

# Houston and Hurricane Harvey:





# 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

This study – written by ISET-International, a nonpro t 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.

## Resilience lessons from the flood

### Preparedness and risk reduction

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.

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.

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.

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.



# Introduction



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.

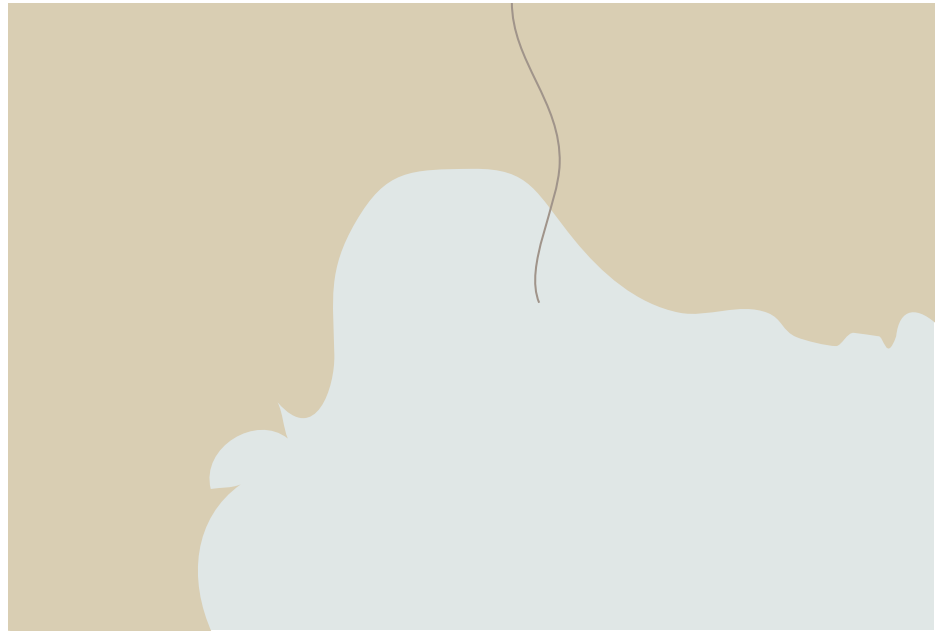
This report in particular explores flood resilience in Houston from a business perspective. Houston is a business city – Houston's and Harris County's economies rank amongst the strongest in the nation. At the same time Houston has been hit with three so-called one-in-500-year floods in three years, 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](#)

# 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.





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.<sup>18</sup>

### 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 unprec(r)-5(e)--tt0 ey13 T79),4TJ T\* [(storttr5-10( )TJ (rm rs foundton as.ey; ( )BT /01\_1 1 Tj -0.01 Tc -33028 [(ext 6t0)-1he H



### 1 55

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

### 1 57

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.

### 1 61

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

### 1 6

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

### 1 73

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.

### 1 76

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.

### 1 7

**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.

### 1 3

**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.

### 1 4

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.

### 1

**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.

### 1 2

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.

### 1 4

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.

### 1

**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.

### 200

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.

### 200

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.

<sup>19</sup> Information for the timeline was obtained from: Harris County Flood Control District, [www.hcfdc.org/flooding-oodplains/harris-countys-flooding-history/](http://www.hcfdc.org/flooding-oodplains/harris-countys-flooding-history/) Weather Research Center Houston, TX, [www.wxresearch.com/almanac/hou-flood.html](http://www.wxresearch.com/almanac/hou-flood.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.

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.<sup>20</sup> 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.<sup>21</sup> 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.

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

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

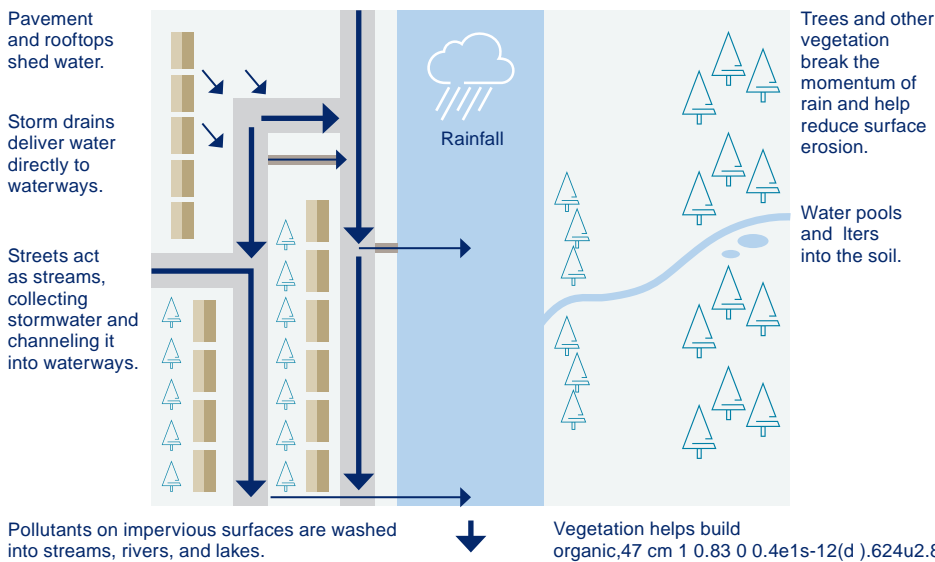


Figure 3. Adapted from D. McNabb: Water Resource Management: Sustainability in an Era of Climate Change

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

## 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."<sup>12</sup>

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, manage 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

### 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 same pattern, these developments can result in a much faster flow of water to the bayou, increasing flood peaks. By following

# 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

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

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 flow 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 effectively operate the reservoirs and gates to maximize protection for downtown Houston.

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.

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 (HCFCD) – 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 HCFCD 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 HCFCD'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.<sup>24</sup> 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 channel 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

## HCFCD buyout program

### Buyout spending since 1965:

### Purchases/impact:

<sup>24</sup> 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](http://forms2.rms.com/rs/729-DJX-565/images/tc_2001_tropical_storm_allison.pdf)

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-funding 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 “x” 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.





and employees practice being ready for

## 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.<sup>27</sup> 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. 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. 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.<sup>9</sup> 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. 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.

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.<sup>28</sup> 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 re-erecting 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.

# Hurricane Harvey: response and early recovery

The intense rains brought by Harvey resulted in

“ 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

“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

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 cafe 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'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



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 lining 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.

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<sup>33</sup>; 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

<sup>33</sup> 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

## 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 home-

owners to purchase flood insurance. The city and county are also working to improve the floodplain management process. The city is currently reviewing the floodplain management process and is expected to release a new floodplain management ordinance in the next few months. The county is currently reviewing the floodplain management process and is expected to release a new floodplain management ordinance in the next few months.

### 4. Elevating and repairing

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problematically, there has been little discussion of the regulatory landscape that gave rise to the 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<sup>35</sup>. 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<sup>36</sup>. 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." – Chron<sup>37</sup>

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

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

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 preparing

# Lessons learned

## Built environment

solutions than widening and straightening

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.<sup>40</sup> 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

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

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 coat 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

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 University

### Coordination/collaboration

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.”<sup>43</sup>

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 raise funds for the benefit of neighbors.<sup>7.8</sup>



# Recommendations

## Preparedness and risk reduction

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.

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.

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.

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.

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

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.<sup>44</sup> “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.

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.

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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.

- . 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.

. 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 strategaopertntit Tw 17.783 0 Td spntit Tw 17.783 hatsilience for some

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 Certificates<sup>47</sup> (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

# Conclusions

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

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## 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-batio5loy

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