6.0	2.5	3.5
Fall (Sept-Nov)	3.0	6.0	2.5	4.0

In the chapter 2 from the U.S. National Climate Assessment, 2014 they affirm that heat waves have generally become more frequent across the U.S. in recent decades and from the chapter Great Plains

from the U.S. National Climate Assessment, 2014 is possible to get projections for the study area. An increase in extreme events can be observed. The historical data gives us that the Harris county has about 7 hot days per year with the temperature higher than 100 °F. Figure 12 show us an increase in the numbers of hot days for the Harris County region of approximately 20 more hot days in the lower emission scenario (B1) and 27 more hot days in the higher emission scenario (A2) by mid-century (2041-2070).

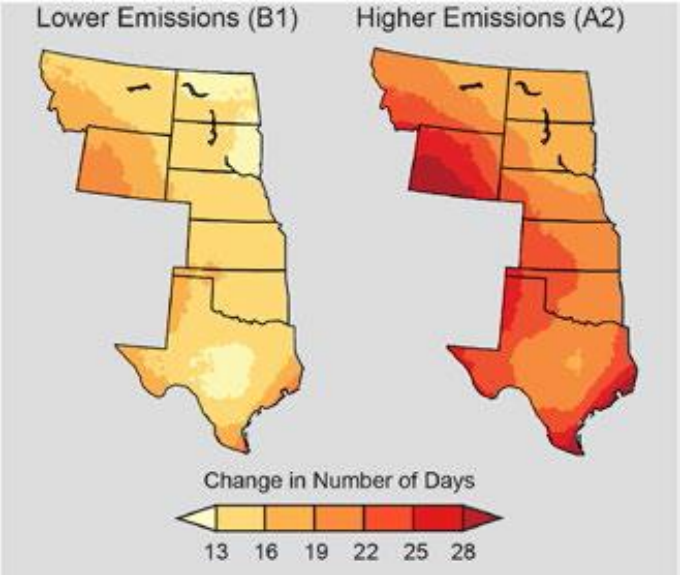

Figure 12: Project change in the number of hot days for the lower emissions scenario (B1) and for the higher emissions scenario (A2) by mid-century (2041- 2070) in the Great Plains.

Figure 13 show us an increase in the numbers of warm nights with the temperature higher than 80 °F, for the Harris County we will have approximately 35 more warm nights in the lower emission scenario (B1) and 46 more warm nights in the higher emission scenario (A2) by mid-century (2041-2070). The projected increase in temperature combine with increase of number of hot days and warm nights represents an increase in the hazard, showing that the county need to be better prepare for heat waves in the future.

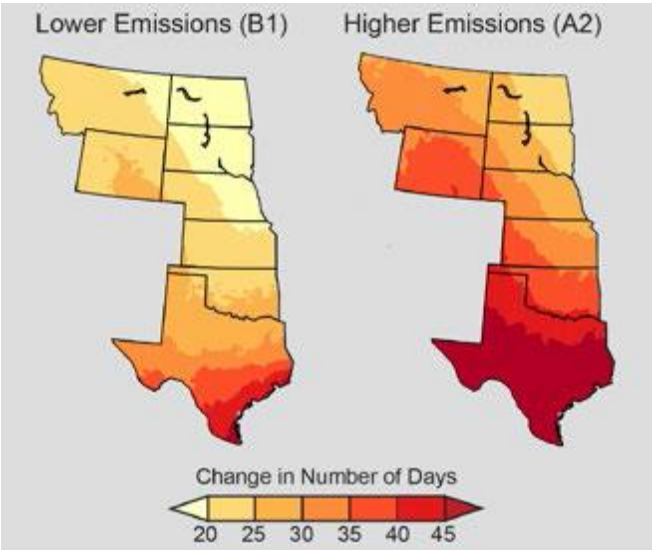

Figure 13: Project change in the number of warm nights for the lower emissions scenario (B1) and for the higher emissions scenario (A2) by mid-century (2041- 2070) in the Great Plains.

Mitigation Plan & Recommendations

According to the Harris County All Hazard Mitigation Plan, 2009 some of the mitigations action already been done to combat extreme heat are: cooling centers to help those residents who may not have adequate air conditioning to stay safe when temperatures are high in libraries, recreation centers, multi-service centers and other facilities that are open to the public, and the City of West University Place require the planting and replacement of trees following new construction and remodeling projects since 2009. The last measure is recommended to be adopted by all cities in the county.

When a heat wave is happening the Houston Health Department (HHD) recommend the following: increase water consumption, check on the elderly, wear light-colored, loose fitting clothing, take frequent cool baths or showers if your home is not air-conditioned and if the house is not air-conditioned, seek accommodations in air-conditioned facilities like cooling centers.

In the Harris County All Hazard Mitigation Plan, 2009 there are mitigation measures for extreme heat for each city in the county that still need money to be realize like:

- develop/expand extreme heat safety outreach program with the goal to reach as many of the citizens as possible to educate them on self-preparedness and how to stay safe during extreme heat conditions;
- conduct study to identify vulnerable populations to extreme heat hazards;
- installation of back-up generator for cooling center;
- develop cooling center plan;
- develop early warning systems using different Medias and especially social Medias;
- awareness of the Cooling Center locations and availability for vulnerable population.

Besides these mitigations actions is also recommend creating more cooling center especially for weekends and non-business hours, hospitals need to be more prepared for the increase of patients in heat waves

times and for the increase of respiratory problems due to increase of pollution and ozone, economic help to vulnerable population to buy air conditions and pay electric bills and increase green areas.

Wildfires

Introduction/ Past Events

Wildfires are part of the natural management of the Earth's ecosystems, but may also be caused by natural or human factors. Certain conditions must be present for a wildland fire hazard to exist: a large source of fuel; conductive weather (generally hot, dry, sunny, and windy) and lack of fire suppression capability due to remoteness or other limitations.

Over 80 percent of forest fires are started by negligent human behavior such as smoking in wooded areas or improperly extinguishing campfires. The second most common cause for wildfire is lightning (Harris County All Hazard Mitigation Plan, 2009). Wildfires in Harris County primarily occur during drought conditions and are caused by human error or carelessness.

Accurate historical occurrence data is difficult to obtain for the wildfire hazard and does not follow a standard criterion. The figure 14 from the Harris County Community Wildfire Protection Plan, 2011 identifies all reported wildfires within Harris County by zip code using the National Fire Incident Reporting System (NFIRS).

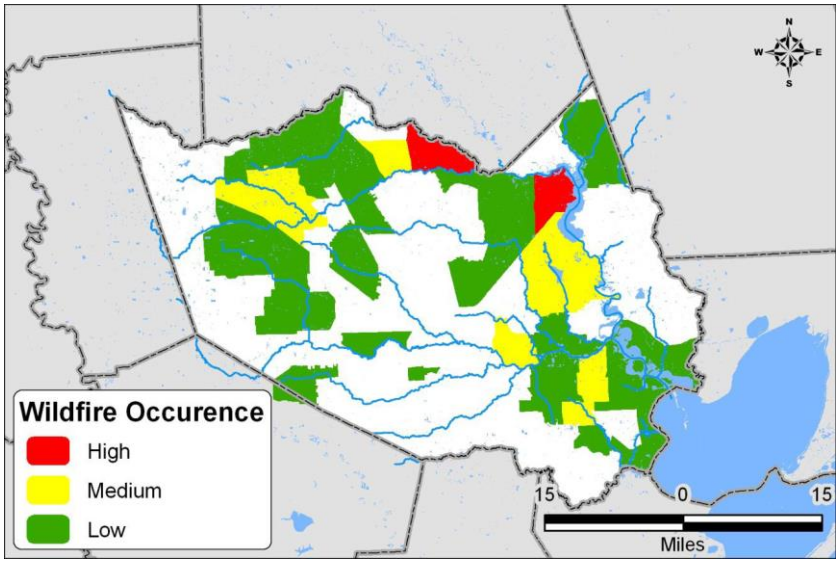

Figure 14: Wildfire Historical Occurrence Information for Harris County.

Wildfires are relatively isolated due to the urbanized environment of the majority of Harris County. Most wildfires are small, less than 5 acres in light fuels, easily contained by local ground crews using direct attack methods. Several times per year, there are 10-30 acres wildfires usually wind-driven at some point, contained by local ground crews using direct and indirect attack methods. The ones with more than 50 acres are rare and required several departments and mutual aid, often need dozer and/or air support to contain. No wildfires of more than 400 acres have been reported in Harris County (Harris County Community Wildfire Protection Plan, 2011).

The most active fire season usually occurs from August to September with another fire season occurring in January-February, but global climate patterns can cause wide variations in fire seasons—in some cases, a fire season can last throughout an entire year.

According to the County Community Wildfire Protection Plan, 2011 the most significant wildfires from the past 25 years are:

- 1979 Woodway Square Apartments. Not a wildland fire *per se*, but included here because the wide-spread use of wooden shingles and high winds created a firestorm that consumed over 324 apartments and 10 city blocks. This fire led to a change in building codes and construction materials;
- 1990 Telge Road Fire. Forest fire which burned over 300 acres. The fire originated as a small outdoor trash fire that spread quickly due to extreme wind conditions and dry fuels. Required the evacuation of two subdivisions.
- 1994 San Jacinto River Fire. A fire involving a ruptured gasoline pipeline underwater during a major flood event. The pipeline was ruptured by flood-related debris moving down river. The fire involved several hundred acres of forest, eleven residential structures, and multiple local, state, and federal resources.
- 2001 Clow Road Fire. 10-acre fire at a below-grade wood recycling facility burned for more than two weeks and cost over $2 million to contain and extinguish.
- 2011 Plum Grove Fire, Mykawa Road Fire, Forest Brook Fire, Forbidden Gardens Fire. Due to the 2011 drought happened many fire events. There were more significant outdoor fire in 2011 than in the past 10 years combined.

Vulnerability

Essentially, every community in Harris County faces some risk from wildfires. The risk is lower in highly-developed communities and higher in more rural communities. According to the Harris County Community Wildfire Protection Plan, 2011 two fire seasons generally occur: during the hotter, drier summer months (August to September) and the dry winters following a hard freeze (January-February). In the summer, the greatest fire weather danger occurs during periods of extended drought and with the occurrence of afternoon thunderstorms. The combination of very dry fuels, hot temperatures, minimum relative humidity of 28 to 35 percent, and gusty winds can result in elevated fire danger especially in the afternoon and early evening.

Drought conditions and other natural disasters (tornadoes, hurricanes, etc.) increase the probability of wildfires by producing fuel in both urban and rural settings. Accumulated debris after hurricanes contributes to overall fire potential, including wildland fire potential. Forest damage from hurricanes and tornadoes may block interior access roads and fire breaks, pull down overhead power lines, or damage pavement and underground utilities.

Most of wildfires in Texas are believed to be human-caused. A primary cause of fires is arson, especially vandalism by school age children and escaped campfires started by the homeless. The presence of wildland fuels near houses like grasses, brush, timber, and slash increase the vulnerability to wildfires. Some residential construction materials are flammable especially in earlier homes and those in more rural settings that may use wood or vinyl siding and cedar shake shingles. The concept of defensive space is foreign to many residents of Harris County, because most residents in the county do not recognize that their community is a risk from wildfires.

Although mobility during fires is generally good across the county, some communities could include neighborhoods with inadequate entrances and exits, narrow roadways, insufficient turning space, or dangerously inadequate firefighting operational space. Evacuation from these communities, particularly if the evacuation has to occur in conjunction with fire and emergency vehicle entry, could be difficult and dangerous for both residents and responders.

Figure 15 obtained from the Harris County Community Wildfire Protection Plan, 2011 show in brown the most vulnerable zones for wildfire in Harris County, these zones are called Wildland Urban Interface (WUI) where human developments and improvements meet and intermix with wildland fuels. These areas where development meets native vegetation pose the greatest risk to public safety and property. Under the right conditions, the results can be catastrophic. With appropriate defensible space around these homes and the mitigation of fuels near residential developments, wildfire risk, even in extreme conditions will be reduced. Most of the identified WUI areas in Harris County are in the northern parts of the county.

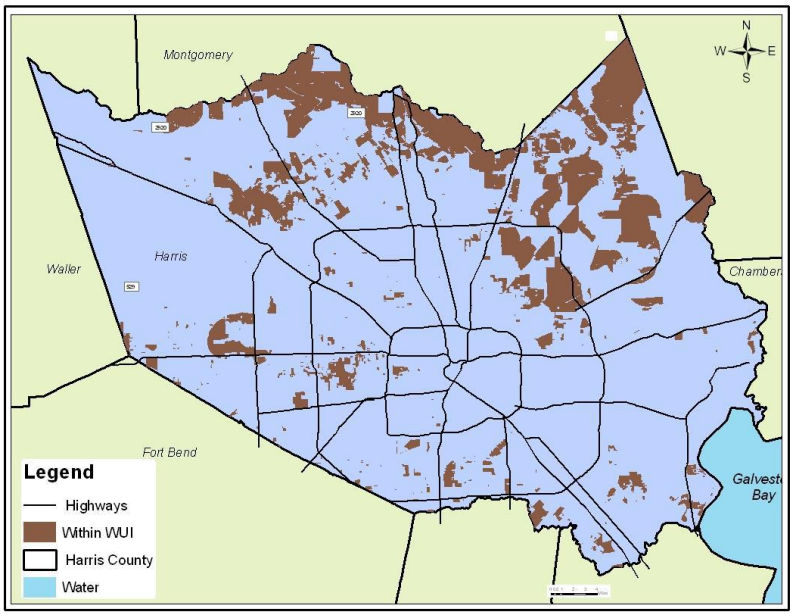

Figure 15: Wildland Urban Interface (WUI) in Harris County.

Climate Change

Higher temperatures lead to increased rates of evaporation, loss of water from plants lead to more rapid drying of soils resulting in hotter summers under drier climatic conditions. Under higher emissions scenarios, widespread drought is projected to become more common over most of the central and southern United States and dry conditions can cause more wildfires (chapter 8 from the U.S. National Climate Assessment, 2014).

The plots available in the U.S. National Climate Assessment, 2014 for the Great Plains were used and reproduced in figure 16. In the top map is the historical maximum annual number of consecutive days in which limited (less than 0.01 inches) precipitation was recorded on average from 1971 to 2000 and we can observe a value of about 20 days for the Harris County region. The bottom maps show the project change in number of consecutive dry days with approximately 2 more days in the lower emission scenario

(B1) and 3 more days in the higher emission scenario (A2) by mid-century (2041-2070) for the Harris County region.

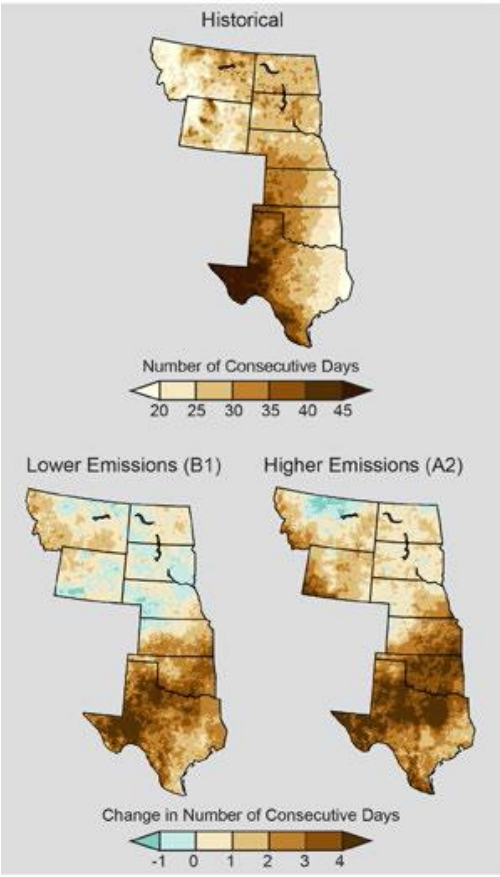

Figure 16: Historical maximum annual number of consecutive days in which limited (less than 0.01 inches) precipitation was recorded on average from 1971 to 2000 in the top map and projected changes in the number of consecutive dry days for the lower emissions scenario (B1) and for the higher emissions scenario (A2) by mid-century (2041- 2070) in the Great Plains in the two bottom maps.

Mitigation Plan & Recommendations

The Harris County has a good wildfire protection plan the Harris County Community Wildfire Protection Plan from 2011. In that plan they affirm that overall, wildfire resources are adequate, but there is need for additional and improved wildfire protection especially during severe and extreme drought conditions.

Some of the new mitigation measures to combat wildfires presents in the Harris County All Hazard Mitigation Plan, 2009 and the Harris County Community Wildfire Protection Plan, 2011 that need to be implemented are:

- Educate the public about the dangers of wildfires and how to reduce risk, because many residents have little understanding about their role in preparing for a potential fire and how to improve their own protection;
- Enhance fire suppression capabilities of each fire department in the county by ensuring the availability of appropriate personnel, training, equipment and planning tools;
- Clean-up of heavy wildfire fuel areas like abandoned buildings, abandoned lands and others;

- Create defensible space around buildings by removing brush and burnable materials from around structure so that firefighters have easy access;
- Develop early warning systems, using different Medias and especially social Medias;
- GIS mapping of vegetative coverage. This would allow us to examine the potential threat of wildfires to existing structures throughout the city;
- Cleaning gutters to prevent build-up of burnable materials;

Tornadoes

Introduction/ Past Events

Tornadoes are considered a moderate threat to Houston. The main causes of tornados in Harris County are severe thunderstorms or hurricanes. Texas is the number one state for the most tornados and damage from tornadoes (NOAA SPC). Harris County in specific has a high chance of tornados compared to the rest of the state. In Harris County the chance of a tornado is above the United States average by 6.4. The chances of Harris County being hit by a tornado is once every 3 months (NCDC). From 1950 to 2004 there have been 212 tornadoes in Harris County causing 12 deaths, 319 injuries, and $504 million dollars in damage overall. Examples of past tornado events in Harris County is in 1983 and 1992. In 1983 multiple smaller tornadoes caused the death of 3 people and $5 million dollars in damage. In 1992 a tornado events injured 32 people and caused $350 million dollars in damage.

Vulnerability

All buildings in Houston are considered vulnerable to tornadoes because it is not possible to determine where a tornado will hit. The buildings included are residential, commercial buildings, and critical infrastructure. The total building value in Houston for residential buildings is $58 billion dollars. The total value for commercial buildings is $10 billion dollars and the total value for critical structures is $7 billion dollars. All of these buildings can be potentially damaged by tornadoes. Based on data of past tornado events a more specific vulnerability cost is determined. For areas in Harris County with high tornado rates the residential building value is $10 billion dollars, commercial is $2 billion dollars, and critical structures is also $2 billion dollars.

Climate Change

The effects of climate change on tornadoes is not well understood. Based on the Severe Thunderstorm Event Database there has been a higher number of deaths due to tornadoes within the past 60 years. This is most likely due to an increased vulnerability of people as the population increases and the concentration of people in tornado areas increases. The number of large tornadoes has been the same over the past 60 years, but the number of smaller tornadoes has increased from less than 200 to around 800 from 1950 to 2010. The connection between the increased number of tornadoes and climate change cannot be made because the weather that causes tornadoes is not related to climate change (Tippett, 2016)

Mitigation Plan & Recommendations

Mitigation actions that are being taken by Harris County to account for tornadoes includes implementing emergency generators for wastewater facilities and community centers, public education on safety, expanding NOAA weather radio distribution system, developing building codes for commercial structures, and roof modifications to better resist tornadoes.

Drought

Past Events

Based on data from the National Climatic Data Center there have only been three droughts in Harris County over 50 years which gives a chance of drought happening once every 4.33 to 19.6 years (NCDC). In 1996 during a drought the rainfall was 10 inches below average. One of the concerns with drought is that it creates dry conditions where wildfires are more likely to occur.

Vulnerability

Drought is a hazard for Houston and Harris County, but is not considered a serious hazard because there is little agriculture in Harris County. Harris County is not considered to be vulnerable to drought because there is not much agriculture so there are no immediate effects to the economy. Specific data for drought in Harris County is not available which makes vulnerability analysis difficult. This is not considered to be critical to address immediately thought because drought does not do much damage to the local areas.

Climate Change

The effects of climate change cause drought to become more likely to occur in the future. As temperatures increase the amount of water that evaporates will increase. Rainfall events also are becoming less frequent which creates more dry periods.

Mitigation Plan & Recommendations

To mitigate drought Harris County has developed a water conservation plan, educated residents on water conservation, used GIS mapping, and done engineering studies on buildings to reduce leaking water.

Winter Storm

Introduction/ Past Events and Vulnerability

A winter storm is an event in which varieties of precipitation are formed that only occur at low temperatures, such as snow or sleet, or a rainstorm where ground temperatures are low enough to allow ice to form freezing rain. Severity of storm can range from a mild snow for few hours to blizzard conditions with blinding snow for several days.

Based on historical data provided by the National Climatic Data Center (NCDC) and confirmed by the Texas Hazard Mitigation Package (THMP), the probability of Harris County being affected by a winter storm event is once every 6.5 years. Houston is prone to storms of varying severity with minor with temperatures at 32 for few hours to severe storms with freezing temperature below 32 for several days with freezing rain, sleet or snow. The City of Houston Hazard Identification and Risk Estimation has ranked winter storm 6th out of ten possible natural hazard threats to the city. Winter storm does not have any geographic boundary; can occur anywhere within the city.

Since 1895, it has only snowed 35 times in Houston at an average of about once every 10 years, though some decades have several instances of recorded snowfall while others have only one each (e.g., the 1930s and 1950s). There were more incidences of snow in the 1980s on average than any other decade recorded, but the 2000s also witnessed more frequent and record-breaking snows:

- December 10, 2008: Tied the earliest snowfall record.
- December 4, 2009: Broke the earliest snowfall record.

Occurrences of freezing rain, also known as ice storms, are slightly less rare than snow in Houston. Some of the most recent ice storms occurred in 1997, 2007, and on February 4, 2011. An overnight event occurred from January 23, 2014 to January 24, another significant icing occurred a few days later on January 28, and a third event took place on March 4. Houston is undergoing a huge urbanization with exponentially increasing population. In addition, the climate change has made the city of Houston highly vulnerable to winter storms in terms of severity and the frequency. We can observe the increase in frequency of winter storms in the recent decades.

Figure 17: Vulnerability of Winter Storm, Houston

The major problem with this hazard is it has no any geographic boundary and can occur at any places. And, the City of Houston has not prioritized this hazard due to its low frequency and no significant records of damage so far. However, it has potential risk for the city of Houston with the increasing urbanization and climate change. The major impacts of winter storm can be summarized as:

- Problems in efficient transportation due to icing of the roads
- Problems in water supply and sewerage lines
- Loss of electric power and telephone services
- Property loss from water damage by unprotected pipes and plumbing.
- Effects on human health due to extreme cold with low class people being the most vulnerable.

Figure 18: Impacts of Winter Storm in Houston

Mitigation Plan & Recommendations

The city's Office of Emergency Management alerts, encourages driver's to "avoid driving unless absolutely necessary if roadways are at risk of icing, and the city has heating centers located in the city to assist people during storms.

The city does not have detailed hazard vulnerability assessment for the winter storm and the city has not prioritized the event despite of potential hazards. After the event analysis, some recommendations for the city of Houston are:

- Prioritization of risks and sufficient preparedness among the public.
- Warnings and alerts from the city's Office of Emergency Management must be made understandable to public.
- Adopt ways to educate people in understanding weather alert bulletins.
- Heating centers in the city should be increased to assist people during storms, with backup supply during emergency.
- Prepare to ensure necessary equipment, adequate personnel and efficient communication during the time of emergency.
- Proper insulation of all exposed pipes and exterior plumbing to avoid water damage.
- Hot water pipes system to reduce the post hazard damage.
- Vehicles equipped for running in snow to accelerate response activity.

Hail Storm

Introduction/Past Events and Vulnerability

Hail is defined as a precipitation in the form of small balls or lumps usually consisting of concentric layers of clear ice and compact snow with size ranging from .2"-4" with mostly less than 2". Large hailstones are spherical in shape with alternate layers of hard and soft ice. Hailstones are formed when raindrops are

blown upwards to a high cold area by the force of wind where the air temperature is below freezing. The process continues with additional coat of water unless the wind is no more able to support the weight of hailstone and they fall to the ground.

Based on historical data provided by the National Climatic Data Center (NCDC), the probability of Harris County being affected by a hail event is once every 0.14 years or every 49.6 days. The City of Houston Hazard Identification and Risk Estimation has ranked hailstorm 8th out of ten possible natural hazard threats to the city.

Hail can fall practically anywhere, at any time of the year. City of Houston has 47 hail reports for the last decade with largest record of 2.75" about 9 years ago. The city has a hail risk score of 2 based on its frequency and severity. With the changing climate, the chances of hail has increased in the recent decades based on past records. The map below shows the frequency of hail events for the state of Texas and Harris county lies in top 20%.

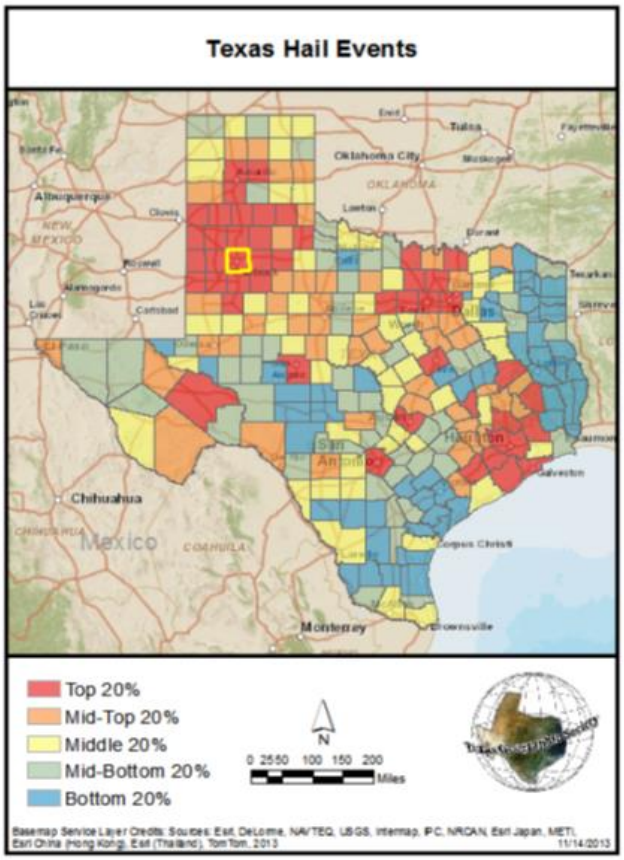

Figure 19: Vulnerability of Hailstorm, Houston

The major problem with this hazard is again that it has no any geographic boundary and can occur at any places as shown in the figure below. In addition, hailstorm is highly unpredictable and has been a major threat to the city of Houston with the increasing exposure and vulnerability.

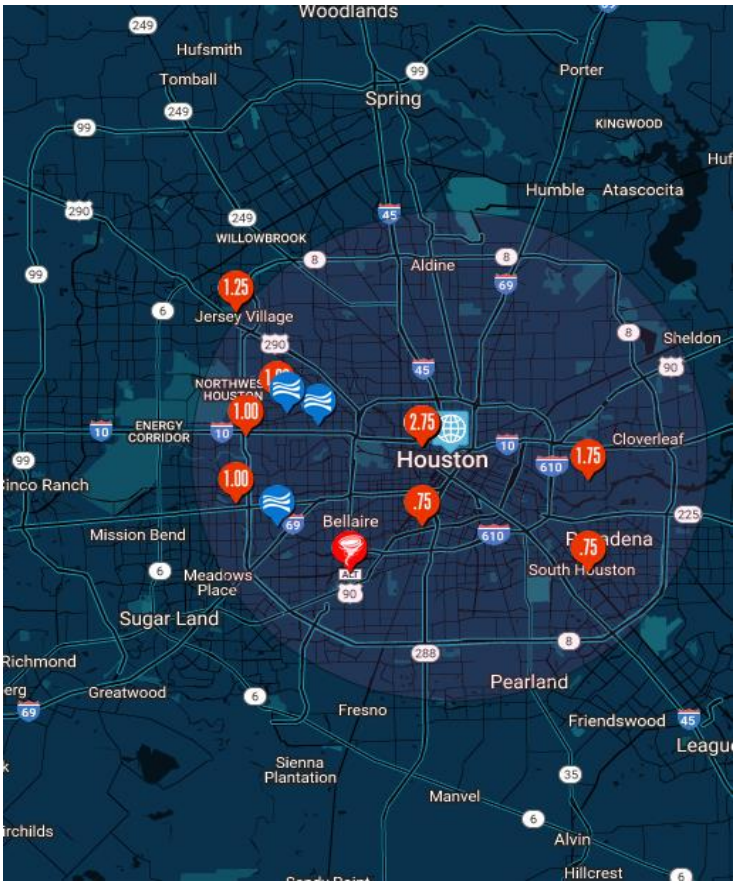

Figure 20: Hailstorm Events, Houston

The major impacts of hail storm can be summarized as:

- Problems in efficient transportation and water supply.
- Loss of property such as house windows, automobiles and outside equipment.
- Highly problematic to people with no proper shelter.
- Loss of electric power and telephone service.
- Some minor injuries can be expected if struck by large hailstones.
- Agricultural impacts

Mitigation Plan & Recommendations

The hazard mitigation plan for the city of Houston does not have organized preparedness plan for the hailstorm and the city's Office of Emergency Management does not have specific emergency plans during the hazard.

Figure 21: Impacts of Hailstorm, Houston

Based on the damage caused by hail, the best recommendation are as follows:

- Prioritization of risks and sufficient preparedness among the public.
- Adopt ways to educate people in understanding weather alert bulletins.
- Use of proper roofing materials and hail resistant glass panes on windows.
- Premium discounts for consumers with hail-proof roofs to encourage people in accepting safety measures.
- Effective warnings and alerts from the city's Office of Emergency Management.

Underwater Houston Live

The event will primarily be a music festival at Eleanor Tinsley Park in Houston, and the theme and name of the event will be "Underwater Houston Live." The events will take place yearly on July 11. Many past public relations campaigns have used live music to promote certain products and brands, but this plan will seek to center music festival around education of weather hazards in Houston. The end goal of the music festival will be to educate those that attend, create a conversation that will stem outside of the music festival, and get citizens more involved in the improvement of the hazard mitigation recommendations made in earlier sections of this plan. There will be three main aspect of the music festival: entertainment, education, protection. The entertainment aspect of the festival will consist of live music, food, and adult beverages. The education aspect of the festival will consist of three speakers related to extreme weather and mitigation, fliers with weather facts, surveys about how people react to mitigation measures and perceptions of how Houston is currently handling extreme weather, workshops surrounding how to prepare for extreme weather, and resources for citizens to reach out to local law makers to decrease vulnerability. The protection aspect of the music festival will consist of insurance sponsors on-sight that will allow participants to sign up for insurance that will protect their property from extreme weather dangers.

Festivities

Live music will be the main source of entertainment at the event. There will be a number of artists approached for this event. Underwater Houston Live will attempt to approach musicians who are popular enough for participants to recognize their names, but not musicians that will be out of our price range. The proposed musicians include Paul Wall, Slim Thug, ZZ Top, Circa Survive, Z-Ro, Widespread Panic, Umphrey's McGee, 311, Mike Jones, and other bands that may take the place of these

performers. The event will host musicians from different genres in order to draw and entertain different cultural backgrounds in Houston. This event does not want to center on one particular group that may like Alternative Rock or Hip-Hop; instead, this event will attempt to draw in many different types of people who are entertained by different types of music. There will also be speakers at the music festival, which will be strategically mixed in with the live music acts. The first speaker will be Mayor Sylvester Turner of Houston, the second speaker will be James Spann, a respected meteorologist from Alabama, and finally Dr. Katharine Hayhoe, a globally renowned climate scientist. These three speakers will be spread out throughout the day, with the Mayor kicking off the event, Dr. Hayhoe speaking at the peak of the event, and finally Mr. Spann speaking near the end of the event. These three speakers will hit on three points, which will be the three main themes of the educational process of the event. Mayor Turner will speak to the theme of what Houston can do and is doing in terms of mitigating extreme weather events. Dr. Hayhoe will talk about her work surrounding how extreme weather will get worse, and what Houston can expect in terms of specific extreme weather events in the future. Mr. Spann will then talk about what people can do in order to protect themselves and the community as a whole from extreme weather events. The event will start at 10 a.m. Houston time, and end at 10 p.m. The event will be free to attend and a meal ticket along with a drink ticket good for three beverages will be provided to citizens.

Promotion

The event will be promoted through strategic paid media like television, radio, and print avenues, but the event will predominantly be promoted social media sites. These social media sites will include Facebook, Twitter, SnapChat and Instagram. In the few months leading up to the music festival, these social media accounts will be used to promote the event, as well as provide incentives for people to attend the event (i.e. more drink tickets, prizes). During the event, the social media accounts will basically cover the event and allow those who are not at the event to see what types of educational material is being promoted, as well as see what musicians are participating in the event. By covering the event using these social media channels, it is this plan's hope that people who can't attend will still gather the educational material that is being disseminated, and further, those who are on the fence about attending can then come out and take part in the event. A hashtag will be created that will be used across all social media platforms. SnapChat filters will also be created that are unique to the event, and SnapChat will be contacted and paid in order to create a story that SnapChat users can contribute to during the event. After the event is over, the social media accounts will be drift off into oblivion. Instead, the accounts will act as severe weather alerts and also avenues to push out year-around educational material regarding mitigation recommendations, as well as ways to prepare for extreme weather events. This educational material will include ways to prepare for storms like hurricanes and tornadoes, as well as ways citizens can communicate with municipal lawmakers in order to enact things like flood gates and other mitigation measures.

Funding

The primary focus of funding for the event will come from sponsors and grant applications. The major sponsors of the event will be insurance companies. Brands such as Geico, State Farm, Progressive, and All State will be invited to sponsor the event. Sponsorship will include booths at the event in order to allow attendees to sign up for insurance that will cover things from automobiles to property. Sponsors will also get publicity on local news agencies that will attend the event, and also social media accounts promoting the event. This social media advertising will be year-around until the pre-promotion for the next event begins. Sponsors will provide a retainer in order to become a sponsor in the amount of

$25,000. These sponsors should make profit based on people purchasing insurance as well as the advertising and public relations exposure that will come with the event.

Education

The most important portion of the event is the educational aspect in regards to extreme weather mitigation. A portion of the education will come from the speakers at the festival, but the rest of the education will come from activities and literature provided at the event. There will be workshops for each extreme weather event that Houston is vulnerable to at different times during the day. This will allow people to see and hear the speakers/musicians they want, while also participating in workshops regarding the extreme weather events they are least experienced and educated with. Packets of information will also be passed out upon entry that will include fact sheets about extreme weather events in Houston, what Houston is doing to protect citizens against said weather events, and finally what citizens can and should do in order to better reduce vulnerability in Houston. Surveys will also be distributed that will measure what citizens of Houston know about extreme weather, and also their perceptions of how Houston is doing in terms of protecting citizens from hazards. Based on these surveys, future events can know what to promote in terms of what avenues to educate people. Open-ended responses will be included to see what people think Houston should improve on in terms of hazard mitigation. In order to receive the mean and beverage ticket, people will have to fill out these anonymous surveys. The invited speakers, workshops at the event, information fliers and packets with fact sheets, along with feedback from the attendees should provide the event with a clear indication that participants are gaining knowledge and education related to extreme weather mitigation; and further, that these individuals will use this information to talk to maniple legislators in order to enact proposed recommendations.

By coupling entertainment with these education measures detailed above, this plan hopes to create an environment where every year people will come have fun, and in many ways, incidentally gain useful knowledge about what weather events make Houston more vulnerable and also what types of strategies the city should enact in order to protect citizens from these hazards. Information is available to people in Houston about extreme weather and how vulnerable they are, but this plan assumes that individuals don't pay attention or really care about said information before it's too late. This event should change that by bringing all different types of people from Houston out to be entertained, and when they leave they will have attended workshops, heard experts speak about hazards in Houston, and also possess a packet of information that they can bring home.

Conclusion

Overall, Houston is a very vulnerable economic hub in the United States. Climate change will exacerbate the effects of weather and climate hazards and further increase these vulnerabilities according to projected data. Exposure is increasing due to a growing population and this cannot be changed, but vulnerability can be combated based on our mitigation recommendations and our proposed PR campaign which will help educate and create awareness in the public.

Who did what

Everyone come up with ideas for the Underwater Houston Live event and reviewed and provided comments on the entire report.

Kushal Adhikari: researched and analyzed the impacts from winter storms, and hail storm.

Rafael Gatto: researched and analyzed the impacts from extreme heat and wildfire. He also researched about Harris county characteristics and climate.

Derrick Holland: researched and analyzed the impacts from hurricanes and tropical storms. He also wrote and researched the PR campaign for the Underwater Houston Live event.

Stephanie Mendoza: researched and analyzed the impacts from flood, sea level rise and lighting. She also organized the report and did all the formatting of the text.

Jon Vue: researched and analyzed the impacts from tornados and drought. He also wrote the introduction and conclusion.

References

CDC. Extreme heat: a prevention guide to promote your personal health and safety. (2004). Retreived from: www.bt.cdc.gov/disasters/extremeheat/heat_guide.asp.

Climate Wizard. (2017). Retrieved from: http://www.climatewizard.org/

Exploring a Changing Coast in the Face of Sea Level Rise – Galveston, Texas. *GeoSpace*. N.p., 19 Apr. (2013). Web. 14 May 2017.

FedStats. (2009). MapStats. Retrieved from MapStats:http://www.fedstats.gov/qf/states/48/48201.html

"Future Sea Level Rise." *Adapting to Global Warming*. (14 May 2017). N.p., n.d. Web.

Gill, Victoria. "Climate Change 'will Make Lightning Strike More'." *BBC News*. BBC, (13 Nov. 2014). Web. 14 May 2017.

Groffman, P. M., P. Kareiva, S. Carter, N. B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis, 2014: Ch. 8: Ecosystems, Biodiversity, and Ecosystem Services. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 195-219. doi:10.7930/ J0TD9V7H.

Harris County All Hazard Mitigation Plan. (2009). Retreived from: http://mitigationguide.org/wp-content/uploads/2013/05/TXHarris.pdf

Harris County Community Wildfire Protection Plan. (2011). Harris County Fire Marshal's Office and the Harris County Office of Homeland Security & Emergency Management. Retrieved from: https://tfsweb.tamu.edu/uploadedFiles/FRP/New_Mitigation/Unsafe_Debris_Burning/CWPP2.pdf

Houston Chronicle. (2009). Greater Houston's Top 100 employers. Houston, TX.

Kang, N. Y., & Elsner, J. B. (2015). Trade-off between intensity and frequency of global tropical cyclones. *Nature Climate Change*, *5*(7), 661-664.

Luber, G., & McGeehin, M. (2008). Climate change and extreme heat events. American journal of preventive medicine, 35(5), 429-435.

Neena Satija, Kiah Collier, Al Shaw, Jeff Larson. (2016, March 12). Houston is a sitting duck for the next big hurricane. Why isn't Texas ready? Retrieved May 10, 2017, from http://grist.org/climate-energy/houston-is-a-sitting-duck-for-the-next-big-hurricane-why-isnt-texas-ready/

NOAA National Climatic Data Center. (2009.). National Climatic Data Cente. Retrieved from National Climatic Data Cente: http://www4.ncdc.noaa.gov/cgiwin/wwcgi.dll?wwevent~storms

NOAA National Centers for Environmental information, Climate at a Glance: U.S. Time Series, Average Temperature. (2017). Retrieved on May 5, 2017 from http://www.ncdc.noaa.gov/cag/

Officals pledge to empty Ike-battered peninsula. (n.d.). Retrieved May 10, 2017, from https://web.archive.org/web/20080916230056/http://news.yahoo.com/s/ap/ike

Roth, D. (2015). *Texas Hurricane History* (Rep.). doi:http://www.wpc.ncep.noaa.gov/research/txhur.pdf

Shafer, M., D. Ojima, J. M. Antle, D. Kluck, R. A. McPherson, S. Petersen, B. Scanlon, and K. Sherman. (2014). Ch. 19: Great Plains. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 441-461. doi:10.7930/J0D798BC.

Texas Division of Emergency Management. (2008). State of Texas Mitigation Plan. Austin: State of Texas.

Texas State Data Center. Texas State Data Center and Office of the State Demographer. (2009). Retrieved from Texas State Data Center and Office of the State Demographer: http://txsdc.utsa.edu/cgi-bin/prj2008totnum.cgi

Tippett, Michael K., Chiara Lepore, and Joel E. Cohen. "More Tornadoes in the Most Extreme U.S. Tornado Outbreaks." *Science* 354.6318 (2016): 1419-423. Web.

The Handbook of Texas Online. The Handbook of Texas Online. (2009). From The Handbook of Texas Online: http://www.tshaonline.org/handbook/online/articles/HH/hch7.html

US Census Bureau. (2009). Census 2000. Census Bureau Homepage. Retrived from Census Bureau Homepage: http://www.census.gov/

US Census Bureau. (2017). Harris County, Texas QuickFacts. Retrieved from: https://www.census.gov/quickfacts/table/PST045216/48201

United States Department of Agriculture. (2007). National Agricultural Statistics Service, Census Publications.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. (2014). Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.

"What Could Disappear." *The New York Times*. The New York Times, (23 Nov. 2012). Web. 14 May 2017.