



Houston and Hurricane Harvey: a call to action

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As part of Zurich’s flood resilience program, the Post Event Review Capability (PERC) provides research and independent reviews of large flood events. It seeks to answer questions related to aspects of flood resilience, flood risk management and catastrophe intervention. It looks at what has worked well (identifying best practice) and opportunities for further improvements. This PERC analysis was written by ISET-International in collaboration with Zurich Insurance Group and the American Red Cross Global Disaster Preparedness Center.

Executive summary

Hurricane Harvey made landfall near Rockport, Texas on August 25, 2017 as a Category 4 storm. Over the next four days, Harvey dropped more than 1 m (40 inches) of rain over eastern Texas, causing catastrophic flooding. The resulting floods inundated hundreds of thousands of homes, displaced more than 30,000 people and prompted more than 17,000 rescues. Total damage from the hurricane is estimated at USD 125 billion,¹ making it the second-costliest tropical cyclone on record after Hurricane Katrina.

This study – written by ISET-International, a nonprofit organization committed to building resilience and catalyzing adaptation to critical social and environmental challenges, in collaboration with Zurich Insurance Group, the global insurer with its Flood Resilience Alliance, and the American Red Cross Global Disaster Preparedness Center – looks in detail at the Houston floods that resulted from Hurricane Harvey. Based on interviews with impacted households and businesses, and with people involved in risk reduction, response and recovery at the city, county and state level, the study identifies lessons learned from the floods. The study also provides recommendations for enhancing flood resilience. We believe that these recommendations can be applied not only in Houston, but across the U.S. and even globally.

The findings from Hurricane Harvey discussed here are part of a wider series of event analysis, called Post Event Review Capability (PERC) that the Zurich Flood Resilience Alliance has been conducting since 2013. The trends are clear. Impacts from disasters are getting worse. Yet after a disaster there is rarely the time to learn what happened and what could be done better next time, although we know that the recovery period is a key window of opportunity to take action to reduce future risk and ensure that disasters will not repeat in a similar way.

The PERC methodology we developed (publicly available at: <https://www.zurich.com/en/corporate-responsibility/flood-resilience/learning-from-post-flood-events>) helps meet this urgent need. PERCs generate actionable recommendations for reducing future damages right when they are needed most. The aim is

to answer questions related to various aspects of flood resilience, including flood risk management, catastrophe intervention and recovery. It looks at what has worked well, shares best practices, and identifies opportunities where there is room for further improvements.

This report follows a dozen PERC studies conducted over the past five years and adds to the global insights gathered from previous big flood events. It also complements a prior study conducted in the U.S. following flooding from intense rainfall and high tides – the South Carolina floods of 2015.

¹ NOAA Office for Coastal Management Fast Facts: Hurricane Costs. <https://coast.noaa.gov/states/fast-facts/hurricane-costs.html>



“There is no doubt that floods in Houston from Hurricane Harvey were an extreme event. However, they are similar to past events along the Gulf of Mexico, and current trends toward more intense hurricanes and rainfall suggest they will continue and may get worse.”

Resilience lessons from the flood

Preparedness and risk reduction

Use forward-looking scenarios to plan for the future. We know the world is changing, both naturally and by human actions. Rather than rely on past conditions, we must begin using regional worst-case historical information coupled with forward-looking climate and development scenarios to inform our planning and make decisions on where and how to build and live.

Limit or prevent federal insurance coverage of new properties in flood zones.

The National Flood Insurance Program (NFIP) should slow or prevent the development of new properties within flood zones. In floodways, new structures should not be covered. In floodplains, there should be more stringent requirements for coverage on new structures.

Make flood insurance more universally appealing for homeowners and businesses.

On the supply side, both the federal government and private insurers should explore options to bundle flood insurance as part of a multi-hazard policy. On the demand side, awareness campaigns are needed for property owners, businesses and insurance brokers regarding the benefits of appropriate coverage, whether or not they are in a designated flood zone, and what this means for recovering quickly and being more resilient.

Build a culture of awareness around risk.

Incentivize incremental, small decisions by residents and businesses that collectively reduce exposure and risk, such as elevating mechanical assets, locating critical materials above ground level, and incorporating risk awareness and preparedness in their day-to-day lives to reduce the surprise element of flooding.

Address household preparedness as part of business preparedness. Businesses depend on staff being able to work through hazard events and/or return to work quickly following a disaster. Businesses can support this by, for example, raising employee awareness of and preparedness for risk ahead of the hurricane season.

Response

Improve messaging around disaster events to more accurately reflect real risk.

The current language we use to describe extreme floods such as “100-year event,” “unprecedented,” “biblical” or “black swan” does little to help people understand their risk nor does it motivate them to take action. Highlight the ways an event is rare, but not anomalous – for example, hurricane seasons as intense as the 2017 season have a probability of about 10 percent of occurring each year.² “Black swan” events are not events with very low probability, but rather events that have not been seen in the past.

Trust the public with information that helps them manage their safety and preservation of assets.

During Harvey, critical information, particularly about reservoirs filling and the need for urgent releases to avoid critical overtopping, was not communicated in ways that supported households and businesses to act, leading to losses that could have been avoided. Authorities need to plan the following in advance:

- How and what to communicate;
- Who will provide the messaging;
- Who this information is being communicated to;
- How messages need to be presented to reach that audience.

Partnerships and relationships are fundamental to resilient response and recovery.

The people and organizations that had pre-established relationships that they could call on for preparedness, response, recovery and business continuity were able to react more quickly and, for those impacted, immediately begin recovery. This type of relationship building needs to be an intentional focus during non-disaster periods.

Use existing assets to provide critical information during disasters.

For example, several of the businesses interviewed for this study used pre-existing security systems to monitor their offices and began recovery planning even prior to regaining access to physical facilities.

² NOAA hurricane data, accumulated cyclone energy.

Recovery

Businesses can play a positive role for their employees and the communities in which they work by providing support to impacted employees and/or communities.

Providing equipment, access to food and showers, covering hotel room costs, assisting with mucking out and offering paid time off for employees can go a long way toward creating a community and culture of assistance. Ideally, businesses should consider and plan for this type of support as part of their business continuity and preparedness so that the resources needed are available and implementation can begin immediately.

Adapt policy and funding mechanisms to increase resilience for poor and vulnerable³ households.

Deferred maintenance is a key resilience gap for vulnerable households. Changing policy and funding allocations to address this gap head-on could dramatically increase resilience for some of the city's most at-risk inhabitants.

Repeat loss properties should not be rebuilt to their prior condition, but rather be bought out or mitigated.

For properties that have been flooded repeatedly, repairs are a temporary patch until the next flood event. For many of these impacted properties the interval between events is becoming smaller as flood events become more intense and more frequent. To rebuild to their prior condition traps owners in a cycle of loss.

Owners need all their options on the table simultaneously.

Currently, impacted businesses and homeowners are often forced to make

decisions about how or whether to rebuild with incomplete information available. More timely information up-front would allow for better long-term strategic thinking and better support decisions that increase resilience.

Increase dissemination of flood risk reduction options for homeowners and businesses.

Risk reduction and resilience-building efforts can be cost efficient but are often carried out too late (e.g., after a disaster has already happened). To increase early uptake of risk reduction measures, insurers, insurance brokers, real estate agents, small business associations and chambers can help support dissemination of risk reduction options through existing channels like newsletters, client interactions and regular meetings.

Invest in regulation, coordinated floodwater detention and neighborhood drainage.

The collective impact of these efforts could significantly reduce city flooding at a fraction of the cost of large infrastructure projects, while at the same time laying the groundwork needed to maximize the operational flexibility and success of larger efforts.

Not acting now to build flood resilience in Houston and Harris County will potentially be very costly in the future.

Hesitancy on the part of leadership to take bold and potentially controversial action and unwillingness on the part of residents to self-tax and act is rapidly leading Houston back onto a business-as-usual trajectory. What appears to have been pushed aside is the reality that lack of action could be very costly for Houston in the future, in ways that could reverberate throughout the entire economy and region.

There is much more that can be said and learned about the flooding that occurred following Hurricane Harvey. There were numerous communities both inside and outside Houston and Harris County that were severely impacted, but whose stories are not told here. Inequity in response and recovery has been a recurrent theme in many of the news articles following the hurricane. In particular, as the recovery unfolds, there is growing evidence of large-scale chemical spills which went undisclosed at the time and which are creating ongoing human health issues.⁴ That this report does not address these communities and issues is in no way meant to diminish the significance of their experience nor their importance.

There is no doubt that floods in Houston from Hurricane Harvey were an extreme event. However, they are similar to past events along the Gulf of Mexico, and current trends toward more intense hurricanes and rainfall suggest they will continue and may get worse.

These events should be a call to action, engaging cities nationwide to rethink their risk landscape and how they continue to modify it, regardless of whether or not they have faced floods in recent years. These events should also push the nation as a whole to rethink what it means to recover from a disaster and how to leverage the recovery phase as an opportunity to reduce risk. In particular, recovery needs to be used as an opportunity to more actively build resilience to future events, not just address past loss experience.

Acronyms

CRS	Community Rating System	NFIP	National Flood Insurance Program
EOC	Emergency Operations Center	NOAA	National Oceanic and Atmospheric Administration
FEMA	Federal Emergency Management Agency	PUD	Public Utility District
HCFC	Harris County Flood Control District	TMC	Texas Medical Center
MUD	Municipal Utility District	USACE	United States Army Corps of Engineers

³ Vulnerability is a combination of physical exposure to risk and the social factors which make it difficult to withstand and recover from the adverse impacts caused by a risk. As a result, households are not equally 'vulnerable' to disasters even if they all have equal exposure.

⁴ E.g. <https://www.independent.co.uk/news/world/americas/hurricane-harvey-latest-houston-chemical-plant-toxic-spill-floodwater-us-oil-recovery-superfund-epa-a7954586.html>; <https://www.houstonchronicle.com/news/houston-texas/houston/article/In-Houston-and-beyond-Harvey-s-spills-leave-a-12771237.php>

Introduction

Since 2013, the Zurich Flood Resilience Alliance's Post Event Review Capability (PERC) has been used to analyze flood events across the globe, from Western Europe, the U.S. and Nepal to Peru. The studies seek to understand what has worked well and what has gone wrong during large flood events by engaging in dialogue with authorities, affected people and organizations. Information, knowledge and insight are collected to provide key findings on what happened and why, and to formulate actionable recommendations that can help build flood resilience.

This report adds to the existing body of work by exploring the Hurricane Harvey flooding in Houston and Harris County, looking at flood preparedness and risk reduction measures in place in advance of the flooding, flood response and the unfolding recovery up to seven months post-flood. This report looks across sectors and scales to understand, for each stage of the disaster risk management cycle, where there was resilience and where there were challenges. It then identifies opportunities to further build resilience in Houston, in the U.S. coastal context, and for cities globally.

This report in particular explores flood resilience in Houston from a business perspective. Houston is a business city – Houston's and Harris County's economies rank amongst the strongest in the nation. At the same time Houston has been hit with three so-called one-in-500-year floods in three years, each time worse. In the words of Judge Ed Emmett, chief executive of Harris County:

*"Harvey caused me to look differently at the world we live in. Three 500-year floods in three years means either we're free and clear for the next 1,500 years, or something has seriously changed."*⁵

– Judge Ed Emmett

Clearly, Houston needs to build its resilience to flooding, particularly for its businesses, to maintain its economic strength. Harvey provides an opportunity to explore both the challenges floods present for businesses and simple entry points for mitigating some of those challenges, as well as the opportunities businesses and communities have to work together in building city-wide flood resilience. For the business audience, for homeowners, for disaster management personnel and for policy makers, we believe this PERC study provides opportunities to learn from Houston's flood experience in ways that will support actions to better prepare for, respond to and recover from the next disaster event.

This post-event review:

- Deconstructs why the flood manifested in the way it did and became a disaster;
- Explores successes and challenges experienced in pre-event risk reduction, response and recovery;
- Highlights the business sector – how it was impacted and how it is supporting recovery;
- Identifies avenues and opportunities for building resilience across all of these areas.

While these floods provide lessons for the Houston area, we believe that these lessons can also be applied to a variety of contexts within and outside of Texas.

The information presented in this report was collected through:

- Interviews with individuals and groups from key governmental agencies and departments, businesses, nonprofits and academic institutions;
- Interviews with flood-impacted households and businesses;
- Review of secondary literature such as newspaper articles, reports and peer-review papers.

⁵ New York Times, November 11, 2017. "Lessons From Hurricane Harvey: Houston's Struggle Is America's Tale." Michael Kimmelman.

Hurricane Harvey

The storm

Hurricane Harvey made landfall along the Texas coast near Port Aransas at about 10:00 p.m. on Friday, August 25, 2017 as a Category 4 hurricane. Wind damage along the coast near the landfall was extreme. However, Harvey quickly weakened. Its forward motion slowed and the hurricane shifted from a wind threat to a flood threat.

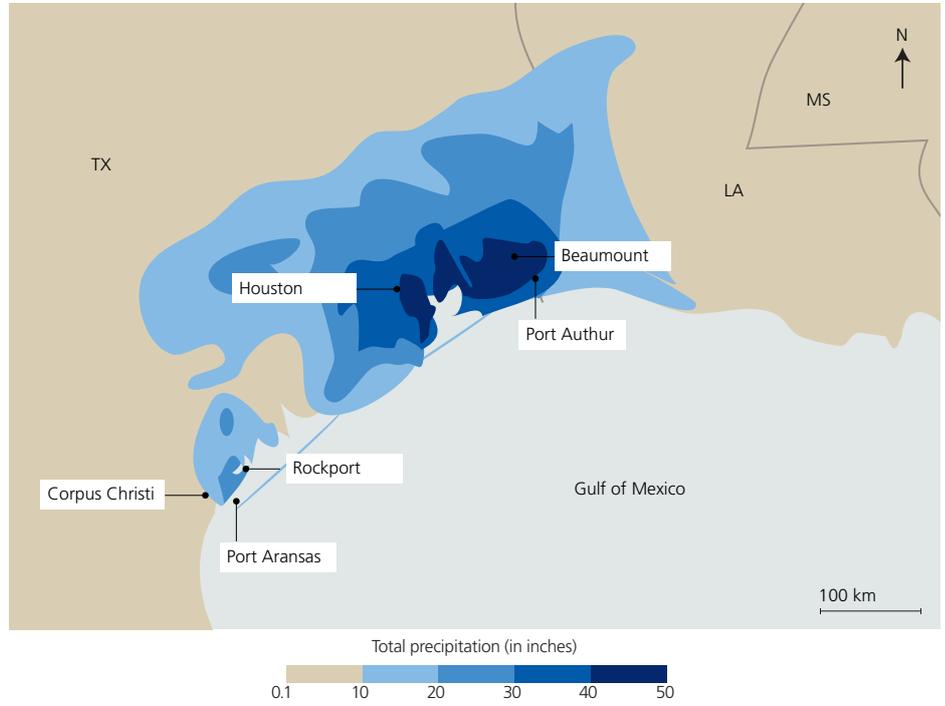


Figure 1: Hurricane Harvey's total precipitation between August 25 and 30, 2017 in Texas and Louisiana. Source: NOAA Climate.gov.



Figure 2: Map of Harris County and the Houston metropolitan area, indicating the locations of Addicks and Barker Reservoir, Brays and Buffalo Bayou and Lake Houston.

Light rainfall began in Harris County on Friday morning. Saturday evening rains intensified dramatically between 8 p.m. and 11 p.m., and flash flooding developed across Houston and Harris County. Heavy rain bands, with rainfall of 13 to 15 cm (5 to 6 inches) per hour in places, swept across the county. Addicks and Barker Reservoirs started filling up rapidly. By Sunday, the United States Army Corps of Engineers (USACE) announced they would start emergency releases through the gates: at 2 a.m. on Monday morning from Addicks and at 11 a.m. at Barker. But just after midnight early Monday morning they opened the gates as Addicks was rising more than 15 cm (6 inches) per hour and they were worried about the pressure on the dams. Addicks began spilling Tuesday morning, despite the releases. Similar spills and emergency releases occurred at Lakes Houston and Conroe as they rapidly rose and overflowed. The Addicks and Barker releases contributed to catastrophic flooding along Buffalo Bayou. All bayous and creeks in Harris County experienced record flooding.

The majority of Hurricane Harvey's rainfall in Houston and Harris County occurred during a four-day period, with total rainfall amounts ranging from 66 to 119 cm (26 to 47 inches)⁶ (See Figure 1 on p. 9). The lowest totals occurred over the northwest and northeast part of the county while the highest totals were measured across the southeast part of the county. Rainfall probabilities were 1 percent (100-year) or higher (500-year+) for all watersheds in the county over this four-day period.

The impacts

Harvey was extraordinary not just for the amount of rain, but also for the geographic extent of the event. Sixty counties across southeast Texas were impacted with heavy rain extending into Louisiana. Storm impacts were also recorded in Arkansas, Alabama, Tennessee, Kentucky and North Carolina.⁷ Compared to the spatially largest rainfall events ever recorded in U.S. history, Harvey exceeded all the previous records back to the late 1800s. The closest comparable event was Hurricane Beulah in 1967.⁸

Disastrous flooding occurred in many of the watersheds in Harris County. Historical records held by previous massive floods in March 1992, October 1994, Tropical Storm Allison in 2001 and the April 2016 Tax Day flood were exceeded by Harvey at many locations. Record flooding occurred at every bridge crossing along Buffalo Bayou. In downtown Houston, water levels exceeded the record set by Allison by 1.5 to 2.1 m (5 to 7 feet). Water levels recorded at the Houston Ship Channel Turning Basin were 1.5 m (5 feet) above the 2016 Tax

Day flooding. Rainfall runoff discharging into the Houston Ship Channel from many of the bayous and creeks draining Harris County resulted in water levels at the 610 bridge⁹ only 9 cm (0.29 feet) lower than Hurricane Ike's storm surge.

At peak flooding, an estimated 25-30 percent of Harris County – roughly 1,150 km² (444 mi²) of land – was submerged. Flooding was unusually deep in some areas, due in part to the intense short duration rainfall and the record flood levels along several creeks and bayous. In a few areas, water levels rose to the second story of structures.

Throughout Texas, 103 people died in storm-related incidents, 36 of them in Harris County.¹⁰ Unlike with other recent Harris County flood events, the majority of the fatalities associated with Harvey were not from drowning in vehicles, but from high water levels and fast-moving water. Notably, Harvey is one of the only flood events where people drowned in their home or work place, and one of the few times where authorities urged residents to climb on to their roofs to escape flood waters.

Official rescues, by federal forces and the Houston Police Department Dive Team, exceeded 13,000 people. A flotilla of private boats rescued an unknown number of additional people. Over 37,000 Texans took refuge in shelters. An estimated 203,000 homes were damaged, of which 12,700 were destroyed, and more than 700 businesses were impacted. Over 100 roads¹¹ were closed in the immediate aftermath, 800 wastewater treatment plants were impacted, and the school district reported USD 700 million in damages.¹²

Energy production in the Gulf of Mexico declined by approximately 21 percent in the wake of Harvey¹³. Many energy-related ports and terminals closed. About 12 percent of total U.S. refining capacity was offline for several days, with Texas refineries affected at Corpus Christi, and later also at Port Arthur and Beaumont.¹⁴ Two refineries had to be shut down following related storm damage and releases of hazardous pollutants, while a chemical plant in Crosby exploded on August 31 due to power failures and flooding. At the time of the publication of this report, there is growing evidence of environmental and human health impacts from numerous hazardous waste leaks, inundated superfund sites and spills from a range of facilities that went unreported at the time of the storm.

The U.S. government estimated damages from Harvey at USD 125 billion, primarily in damage to homes and commercial property. In addition to direct physical losses, the weather intelligence consultancy Planalytics estimates the loss of revenue incurred by the Houston area's retailers and restaurants alone to be approximately USD 1 billion.¹⁵

Only a small fraction of this amount is insured. Insurers estimate the total insured losses from Hurricane Harvey at USD 19.4 billion, including USD 8.4 billion in flood losses insured by NFIP, USD 2.7 billion in insured vehicle losses, USD 4.9 billion in insured commercial losses, and USD 3.4 billion in other losses.¹⁶ In addition, 738,000 people registered for assistance with FEMA, with its assistance payouts reaching USD 378 million.¹⁷

⁶ Heavy rainfall and flooding was not restricted to Harris County alone – in particular, the Beaumont-Port Arthur area also experienced torrential rains and record flooding. Detailed exploration of the events outside of Harris County are beyond the scope of this report. However, some of the businesses interviewed as part of this study were in the Beaumont area.

⁷ Office of the Texas Governor- Greg Abbott. October 20, 2017. "Governor Abbott Renews State Disaster Declaration For 60 Texas Counties Affected By Hurricane Harvey."

⁸ Texas A&M Today, September 7, 2017. "Texas A&M Expert: Rainfall from Harvey Shattered Every Record." Keith Randall

⁹ At the NOAA Manchester tide gage.

¹⁰ National Oceanic and Atmospheric Administration and the National Weather Service. January 23, 2018.

"National Hurricane Center Tropical Cyclone Report Hurricane Harvey." Eric S. Blake and David A. Zelinsky.

Nonetheless, many homes, even within the 100-year floodplain, lack flood insurance. Harris County Flood Control District estimates that 83 percent of the 1.4 million buildings in Harris County lacked flood insurance when the storm hit.¹⁸

Houston's history of flooding

The total rainfall associated with Hurricane Harvey was extreme, setting multiple new continental U.S. records. However, even though Harvey has been labelled as an "act of God" and an "unprecedented" flood event, the intensity of rainfall associated with Harvey is not without precedent along the coastline of the Gulf of Mexico and the damages caused by Harvey are as much an act of man as an act of nature.

Built on flat, low-lying clay soils crisscrossed by meandering bayous, Houston has been prone to flooding since its founding. However, there is no such thing, even in Houston, as a typical flood. Every single one of the major historic floods in Houston has been different: They started differently, manifested differently and impacted differently. With this in mind, as Houston recovers from Harvey everyone should be careful not to focus on the next "Harvey;" but rather focus on building resilience and preparing for the next big event, whatever that may be.

"The Houston/Galveston area has a rich history of tropical cyclone hits, including the infamous 1900 Galveston hurricane, the deadliest natural disaster in United States history, Tropical Storm Claudette (1979), which produced the still-standing continental U.S. record 24-hour rainfall total of 1.1 m (43 inches) in Alvin, Texas 32 km (20 miles) south of Houston, Tropical Storm Allison (2001) which devastated the Houston area while becoming the costliest tropical storm in United States history, Hurricane Ike (2008) which produced a deadly and destructive storm surge along the upper Texas coast, and Hurricane Harvey (2017) which produced unprecedented flooding in Houston and surrounding areas." – Houston/Galveston National Weather Service Office



¹¹ National Public Radio, September 7, 2017. "Scores Of Roads Closed. 50,000+ Displaced. Houston Still Has A Long Way To Go." David Schaper.

¹² Houston Chronicle, September 8, 2017. "Houston-area schools with the worst Hurricane Harvey flood damage." Tushi Kamath.

¹³ BV report, August 2017.

¹⁴ Reuters, September 2017.

¹⁵ Planalytics, August 2017: <http://www.planalytics.com/houston-stores-facing-flood-devastation/>

¹⁶ Texas Dept. of Insurance, April 12, 2018. "Hurricane Harvey Data Call." www.tdi.texas.gov

¹⁷ Washington Post, September 2017: https://www.washingtonpost.com/national/texas-officials-hurricane-harvey-death-toll-at-82-mass-casualties-have-absolutely-not-happened/2017/09/14/bff3ffea-9975-11e7-87fc-c3f7ee4035c9_story.html?noredirect=on&utm_term=.7bc9c4a6e75b.

¹⁸ Houston Chronicle, April 10, 2018. "Harris County seeks billboard campaign encouraging residents to buy flood insurance." Mihir Zaveri.

Flood timeline¹⁹



1900
1907
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1900

The Great Storm of 1900, Galveston, Texas. A category 4 hurricane with a 4.6 m (15-foot) storm surge makes landfall at Galveston, one of the biggest cities in Texas, killing 6,000 to 8,000 people. Associated widespread flooding in Harris County results in USD 30 million to 40 million in property damage. This is the deadliest hurricane and disaster in American history, ending the golden era of Galveston. Nonetheless, Galveston committed to recovery, elevated the city and built a sea wall in the decade that followed.

1907

Much of Houston and Harris County flood in a major storm.

1908

First drainage district created in Harris County, in Brays Bayou watershed.

1913

Major storm results in flooding on Buffalo, White Oak, Brays and Greens Bayous.

1915

Hurricane similar to the 1900 storm makes landfall in Galveston. Due to the Galveston sea wall, death toll in town is 11. An associated 51 cm (20 inches) of rain in Harris County causes damage across the county estimated at USD 54 million, including heavy flooding on Buffalo Bayou.

1916

First United States Geological Survey (USGS) topographic maps published for Harris County.

1929

April, enormous storm hits Houston and Harris County. Twenty-five cm (10 inches) of rain falls in 14 hours.

All bayous are out of banks. Structures across the county suffer extensive damage and downtown Houston is heavily impacted.

May, a second major storm hits Harris County, causing structural damage, street flooding and agricultural damage.

1932

A hurricane hits Freeport. In Harris County, there is widespread flooding on all bayous.

1935

December, massive storm floods Houston and Harris County. Multiple bayous are out of banks. Two-thirds of rural Harris County is flooded, seven people are killed, 40 percent of buildings and almost all bridges in Houston are damaged beyond repair, and property damage is double that caused by the 1929 floods.

1937

Harris County Flood Control District founded in response to the 1935 floods.

1941

Hurricane near Freeport results in four deaths and flooding throughout Houston.

1943

July, a hurricane near Galveston causes extensive flooding in Harris County causing USD 16.5 million in damages.

October, a hurricane near Freeport floods over 11,000 structures in Harris County.

1945

Hurricane results in 46 cm (18 inches) of rainfall in 24 hours, the heaviest rainfall ever recorded to date in Harris County. Flooding is reported on all bayous.

1955

North Harris County thunderstorm results in 25 cm (10 inches) of rain in less than 24 hours, flooding homes.

1957

Hurricane Audrey makes landfall along the Texas/Louisiana border with 3.6 m (12-foot) storm surge. Over 600 people are killed, with widespread flooding including throughout Harris County.

1961

Hurricane Carla, the largest hurricane ever recorded to date, kills 34 and causes damages exceeding USD 300 million. Heavy flooding in southern Harris County.

1969

Thunderstorm preceding a cold front results in intense rainfall, flooding more than 250 structures and causing over USD 3.3 million in damages.

1973

Major storm brings 25 to 38 cm (10 to 15 inches) of rain in Harris County. Ten lives are lost and damages exceed USD 50 million.

1976

25 to 33 cm (10 to 13 inches) of rain in six hours results in flooding along Brays Bayou and within the Texas Medical Center.

1979

July, Tropical Storm Claudette comes onshore near the Texas-Louisiana border and then stalls, dropping a record 1.1 m (43 inches) of rain in 24 hours in Alvin, Texas, 32 km (20 miles) south of Houston. Total damage exceeds USD 700 million. This is the still-standing continental U.S. 24-hour rainfall record.

September, Tropical Storm Elena floods downtown Houston and causes one death.

1983

May, thunderstorm floods several bayous, damages exceed USD 14 million.

August, Hurricane Alicia results in 28 cm (11 inches) of rain and flooding along all the bayous. Damages approach USD 1 billion, primarily due to wind damage.

September, 23 cm (9 inches) of rain south of downtown kills four and floods 1,000 homes along Brays Bayou. Damages exceed USD 38 million.

1984

23 cm (9 inches) of rain in 24 hours in northern Harris County. More than 200 homes are flooded, with damages exceeding USD 32 million.

1989

May, 18 to 36 cm (7 to 14 inches) of rain over much of Harris County. Buffalo and Green bayous flood.

June, remnants of a tropical storm produce 15 to 30 cm (6 to 12 inches) of rain. 1,100 homes are flooded. In combination with the May floods, a presidential disaster declaration is issued.

1992

Flooding on White Oak, Buffalo and Brays Bayous, including record flooding on Brays. One death, more than 1,500 structures flooded, and much of Interstate 10 highway is underwater.

1994

Hurricane Rosa causes widespread flooding in Texas. Twenty-six counties are declared federal disaster areas, 22 are killed, with damages around USD 700 million. In Harris County, rainfall is over 76 cm

(30 inches) in three days. Most bayous are out of banks and flooding devastates north Houston. At least 10,000 are forced into shelters in an 80 km (50-mile) radius around Houston.

1998

September, Tropical Storm Frances causes extensive flooding; 1,300 structures are impacted along White Oak bayou.

October & November, major storms flood hundreds of structures in north Harris County.

2001

Tropical Storm Allison severely damages downtown businesses and hospitals. Twenty-two deaths, north downtown Houston and Texas Medical Center virtually shut down, two million people impacted. More than 95,000 vehicles, 51,430 homes and 1,700 businesses are damaged in Houston; USD 970 million is granted in federal and state recovery aid. Declared a one-in-500-year event (0.2 percent annual exceedance probability).

2002

Nine straight days of rain over northeast Harris County. White Oak, Greens and Halls bayous out of bank, 2,000 homes flood.

2006

Intense rainfall; nearly 15 cm (6 inches) of rain falls in 75 minutes near Hobby Airport and 20 to 25 cm (8 to 10 inches) in 3 hours. 3,370 homes, 561 apartments and one nursing home flood.

2008

Hurricane Ike makes landfall in Galveston. Storm surges and winds cause major damage. Ike's eyewall passes

over Houston causing wind damage and disrupting power. Storm surge in Houston floods 2,500 structures, rainfall floods an additional 1,300. Damages exceeded USD 20 billion, due to wind and flooding.

2009

Heavy rainfall from slow moving thunderstorm causes extensive flooding. Five deaths, highway closures and record high watermarks on some creeks. 2,305 structures flood.

2012

High-water rescues in Cypress Creek watershed after several days of heavy rainfall.

2015

Memorial Day Flood. Storms over Memorial Day weekend in late May drop more than 30 cm (12 inches) of rain in 10 hours; in Brays watershed rainfall is nearly 28 cm (11 inches) in 3 hours. Flooding kills seven, damages 6,000 structures north and west of downtown Houston, USD 460 million in damages. Declared a one-in-500-year event.

2016

Tax Day Flood. Over two days in mid-April 30 to 41 cm (12 to 16 inches) of rain falls countywide in 12 hours resulting in historic flooding in northern and western Harris County. Addicks and Barker Reservoirs set record pool levels. 9,820 structures flooded and eight deaths. Declared a one-in-500-year event.

2017

Hurricane Harvey, the second-costliest, but wettest tropical cyclone ever. 25 to 30 percent of Harris County is submerged. Declared a 1-in-500-year event.

¹⁹ Information for the timeline was obtained from: Harris County Flood Control District, www.hcfcd.org/flooding-floodplains/harris-countys-flooding-history/ Weather Research Center Houston, TX, www.wxresearch.com/almanac/houflood.html

Why is Houston so flood prone?

Houston is located in a multi-hazard landscape that includes floods, extreme temperatures, tropical storms, hurricanes and tornadoes. Flooding, in particular, is a problem due to several interrelated natural and man-made factors, from soils and natural landscape to loosely managed expansion and growth. Within this landscape, rainfall intensity appears to be increasing. These multiple factors combine to create conditions conducive to flooding throughout the region.

Physical context

In much of Harris County, the soils are clay, so naturally quite impervious. As a result, replacing natural surfaces with designed, impervious surfaces like roads and homes does not always change total runoff and infiltration as much as it might elsewhere. However, when land is developed, it is graded and sloped to channelize rainfall, which significantly changes the timing and behavior of runoff. Compared to a natural landscape, rainfall runoff is accelerated in a

developed, graded and channelized landscape. Without on-site runoff detention, peak runoff from developed areas occurs almost immediately and can be up to three times as large as peak runoff from an undeveloped landscape.

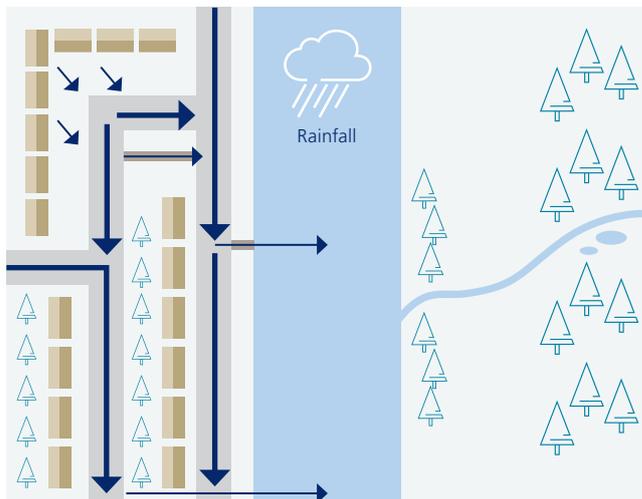
Runoff collects in smaller waterways and streams which flow to the bayous. Harris County is drained by 4,000 km (2,500 miles) of creeks and rivers that coalesce in 22 major bayous. In the Houston area today, a bayou describes a slow-moving, meandering stream or river, sometimes with marshy lake or wetland sections. However, in pre-development eastern Texas, a bayou was probably more accurately described as a channel of moving water within a larger, flat and low-lying marshy area. These areas would fill with flood-water during heavy rains, then slowly drain during drier periods. As development has grown up around them, often on fill, the wetlands which stored and slowly released rainwater have been replaced with roads, homes and graded yards. Rainfall runs off faster into the bayous than in the past, and the bayous have less capacity to retain and slowly release water. Instead, they rapidly become raging rivers that easily overflow their banks, flooding the land and structures that border them.

Storms in the Houston area are often a combination of rainfall and high winds. These winds result in storm surge – elevated water levels – in Galveston Bay and the ship channel. High water levels can slow and back up drainage of the bayous, resulting in greater flooding, particularly downtown, and south and east of the city.

Developed lands

Rain pours more quickly off of city and suburban landscapes, which have high levels of impervious cover.

Pavement and rooftops shed water.
Storm drains deliver water directly to waterways.
Streets act as streams, collecting stormwater and channeling it into waterways.



Natural lands

Trees, brush and soil help soak up rain and slow runoff.

Trees and other vegetation break the momentum of rain and help reduce surface erosion.
Water pools and filters into the soil.

Pollutants on impervious surfaces are washed into streams, rivers, and lakes.

Vegetation helps build organic, absorbent soil.

RUNOFF

Figure 3. Adapted from D. McNabb: Water Resource Management: Sustainability in an Era of Climate Change

In this already flood-prone natural environment, rainfall intensities appear to be increasing. The National Oceanic and Atmospheric Administration (NOAA) is in the process of updating the precipitation intensities for the state of Texas. Prior to the December 2017 release of new calculations for public comment and review, the 24-hour 1 percent annual probability storm event (the “100-year” storm, calculated in 1961) for Harris County was 33.5 to 34.3 cm (13.2 to 13.5 inches) of rain.²⁰ The new value, using an additional 50 years of data, is 41 to 43 cm (16 to 17 inches), an increase of about 30 percent.²¹ The old “100-year” event is now estimated to have a 4 percent annual probability – it is actually a “25-year” event.

In this context of flood risk, Houston has pursued flood mitigation through a variety of measures, but mitigation efforts are limited by the regulatory environment, funding and rapid development.



- 1 Build on elevated ground outside the floodplain (F, L, TR)
- 2 Take regular care of the ground, clear broken branches (E, H, S)
- 3 Use the least risky side, protect the real estate with protective infrastructure (A, TR, L, FS)
- 4 Drain outdoor spaces, avoid sealed surfaces (H, F, TR, L, FS)
- 5 Protect the garage entrance from flooding (H, F, TR, FS)
- 6 Protective dyke (F, A, TR, L, FS) or protective spur (A, TR)
- 7 Assess the foundation ground (E)

Key

- E Earthquake
- H Hail
- F Flood
- A Avalanche
- TR Torrential rain
- L Landslide
- FS Falling stones
- S Storm

Figure 4. Zurich illustration of a well-protected home.

²⁰ U.S. Department of Commerce, 1961. “Technical Paper 40: Rainfall Frequency Atlas of the United States.”

²¹ NOAA Atlas 14 Volume 11 Version 2

Regulatory environment

"In Houston – as in almost no other American city – government is limited (as is trust in government) and philanthropy is strong and deeply involved in city building efforts."²²

The state of Texas, and its counties and cities, operate within a pro-business and low governance context. Houston in particular has no zoning. While there are many players across local, county and state levels, limited funding (as a result of low taxes) contributes to a landscape where these entities' capacities to act are constrained. In this context, local governance units have emerged to provide services to local districts.

Lower level administrative entities include, amongst others, Public Utility Districts (PUDs), Municipal Utility Districts (MUDs), Municipal Management Districts and local government corporations. PUDs and MUDs provide key utilities, such as water, waste collection, sewer and drainage, in unincorporated county areas where no cities exist to provide such services. They are often set up by developers as part of large developments – many of these have effectively become small, developer-established towns – and issue bonds to cover infrastructure costs.

Municipal Management Districts or "Improvement Districts" are a means to allow commercial property owners to work together to supplement city and county services and improvements. In Municipal Management Districts, property owners identify common problems and issues in their area. They also use the Municipal Management Districts to implement solutions. Municipal Management Districts act like MUDs to construct, finance and operate water, sewer, drainage, road and park improvements. As development progresses, these districts can then provide supplemental services, and most traditional Municipal Management Districts do so. Services provided, and the authority to raise money and take action, vary by district.

There are also often private-public partnerships within the regulatory landscape involved in city-level decision-making. These partnerships intend to decentralize decision-making across the city.

The result is a complex regulatory environment involving a variety of public and private players with jurisdictions that often overlap. This, in combination with rapid development and a flood-prone physical environment, has implications for the effectiveness of flood risk reduction measures across Houston.

Development environment

The Houston metro area is home to approx. 6.5 million people and encompasses 2,575 square km (1,600 square miles) of housing developments, roads, bayous, business areas and greenspace (U.S. census). The low regulation environment has made Houston the "City of Opportunity" – a major economic engine in the U.S. This economic growth is driving a population boom that fuels accelerated and ongoing development across the metropolitan area.

Growth is enabled by a lack of zoning and a relatively loose regulatory landscape. Particularly with respect to flood mitigation, the regulatory landscape is still catching up. Strong property rights in the state result in little or no control on where infrastructure is built. As a result, floodplains, wetlands and other marginal lands have been extensively developed.

While rapid, loosely regulated development in Houston is key to providing more affordable housing throughout the region, it has exacerbated local and regional flooding issues. Development on fill within the floodplain changes the shape of the floodplain and displaces water to other locations. Drainage is built to code, and therefore sized for specific events – the "10-year" or "100-year" flood for example – with little consideration for where water will go in events that exceed those thresholds. Even with grading and sloping to

promote drainage, the land is fundamentally flat and water often pools in low-lying drainage areas such as roads, restricting transportation and access. And, while stormwater detention is required for all new development, detention is designed on a development-by-development basis rather than through larger land-use planning efforts (See Box 1 on the adjacent page). Detention therefore primarily consists of stand-alone features instead of more regionally coordinated drainage and detention efforts.

The formation of PUDs and MUDs further speeds development by accelerating access to utilities, but also incentivizes the use of groundwater for potable water supply because it is easier and cheaper than developing surface-water supplies. This has resulted in subsidence across the Houston metro area, increasing, and in some cases creating, flood risk in areas where it previously was not an issue. Though the Harris-Galveston Subsidence District is working, successfully, to address these issues, prior subsidence and development have changed flood water runoff patterns and behavior in Houston, making the area more flood-prone overall.

Even more concerning, development has taken place in key flood mitigation areas, including stretches within the flood pools of Addicks and Barker Reservoirs, and within floodways, including those below Addicks, Barker, Lake Houston and Lake Conroe dams. Development in these high-risk areas not only puts structures at risk, it limits the operational flexibility of these structures. During extreme events like Harvey, dam operators were caught between limiting releases and flooding homes and businesses within the reservoir pools or increasing releases and flooding homes and businesses below the gates.

"Houston is located in a multi-hazard landscape that includes floods, extreme temperatures, tropical storms, hurricanes and tornadoes. Flooding, in particular, is a problem due to several interrelated natural and man-made factors, from soils and natural landscape to loosely managed expansion and growth. Within this landscape, rainfall intensity appears to be increasing."

²² Houston Chronicle, February 26, 2018. "How does a 'local government corporation' like Houston First work?" William Fulton.

²³ <https://www.rebuildhouston.org/>



Box 1. Unintended consequences

While there are policies in place to reduce flood risk, these policies can sometimes favor unintended decision-making and result in practices that exacerbate flooding.

Along Brays Bayou just west of Meyerland there are a series of 9.9-acre businesses which are mainly composed of concrete parking lots next to 12-lane highways. The lots these businesses are on are exactly 9.9 acres because, when they were built, properties of less than 10 acres were not required to put in stormwater detention. It was much cheaper for the developer, and

provided more usable space for the property owner, to make the lots 9.9 acres rather than 10 acres.

These properties with their expanses of concrete are not the sole cause of Meyerland flooding, but they are likely to have contributed. Carefully graded to route all water off the parking lots as quickly as possible, these and similar developments result in a much faster flow of water to the bayou, increasing flood peaks. By following the letter of the law rather than its intent, developers and owners have

unintentionally increased downstream flood risk.

The challenge moving forward is to develop regulations that reduce risk without creating unanticipated loopholes that result in unintended, widespread societal losses and damages. The ReBuild Houston initiative has begun to address these issues. Fees, based on the amount of impervious cover, are being collected and used to fund new drainage infrastructure and improvements.²³

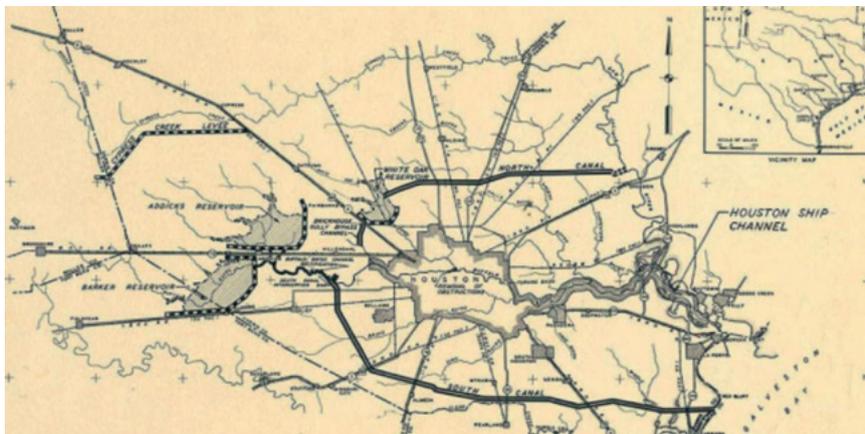


Figure 5: Original 1940 Flood Control Plan for Houston, showing Addicks and Barker Reservoirs to the west, the Cypress Creek levee to the west-northwest, White Oak Reservoir to the northwest, and North and South Canals circling the city and emptying into Galveston Bay to the east. (Source: USACE, 1940).

Risk reduction

Given the manner in which Houston’s physical, regulatory and development context interact to shape Houston’s flood risk, the government, businesses and private citizens have over the years made regulatory, infrastructural and personal efforts to mitigate their risk. These efforts range from large-scale federal mitigation structures and land conservation efforts, to organizational and preparedness plans at the household level. Taken together these measures help to reduce Houston’s overall flood risk. However, given the devastating impacts of Harvey, work remains to be done.

Regulatory and infrastructural flood risk reduction

Federal level

At the federal level, the USACE is responsible for widening and straightening bayous, operating the Barker and Addicks flood control reservoirs, and maintaining the ship channel.

Federal involvement in flood control in Houston began after massive floods in 1929 and 1935. The initial USACE vision for flood mitigation (See Figure 5 on p. 17) included three flood

control reservoirs – Addicks, Barker and White Oak – with two conveyance channels running north and south of the city to move water from those reservoirs out to Galveston Bay, and a levee in the western portion of Cypress Creek watershed to prevent surface runoff from flowing into Addicks reservoir.

Addicks and Barker Reservoirs were constructed between 1938 and 1948. Assuming that the reservoirs would not fill regularly, and if they did, that damages would be minimal as the area was rice fields and cattle pastures, the USACE bought only the land behind the reservoir that would flood in a 1 percent annual probability (a 100-year) event. The plans for the White Oak reservoir, Cypress Creek levee, and North and South Canals were never implemented. It was determined to be more economical to increase the capacity of the reservoir to accommodate overflow from Cypress Creek than to build a levee, and that rising land costs and rapid development made construction of White Oak Reservoir and the discharge canals impracticable. Instead, channel improvements to convey up to a 10-year event were recommended for Buffalo, Brays and

White Oak bayous. The work on Brays and White Oak was completed in 1971 and 1975 respectively; work on Buffalo Bayou was delayed by public opposition and ultimately only implemented for portions of the bayou (See Figure 6 below).

When the weather is dry, the reservoir pool areas upstream from the Addicks and Barker dams are grassy parks where local residents ride bikes and take their dogs for walks. During intense storms, the reservoirs have been highly successful in providing floodwater storage and preventing flooding along Buffalo Bayou and through downtown Houston. However, the flooding from Harvey highlighted a number of serious issues related to ongoing development, oversight and maintenance.

Since 1938, continued development downstream of the reservoirs has encroached on and diminished non-damaging channel capacity. To address downstream encroachment, gates were put on the dam outlets in 1963 and releases were reduced several times over the years. Current releases are limited to a maximum of 607 cubic meters per second (2,000 cubic feet per second). The gates and controlled releases have reduced downstream flood impacts but have prolonged storage of rainfall runoff behind the dams. The dams were reinforced to address serious seepage problems

“During intense storms, the reservoirs have been highly successful in providing floodwater storage and preventing flooding along Buffalo Bayou and through downtown Houston. However, the flooding from Harvey highlighted a number of serious issues related to ongoing development, oversight and maintenance.”

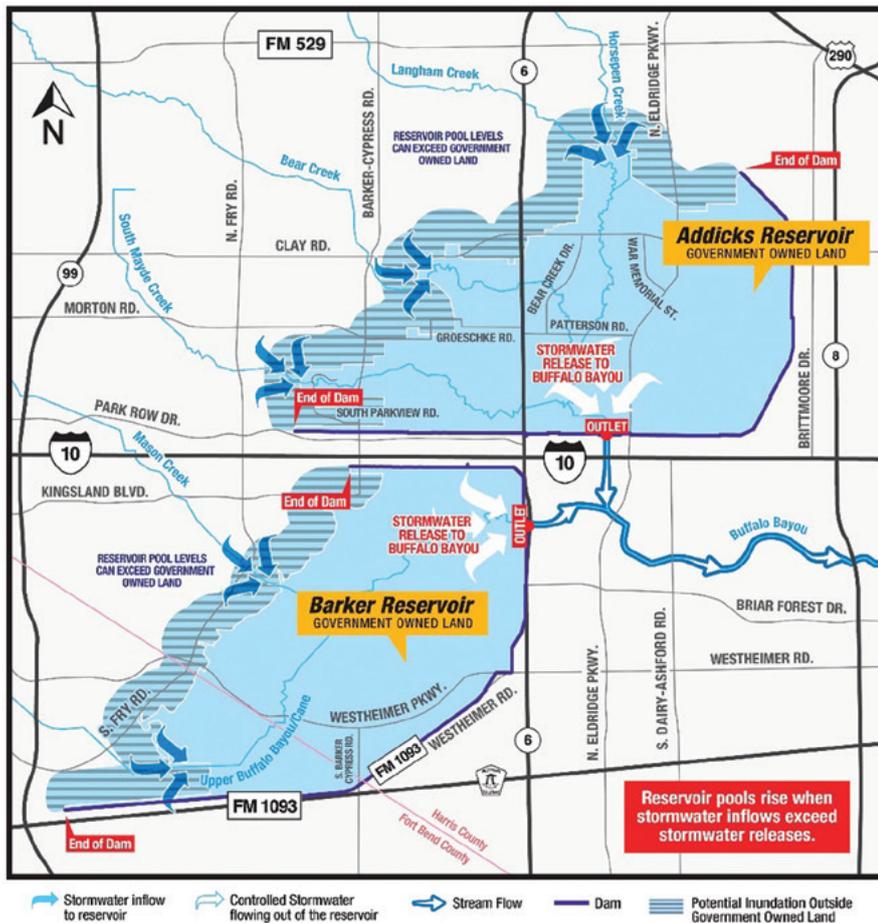


Figure 6: Detailed Addicks and Barker Reservoirs map. Source: HCFCD.

in the late 1970s. However, it remains that they were never designed for long-term water storage and doing so compromises their safety. At the same time, upstream development has increased both the volume and rate of inflow into the reservoirs, and continuing development threatens to maintain this trend.

Equally problematic, there are now thousands of households and businesses that have been constructed within the reservoir pools, below the dam release gates, and below the reservoir spillways. This development, both upstream and downstream of the reservoirs, is a problem for Harris County and the city of Houston because it now limits how the dams can be operated. Development in and around the reservoirs, and encroachment on the bayous has compromised the ability to flexibly operate the reservoirs and gates to maximize protection for downtown Houston.

State level

Since the formation of the Harris County Flood Control District in 1937, the state's involvement in flood mitigation for Harris County and the city of Houston has primarily been through

providing state funding. The state administers state and federal funding for hazard mitigation programs; however, the funding is limited.

County level

The Harris County Engineering Department is responsible for the regulatory side of flood risk reduction in Harris County. They establish and enforce floodplain management regulations and drainage and stormwater detention requirements at the county level. They also oversee the adoption of and compliance with the Community Rating System (CRS) ordinances to qualify for NFIP.

Harris County Flood Control District (HCFCFD) – established in 1937 by the Texas Legislature to serve as the local partner for major federal flood risk reduction projects – addresses the physical and operational side of flood risk reduction from “bayou to bay.” They maintain and provide flood mitigation on the 4,000 km (2,500 miles) of river channels and storage structures across the county. They also implement one of the largest ongoing home buyout programs for high risk and repeat loss

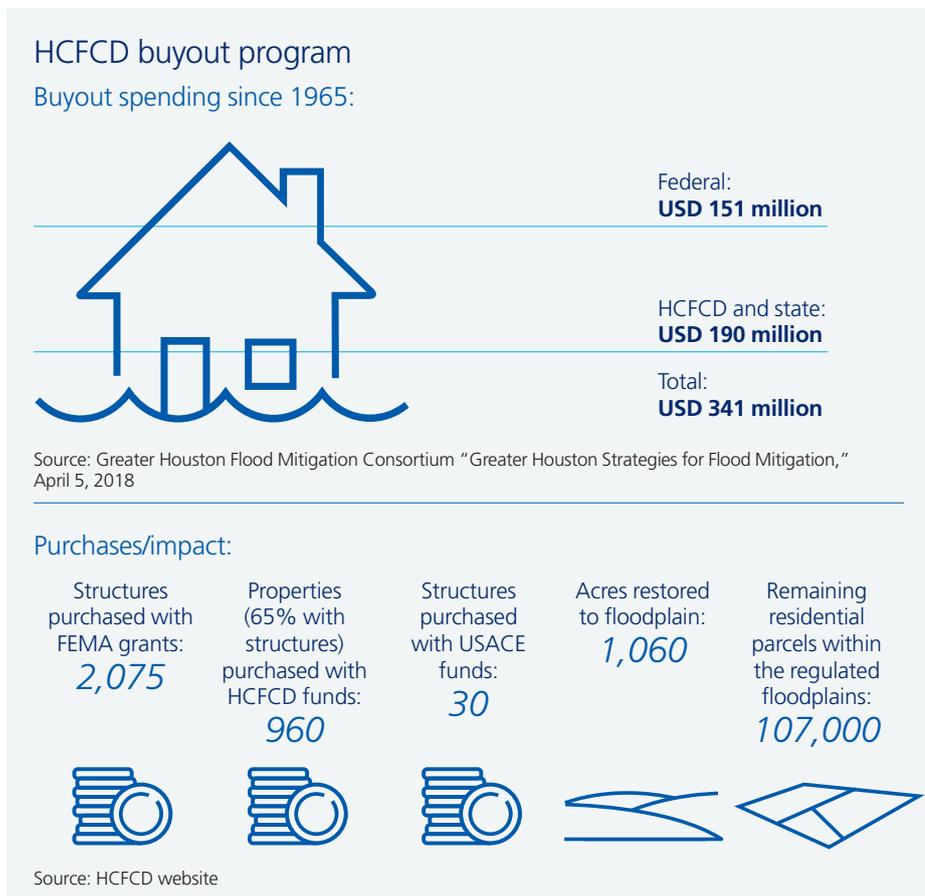
properties in the U.S. Their mandate, however, does not include land use policy, development, regulation or drainage that affects how rainfall arrives in the bayous and waterways.

The largest flood mitigation projects implemented by HCFCFD include channelizing (straightening, widening and lining) bayous, coupled with buyouts and stormwater detention basin development, to improve conveyance, leave space for water and minimize overbank flooding. Larger projects are implemented in collaboration with the USACE using federal funding and local matching funds. Recently completed bayou projects such as on Sims Bayou have been effective in limiting the extent of damage to some areas of Houston. Nonetheless, even with completed projects there is residual risk. Some sections of bayous, even when mitigation projects are completed, overflow in storms with an annual probability of 5 percent or 10 percent. Ongoing upstream development and localized subsidence continue to intensify this risk and over time reduce the success of HCFCFD's flood risk mitigation projects.

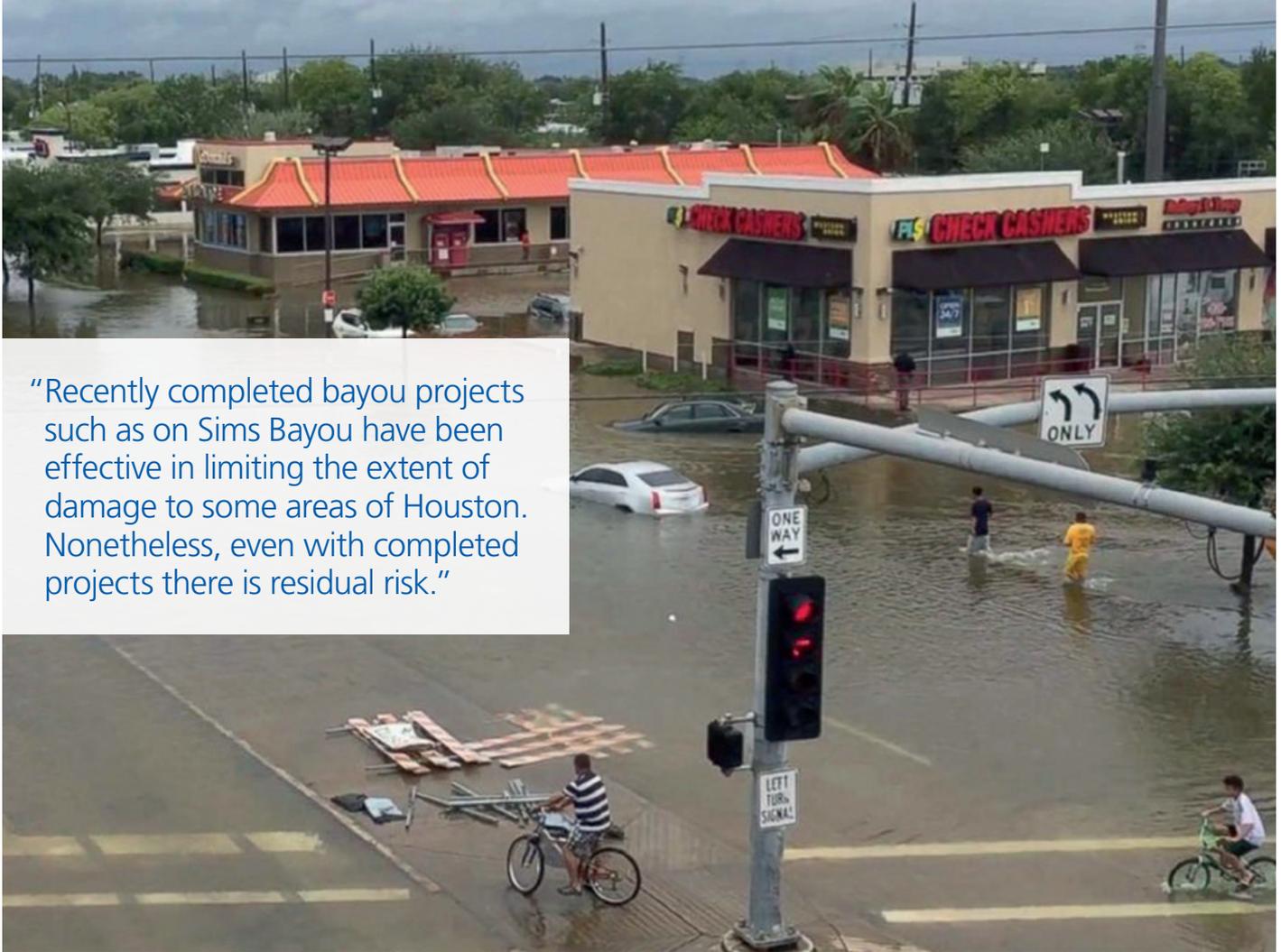
Current and past mitigation work on two of the largest bayous, Brays and Buffalo Bayous, is described below:

Brays Bayou flows to the southwest of downtown Houston and passes through the Texas Medical Center. Channelization and concrete lining of Brays Bayou was completed in 1968. Based on available data and modeling capabilities available at the time of construction, the channel was designed to accommodate a 1 percent annual flood event. Subsequent investigations, however, suggested that the impact of urbanization far exceeded initial calculations. Just prior to Tropical Storm Allison in 2001, Rice University estimated that Brays Bayou was likely to contain only a 10 to 20 percent annual rainfall event.²⁴ Projects in various locations along Brays Bayou have been ongoing since Tropical Storm Allison; plans for a larger, more comprehensive mitigation project is ready to go but awaiting funding.

Buffalo Bayou, the principal river of the Houston metro area, crosses central Harris County from west to east. The upper watershed of Buffalo Bayou flows into Addicks and Barker reservoirs; the lower watershed starts at the outflow gates of Addicks and Barker reservoirs and flows east through downtown Houston, through the ship channel and into Galveston Bay. East of the reservoirs, Buffalo Bayou is a combination of straightened, widened channels sections and a heavily wooded natural channel in a primarily residential area. Many structures, particularly in the natural channel area where channel capacity was far too small for the



²⁴ RMS Event Report, 2001. “Tropical Storm Allison, June 2001,” p.7. http://forms2.rms.com/rs/729-DJX-565/images/tc_2001_tropical_storm_allison.pdf



“Recently completed bayou projects such as on Sims Bayou have been effective in limiting the extent of damage to some areas of Houston. Nonetheless, even with completed projects there is residual risk.”

volume of water, flooded during Harvey. Directly below the dams was also a high impact area; emergency dam releases inundated numerous homes and businesses.

The other key flood risk reduction effort at the county level is the establishment and operation of the Harris County Emergency Operations Center (EOC). When Hurricane Ike hit in 2008 causing severe wind damage and power outages, the Harris County EOC had limited seats – only 24 people could work together in the room at any one time. Recognizing the need to expand their capacity and staffing for future events, the Harris County Office of Homeland Security & Emergency Management (HCOHSEM), working with local partners and agencies, has made significant investments in physical space, training and technology to turn the Harris County EOC into a state-of-the-art facility that other cities now visit and learn from. The wind-resistant facility includes back-up generators, a water filtration system, 98 workspaces, sleeping accommodations, showers and bathrooms as well as space for coordination amongst partners during events.

Local authorities

The “rooftop to bayou” responsibility – everything between the initial rainfall and runoff arriving in the streams and rivers – lies within a complex network of often overlapping jurisdictions across the county. Countywide, there are nearly 250 elected officials involved in the administration of drainage and flooding

issues, including 34 floodplain managers. Actions taken at this level include development and enforcement of floodplain regulations, drainage plan reviews for development, the NFIP Community Rating System and street drainage. Often, engagement requires the involvement of and co-financing from several local bodies, including cities, management districts, local government corporations, MUDS and PUDS.

The jurisdictional complexity at the local level is complicated by ambiguous responsibilities. For example, for many MUDS and PUDS drainage is not addressed by any other entity, but also not actively delivered by MUDs and PUDs due to a poor understanding of their responsibility and/or a poor understanding of what they could or should be doing. The combination of multiple responsible entities and poorly understood mandates contribute to cross-jurisdictional issues that constrain comprehensive flood risk mitigation and disaster reduction regionally.

There are many small-scale efforts that could be undertaken at the local, PUD, MUD and city neighborhood level to significantly reduce flood-related damages. This includes actions as simple as education programs for residents on clearing drains before storms and maintaining the drainage capacity on their property by not paving over drains for additional parking. These actions have the potential to save millions of dollars in damage and collectively have an impact on the scale of the bayou mitigation

projects. However, ambiguity about who is responsible for street drainage, coupled with a general public and political preference for large-scale solutions that will “fix” the flooding problem, has left the drainage issue primarily on the sidelines.

Land conservancy

In the pro-development, pro-growth environment of Houston, there is a growing awareness of the need to leave space for water in order to meaningfully reduce flood risk. Large-scale projects – such as levees, canals and reservoirs – are expensive solutions to flood threats to development that are substantially caused by the development itself, and all of them come with residual risk and storm thresholds beyond which they will fail. There is a growing realization that softer solutions, not just more engineering, are needed. Land conservation is one of these.

A variety of citizen groups, nonprofits, PUDs and MUDS in the Houston area are working on land conservation efforts that address not just conservancy, but also flood mitigation. These range from small-scale efforts by a limited number of players, to much larger, multi-stakeholder, multi-thousand-acre activities. Two such efforts, at opposite ends of the scale, are described below.

On the larger end of the scale, the Katy Prairie Conservancy has preserved 20,000 acres of prairie in northwest Harris County beyond Addicks and Barker reservoirs, both for flood mitigation and for biodiversity protection.

The land is protected through a variety of conservation easements, land purchases, and real estate donations and sales. As a part of Strategy 5 of the Cypress Creek Overflow Project, the conservancy has been exploring the potential to purchase an additional 5,000 to 6,000 acres of land for restoration, and also surround it with a berm to provide stormwater capture and infiltration.²⁵ However, there are concerns about how effective this will be for its cost, and the purchase of additional land is in competition with developers vying for the same acreage, which adds to the expense and highlights the challenge of retaining open space in a region of rapid development.

At the local level, the Cypress Forest Public Utility District began exploring the purchase of 258 acres of land from the Raveneaux Country Club in 2005, to prevent the land from being sold for development. The proposed purchase was primarily a defensive move on the part of current residents – development on the parcel, which lies along Cypress Creek, is likely to have exacerbated flooding of existing homes. When Raveneaux refused to sell the land to the PUD, Cypress Forest PUD exercised the strongest leverage point they had and declined to provide the country club with utilities, bringing Raveneaux back to the negotiating table.

Cypress Forest PUD ultimately required sign-off from the attorney general, the Texas state governor and regulatory agencies, but obtained the needed authority, generated public funding through a bonding authority, and bought the majority of the land from Raveneaux for use as a golf club and park. Raveneaux retained 27 acres, but Cypress Forest PUD was able to impose restrictions on how that acreage could be developed. The success of this measure prevents the development of a substantial

stretch of land bordering Cypress Creek, leaving more space for water during intense rainfall events and preventing floodwater from being displaced into existing development.

These two stories of land conservancy for flood mitigation are specific examples of the growing awareness and engagement by Houston residents around flood mitigation. They illustrate community-level flood risk understanding in the Houston area, and the commitment of individuals and organizations to take action to reduce their risk where possible while providing additional recreational and biodiversity co-benefits.

Business preparedness and risk reduction

Even the best large-scale risk reduction efforts, combining grey infrastructure such as dams, levees, drainage systems and pumps with “green” solutions such as leaving space for water, using porous pavement to increasing infiltration, and designing parks to provide floodwater storage co-benefits, will never reduce flood risk to zero. Additional, smaller-scale risk reduction efforts at the community and business level can further reduce flood risk in conjunction with the large-scale risk reduction efforts discussed above.

Business continuity plans, for both large and small businesses, can reduce risk while also providing a guide for continuing business operations throughout disruptions. As distinguished from recovery plans, where actions are more reactive to circumstances, business continuity plans are proactive. Their focus is on how best to stay operational during disruptions, get back to normal operations quickly if there are disruptions, and on mitigating potential impacts of a disaster ahead of time. For businesses that count on a dependable supply chain, planning how to address disruptions in service and

identifying potential alternative sources of materials can be critical to staying operational or operating at capacity. This requires building relationships with providers and understanding the potential for disruptions to transportation and access. Identifying alternatives can be the foresight that keeps a business viable during and following a disaster.

Formal business continuity plans include several key steps for ensuring continued operations – a business impact analysis, recovery strategies, plan development, testing and exercises.²⁶ Through business interviews conducted for this report there were several key factors that emerged regarding continued business operations and recovery support:

1. Identification of key assets: Resilinc, a company focused on supply chain risk management, recommends conducting a “what if?” scenario to identify the aspects/assets of a business, that, if impacted, would undercut its operability. Identifying and making plans to address this “existential threat” before a disruption occurs are key steps that businesses can take to mitigate their risk. A coffee shop, for example, may want to ensure that their espresso machine is well clear of potential floodwaters; a business dependent on data must backup their data on the cloud or in a redundant data co-location center and ensure their IT is not located in a flood-prone basement.

2. Preparedness as “business as usual:” IronEdge Group, for example, integrates preparedness into their daily operations by incorporating “disaster recovery” days on a regular basis into their daily routines. Leadership will spontaneously announce drills – “it’s flooding today, work from home” –

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²⁵ <http://www.katyprairie.org/ccop/>

²⁶ More information regarding business continuity is available through the U.S. federal government at Ready.gov, for small businesses continuity through the Red Cross Ready Rating program at www.readyrating.org, or regarding flood resilience more broadly at <http://floodresilience.net>

and employees practice being ready for disruptions, regularly backing up their data and being prepared to work outside the office by bringing home laptops, earphones and other necessary equipment. If preparedness becomes business as usual, then employees will already be proactively taking steps to maintain key business operations regardless of what happens.

3. Infrastructure solutions: There are many small-scale, relatively inexpensive actions businesses can take to increase their flood resilience. These begin with risk aware thinking and action, such as not storing critical documents and equipment below or at ground level. Slightly more proactive thinking might include purchasing and knowing how to install flood gates on doors to prevent flooding or purchasing equipment with motors on the top rather than the bottom so that they will remain functional even if flooded. For multistory buildings reliant on elevators, “float buttons” in the elevator shaft that automatically move the elevator to the top floor when triggered, coupled with putting control panels on the second floor or higher, can prevent loss and dramatically speed recovery. Actions taken in response to potentially imminent flooding include relocating key equipment to higher elevations prior to the flood event. Finally, there are investments that would primarily be used in disaster scenarios, such as the purchase of backup generators to allow businesses to stay open during power outages. Consideration of the types of actions that could benefit your business in advance of an event, coupled with advanced action, can significantly reduce losses and speed recovery.

4. Utilize existing assets during flood events: Several companies interviewed for this study used their security systems to track conditions in their physical business locations during the floods when they were unable to access their facilities. This helped them to begin to understand their damages and potential losses, and also allowed them to begin recovery and reconstruction actions such as lining up contractors before they had even returned to the premises after the flood. Planning for such use and developing ways to assure assets continue to function and can be remotely accessed could provide significant co-benefits from an existing system primarily used for other purposes.

5. Employee preparedness: Including household preparedness in business preparedness plans can build community resilience and ensure that employees are able to continue working through or return to work more quickly following a disaster. Staff members of the EOC in Harris County, for example, have a household plan in place in the case that they are called in to staff the EOC during a disaster. Key to business-employee preparedness is that the business is able to communicate with its employees; this means regularly updating employee emergency contact information and/or having a clearly communicated plan for employee check-in. Raising employee awareness a day or two prior to an event by posing key questions about stockpiles of food and water, backup power or lodging in case of dwelling damages, and security of key documents can help raise their risk awareness and potentially reduce their damages or losses, hastening their return to work.

6. Insurance: Flood insurance is valuable for business recovery – it increases options, speeds recovery and prevents the need to borrow money or dip into savings to rebuild. Businesses have many different insurance options. Multi-hazard policies can be particularly effective, providing flood coverage as well as coverage for fire, sewage backup and other hazards. Businesses should critically explore their insurance options and talk with a range of experts, if needed, to really understand their risk and the options to financially transfer that risk. In weighing cost of coverage, storefront businesses in particular should balance cost against not just the potential cost of damages, but the added cost of being non-operational or displaced potentially for six to nine months or more while repairs are made. Not only will they have to re-attract clientele, for most the lost revenue is permanent – people do not read six newspapers on Saturday because they could not buy them during the week.

7. Recovery support: Businesses can play a positive role for their employees and the communities in which they work through providing support to impacted employees and/or communities during the response and recovery. Providing equipment, access to food and showers, covering hotel room costs, assisting with mucking out and offering paid time off for employees can go a long way toward creating a community and culture of assistance. Ideally, businesses consider and plan for this type of support as part of their business continuity and preparedness so that the financial resources needed are available and implementation can begin immediately.



“Homeowners’ lack of risk awareness cannot be placed fully on them – there has historically been an unwillingness to restrict building in high flood risk areas or require that builders clearly disclose potential risk to real estate brokers and potential buyers.”

Household risk reduction

Harris County and the City of Houston, together, have a higher number of severe repetitive loss properties – properties that have had at least four claims of more than USD 5,000 each or with total claims exceeding the value of the structure – than any other jurisdiction in the U.S.²⁷ At the same time, more than 50 percent of the Harris County homes damaged in the Harvey flooding were outside any designated floodplain. This combination emphasizes both the high flood risk in Houston and the evidence that floodplain designation alone does not accurately indicate flood risk. In Harvey, this was coupled with a broad lack of awareness on the part of many of the flooded households regarding their risk – particularly homeowners within the Addicks and Barker reservoirs, around the edges of Lakes Conroe and Houston, and below the spillways and gates of all of the areas dams. In Houston and Harris County, all homeowners need to be aware and prepared for floods.

Homeowners’ lack of risk awareness cannot be placed fully on them – there has historically been an unwillingness to restrict building in high flood risk areas or require that builders clearly disclose potential risk to real estate brokers and potential buyers. This extends to sale requirements – currently, homeowners are not required to disclose prior flooding when they sell their homes.

Risk reduction strategies for existing exposures that homeowners are currently using in the Houston area range from simple preparedness to heavy infrastructure solutions:

1. Insurance: Though flood insurance uptake in Harris County is low, for the homeowners who carry it, having insurance dramatically increases post-flood options and speeds up recovery. Without insurance, homeowners are often caught choosing between multiple poor options such as selling at a greatly reduced value, taking out loans – generally on top of an existing mortgage – to finance repairs, or simply walking away and letting the house go into foreclosure. For those who

opt to repair, they cannot begin until they secure financing. However, the scope of flood insurance through NFIP is limited. It primarily addresses building back to the same condition as before the flood and does not allow for any mitigation efforts against future flood damage. To integrate flood resilience measures into the recovery and rebuilding process, homeowners generally must take out loans or dip into savings.

2. Home elevation: For homeowners who can afford it, elevating their homes is one of the primary actions being taken to reduce flood risk. Ideally, homes are raised above the high flood level, but doing so can be expensive and impractical. Currently, costs range from USD 75 to 100 per square foot.²⁸ While FEMA does provide limited support (up to USD 30,000) through their Increased Cost of Compliance (ICC) coverage, which goes specifically toward flood mitigation actions, it is typically not enough to cover the full costs of elevation. Moreover, in order to receive ICC coverage, homeowners need to have insurance through NFIP and their home must meet the criteria for being “substantially damaged” and/or be a repetitive loss property. These requirements, plus the overall cost of elevation, frequently deter homeowners from investing in home elevation to reduce their flood risk.

3. Buyout programs: In NFIP compliant communities, a portion of FEMA recovery money is available for buyouts. In Houston and Harris County, the buyout program is implemented through Harris County Flood Control District. Buyouts have the advantage of moving people and structures away from harm, avoiding future flood impacts, decreasing payouts for insurance and developing additional community open space. However, the process is slow and the money available for buyouts is generally far smaller than the interest in being bought out. Additionally, buyouts are generally highly strategic and combined with other projects and priorities, so many homeowners interested in being bought out may not qualify.

²⁷ FEMA Severe Repetitive Loss Property data, as reported by Nicholas Pinter, Nick Santos and Rui Hui, UC Davis Center for Watershed Sciences. <https://californiawaterblog.com/2017/09/01/preliminary-analysis-of-hurricane-harvey-flooding-in-harris-county-texas/>

²⁸ www.citylab.com/design/2017/12/the-house-of-the-future-is-elevated/540327/

Box 2. Flood insurance: What businesses (and homeowners) need from the industry

Insurance coverage and associated services, such as advice on which contractors to reach out to and what the recovery process entails, have a positive effect on the speed of household and business recovery and foster a feeling of support in home and business owners. There is thus a big additional benefit to retaining insurance beyond the immediate financial support at the core of the insurance service. Yet, in Houston, as is seen repeatedly in flood disasters across the U.S., the majority of homeowners and even many businesses in the designated floodplain do not retain flood insurance; of those that do, many drop their coverage after a few years without an event.

Coverage gaps

Hurricane Harvey, though it brought strong winds to certain coastal areas of Texas and beyond, was mostly a flood disaster in Harris County. However, traditional hurricane insurance coverage for businesses focuses more on wind cover than flood cover. Customers and their brokers need to carefully review terms and conditions to ensure customers get the cover that they need, and that they clearly understand the coverage they have. It helps nobody if, pre-event, buyers think one cover is needed, but actual losses fall into a different cover. It is equally problematic if they believe they have purchased coverage only to discover that was not the case following an event.

Coverage limits

Owners also need to be advised of the limited coverage that standard NFIP, or even many commercial policies, provides as it may be inadequate for the loss potential. Particularly for commercial operations, all too often the purchased coverage is low, has a large deductible, or has a big proportional participation and only when a multimillion-dollar flood loss has occurred is it discovered that much different coverage was needed.

Triggers of coverage

In Harvey, a large proportion of the economic losses sustained by businesses relate to property access issues. Many properties were not physically affected by the floods but were inaccessible to customers and/or owners were unable to resume operations immediately. Businesses, their brokers and their insurers need to look carefully at what coverage is needed

versus what is provided, as well as what will trigger the coverage – e.g., lost revenue alone versus physical damages.

Main exposures to financial losses

Among businesses that were physically flooded, smaller retail businesses – particularly those that provide consumer services – suffered significantly. It is difficult for them to make up in the future for revenue lost in the past. These businesses need the insurance industry and their brokers to help them access and interpret flood maps, understand the local drainage, rainfall and groundwater flood risk, and if there is the slightest chance of any type of flooding occurring, to recommend they purchase good flood coverage.

Incentivizing the uptake of natural hazards insurance by providing a multi-hazards program

Only 15 percent of the homes in Harris County carry NFIP insurance.²⁹ Beyond the coverage aspects discussed above, we found two particular reasons flood insurance lacks attractiveness:

1. Potential buyers feel safe and see no need to purchase flood insurance. This is especially the case when people are outside of a federally designated flood zone or otherwise believe they are not exposed to flooding.
2. The perception that flood insurance is too expensive. Much of this is probably due to the inaccurate assessment of flood risk and lack of awareness of the potential costs and losses in a flood. Better risk understanding would make flood insurance costs look more reasonable.

To overcome these uptake issues, the insurance industry needs a more attractive product range. Multi-peril cover, both for commercial properties and as a transition from NFIP, could address both of these challenges. There is virtually no location in the U.S. that does not face some peril, making a multi-hazard policy of value to everyone nationwide. Ideally, the federal government would work with insurance and reinsurance companies to explore the feasibility of a multi-peril natural hazards insurance program that could extend the current NFIP. Such a program could provide much better diversification of risk and at the same time be far more attractive to potential buyers.

Introducing resilience into the rebuild process

Though losses are never desirable, with them often comes an opportunity to reduce future risk by not just “building back,” but by reflecting and incorporating flood mitigation elements – from easy to complex depending on risk level, financial ability and available time. For example, there is often no direct cost associated with replacing an electric or electronic item and putting it upstairs rather than back into the basement, or with designing a solution so that item is floodproofed in its current location, for example by raising it above the flood water level.

If these actions are taken during the recovery process, the financial cost is often significantly less than if the risk improvements were done as a separate remodeling period. This is not to say that the cost of such improvements should be borne by the insurance industry alone. However, it is in both the insurers and owners interest to reduce risk, and owners are more likely to take action if their insurers suggest and incentivize it.

Avoiding repetitive losses by learning from the past

Ideally, insurers would support the increase of resilience in all their insurance processes. However, this requires that the industry understand why the loss occurred in the first place, which in turn requires an inquiry into what happened and why after the event. This is one of the reasons why Zurich has established this PERC methodology – to consistently and incrementally learn from large flood events. In Harvey, as in other locations where PERCs have been conducted, we found no consistent, or even a reasonably large number of random, analyses highlighting for businesses and their insurers what went wrong, why it went wrong and what could be learned from it. Systematic learning from losses is a missing key piece that needs to be addressed going forward. This is essential to not only enhance the uptake of insurance coverage going forward, but to ensure insurability can at least remain at the current level in spite of changing, and in most places increasing, hazard, exposure and vulnerability across the U.S.

²⁹ New York Times, August 28, 2017. “Homeowners (and Taxpayers) Face Billions in Losses From Harvey Flooding”. Mary Williams Walsh. Data for businesses unavailable.

Hurricane Harvey: response and early recovery

The Harris County EOC was up and running days before Hurricane Harvey made landfall, prepping assets and personnel, monitoring the situation and pushing out key preparedness messages to the public. However, as Harvey made landfall on August 25, 2017 and widespread flooding inundated thousands of homes across the county, the Greater Harris County 911 Center and the Harris County EOC both became overwhelmed with calls requesting assistance (they ultimately received over 120,000 calls).

The intense rains brought by Harvey resulted in an initial round of flooding as bayous flowed out of bank and local drainage systems were overwhelmed. A second round of flooding began about 48 hours later as the gates on the Addicks and Barker reservoirs were opened. This operational flooding, which took many of the downstream residents and businesses by surprise, went on for several days until the pressure was adequately relieved on the dams upstream.

Response organizations were quickly stretched to capacity. Overwhelmed by the need, with state resources unable to get in to assist, and facing life and death situations, Harris County Judge Ed Emmett took the unusual step to call on members of the public with boats or high-water vehicles to help with rescues. The Harris County EOC provided structure for this involvement, having volunteer first-responders call in to report their location and matching them with nearby people needing rescue.

"We can't wait for assets to come from the outside. So those of you who have boats and high-water vehicles that can be used in neighborhoods to help move people out of harm's way: We need your help."
– Judge Ed Emmett³⁰

In total, the Harris County EOC remained open 24 hours a day, 7 days a week for 26 days, with initial response activities gradually shifting into early recovery. During this time the EOC was in constant contact with the Texas Medical Center and its affiliate branches to ensure open communication about the status of hospitals and where to send patients during the event. Retail stores, telecommunication stores and grocery chains, were also all present in the EOC during the hurricane and worked with government partners to ensure the continued provision of key services.

Snapshots of response and early recovery

Because the Harris County EOC and key disaster response organizations were overwhelmed, as is typical in an event of this scale, people and businesses self-organized in different ways to implement their own response and early recovery. The following snapshots – a handful among the thousands that occurred during Harvey – illustrate the myriad ways that businesses and households prepared, responded and are recovering from the impacts of Hurricane Harvey.

"In our detailed look at the profile of businesses affected, the majority were micro (90.88%) and small (8.25%) businesses with less than 10 and less than 100 employees, respectively. These types of companies are more likely to be credit- and cash-constrained, and the interruptions cause by Harvey will make it especially difficult for these businesses to open their doors even as conditions start to improve."
– Dun and Bradstreet³¹

Businesses – trajectories of capacity

Knife River, a construction materials and contracting services company

A few days in advance of the storm, the Knife River office in Beaumont, Texas, as it had done many times before, began its hurricane preparations. They readied the company for both wind and water damage across 13 building materials yards, a barge site and two rail sites – but never expected such extensive flooding. Beaumont and nearby Port Arthur were inundated first by intense rainfall and several days later by dam releases upstream. In places water was 3 to 4.6 m (10 to 15 feet) deep and neighborhoods and whole towns were completely cut off for days.

The company's first concern was their 117 staff. Lacking a pre-planned communication strategy, they made one up on the spot. They created a full list of local employees and their contact information and updated it daily with each person's status as to whether or not they were flooded and/or evacuated.

One of the immediate needs for almost everyone was potable water. The municipal water supply was contaminated, as were personal wells, resulting in water shortages everywhere. The Knife River office in central Texas brought in big water tanks and two pallets of bottled water, in addition to care packages of quick-use foods, disposal supplies and clothing. In the first week the company was closed, they paid everyone for a full week anyway. Knife River's parent company started a fund to collect donations for the Beaumont office, so they were also able to help those staff most impacted with hotel costs, clothing and basic needs.

"It's the culture here, you help one another."
– Knife River Interview, February 7, 2018

The company worked hard to get people back to work quickly. Because Knife River sells construction material, business was nonexistent until the floodwaters receded. Instead, staff worked to address the huge number of flood-damage repairs the company's facilities needed. Recovery of assets and basic functionality took about a month and a half, and there are ongoing issues with things that were weakened by flooding.

As of February 2018, business, which is interlinked to the financial viability of the community, was still slow. The community was badly impacted; most of the capital that would go to projects like landscaping and patios was being used for recovery. However, none of the company's employees moved away as a result of the event: a major success.

This type of response was not limited to Knife River alone – many companies in the area responded similarly, as did churches. Indeed, the business community and local churches were perceived by many community members as more helpful in response and early recovery than many government organizations.

³⁰ Houston Chronicle, December 9, 2017. "Nature ruled, man reacted. Hurricane Harvey was Houston's Reckoning." Susan Carroll

³¹ Dun & Bradstreet, September 8, 2017. "Mitigating the Effect of Natural Disasters on Your Supply Chain." Brian Alster



“Data Foundry gave impacted staff members time off, brought in needed materials and tools from Austin to support staff members in mucking out their homes, and covered the costs of hotel rooms. Families organized clothing donations, and staff members collected USD 20,000 in donations which the company matched.”

While Knife River did not have a written plan before Harvey, they are now writing down what they did as well as key lessons learned, including:

- Know your employees and have contact information for each of them that will allow you to track them down in an emergency, including their home address in case you need to physically check on them.
- Make laminated cards that everyone keeps in their wallet, with the company's emergency contact list, and communicate the expectation that in an emergency when people are not at work, they will check in within 24 or 48 hours.
- Be prepared for loss of water, sewer and cell service – particularly water.

Chapparral Management, a community management services company

As Hurricane Harvey stalled over Houston, the CEO of Chapparral Management Company monitored the status of her employees, her offices and the storm via text messages, news articles and online drone footage. While her employees had implemented their disaster preparedness plan in the days leading up to the hurricane, including stacking everything on the top of desks, covering computers and backing up key documents, the floodwaters were higher and stronger than anticipated leading to severe infrastructural damage as well as the destruction of equipment and furniture in their offices.

Seven days later, when they regained access to their offices and she was able to survey the extent of the damage left by 1.1 m (42 inches) of water flowing through the office, the CEO pondered two very different pathways – close her business of 32 years and gracefully retire or dig in and start the long road to recovery.

Fast forward six months and Chapparral Management Company is back up and running with plans to not only rebuild, but to build back bigger and better. The CEO had always wanted to expand her offices to include a training center with conference rooms for community organizations; she is using the flood recovery as an opportunity to realize her dream. Chapparral Management Company is also integrating lessons learned from Harvey into their rebuilding. Instead of keeping electronics and equipment on the first floor, all key equipment will now be housed on the second floor and all key documents are backed up online.

Data Foundry, a data center co-location provider

“Extenuating circumstances require exceptional responses.”

– Data Foundry, March 7, 2018

Preparedness is a fundamental part of Data Foundry's business model. To ensure continuity of operations throughout Harvey, they began preparations about a week in advance. They stockpiled food and water, and topped off all their generator fuel tanks to assure they could maintain power and cooling. They set up beds and cots, and brought in temporary toilets for staff and on-site business customers in case access and utilities were cut off. The phones were set to ring to their Austin office, and pre-identified staff members started prepping to be away from their homes and onsite throughout the event.

Their site location – outside the 500-year floodplain and elevated an additional 91 cm (3 feet) – ensured they stayed dry during Harvey, but some routes to and from their site were cut off. However, because they stayed dry, and because the data center was built to sustain Category 5 winds, Data Foundry had little to worry about. The utilities stayed on and their task became one of simply monitoring the situation. As a result, they quickly shifted their focus to the realities of the event unfolding around them.

Though the company itself was not impacted, many of their staff suffered serious flooding, and seven had homes that became unlivable. In the immediate aftermath the company sent out boats, gas and other materials, and started reserving hotel rooms for impacted families. In the weeks following Harvey, the company and families of staff rallied around their impacted employees. Data Foundry gave impacted staff members time off, brought in needed materials and tools from Austin to support staff members in mucking out their homes, and covered the costs of hotel rooms. Families organized clothing donations, and staff members collected USD 20,000 in donations which the company matched.

As situations for impacted staff stabilized, company employees expanded their support to help friends and family of staff, which ultimately speaks to Data Foundry's culture. They are a family-owned business and treat staff like family. As their vice president noted:

“Helping our staff get through the aftermath was the least we could do – they were at the data center during Harvey leaving their families at home. Businesses don't deliver for their clients without their staff.”

– Cameron Wynne, Data Foundry, March 7, 2018

IronEdge Group, an IT services company

IronEdge Group, a company based in Houston and San Antonio, Texas, practices for disasters on a regular basis with “disaster recovery” days. On these days, staff are expected to be ready to work from anywhere and to have brought home the necessary equipment including headphones, laptops and have the key software loaded onto their computers.

This preparedness came into play when Hurricane Harvey hit. Located near the Energy Corridor area, which was inundated by the floods, their office remained largely untouched. However, access was another issue. Cut off from their office building because of road closures and damage, employees worked from home continuing to serve the businesses clients throughout the duration of the event.

However, they did have one incident from which they are learning for the next event. A few team members went to Orange and were caught in the Beaumont-Port Arthur-Orange flooding, which impacted utilities more heavily than the Houston flooding. Losing contact with those team members led to concern that did not abate until they re-established contact. This is probably an unavoidable aspect of working remotely during disaster events but highlights the necessity of setting clear expectations about communication to avoid spurious loss of contact and needless worry.

Bean's Cafe/Property Management Firm

The owner of Bean's Cafe, a locally run coffee shop situated next to other small businesses in a strip mall in the Energy Corridor, did not expect her business to flood. She kept the cafe open during the first few days when Harvey's rains were pounding the city, and when she closed on Saturday evening (August 26, 2017), she did not even think about moving her equipment to higher ground, because, after all, the shop was not in a mapped floodplain.

She wishes now that she received more forewarning about the gates opening at Addicks and Barker Reservoirs so that she could have saved more of the equipment that are key to the operation of her business. She does not know how much water originally flooded her cafe, but when she was able to get in to assess the damage, 10 days later, the shop still had 46 cm (18 inches) of water in it.

“Communities generally seek to clean up and return to ‘normal’ as quickly as possible following a disaster. This is understandable, but it misses one of the most powerful ways to reduce risk – by holding onto and using disasters to maintain awareness and preparedness and to foster a culture of resilience.”

While her espresso machine and coffee grinders made it through unscathed, the two commercial refrigerators she used for storing food and milk were damaged beyond repair. Had the motors been situated on top of the refrigerators, rather than on the bottom, they more than likely would have been fine, saving her about USD 20,000 in equipment losses. She could have purchased commercial refrigerators with top-motors but did not think she needed to spend the extra money.

Though the café did not have flood insurance, the property management company – Vista Property Management – did. Vista’s insurance covered the physical structure – walls, floors, built in plumbing and electricity, and the counters. As a result, the café owner only had to replace her moveable assets such as tables, chairs and equipment. Had the cost or time required for recovery been higher, she is not sure she could have come back.

Six months into the recovery, Bean’s Cafe has reopened, and business is slowly returning (60 percent of the previous turnover) with both regulars and new customers stopping by. However, recovery will take time as neighboring businesses and residential neighborhoods were hard hit and there are still a lot of vacant offices and homes.

Vista Management Company, a property management company

Vista Management’s decision to purchase flood insurance was, in part, to ensure that they could help their tenants come back after a flood. This foresight, coupled with a close-knit, collaborative recovery effort on the part of Vista Management and all the tenants, is probably the key element in the recovery rather than failure of many of these businesses.

As soon as Vista Management realized the extent of the flood impacts to the Cypresswood strip mall, they called every tenant to check in. Before the flood waters cleared, they held an organizational meeting off-site to assure the tenants of the plans to rebuild, help them understand the extent of Vista Management’s insurance policies and to gain their cooperation. Within days Vista Management had remediation and maintenance teams onsite as well as volunteers helping with the muck out. They provided storage pods for each business, so the businesses would have a secure location for their equipment and goods until they could move back into their storefronts. They engaged suppliers, various contractors, and maintenance teams before the waters receded.

With hard work and a lot of mutual support, the businesses began to move back in within three months. The second property Vista managed that flooded was along Cypress Creek where the ground floor recorded 1.1 m (45 inches) of water, but it cleared in three days. The additional setback at Cypresswood was the elevator – it was damaged by the flood waters and no longer manufactured so there are no spare parts available. Instead Vista Management had to hire an engineer, create new drawings, send the specifications to a manufacturer, demolish the wall, wait for the manufacturer to build an entire new system, rebuild the shaft and finally install the new equipment. The earliest this could be expected to be done was May 2018, nine months after the flood.

Looking forward, Vista Management will install the new elevator control board and all operating systems that flood water could damage 1.2 m (48 inches) off the floor, even though it is more expensive to do it that way. The new elevator will also have a float switch in the pit which, if triggered, automatically moves the elevator to an upper floor, protecting the cabs and internal controls. Vista Management considers the extra expense to be without question worth it and would like to see the issue of elevator flood resilience addressed nationally. For Vista Management, the elevator has been their largest expense and cause for big rent loss issues. The president of Vista Management noted that if insurance companies gave a reduction for a mitigated elevator, it would incentivize action. But even something as simple as insurance companies sending out notices each hurricane season to remind building owners of the pending problems should flood waters enter their buildings could be hugely beneficial.

Once the majority of the businesses in the strip mall were rebuilt and open for business in late February, Vista Management hosted a grand reopening to signal their tenants return and to encourage the community to support those businesses in rebuilding their clientele.

Household level

The Smiths³²

Almost six months after Hurricane Harvey, longtime Houston residents, the Smiths, are still waiting for their home, inundated from rising waters from nearby Brays Bayou, to be elevated and renovated. While they witnessed floodwaters from the Memorial Day floods come within centimeters (inches) of their home, this is the first time their home, situated just a few blocks away from Brays Bayou, has flooded.

³² To protect the privacy of individuals, names have been changed

As Harvey stalled over Houston, the Smiths watched the reading level on the stream elevation gage nearest their home steadily rise. On August 26, 2017 the gage read 16.2 m (53.3 feet); the following day they could no longer get out of their house.

Almost immediately, they started the recovery process. On August 28, they were on the phone filing a claim with NFIP and lining up the contractor who had just finished their renovation project to now re-renoate, and to elevate.

The Smiths had considered elevating their house following the near misses of the Tax Day and Memorial Day flood but had not committed. When Hurricane Harvey hit, the decision was obvious, the house would go up 1.2 m (4 feet). For them, the value of elevating their house is in knowing that they most likely will be safe from future flooding events and that, when the time comes to sell, they may be able to recoup the original value of the house.

Another side of recovery

The Smith's case study is an example of a well-to-do family whose recovery has been enabled by access to insurance, proactive risk reduction in recent years, and direct relationships with contractors. They are far ahead of many of

their neighbors, who are still living in temporary housing eight months after the hurricane and just starting to make decisions on what to do.

This situation has been even harder for low-income households, many of whom have seen their ability to recover decrease with every disaster that hits Houston. Poor households often do not have flood insurance due to a lack of affordable flood insurance options, do not qualify for FEMA aid because of deferred maintenance on homes,³³ and have to decide between working on rebuilding their home or doing outside work for pay. Further, with limited capacity to elevate their homes and limited options for housing, many people continue to live in their flood-gutted homes out of necessity. Buyouts do not offer much recourse as the median value – USD 48,000 – is currently not enough to support relocation.

There are multiple nonprofit organizations in Houston working with low-income neighborhoods, and new grant mechanisms have emerged to support these organizations. The 2-1-1 program helps connect residents with social service resources. From August 2017 through December 2017, the Greater Houston 2-1-1 line received over 366,000 calls, many from flood-impacted residents. The Harris

County Long Term Recovery Committee is coordinating organizations, who are collectively working on a wide variety of recovery issues, to help meet these needs.

Pre-existing resources bases have been complemented by post-flood emergent resources. At state level, the Texas OneStar Foundation created the Rebuild Texas Fund, and Houston's mayor and Harris County Judge Emmett started the Hurricane Harvey Relief Fund.

Additional recovery support has come from emergent grassroots individuals and organizations. For example, West Street Recovery, a group that emerged in response to Harvey, is working with community members to help rebuild flood damaged homes. As an organization they are focused on reinvesting funds into the local community through buying construction materials and other equipment locally. While they cannot build back fully or help homeowners to mitigate their flood risk through elevation or similar strategies, the organization is focused on providing safe spaces for families to live within their homes. This includes fixing kitchens, bathrooms and one bedroom. By most standards, it is not "move-in" condition; but it is better than what people would have otherwise.

Box 3. Taking pride in flood resilience

Communities generally seek to clean up and return to "normal" as quickly as possible following a disaster. This is understandable, but it misses one of the most powerful ways to reduce risk – by holding onto and using disasters to maintain awareness and preparedness and to foster a culture of resilience.

Galveston, Texas is a stellar example of disaster-aware culture. Galveston wears its battle scars with pride and resilience. Plaques on historic buildings mark the high flood lines of the worst disasters, including the Great Storm of 1900, which claimed at least 8,000 lives. It is almost impossible, even for short-term tourists, to remain unaware of the flood and storm surge risk in Galveston; to downplay the depths waters can reach; or to pretend "the Great Storm of ..." was somehow an aberration that will never reoccur.

Following Harvey, there is debate about whether homeowners should be required to disclose the flood history of their home when they sell. They should instead perhaps be encouraged to mount a plaque on the house proclaiming: "This home survived Harvey; the water was ---- deep." Homes next to parks and waterways will always be appealing. If the homeowners know to buy flood insurance and have a plan to move assets to the second floor, they can be safe as well.



Hurricane Ike flood marks from September 2018. Source: Karen MacClune, ISET

³³ The disqualification of households with deferred maintenance issues in recovery funding allocation is highly controversial and has, and continues to be, challenged in court.

Long-term recovery and resilience

In transitioning from response and short-term recovery to long-term recovery, Houston is faced with navigating a complex governmental context in order to make decisions about what that recovery will look like and how those actions can be leveraged to build future flood resilience.

“We really need to take ownership of flood control. We need to take ownership of it at all levels of government.” – Judge Ed Emmett³⁴

Box 4. Harvey as disaster versus opportunity

While disasters leave a swath of destruction in their wake, for a certain subset of the population these events offer economic opportunity. Those employed in the construction and recovery industry often experience a boost in business following disasters because of the acute need for their services. However, the sudden increase in business can leave these companies shorthanded. Workers that are prepared to step-in and fill these shortages can benefit.

The flow of Mexican/Latino immigrants to New Orleans following Hurricane Katrina in 2005 is one example. Aided by a sanctions lift on companies who hired workers without documentation, the influx of Mexican immigrants to the New Orleans area eventually resulted in the re-opening of the Mexican Consulate to support the increased numbers of Mexican citizens in the area.

This demographic shift shows the willingness and adaptive capacity of Latino/Mexican immigrants to respond to emerging opportunities. Granted, this often means picking-up and moving to a new place on a moment's notice – but for many, the economic promise of these jobs is worth the move.

The recovery and reconstruction period following Hurricane Katrina, however, also revealed a negative side of these opportunities including lax worker protection and wage theft. As Houston settles into long-term recovery and looks for ways to fill labor shortages, efforts should be made to ensure the continued protection of workers. Such efforts can add a silver lining to an otherwise catastrophic event.

Recovery priorities

The city and county are proactively identifying and prioritizing flood recovery and resilience actions and, where those actions do not require new funding streams, rapidly implementing them. Key among these include strengthening floodplain regulations. By December 2017 Harris County had strengthened regulations, and Houston followed suit in April 2018. Both jurisdictions now require homes within the 100-year and 500-year floodplain to be elevated 61 cm (2 feet) above the 500-year flood level, some of the most stringent criteria in the nation. This does not address the nearly 50 percent of impacted structures that lie outside mapped floodplains, but nonetheless is a strong start.

Buyout of particularly high-risk, repeat loss properties is a second focal point in the aftermath of the event. Recent HCFCD projects have clearly demonstrated that, even in the flat landscape and clay soils of Houston, leaving space for water by widening bayous and creating detention ponds that double as parks and recreation spaces can successfully mitigate flood risk. In most of the already developed urban areas, however, this means buying out and demolishing structures. There has been a surge of interest in buyouts in the aftermath of Harvey. Unfortunately, existing funding streams are not designed to take advantage of the post-flood environment. It is still not clear, at the time of the publication of this report, how much funding will be available and what houses and areas should be the focus of the program. Many households are struggling with choices. As a homeowner facing these choices himself noted:

“Really the way people are looking at it is:

- 1. Sell as is for lot value;*
- 2. Tear down and build new;*
- 3. Repair to as was and pray;*
- 4. Elevate and repair.*

Buyouts are so slow and far into the future that no one is able to consider them.”

Not knowing if they might eventually be eligible for a buyout incentivizes the rebuilding of damaged homes and/or selling to builders, perpetuating the stock of at-risk housing. Ideally, funds would be made rapidly available and matched with structures that are pre-identified as buyout targets so that at least some percentage of purchases could be implemented immediately after a flood. Currently, not just in Houston but nationally, we are missing this opportunity, resulting in both governments and homeowners ultimately spending more money – on rebuilding homes that should instead be removed and on short-term measures while waiting months or years for buyout clarity. There may be also a role for the banking sector to help inform their mortgage holders about flood risk, even if the property sits outside a designated flood zone.

The third key priority emerging in recovery is large infrastructure projects. Interestingly, many in Houston are looking for opportunities to leverage the recovery processes not just to address flooding but to build resilience more broadly. As a result, two of the largest infrastructure projects under discussion – the Ike Dike and the Mid-Bay Solution – would have provided relatively little benefit during Harvey. Instead, these solutions recognize that, as destructive as the hurricane was, the greatest threat to the city is a major hurricane that comes directly up the ship channel. The resulting storm surge has the potential to inundate the refineries and petrochemical plants along the channel and far surpass the damages caused by Harvey.

The leading infrastructure solution being proposed to address flooding is the construction of a third reservoir to address overflow issues from the Cypress Creek basin into Addicks Reservoir. However, it comes with a USD 500 million price tag and to date no one has stepped forward to cover that cost. Perhaps even more problematically, there has been little discussion of the regulatory landscape that gave rise to the

³⁴ Houston Chronicle, October 15, 2017. “Emmett issues 15 recommendations to boost regional flood control.” Mihir Zaveri

flooding at Addicks and Barker Reservoirs – the lack of regulation and risk landscape awareness within and below the reservoirs and the construction upstream that is increasing runoff volume. Unless these issues are addressed, a third reservoir is likely to have only a limited period of successful operations before it too fails.

Recovery gaps

Even as certain recovery initiatives have been prioritized, significant gaps remain. The most visible of these are funding for recovery, inequitable distribution of relief funds and a broad need for drainage improvement and maintenance.

Funding is always a core requirement for rapid recovery, and for Houston and Harris County this has been a challenge. Total U.S. losses from Hurricane Harvey are estimated at USD 125 billion. Insurance, both private and through NFIP, have been a critical source of funding for private residents and businesses who had coverage. In Texas, insurance payouts have already injected an estimated USD 7.7 billion into the post-flood Texas economy. Insurers estimate they will ultimately pay out a total of USD 19.4 billion, including USD 8.4 billion in flood losses insured by NFIP, USD 2.7 billion in insured vehicle losses, USD 4.9 billion in insured commercial losses, and USD 3.4 billion in other losses.³⁵ In addition, as of December 2017, FEMA had paid about USD 370 million in individual assistance and USD 1.47 billion for hotel bills and emergency home repairs, while the Small Business Administration had issued USD 2.84 billion in low-interest loans to homeowners and businesses.

However, this amount is only a fraction of the estimated damages. The Texas governor has

appealed for an additional USD 61 billion in federal assistance, largely for public infrastructure projects.

Though insurers and the federal government have responded quickly with funds, the state has been slower to act. Houston asked the state for funding from the state's USD 10 billion "rainy day fund" to jump start recovery, including the third reservoir. However, at the time of this writing, the city has received only USD 100 million for debris removal and USD 50 million to avoid a tax hike in October 2017.³⁶ They had received no state money to begin infrastructure repairs or flood risk mitigation projects, nor money to help those who lost homes.

There are also funding challenges at more local levels, even given increased public interest and political will around taking action. Though everyone wants something to happen, local voters are not indicating a willingness to pay increased taxes to support action. Ultimately, however, lack of action leaves the same vulnerabilities in place, with the potential for long-term economic impacts that far exceed tax increases to support action today.

"Houston area residents overwhelmingly support construction of a third west side reservoir, buyouts of vulnerable homes and other steps to protect lives and property from floods – yet slightly fewer than half are willing to pay for such measures through higher taxes." – Chron³⁷

What funding is available has been inequitably distributed, a typical challenge in the wake of disasters nationally and worldwide. While Harvey impacted homes in both high- and low-income neighborhoods, homes in higher-income communities are receiving more of the attention. This has probably led to greater overall attention than the hurricane otherwise might have received, and with it an

associated increase in local and federal response and funding, as well as greater philanthropic response. However, many lower income and vulnerable communities have yet to receive needed support and assistance, even though their needs are greater. The percentage of lower-income households with insurance is generally much smaller than for higher-income families. Additionally, issues such as deferred maintenance have disqualified many vulnerable households from receiving FEMA individual assistance. Lower-income families are also less likely to have financial safety nets or the ability to borrow money, leaving them harder hit and less able to recover. As discussed in the Greater Houston Flood Mitigation Consortium's April 2018 report, there are a variety of other funding sources that could be utilized to address some of these gaps. These sources include, "Tax Increment Reinvestment Zones (TIRZs) affordable housing dollars, social impact bonds, catastrophe bonds and resilience bonds," amongst others.

In terms of action, there has been relatively little discussion about the broad need for drainage improvements and maintenance, though this issue has been highlighted by the Greater Houston Flood Mitigation Consortium and others. The consortium in particular has flagged the need for "street-by-street drainage upgrades and low impact development measures," the cumulative impact of which "could be as significant as the impact of major projects."³⁸ This is because, particularly in many of the older neighborhoods, the storm sewer network is undersized and streets are not designed to convey stormwaters. As a result, water builds up in neighborhoods until levels are high enough to flow overland. Poor drainage and sheet flow, collecting and moving in unplanned and unmapped ways, caused significant flooding in areas outside the floodplain.

³⁵ Texas Dept. of Insurance, April 12, 2018. "Hurricane Harvey Data Call." www.tdi.texas.gov

³⁶ Houston Chronicle, April 5, 2018. "Harris County's recovery from Harvey may hinge on state funds." Mayra Cruz.

³⁷ Chron, February 12, 2018. "After Harvey, slight majority still opposes more taxes for flood control projects, survey says." Mike Snyder.

³⁸ Greater Houston Flood Mitigation Consortium, April 2018. "Greater Houston Strategies for Flood Mitigation."

³⁹ RMS Event Report, 2001. "Tropical Storm Allison, June 2001." http://forms2.rms.com/rs/729-DJX-565/images/tc_2001_tropical_storm_allison.pdf

Box 5. The Texas Medical Center: A Hurricane Harvey success story³⁹

In 1976, heavy rains caused over USD 20 million in flood-related damage in the Texas Medical Center (TMC) and catalyzed the first of a series of flood mitigation efforts. Flood control devices such as floodgates, designed to retain the 1976 flood level (which was considered to be about a 100-year event), were installed. The Rice/TMC Flood Alert System (FAS), which uses radar to estimate rainfall over the Brays Bayou watershed and predict flood conditions within the TMC, was developed in 1977.

In 2001, when Tropical Storm Allison struck, the FAS was fully operational. In the early morning hours on June 8, the FAS went to full alert (red) status. Over the course of the next two days, 38 cm (14.9 inches) of rain fell in the TMC, with over 22 cm (8.5 inches) falling during one two-hour period. While water remained within the banks at Brays Bayou, the water levels stayed at high levels for eight to nine hours, hindering drainage. Drainage systems were rapidly overwhelmed and began backing up into the streets north of the TMC and downhill through the TMC toward Brays Bayou. In some areas, water was up to 1.5 m (5 feet) deep within the TMC.

Floodwaters entered underground parking garages, tunnels, air vents and loading docks, and spread throughout the TMC complex via

connecting tunnel passages. Even where limited surface flooding occurred, underground flooding was heavy in areas connected to the basement tunnel system. As floodwaters increased, water entered the ground floors of several TMC buildings and overtopped floodgates installed after the 1976 flood.

Importantly, these basements and ground floors contained diagnostic equipment, laboratories, electrical infrastructure (i.e., back-up power generators) and heating, ventilation and air conditioning equipment. Floodwaters caused power outages in many of the buildings on the campus (including a Level-1 trauma center). As a result, more than 1,000 patients were evacuated.

Ultimately, nine of the 13 hospitals in the TMC closed due to damages from the floodwaters. Total damages for the TMC complex exceeded USD 2 billion, more than 30 percent of Tropical Storm Allison's total gross damage. Over 30 separate institutions submitted requests to FEMA for federal assistance. Full recovery took over 18 months.

The TMC took Tropical Storm Allison as the wake-up call it was and immediately began implementing new, more stringent measures to reduce disaster risk. In Hurricane Harvey, these actions were tested and proved to be one of the greatest success stories of the storm. All of the TMC hospitals remained fully operational throughout Harvey (with the exception of Ben

Taub Hospital, which had to evacuate three patients and had compromised pharmacy operations) despite many challenges to staff, including the inability to get in and out of the TMC, home evacuations, challenges with potable water and electricity outages. For example, over 15 percent of the Houston Methodist Hospital's workforce was affected by the loss of a home or car, or impacts to family members.

Following Harvey, TMC emergency operations teams attribute this success to five main factors:

- Implementation of flood protection infrastructure;
- The development of a culture of resilience;
- Technological developments that enabled better communication;
- Operations and preparedness of staff;
- Care coordination.

As they have developed new systems and plans, the hospitals have focused on taking an all-hazards approach rather than prepare for any one specifically. Every response is operationalized the same way.

What did not happen at TMC during Harvey should serve as inspiration for Houston and the nation as a whole. "Disasters" are not inevitable, and preparedness and planning can make all the difference in the world.



Lessons learned

Built environment

Key lesson: Engineering has a critical role in flood risk reduction, but it must be complemented by softer solutions and be part of an integrated approach to flood risk management. This also means that all actors need to play their part and take responsibility – it is not “somebody else” who will solve the flood risk problem.

Hurricane Harvey highlighted the limits of engineering “solutions” to flooding. Particularly in a low-regulation, changing landscape where storm intensity and frequency is increasing, we can no longer rely on the built environment alone to “control” flooding, if indeed we ever could.

This is particularly evident when we look at the location of the flood impacts during Harvey. The hurricane damaged more than 204,000 homes and apartment buildings in Harris County. Nearly three-quarters of those lay outside the 100-year floodplain. And Harvey was not anomalous; more than 55 percent of the homes damaged during the Tax Day storm in 2016 were also located outside the floodplain, as were more than one-third of those flooded in the 2015 Memorial Day floods.⁴⁰ More than half of the homes damaged by Harvey were outside all floodplain designations. This implies that, even with the far more restrictive regulations just passed by the city of Houston – requiring all homes in the 100- and 500-year floodplains to be elevated 61 cm (2 feet) above the 500-year flood level – such regulations would still have fallen short of protecting more than 100,000 Harris County homes that flooded in Harvey.

The extensive damage across the county to structures outside the designated 100- and 500-year floodplains clearly indicate that the floodplain maps are insufficient. It also suggests that the existing drainage systems are insufficient to handle the rainfall intensities increasingly being seen in the region. If true, this points to the need for much broader

solutions than widening and straightening bayous and building reservoirs. Instead, this calls for solutions – implemented across the whole county, not just in mapped floodplains – such as leaving more space for water, restoring wetlands which can retain and slowly drain runoff, and shifting construction to pier-and-beam rather than slab-on-fill. In higher risk areas, such as the Bellaire neighborhood next to Brays Bayou, homeowners are already turning to more aggressive solutions, elevating their homes anywhere from 1.2 m (4 feet) to a full story off the ground.

Though such approaches present challenges for the Houston region, the very pace of development also provides opportunity. Houston currently rebuilds itself every 50 years, with older structures removed to make way for new ones. By putting into place plans now for leveraging that redevelopment, the Houston of the future could dramatically reduce its flood risk with minimal cost to today’s taxpayers.

Regulatory landscape

Key lesson: For drainage, reservoirs and bayou projects to successfully perform as designed, the regulatory landscape must understand, create and maintain the surrounding environment required for successful performance.

The lack of a consistent, regionally coordinated regulatory environment is causing shortcomings in the built environment that exacerbate flood damages. Hurricane Harvey clearly highlighted the areas where the federal government, the state, the city of Houston, Harris County and smaller jurisdictions have struggled to do this.

The Addicks and Barker reservoir story provides a compact snapshot of the types of regulatory challenges and entry points available for building flood resilience in Houston and in Harris County. In Harvey, over 9,000 homes and numerous businesses located in the flood control reservoirs and downstream of the spillways were heavily impacted, and in spite of the slow onset of the event even moveable assets were lost. This

highlights an extreme version of how disasters are anything but natural – there is an enormous man-made component. There were numerous points at which these impacts could have been mitigated:

- When land was initially purchased for the reservoirs, dams should not have been sized to impound water beyond those boundaries;
- Construction of homes and businesses within the reservoirs and their delineated floodways should not have been approved in the 1990s/2000s;
- When those homes were sold, there should have been adequate disclosure to both real estate agents and buyers regarding the risk;
- When areas upstream of the reservoirs were permitted for development, permits should have required greater mitigation of downstream impacts;
- When flood maps were developed and disseminated they should have shown the full potential extent of the reservoir flood pools;
- The USACE, Harris County and the city of Houston should have evaluated, well in advance of an event, the possible impacts of floodwater within the reservoir and of high volume emergency releases downstream of the reservoirs, so they would be prepared to warn residents at risk;
- As the reservoirs began to fill rapidly during Harvey, the potential for in-reservoir and downstream flooding should have been immediately communicated to the public with warnings to secure all moveable assets well above grade. Many homes and businesses inside the reservoirs were in fact unaware that they were located in a flood zone.

“When I started to rent this house, nobody told me. Even the insurance company told me that it was not a flooding area.”
– Jeremy Boutor, Addicks Reservoir resident⁴¹

“The extensive damage across the county to structures outside the designated 100- and 500-year floodplains clearly indicate that the floodplain maps are insufficient. It also suggests that the existing drainage systems are insufficient to handle the rainfall intensities increasingly being seen in the region.”

⁴⁰ Houston Chronicle, March 30, 2018. “Harvey’s Floods: Most homes damaged by Harvey were outside flood plain, data show.” David Hunn, Matt Dempsey and Mihir Zaveri.

⁴¹ Texas Tribune and ProPublica, October 12, 2017. “Everyone Knew Houston’s Reservoirs Would Flood – Except for the People Who Bought Homes Inside Them.” Neena Satija, Kiah Collier and Al Shaw.

This list is not exhaustive, yet it points to just how broad responsibility often is. Indeed, it is often because responsibility crosses sectors, jurisdictions and scales. Because potential entry points for action are distributed so broadly in time, those involved feel they can leave responsibility to someone else. Ideally, in the post-Harvey landscape, no single jurisdiction or scale will be tasked with fixing these past errors. Instead, response needs to be taken by all jurisdictions across all scales. Efforts need to focus not just on fixing today's problems but on maintaining an ongoing awareness and engagement.

If the regulatory gaps highlighted in the Addicks and Barker Reservoir story and similar events that occurred across Harris County during Harvey are not addressed, new reservoirs, bayou projects and other large-scale efforts could eventually suffer a similar fate. The physical structures for flood risk mitigation are only as good as the regulatory environment that supports, enables and maintains them.

Culture of awareness

Key lesson: Many of the damages suffered by individual homeowners and businesses could have been at least partially mitigated had there been better risk awareness coupled with better communication of risk.

In addition to a flood-responsive regulatory environment and a strong built environment, flood resilience requires broad-based community awareness and preparedness.

Ideally, risk awareness becomes both an individual trait and part of the larger culture. In Galveston, watermark signs memorializing past floods assure that everyone in the city, resident, business and tourist alike, are aware that deep floods happen regularly. Similar signs on homes and businesses impacted by Harvey would be a strong first step, both celebrating Houston's strength in recovery while also highlighting the need to stay prepared. Some businesses along the shores of Lake Houston are beginning to do this. In addition, signs are needed within and around the edges of Barker and Addicks reservoirs highlighting that these are more than parks and making clear to people when they are entering the flood pool boundaries.

The discussion of whether flood-impacted houses should disclose prior flooding when they are sold presents a regulatory opportunity to further support a culture of awareness. Ideally, Houston and Harris County will make such disclosure mandatory. However, even in the absence of regulation, this type of information is becoming more available through the web. For example, Buyers BeWhere, an experimental website created by

Texas A&M research staff, currently provides hurricane, flooding and wildfire risk information on a property-by-property basis for Harris and Galveston Counties. Such information is likely to become more readily available in the future.

Ultimately, awareness needs to be translated into action, and too many businesses and homeowners in Houston failed to take even simple actions that could have significantly decreased their losses. In addition to carrying flood insurance and knowing the risk environment in which they are located, all businesses and homeowners can and should practice simple flood protective actions. These measures include staying alert and moving moveable assets before floodwaters enter the building, to the extent possible maintaining mechanical systems above grade, and taking advantage of simple flood resilience investments like float switches on elevators and flood barriers on doors. Businesses should, in addition, know in advance their weak points that could decimate the business if impacted and be proactively identifying ways to address that gap if needed. This includes knowing how to reach staff, and if possible being prepared to help staff respond and recover so they can keep showing up at work.

Flood insurance

Key lesson: Flood risk is far more widespread than flood insurance uptake. Many people still think of flood risk as rare and limited to the 100-year floodplain. As Harvey and past flooding events in the area have demonstrated, neither is true. This illustrates that owners and renters should be more proactive about assessing their need for flood insurance. HCFCD is currently planning to promote this message through a billboard campaign. Ideally, insurance brokers, as the main interface between property owners and the insurance world, could take the lead on this type of messaging.

This could be coupled with multi-hazard policies that include flood insurance, making the perceived cost-benefit more appealing and simplifying the decision-making by not requiring a separate line of coverage for flooding. However, even just modifying NFIP to cover any flood event (e.g., rainfall, water line break, etc.) would make it far more appealing and allow agents to more readily justify encouraging virtually anyone to take out coverage.

At the same time, NFIP should reconsider the regulations cities, counties and states need to meet for their residents to qualify for federal flood insurance. Currently, NFIP is subsidizing floodplain development.

"We ought to call federal flood insurance what it actually is. It is subsidized floodplain development. The Netherlands – the global gold standard for water management – does not offer a national flood insurance program for just this reason."
– Phil Bedient, Rice University⁴²

Coordination/collaboration

Key lesson: In Houston, governance and regulation at all levels is limited. While this presents challenges, it also offers opportunities for collaboration and coordination in diverse sectors – from community development organizations to disaster response.

Limited governance and regulation at all levels has led to a highly fragmented landscape with not enough big picture coordination, with people and organizations carefully staying within their own mandates. The resulting fragmentation is a source of challenges in building flood resilience in Houston and Harris County. However, perhaps because there are gaps in leadership and coordination, collaboration among organizations in some sectors is very high and one of the few ways to get bigger picture issues and efforts accomplished. For example, the Local Initiatives Support Corporation (LISC) has been especially proactive in linking resources and funding with community development organizations; the Greater Houston Flood Mitigation Consortium has convened a broad group of academic institutions, funded by a network of foundations and the Houston Endowment to "translate data into actionable information to help guide decision-makers during the region's redevelopment."⁴³

This exemplifies the "culture of assistance" that exists in Houston and Texas and which was highlighted in the days and weeks following the hurricane. The Cajun Navy (a group of volunteer private boat owners who assisted in search and rescue in the aftermath of Hurricane Katrina and reactivated in the aftermath of Harvey), the stories of neighbors helping neighbors, businesses stepping in to support their employees and their broader communities – all of these typify the Houston culture of "if people need help, you help them." This ethos extends to the philanthropic community, where businesses and private donors alike raised hundreds of millions to help Houston rebuild. This kind of broad social mobilization in response saved lives and in recovery is rebuilding livelihoods. It is part of the fabric of Texas culture and one that should be emulated elsewhere.

⁴² As quoted in New York Times, November 11, 2017. "Lessons From Hurricane Harvey: Houston's Struggle Is America's Tale." Michael Kimmelman.

⁴³ Greater Houston Flood Mitigation Consortium's mission statement: www.houstonconsortium.com

Recommendations

Preparedness and risk reduction

Use forward-looking scenarios to plan for the future. As a society, we continue to use historical data, statistical analysis and current conditions to design infrastructure that will still be in use 50 years into the future, and then wonder why it is inadequate. We know the world is changing, both naturally and by our actions – land subsidence from groundwater pumping, increased runoff from development, reduced water storage as we grade and pave wetlands, putting more assets in unprotected, exposed areas; coupled with increasing temperatures and storm intensity are resulting in increased flood damages. Rather than rely on past conditions, we must begin using regional worst-case historical information coupled with forward-looking climate and development scenarios in our planning.

Limit or prevent the availability of federal insurance coverage for new properties in flood zones. The National Flood Insurance Program (NFIP) is currently available to any home in the U.S. in participating communities. However, by making flood insurance available to new homes built in floodways and the floodplain, we are increasing the high-risk flood insurance pool nationally and putting the future financial viability of NFIP at risk. The failure of NFIP would leave homeowners of existing properties across the country, many built before we understood their flood risk and others with risk thrust upon them by upstream construction, at enormous financial risk with no meaningful recourse. Instead, new structures in floodways should not as easily, or as a standard, be eligible for coverage, and significantly more stringent requirements for coverage, like those adopted by Houston and Harris County, should be imposed on new structures within the floodplain.

Make flood insurance more universally appealing for homeowners and businesses. On the supply side, both the federal government and private insurers should explore options to bundle flood insurance as part of a multi-hazard policy. This could make flood insurance more appealing and more affordable, resulting in increased uptake. On the demand side, education campaigns are needed for both property owners and insurance brokers regarding flood risk, which is far more widespread than just the 100-year floodplain; flood damage costs, which are generally far more severe than homeowners and businesses realize; and how carrying flood insurance increases options and speeds recovery.

Build a culture of awareness around risk.

Creating a culture of awareness around risk can support the public in making informed decisions about risk mitigation, including evacuation. Installing past-flood water level signs as they have in Galveston, disclosing previous flooding of homes to potential buyers, adding signs to the Houston park-reservoirs indicating that you have entered a flood-control reservoir, and integrating disaster preparedness into day-to-day routines are all steps that contribute to creating a culture of awareness around risk. This in turn can incentivize incremental, small decisions by residents and businesses that collectively can dramatically reduce exposure and risk, such as elevating mechanical assets, locating critical materials above ground level, and incorporating risk awareness and preparedness in their day-to-day lives.

Address household preparedness as part of business preparedness. Several of the businesses interviewed for this report incorporate employee awareness of, and preparedness to address potential risk in their business preparedness plans. This supports staff to be better able to continue working through hazard event and/or return to work more quickly following a disaster.

Response

Improve messaging around disaster events to more accurately reflect real risk.

The current language we use to describe extreme floods such as “100-year event”, “unprecedented,” “biblical” or “black swan” does little to help people understand their risk. If anything, it minimizes the issue, making people believe such an event will not occur again in their lifetime. Instead, more careful use of language and comparing events with similar events that have occurred elsewhere in the state or region, can highlight the ways an event is rare but not anomalous – for example, hurricane seasons as intense as the 2017 season have a probability of about 10 percent in any given year.⁴⁴ “Black swan” events are not events with very low probability, but rather events that have not been seen in the historical record. This, in turn, will support an ongoing awareness of risk and incentivize risk reduction behaviors.

Trust the public with information that helps them manage their safety and preservation of assets. During a disaster, timely dissemination of information gives people more opportunity to protect themselves and their assets. In Harvey, critical information, particularly about reservoirs filling and releasing,

was not communicated effectively. As a result, households and businesses were unable to accurately explore their options and make informed decisions regarding personal and property safety. Key to successful communication is to plan in advance how and what to communicate, know who will provide the messaging, and identify who this information is being communicated to and how materials needs to be presented to reach that audience.

Partnerships and relationships are fundamental to resilient response and recovery. The people and organizations that had pre-established relationships that they could call on for preparedness, response, recovery and business continuity were able to react more quickly and, for those impacted, immediately begin recovery. This type of relationship building needs to be an intentional focus during non-disaster periods.

Use existing assets to provide critical information in disasters. For example, several of the businesses interviewed for this study used pre-existing security systems to monitor their offices and began recovery planning even prior to regaining access to physical facilities. However, the reliability and integrity of these systems can be highly dependent on core services like power. If you intend to rely on them in emergency conditions, make sure they will be operational under those conditions.

Recovery

Businesses can play a positive role for their employees and the communities in which they work through providing support to impacted employees and/or communities.

Providing equipment, access to food and showers, covering hotel room costs, assisting with mucking out, and offering paid time off for employees can go a long way toward creating a community and culture of assistance. Ideally, businesses should consider and plan for this type of support as part of their business continuity and preparedness so that the financial resources needed are available and implementation can begin immediately.

Adapt policy and funding mechanisms to increase resilience for poor and vulnerable households. Deferred maintenance is a key resilience gap for vulnerable households – households fail to qualify for recovery aid due to pre-existing household structural issues. However, those structural issues are often the result of poverty, not negligence, and they frequently exacerbate the impacts residents suffer

⁴⁴ NOAA hurricane data, accumulated cyclone energy

in disaster events. In turn, increased impacts push the same residents further into poverty and further decrease their ability to make structural repairs. This negative cycle is an issue in Houston and nationally. Changing policy and funding allocations to address this gap head-on could dramatically increase resilience for some of the city's most at-risk inhabitants.

Repeat loss properties should not rebuild as-was but instead should be bought out or mitigated. For repeat loss properties, repairs are a temporary patch until the next flood event, and for many of these properties the interval between events is becoming smaller as flood events become more intense and more frequent. In particular, though the U.S. government has unambiguous data on the location and cost of NFIP-insured repeat loss properties, we continue to subsidize these properties with regular NFIP payouts. A second or third NFIP payout to any one property should trigger an automatic option to buy out the property and retire the land and/or require mandatory, meaningful flood mitigation before the property is re-eligible for NFIP. In the long-run, this would save significant taxpayer money. In parallel, owners, governments, insurers and aid organizations alike need to recognize and advocate for the retirement or mitigation of such properties. To rebuild as was traps owners in a cycle of loss.

Owners need all their options on the table simultaneously. Currently, impacted businesses and homeowners are often forced to make decisions about how or whether to rebuild with incomplete information. Obtaining Small Business Association loans or qualifying for homeowner buyouts often takes months or years in the aftermath of an event, and owners are unable to afford to wait. This can lead to rebuilding as was, or force owners to sell their properties at post-event prices, resulting in a significant financial loss. More timely information up-front would allow for better long-term strategic thinking and better support decisions that increase resilience.

Increase dissemination of flood mitigation options for homeowners and businesses. Insurance covers much of the financial costs of a loss but avoiding flooding and loss altogether through mitigation is always preferable. There are an increasing number of low-cost, relatively

simple flood mitigation options that can help prevent or reduce losses up-front. Insurers, insurance brokers, real estate agents, and small business associations and chambers could help support dissemination of some of these options through existing channels like newsletters, customer interactions and regular meetings.

Invest in regulation, coordinated floodwater detention and neighborhood drainage. There is significant discussion about the need for a third reservoir, for more bayou mitigation, for tunnels and pumps to bypass the bayous, and reroute rainfall and runoff to the bay after Harvey. However, without land use regulations that limit development in floodways, floodplains and reservoir pools, more coordinated land development and flood detention efforts, and mandates to improve and maintain neighborhood-level drainage, these large-scale projects will rapidly suffer the same challenges currently seen at Addicks and Barker Reservoirs. Regulation, coordinated flood-detention, and drainage are not high-visibility projects demanded by the public. However, the collective impact of these efforts could significantly reduce city flooding at a fraction of the cost of large infrastructure projects, while at the same time laying the groundwork needed to maximize the operational flexibility and success of larger efforts. Houston and Harris County need to begin actively discussing, promoting and implementing these actions.

Not acting now to build flood resilience in Houston and Harris County will potentially be very costly in the future. Hesitancy on the part of leadership to take bold and potentially controversial action and unwillingness on the part of residents to self-tax and act could leave Houston on a business-as-usual trajectory. Initial strong steps were taken in the policy arena following Harvey, but risk reduction actions are stalled, tied up in discussion over what should be done and who should pay for it. What appears to have been pushed to the side is the reality that lack of action could be very costly for Houston in the future, in ways that could reverberate throughout the entire economy and region. Action, addressing everything from funding sources to drainage to large-scale mitigation, is needed and must occur at, and be coordinated, across scales and jurisdictions.

Box 6. Investing in protection against serial flooding

Floods have historically been infrequent, isolated and inherently unpredictable events. That has changed for two reasons:

- We are increasingly building in river deltas, flood plains and other low-lying areas in response to growth and population pressure.
- Climate is changing, increasing the frequency and severity of weather events and contributing to sea level rise.

Together, these are altering the nature of floods, changing them from occasional risks to serial certainties.

This new reality is on display in Houston, which has experienced three “500-year floods” in the past three years, as well as in numerous other cities. Miami, Charleston and Norfolk all regularly flood, even in good weather, and that flooding is getting worse over time. Serial flooding will grow in frequency and severity until we invest in better flood mitigation for vulnerable cities and their stakeholders.

The challenge is not solutions – we have those at hand. It is funding, because we perceive flood mitigation as expensive. Though it might seem costly when floods are rare, serial flooding makes mitigation much cheaper than the “cost of not” investing.

To fund flood mitigation, it helps to quantify that “cost of not.” It starts with direct flood damage to property, infrastructure and peoples’ health. Yet, as large as these direct costs can be, serial flooding makes them the tip of the iceberg. Serial flooding threatens the foundations of our cities’ social and economic viability.

Small businesses generate about two-thirds of new jobs. Yet 71 percent of small businesses do not reopen after being flooded, and of those that do, 89 percent do not survive the next two years. Serial flooding can reduce or reverse job growth in vulnerable cities. And, the impact of serial and intensifying flooding will at some point trigger major readjustments in property markets with significant social and economic implications for those communities and regions.⁴⁵

Faced with accumulating direct losses from serial flooding, people and businesses will vote with their feet. The full “cost of not” investing

⁴⁵ <https://www.bloomberg.com/news/features/2017-04-19/the-nightmare-scenario-for-florida-s-coastal-homeowners>

⁴⁶ <http://www.greenwood-ag.com/>

Contributed by Greenwood Strategic Advisors, a Swiss firm specializing in city simulation technology and innovative financing for city infrastructure.⁴⁶

to protect against serial flooding includes job and population losses, lost income and falling property values, and lost tax revenues at all levels of government.

Greenwood is using a dynamic city model to evaluate the “cost of not” making city investments, under a range of scenarios that includes serial flooding. The schematic illustrates the key elements included in cities and in the model, and their interconnections.

In a comparable city, Greenwood’s use of this model to measure serial flooding impacts has revealed two “cost of not” consequences that Houston and other flood-prone cities should take to heart.

- New flood mitigation for the business district can protect job growth, at a one-time cost equal to 5 to 10 percent of total annual personal income generated in the city. Without that investment jobs are likely to be lost, and population to decline over time, in response to accumulating physical damage, mental distress and social disarray from serial flooding.
- As jobs and population decline, so too do the local economy and city, state and federal tax revenues generated in the city. State tax losses alone, over a 25-year period, could come to about half the cost of the needed flood protection.

It seems obvious that the homes, jobs, infrastructure, and lives woven into the social fabric of this city are worth a great deal more than 5 to 10 percent of one year’s worth of the income earned there. What is blocking flood mitigation is the mistaken assumption that future life in this city can go on much as it has in the past. Government and holders of city debt are unaware that future tax revenues and debt service can decline sharply in the absence of flood mitigation actions. They are equally unaware that the full monetized value of flood mitigation significantly exceeds its cost.

Measuring the social, economic and fiscal cost of not investing in flood mitigation is a vital first step in creating the political and public will to act. The “cost of not” making that investment is also the source of funding for the investment. By mitigating the impacts of serial flooding and thereby avoiding property losses, tax revenue

losses, losses on public debt, and other monetized forms of flood damage, flood mitigation investments create substantial and certain future funding, while maintaining intrinsic value. Model simulations reliably quantify the magnitude and timing of these avoided losses and enable future funding.

To access and use that future funding calls for flood-defense financing with three distinctive characteristics. It must:

- Bridge the gap between when the city pays for its flood defense investment (i.e., soon) and when avoided losses will generate funding (i.e., later);
- Eliminate public borrowing and keep investment costs off the public books until future mitigation-based funding is covering them;
- Be accessible and attractive to pension funds and insurers, who eagerly seek quality long-dated assets but have limited capacity for illiquid investments and cannot invest without near-term returns.

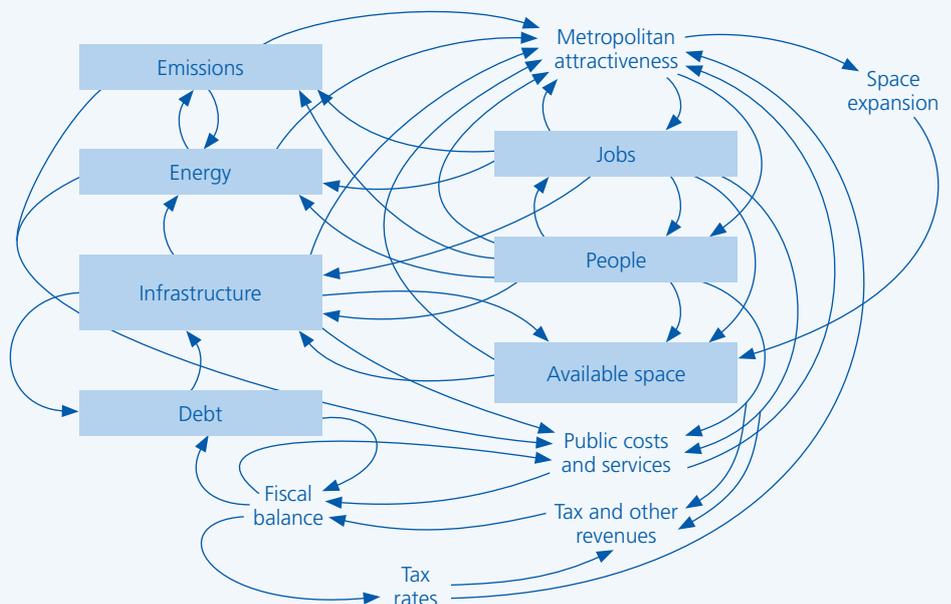
Pension funds, for example, are responsible for investing quite large pools of money to generate returns that will fund clients’ retirements. City infrastructure would be ideal, but as they are traditionally offered, such investments are quite illiquid and have been difficult to find in suitably large sizes and volumes.

A new type of investment instrument, Credit Participation Certificates⁴⁷ (CPCs), is designed to be tradable in liquid exchange-based markets and thereby attract new financing for city investments. Tradability of infrastructure CPCs depends critically on reliable and regularly updated valuations of these investments, which city simulation models such as Greenwood’s provide. CPC financings involve no public borrowing and can maintain costs off government books until the investment is generating suitable funding. From that point it automatically comes onto the public books, where most public investments naturally belong.

Cities have a huge unmet need to finance large infrastructure investments. Institutional investors have a huge unmet need for liquid, tradable infrastructure financings with large scale and volumes. Because of their unique characteristics, CPC infrastructure financings can mobilize large new volumes of financing for public investments that generate their own funding through social, economic, income and public revenue growth. This can provide significant relief for public budgets and balance sheets, even as it increases the volume of financing for investments that increase city resilience and sustainability.

Citizens will be the main beneficiaries of such investments, from resulting improvements in cities where they live and work and from higher and more secure returns from pensions.

The metropolitan system of systems



⁴⁷ CPCs have been developed and commercialized by UFT Commercial Finance LLC.

Conclusions

In the Houston Harvey flooding, over 9,000 homes and numerous businesses were located both in Houston’s flood control reservoirs, and downstream of dam gates and spillways. Not only were structures heavily impacted, moveable assets were lost, in spite of the slow onset of the event. This case highlights an extreme version of how disasters are anything but natural – there is an immense man-made component. However, this also means there is also an enormous amount we can do to mitigate our risk.

Given Houston’s history of flooding and its physical and development landscape, the question is not whether it will flood again, but when and how badly. The city and county have already taken bold policy steps to reduce future risk. The challenge now is to take equally bold funding and implementation steps across all scales: from major infrastructure to street drains, through awareness raising, and for the state of Texas and the federal government to help support those steps. How the city and county decide to mitigate future flood risk, and how aggressively they pursue that mitigation, will determine the extent of the impacts from the next event.

At the same time, residents and businesses cannot sit back and wait for the authorities to fix things for them. They need to become proactive about asking for, expecting and self-taxing themselves to pay for action. They must also remember that even the best flood mitigation leaves residual risk. Businesses of all types and residents must become far more proactive about understanding and taking action to prepare for and/or mitigate that risk.

These lessons and recommendations are true not just in Houston and Harris County but nationally.

Too often, we look at disasters elsewhere as a curiosity, somehow assuming “that would never happen here.” Yet the stories from Hurricane Harvey make it clear that is exactly what Houstonians thought too – the size of the event and the extent of the risk landscape far exceeded what anyone expected. The reality is, not only could a disaster happen in your community, at some point it will. As a nation, we must begin to look at extreme events that happen within our regions not as curiosities but as wake-up calls, and adjust our planning, preparation, regulation and action accordingly.



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This report presents a snapshot of events and responses during the Hurricane Harvey flood in Houston in August 2017. It is not comprehensive – much more could be said on the degree of resilience of Houston during the floods. What this report does provide is a collection of short, field-tested examples of resilient systems and actions as well as a discussion of what it is that makes those resilient. It also describes factors which limited the ability of people, businesses and systems to weather the storm.

This publication has been prepared by Zurich Insurance Group Ltd, ISET-International and the American Red Cross Global Disaster Preparedness Center and the opinions expressed therein are those of Zurich Insurance Group Ltd, ISET-International and the American Red Cross Global Disaster Preparedness Center as of the date of writing and are subject to change without notice. This publication has been produced solely for informational purposes. All information contained in this publication have been compiled and obtained from sources believed to be reliable and credible but no representation or warranty, express or implied, is made by Zurich Insurance Group Ltd, ISET-International and the American Red Cross Global Disaster Preparedness Center or any of its subsidiaries (the 'Group') as to their accuracy or completeness. This publication is not intended to be legal, underwriting, financial, investment or any other type of professional

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Photography: Getty images, p.11 – Flooded Bayou, Karl Spencer, p.17 – Flooded streets during Hurricane Harvey, Eric Overton, p.23 – Overflowing, Bobby Ware, p.28 Flooded Suburban Texas Street from Hurricane Harvey, Citysqwirl, p.35 – High angle view of cityscape Against Sky, Matthew Davidson / EyeEm, p.44 – Flooded House, Visual Intermezzo

About the Zurich flood resilience alliance

An increase in severe flooding around the world has focused greater attention on finding practical ways to address flood risk management. In response, Zurich Insurance Group launched a global flood resilience programme in 2013. The programme aims to advance knowledge, develop robust expertise and design strategies that can be implemented to help communities in developed and developing countries strengthen their resilience to flood risk.

To achieve these objectives, Zurich has entered into a multi-year alliance with the International Federation of Red Cross and Red Crescent Societies, the International Institute for Applied Systems Analysis (IIASA), the Wharton Business School's Risk Management and Decision Processes Center (Wharton) and the international development non-governmental organization Practical Action. The alliance builds on the complementary strengths of these institutions. It brings an interdisciplinary approach to flood research, community-based programmes and risk expertise with the aim of creating a comprehensive framework that will help to promote community flood resilience. It seeks to improve the public dialogue around flood resilience, while measuring the success of our efforts and demonstrating the benefits of pre-event risk reduction, as opposed to post-event disaster relief.

