1 Fact Sheet
WHAT IS A FLOODPLAIN?

The Federal Emergency Management Administration (FEMA) defines a floodplain as any land area susceptible to being inundated by floodwaters from any source. This can include coastal areas impacted by storm surge, land along a river or bayou that is flooded when that waterway rises out of its banks, or low-lying land that fills with water when it rains. Flooding occurs in a wide range of landscapes due to rainfall or storm surge.

Legal Definition

In addition to being a naturally occurring phenomenon, a floodplain is a legally defined concept. FEMA designates floodplains across the nation, which accommodate several purposes:

The designated floodplains are used to set rates for flood insurance.

- Mortgage issuers usually require flood insurance for any property in the designated floodplain.
- Cities set specific building regulations for any properties within the designated floodplain.
- Models based on designated floodplains can be used to warn residents of impending flooding and to issue evacuation orders.

Types of Floodplains Designated by FEMA

The **floodway** is "the channel of a river or other water course and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height." In a flood event, the floodway functions as part of the waterway, and is filled with flowing water.

The **1 percent (100-year) floodplain** is land that is covered in water during a flood event that has a 1 percent chance of being equaled or exceeded each year.

The **0.2 percent (500-year) floodplain** is land that is covered in water during a flood event that has a 0.2 percent chance of being equaled or exceeded each year.

These designations are based on computer models and statistical estimates of the 1% and 0.2% rainfall amounts. Fundamentally, a designated floodplain is a modeled estimate.

It is generally safe to say that land inside the designated floodplain is at risk of flooding, that land inside the floodway is at higher risk of flooding than land in the 1% floodplain, which is at higher risk of flooding than land in the 0.2% floodplain. However, land outside the designated floodplain can still be at risk of flooding, and land inside the 1% (100-year) and 0.2% (500-year) floodplains may flood more often than the designations indicate.

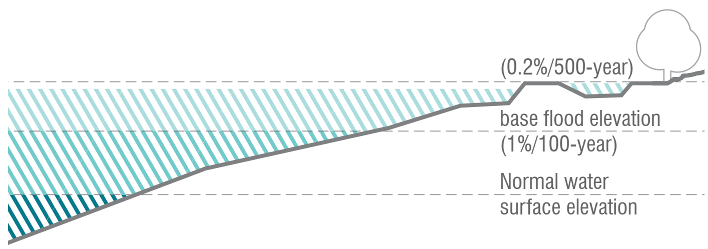
Types of Flooding

River Flood occurs when water levees in a river or stream rise over the banks and flood adjacent areas.

Coastal Flood occurs in coastal areas caused by strong winds, high tides and low atmospheric pressure close to the eye of a hurricane. As the eye hits a shore and moves inland, it causes a storm surge.

Surface/Overland Flood occurs in areas when more rainfall occurs than the capacity of the stormwater drainage system.

Figure 1 Hunting Bayou, Kashmere Gardens



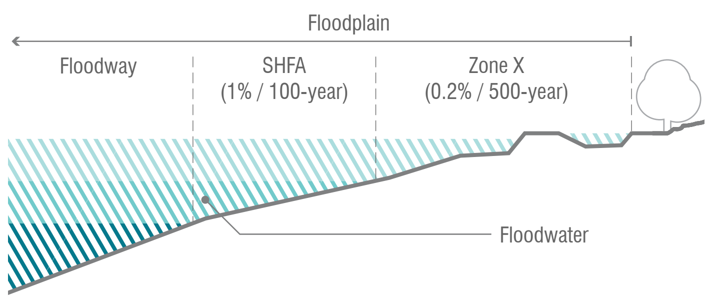


Figure 2 Components of a Floodplain

KEY POLICY QUESTION

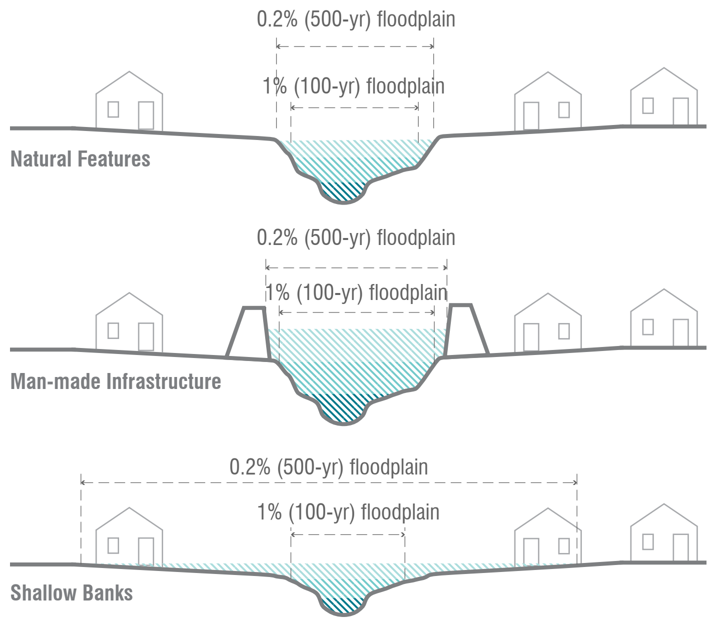
In a flat landscape, should we base infrastructure and development decisions on the FEMA-designated floodplains when we know that land outside those floodplains is also at risk of flooding?

In some landscapes, floodplains are clearly defined by **Natural Features**. In a river valley, for example, there is often a flat area around a river that floods frequently, and land above steep banks on either side that the river never reaches. Here, the 100-year and 500-year floodplains are quite similar in their extent. Here, the designated floodplain is also a natural floodplain that is visible in the topography. In the Houston area, the lower San Jacinto River is like this.

In some landscapes, the floodplains can be clearly defined by **Man-made Infrastructure**. Levees hold floodwaters back and create a clear boundary: land between the river and the levees is likely to flood, and land beyond the levees is not. In the Houston region, the Brazos River is like this.

In many parts of the Houston region, floodplains are not clearly outlined by **Elevation Differences**. In a flat landscape, water spreads broadly once it rises out of the banks of the bayou. The FEMA modeled floodplains are more uncertain in this type of topography. A small rise in rainfall volume can lead to a large increase in the area flooded. There is no geographic feature that protects a house on the far side of the designated 100-year floodplain from flooding.

In some areas, **Undersized Stormwater Systems** contribute to localized flooding in areas that are not near a river or bayou. In these areas, flooding can occur no matter how low or how high the water may be in the nearest waterway. Since these areas are not near a waterway, they may not be included in FEMA floodplain mapping.



COMMON MISCONCEPTIONS

Misconception- The 100-year floodplain only gets inundated once every hundred years.

Fact- The 100-year floodplain has a 1% chance of being flooded in every given year. This means statistically, the 1% (100-year) flood has about a 26% chance of occurring during a 30-year period of time.

Misconception- The 500-year flood only happens once in 500 years.

Fact- The 500-year flood has a 0.2% chance of occurring every single year. Again, this means that statistically, the 0.2% (500-year) flood has a 6% chance of occurring during a 30-year period of time.

Misconception- If a property is not in the mapped 100-year floodplain, it will not flooded.

Fact- Most homes in the Greater Houston region are at risk of flooding regardless of what floodplain they are mapped within.

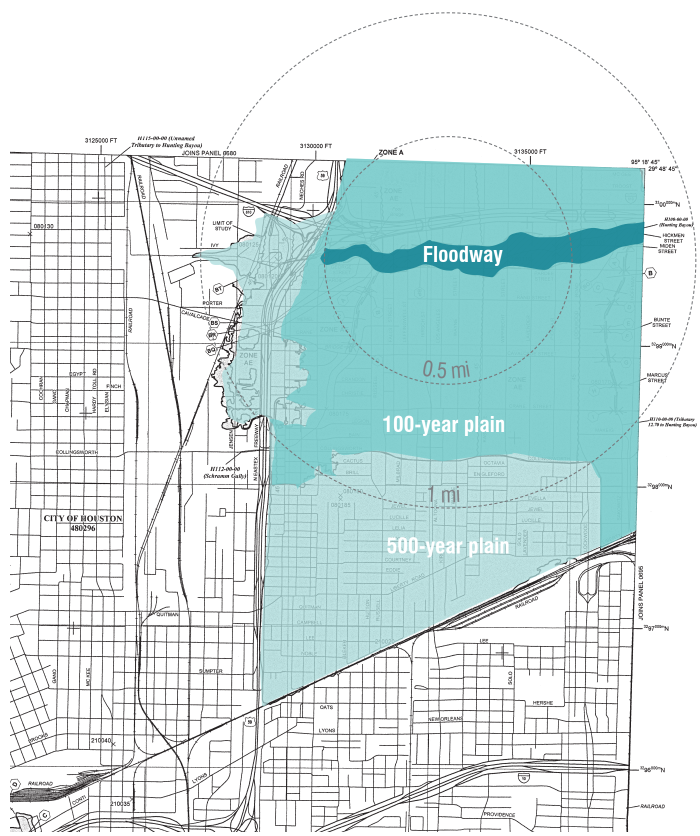


Figure 3 Kashmere Gardens Floodplains Extending Far from Hunting Bayou

For More Information Visit

Find out If You're in a Floodplain
msc.fema.gov/portal/search

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

2 Fact Sheet HOW DO WE ASSESS DAMAGES?

Flood events cause a great deal of disruption to the daily lives of people and to the economy. After a flood event, in order for a city to recover and rebuild with greater resiliency, it is important to accurately identify which homes were flooded, which neighborhoods and their infrastructure experienced the greatest stress, and why. However, every method is incomplete and can take months to collect. Additionally, most metrics focus on quantity of damage rather than the ability of someone affected to recover from that damage.

Damage assessments are necessary to identify the need for aid, as well as what type of projects are needed for future flood mitigation. Displaced families need refuge and relocation, damaged properties need repair or buyouts, and the city needs projects to mitigate future flooding. Studying the types and causes of damage helps identify areas for research and policy changes, for example, developing new building codes for higher resiliency.

Stream Gages (Real-time)

Water levels of waterways are measured continually and this information is available in real-time to public and emergency management officials.

How They Work

Stream gages are placed along waterways by Harris County Flood Control District (HCFCD) and provide live information on the elevation of the water. The map on the left is a snapshot of stream gages during Harvey. It shows green markers where the water was in its banks and a red exclamation mark where it had overflowed.

Benefits & Limitations

Stream gages are extremely accurate at measuring water levels; however, they leave several gaps in information. They are spaced 1-5 miles apart and provide no information on street or neighborhood flooding outside the stream's floodplain. Also, multiple gages were destroyed during Harvey and stopped providing information as the storm continued.

Inundation Modeling (0-3 Weeks)

FEMA runs inundation models immediately after a storm, and media outlets, such as New York Times, use them to map initial damage assessments within days of the event.

How it Works

Inundation models typically feed predicted or observed rainfall amounts into standard hydrological models to calculate where the water flows along major streams. This information is overlaid with data on built structures to estimate which structures may be damaged along modeled streams.

Benefits & Limitations

Typical inundation models are useful for estimating stream flooding, but only provide a simulation of structures that may have flooded by the stream overflowing. They fail to evaluate localized and street flooding not caused by stream overflow. During Harvey, for example, there were some severely flooded neighborhoods that did not appear on these stream floodplain maps.

TYPES OF DAMAGE

Minor Home Flooding could require new flooring, walls, and insulation.

Major Home Flooding could require families to seek extended refuge or permanently relocate.

Emergency Needs such as boat rescues or medical needs.

Food Needs at shelters or homes during extended flooding events.

Utilities Damage such as water and power outages could cause temporary or permanent relocation.

Vehicle Damage may prevent people in areas without public transit options from getting to work.

Road Closures may prevent people from getting to work or schools.

Small Businesses may lose employees or revenue due to damage.

Schools may close and require students to relocate to other schools.

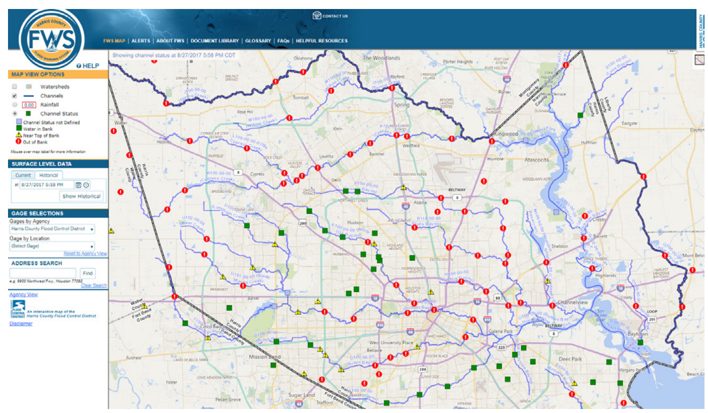


Figure 1 Stream Gage Map on HCFCD Website

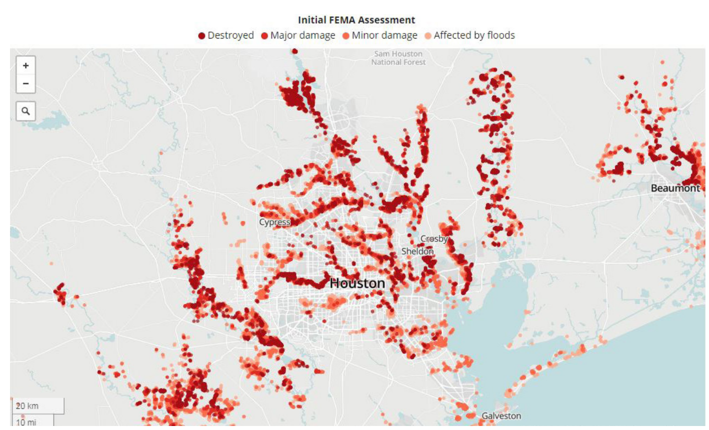


Figure 2 FEMA Initial Assessment

KEY POLICY QUESTIONS

Are major decisions on flood mitigation projects and policies made with incomplete information?

How can we insure all neighborhoods get the same quality of information?

Can we improve damage assessments?

Aerial Imagery (0-3 Weeks)

Aerial imagery captures a visual account of flooding at one point in time.

How They Work

Aerial photos are produced in collaboration by National Ocean Service, Texas Parks & Wildlife, Digital Globe, OpenStreetMap, ESRI, and others.

Benefits & Limitations

These are useful in visualizing the areas and extents of damage, but they can not be taken during the storm due to cloud obstruction. They are taken after the storm has cleared so they only capture areas where the water does not recede quickly, and usually do not show the maximum height of flooding.

Emergency Calls (3-6 Weeks)

311, 211, & 911 emergency calls are directed to the City for people in need.

How They Work

Every 311 call is recorded and archived. Within weeks of a flooding event, the city and public agencies gather data on 311 calls and produce a map identifying areas of high call volumes.

Benefits & Limitations

While this method is slower than inundation models, it provides a more accurate picture of the areas that need attention. However, most of the call information is manually entered leaving lots of room for error. Additionally, not everyone in an emergency is able to make a call and therefore is not counted in this method. Often, even if someone is able to make the call, they may choose to just call family or friends for help instead of 311.

Insurance & FEMA Claims (6 Months-1 Year)

HCFCD highly encourages everyone to purchase flood insurance through the National Flood Insurance Program (NFIP). Mortgage lenders require Flood Insurance for homes in the 100-year floodplain. FEMA disaster relief funding is available to help homeowners, small business owners, and non-profits.

How They Work

After a flood event, homeowners with flood insurance file claims and others file for disaster relief funding from FEMA. A comprehensive, door-to-door analysis of insurance claims is conducted by the NFIP and FEMA compiles a thorough set of disaster relief applications.

Benefits & Limitations

This is one of the most accurate methods of assessing damages because it is not a modeled estimate. However, it may take up to a year to collect and does not count anyone who does not file a claim. For example, many homeowners who own their homes outright without a mortgage (as is the case in many low-income neighborhoods), or live outside the 100-year floodplain, do not own flood insurance. Since renters often do not own flood insurance and are also under-counted in this method. FEMA disaster relief applications are available to everyone; however, not everyone applies because of the lengthy and complicated process.

Figure 3 Before / After Satellite Imagery

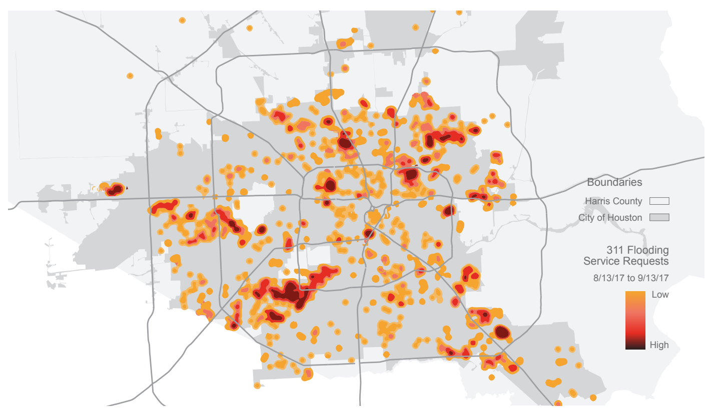


Figure 4 311 Call Data by City of Houston (Mapped by CDRC)

For More Information Visit

Kinder Institute Harvey Story Map
arcg.is/beKCS

Harvey-related 211 Calls Data Dashboard
DataHouston.org/story/UnitedWay211.html

FEMA Assistance Dashboard
DataHouston.org/story/FEMAassistance.html

Stream Gages
HarrisCountyFWS.org

Disaster Aerial Imagery
esri.com/services/disaster-response/hurricanes

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

3 Fact Sheet

WHAT IS A DETENTION BASIN?

What Is a Detention Basin?

Stormwater detention basins collect and temporarily store stormwater, while releasing lesser amounts, lowering the risk of flooding downstream. Detention is not to be confused with retention which retains stormwater indefinitely.

These basins are large excavated areas, designed to remain empty except for during large storm events, or are designed to have a permanent shallow pool of water with capacity above the normal water level to store stormwater.

Why Do We Need Detention?

Impervious surfaces, such as roads, homes, and parking lots, increase the rate and volume of stormwater runoff during storms, which can cause flooding downstream. Detention captures and stores this additional runoff. It is one of several tools that can be used to mitigate downstream flooding.

Detention in the Houston Area

In the Houston area, detention is created in two ways. **On-site Detention** is built as part of private developments, or public projects (e.g. highway expansions), to mitigate the impact of the development. On-site detention is usually required by city and county development regulations and funded by the developer. Detention basins are the most commonly used solution for detention, but oversized storm sewers or Low Impact Development (LID) practices such as bioswales, rainwater harvesting, and preserving natural habitats to capture and filter stormwater runoff on-site, at the source, can also be used. **Regional Detention** is built by flood control agencies to address flooding on a larger geographic scale, and is funded by taxes or stormwater fees paid by a number of developers. Regional detention is used to reduce existing flooding or help prevent increased flooding from new developments.

How Do Detention Basins Work?

Detention basins are designed to allow for a large amount of inflow to be captured and stored while allowing for a small amount of outflow to be released at any given time. When a storm event occurs, the detention pond fills up and stores water temporarily, reducing flooding and erosion downstream. Runoff enters the basins by flowing in from the surrounding land as overland flow or from a channel or pipe. Water is usually released from the basin by gravity, through an outfall channel or pipe. As the water in the receiving channel drops, more water is able to leave the detention basin, until it is emptied or restored to its designed pool level. Unlike most large federal flood control facilities, detention basins do not usually have adjustable gates or valves; the basins fill and empty based on the size of inlet and outlet channels and pipes.

How Do We Determine the Size of a Detention Basin?

The size of a detention basin can be determined using flow hydrographs, which show water flows in and out of an area over time. Detention basins serve to slow down runoff into a river, stream, or bayou by releasing water more slowly, thereby reducing peak flow rates which cause receiving streams to overflow.

Detention basins hold certain volumes of water, calculated for peak flowrates to match pre-development levels. They are typically designed to hold water for 24hr rainfall events, but different duration goals affect the size of the detention basin. Other factors that affect the design volume include rain intensity, size of drainage area, and Low Impact Development practices. Once required detention volume is determined, the width, length, and depth of the basin can be designed.

Figure 1 On-site Detention

Figure 2 Regional Detention

KEY POLICY QUESTIONS

Are current detention standards enough for new developments?

Where do we need more regional detention?

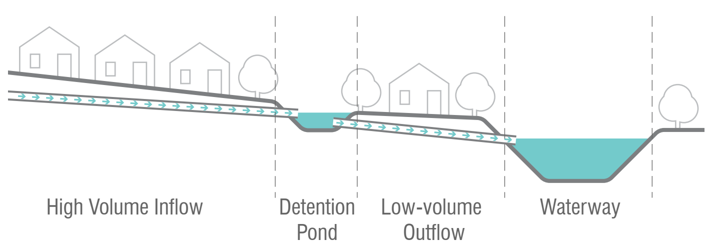


Figure 3 Detention Diagram

KEY TERMS

Stormwater Runoff is water that flows over ground surface into drainage areas. Increased pervious the land means less stormwater runoff and more rainwater absorbed. Increased development means increased impervious surface, creating more runoff and less rainwater being absorbed.

Flowrate is the volume of water that passes per unit of time (ft3 or cfs). The smoother the ground cover (e.g. concrete), the faster the flowrate.

Hydrograph is a graph of variable flowrate over time at a given location

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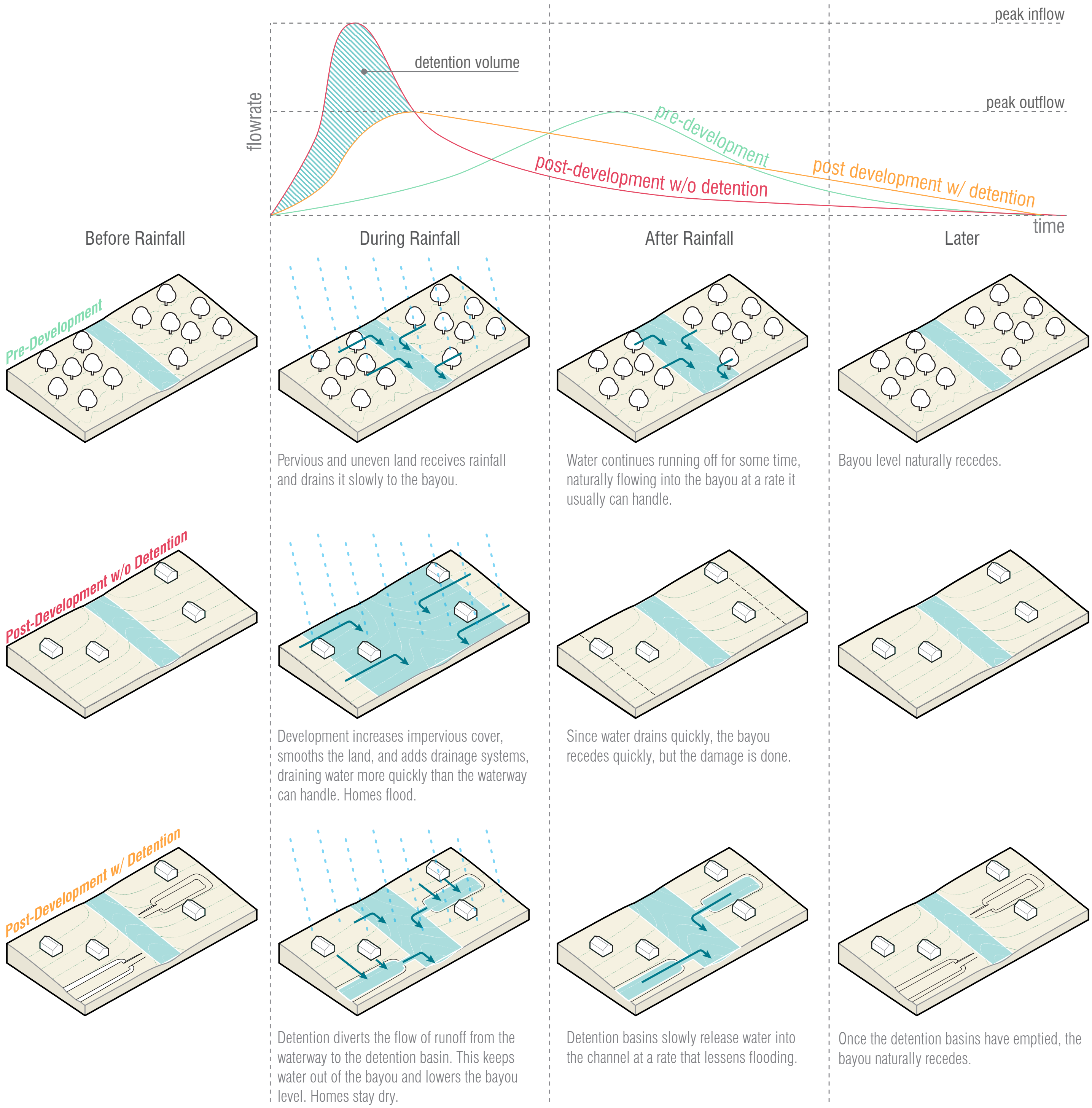

Figure 4 Flowrate Matrix

For More Information Visit

H-GAC LID Resources
h-gac.com/community/low-impact-development

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

4 Fact Sheet
HOW ARE FLOODPLAINS DESIGNATED?

Floodplain boundaries are not visible lines within the natural environment, rather they are lines drawn on a map to approximate areas susceptible to flooding. While it is not an exact science, floodplain mapping can approximate what areas will be inundated during a specific storm event. Floodplain maps are intended to be used as a tool for cities, homeowners, developers, and insurance companies to understand the risk of flooding at locations near streams, bayous, or other riverine features.

Steps to Determining Floodplain Boundaries

Step 1

Determine rainfall amount in given storm event; a statistical analysis is performed on the historic rainfall records to determine the 1% AEP rainfall amount. These values, from past rain events, reflect a storm that lasts exactly 24 hours. These rainfall amounts are utilized in the development of hydrologic models as discussed in Step 2 below.

Step 2

Determine how much floodwater will be generated in a given storm event. This can be determined using a **Hydrologic** model. These models take the amount of rain that falls on the ground and determine how much soaks into the ground, how much runoff is generated, and how long it will take runoff to travel to a stream. Factors that affect the amount of floodwater:

- Rain amount
- Soil type
- Land use
- Terrain
- Shape of watershed
- Slope
- Type of drainage pathways

Step 3

After determining the amount of floodwater, the next step is to determine how high the floodwater will get in and around a river, which can be done using a **Hydraulic** model.

Factors that affect the height of floodwater:

- Channel size
- Channel shape
- Channel material
- Downstream capacity

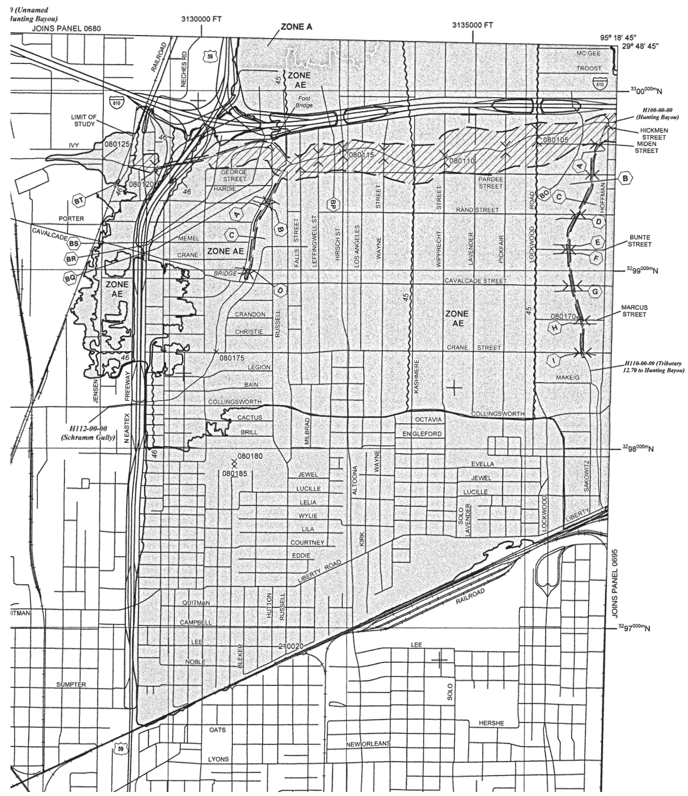

Figure 1 FIRM Map with Floodway, 100-year (SFHA), & 500-year (Zone X) Floodplains

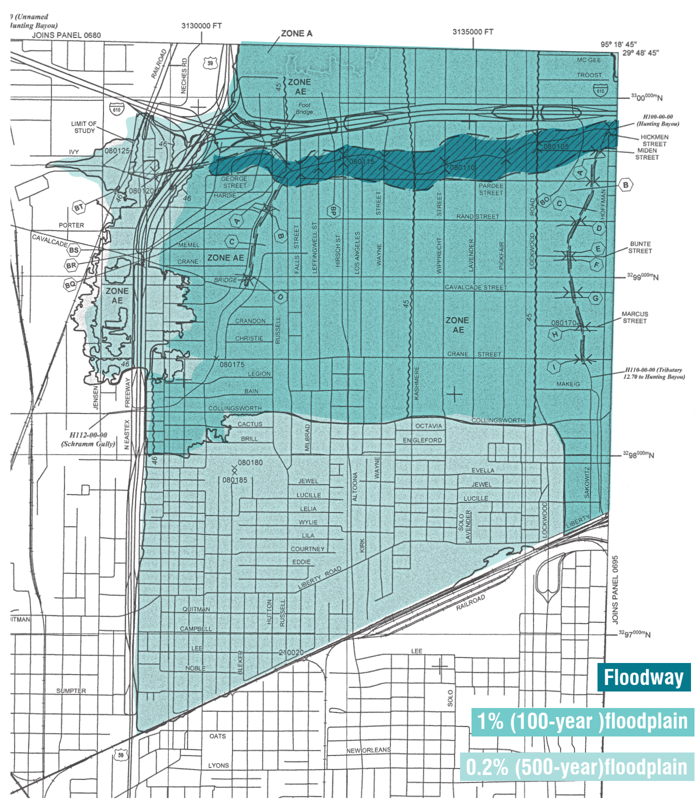

Figure 2 FIRM Map with Floodway, 100-year, & 500-year Floodplains Highlighted

KEY POLICY QUESTIONS

Should we change the way we map floodplains?

How will floodplain maps change based on updated rainfall data?

Topographic data are used in conjunction with the **Modeled Flood Elevations** to determine where to draw the **Floodplain Boundary**. When an elevation at a certain location is determined, the floodplain boundary is determined by where that elevation intersects the ground on both sides of the channel (bayou, river, etc.). It is typical to map the floodplain boundary resulting from the 1% AEP and 0.2% AEP and the floodway.

The Federal Emergency Management Agency (FEMA) keeps floodplain maps for all studied areas, which are used for insurance and regulatory purposes. Floodplain boundaries can change due to new development, erosion and changes in topography, and more detailed analyses. The process to change a mapped floodplain boundary can take several years, due to coordination and data review.

FEMA maps only show areas that are susceptible to inundation by bayous and creeks overtopping their banks in watersheds greater than one square mile. However, flooding occurs outside of these boundaries as well, whether due to heavy rain, undersized storm sewer systems, sump areas, land use etc.

Of all of the severe storms that have occurred, and all of those that will occur in the future, none is likely to create the exact floodplain boundaries represented on a floodplain map. Some reasons that cause this difference include

- Rain does not fall evenly or in predictable patterns that match with our analysis assumptions
- The nature of riverine environments is ever-changing
- Land use changes are always occurring
- Heavy storms can bring debris and obstructions that alter the path and depth of floodwater

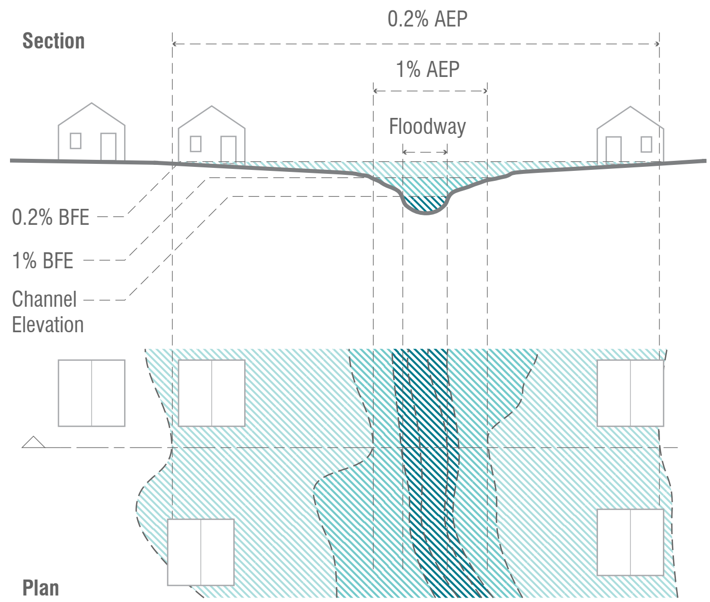

Figure 3 Plan & Section of Floodplains

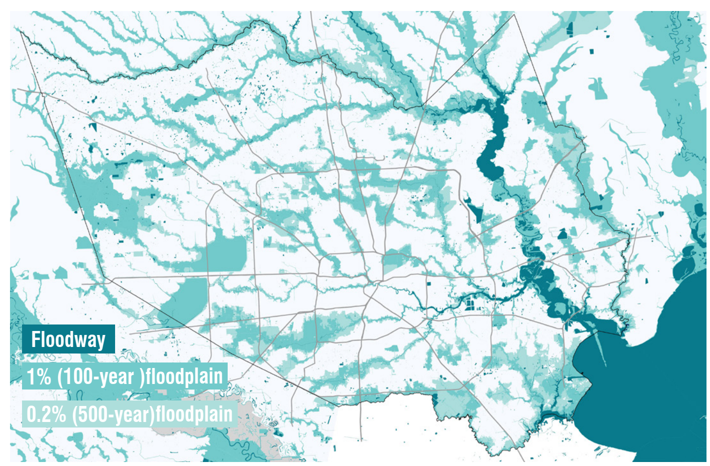

Figure 4 Floodplain Map of Harris County

KEY TERMS

In simple terms, hydrology determines how much water reaches channels, and hydraulics determines how high the water rises and how fast it moves in and through channels:

Hydrology - The study of rainfall and runoff in connection to geography and geology - how water moves through the hydrologic cycle.

Hydraulics - The study of the motion of water - hydraulic analysis is done to model stormwater flows.

Floodplain - Any land area bordering a river, stream or bayou that is naturally susceptible to flooding by an Annual Exceedance Probability (AEP) storm event.

Annual Exceedance Probability Storm Event - The probability of that storm event exceeding a particular storm discharge or flood level within one year. For example, equivalent return period terms,

1% AEP = a flood that has 1 in 100 chance of occurring in any year.

0.2% AEP = a flood that has 0.2 in 100 chance of occurring in a year.

For More Information Visit

FEMA Map Service Center
msc.fema.gov/portal/search

Hrarris County Flood Control District Flood Education Mapping Tool
harriscountyfemt.org

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

5 Fact Sheet
HOW DOES RAINFALL DRAIN AWAY?

All of the Houston region drains to Galveston Bay. While some of the rain that falls evaporates or soaks into the ground, the vast majority of the rain will eventually flow to the Bay. But its path can be complicated, and the water flowing through every piece of that path can result in flooding. While bayous rising out of their banks is the most obvious cause of flooding, much of the flooding we see comes from water that has not yet made it to a bayou. Bayous are only part of our stormwater system. Water flows at different rates over different ground surfaces. It flows slowly over soil covered with prairie or vegetation because such land is absorptive, while it flows quickly over pavement or concrete. Flooding can be caused in both instances, if water does not drain quickly enough it will pond and create overland flooding, and if it flows too quickly into a bayou that does not have adequate capacity, it can cause the bayou to overflow and flood the areas around it.

Path of Water

Water that falls within a watershed may drain naturally as overland flow or through man-made features, such as storm drains or diversion channels. Any rainwater within a watershed boundary that becomes runoff will start out as overland flow and eventually make its way into a creek or bayou and ultimately into a reservoir or the ocean.

- Rain that falls on land will either evaporate, soak into vegetation, infiltrate into soil, or run off.
- Rain that lands on impervious surfaces, such as pavement, will drain off of those surfaces at a faster rate. Roofs and large areas of pavement often have drains that connect directly to ditches or storm sewers.
- In developed areas, water flowing across the ground will soon reach a man-made drainage system. Some areas have open ditches along roadways that collect water. Others have underground storm sewers that collect water from inlets and drains. Both ditches and storm sewers are built to slope towards a larger waterway.
- In major rain events, storm sewers and roadside ditches overflow. In the City of Houston, storm sewers are designed to handle a storm that has a 50% chance of happening in any given year, which is about half as much rain as the 1% "100-year" event. Streets are designed to fill with water and act as drainage channels to drain water from the 1% event. If the streets cannot handle the rainfall, water starts running overland. This is called "sheet flow", and it may flood houses. The ditches and storm sewers convey water to primary waterways (larger streams, creeks, and bayous).
- Small channels or tributaries often combine together to become a larger common body of water. As the larger waterways fill with water, the tributaries fill up as well, backing water up to the surrounding areas.
- In order to reduce the amount of water flowing into a large channel, or bayou, sometimes detention ponds will be used to temporarily store water.

KEY POLICY QUESTIONS

How do we ensure our natural and man-made drainage systems keep up with development?

How do we ensure that drainage is maintained and operating as it is intended to?

How do we secure funding for drainage infrastructure upgrades?

Figure 1 Brays Bayou Watershed Draining to Galveston Bay Through the Ship Channel

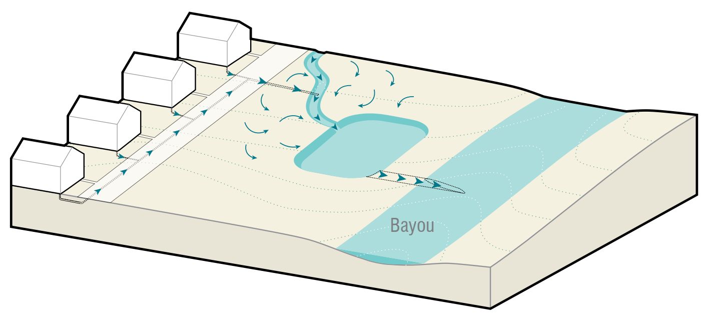

Figure 2 Path of Water in a Development

KEY TERMS

Watershed
Is a geographical area of land that drains to a larger body of water.

Bayou
Is a channel of water in a relatively shallow region. In Houston, most streams (which might be called rivers or creeks elsewhere) are called bayous. All bayous in the Houston region carry water downstream to Galveston Bay.

Stormwater
Is water resulting from rainfall on land.

Storm Sewer Pipes
Located under city streets and carry stormwater to bayous. They are different from sanitary sewer pipes, which carry sewage from kitchens and bathrooms.

Harris County Flood Control District (HCFCD)
Is a distinct governmental entity with the Commissioners Court acting as its board of directors.

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Responsibility & Maintenance of Facilities

As rainwater travels from a site to a storm drain system or channel and ultimately to a larger body of water, different organizations are responsible for the infrastructure and conveyance of the water. Responsibility and maintenance of facilities are discussed below.

Cities have jurisdiction over local stormwater infrastructure within their city limits. These systems include:

- Storm sewers
- Roadside ditches and culverts
- Small local channels
- Local storm drains

In unincorporated areas, jurisdiction falls to the county. Most stormwater infrastructure is owned and maintained by governmental entities, such as cities, counties, or municipal utility districts. These governmental entities fund infrastructure and maintenance through taxes and sometimes stormwater fees. Developers might initially construct the infrastructure, but then usually turn them over to these governmental entities to maintain.

Harris County Flood Control District (HCFCD) maintains and has jurisdiction over:

- Bayous
- Tributaries
- Creeks
- Some enclosed channels
- Regional detention ponds

They use a combination of local, state, and federal money to fund drainage projects, using property taxes, bond proceeds and/or grants. Large rivers and bayous are also maintained by the HCFCD and can receive funding from the United States Army Corps of Engineers (USACE) for large flood control projects.

USACE is responsible for maintaining federal projects, such as, large levees and dams, regional reservoirs, and navigable channels. These projects are federally funded through general funds and specific appropriation by the US Congress.

Aging Infrastructure

Stormwater Infrastructure is intended to convey stormwater runoff to our streams and creeks. **Sanitary Sewer Infrastructure** is intended to carry sewage from homes and businesses to treatment plants before being discharged into our streams and creeks. These systems should be completely separate from each other. However, many sanitary sewer systems are aging, leaky, and do not have proper connections. Thus during flooding events water meant to be conveyed in stormwater systems ends up filling the sanitary sewer systems and these systems become overwhelmed, causing them to overflow without being treated. This is a public health concern. Sanitary sewer overflows release possible disease-causing pathogens into the floodwaters.

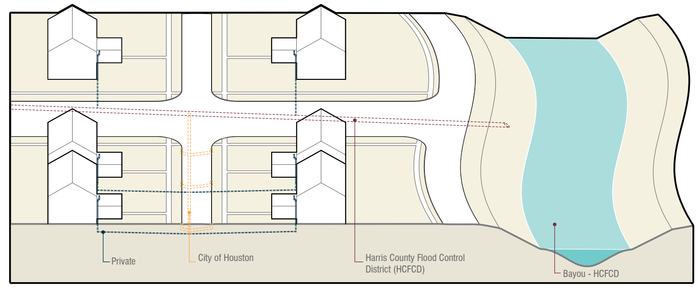
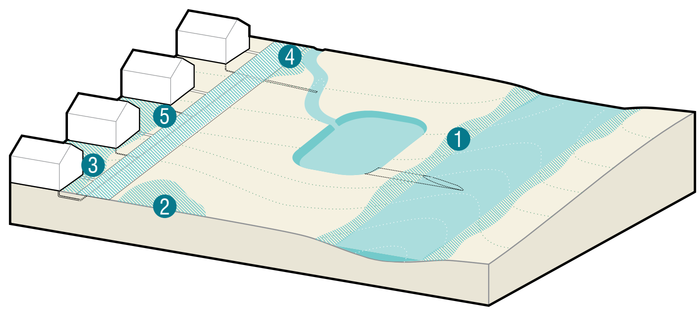


Figure 3 Water Drainage Facilities



Types of Flooding

1. Channel overflowing its banks and inundating adjacent areas.
2. Unintentional ponding of water in low-lying areas that are not directly connected to a channel.
3. Overland runoff flowing across property.
4. Streets flooding when the capacity of infrastructure is exceeded.
5. Flooding due to storm sewers and ditches backing up as major drainage channels fill.

For More Information Visit

HCFCD on Watersheds
hcfcd.org/drainage-network

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

6 Fact Sheet
WHAT IS STORM SURGE?

What Is a Storm Surge?

Storm surge is the rise of seawater level pushed towards land by the high winds of a storm. Storm surge typically accounts for the deadliest and most destructive outcomes of a hurricane, tropical storm, or depression. The highest death tolls in the largest hurricanes are caused by surge. Due to the shapes of our coastline and Galveston Bay, the Houston area's storm surge risk is quite high.

In the open ocean, counter-clockwise winds push water ahead of the storm, causing vertical circulation within the ocean as if the winds were rolling water forward. As the storm moves towards the coast, where the water is shallow, the vertical circulation of the ocean continues its momentum and raises the level of the water. Figure 1 illustrates the basic dynamics of storm surge. In addition, compound flooding may occur when storm surge or high tides prevent rainwater from draining and exiting a waterway, causing waterways to overflow and flood adjacent areas.

Key Differences Between Surge & Pluvial Flooding

Storm surge and rainfall can both cause flooding, but there are key differences. **Storm Surge** can begin to rise a day or so before the storm hits (see Figure 3), which can flood low-lying highways and cut off escape routes. When storm surge hits land, water can rise several feet within minutes, and pound buildings with a force powerful enough to destroy them entirely. **Rainfall Flooding** is caused by extreme amounts of rainfall that cause waterways or areas meant for water retention, such as reservoirs, to pool and overflow. Rainfall flooding can be large-scale or localized, depending on the storm event. Sometimes storm surge and heavy rainfall occur at the same time; this is referred to as a **Compound Flood**. In a compound flood, high water levels from the surge can block floodwaters from draining into the ocean, causing more flooding inland, or extreme rainfall can amplify an existing flood from storm surge.

What Affects Storm Surge?

Storm surge is dependent on several storm characteristics and geographical features, including:

Storm Size - Larger wind fields increase surges.

Storm Intensity - High wind speeds increase surges.

Forward Speed - Slow storms increase surge in inland bays and estuaries. Fast storms increase surge along coasts.

Central Pressure - Low pressures increase surges.

Approach - Perpendicular approach to the coast increases surge.

Astronomical Tide - High tide increases surge height.

Local Features - Complex coastal and inland features (e.g. bays, estuaries) affect surge behavior.

Ocean Bottom - Wide shelves and gentle slopes increase total surge height, but produce smaller waves. Narrow shelves and steep slope decrease surge height but produce larger waves.

Slight alterations in storm path coupled with any of these factors make storm surge height difficult to predict. The right amalgamation of these factors could cause the "perfect storm" or worst-case scenario.

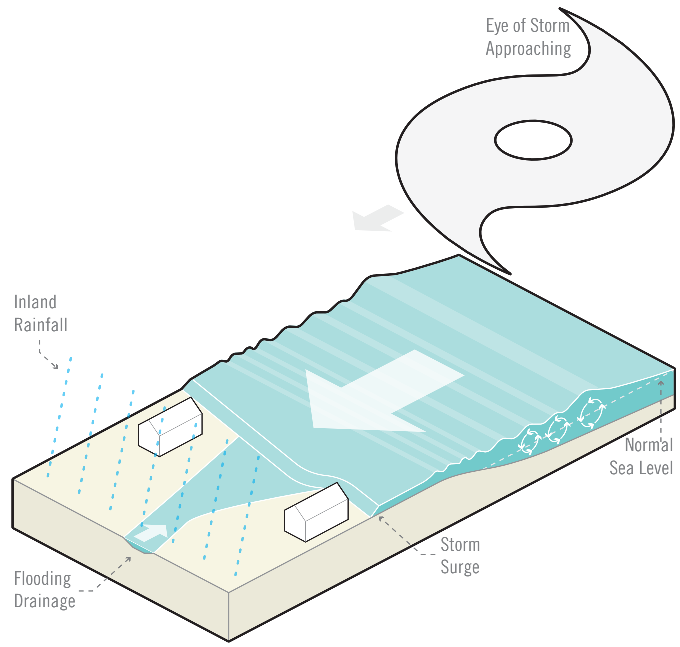


Figure 1 Storm Surge Basics

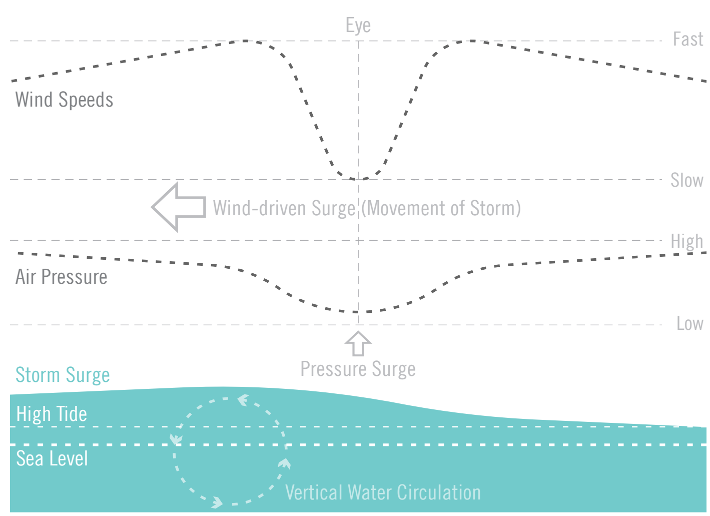


Figure 2 Section of a Storm Surge in Open Ocean

"Adding to the destructive power of surge, battering waves may increase damage to buildings directly along the coast. Water weighs approximately 1,700 pounds per cubic yard; extended pounding by frequent waves can demolish any structure not specifically designed to withstand such forces. The two elements work together to increase the impact on land because the surge makes it possible for waves to extend inland."

National Hurricane Center (NHC).

The category of a hurricane is not a good predictor of the intensity of the surge. For example, Hurricane Katrina was a category 3 storm with surges up to 28 feet tall, while Hurricane Charley was a category 4 storm but had surges up to only 8 feet. The National Weather Service has now begun to predict surge separately from the category of the storm which is based only on wind speed.

What Effects Do Storm Surges Have?

According to the National Hurricane Center (NHC), storm surges flooding accounts for nearly half of all deaths during a hurricane, tropical storm, or depression in the US since 1963.

Before a storm makes landfall, water levels along the coast increase. Figure 3 shows water levels at three feet above average as early as 24 hours before the landfall. These levels can potentially flood evacuation routes and strand people from reaching essential supplies, family members, or safety on higher grounds. In addition, the water rises in waves increasing the risk of damage. Six inches of rushing flood water can trip a person and two feet of rushing water can move a car according to the National Weather Service (NWS).

Storms surge may also increase inland flooding due to elevated levels in bays and estuaries, impeding natural drainage for rainfall. This causes flooding in areas otherwise thought to be high enough in elevation to avoid water intrusion. On the Gulf Coast, if the eye of the storm comes ashore south of the pass between Galveston Island and the Bolivar Peninsula (Bolivar Roads), the highest winds and surge will enter Galveston Bay and the coastal surge elevation within the bay will be further increased by the shape of the bay.

In Houston, Harvey's storm surge only reached around 3 to 6 feet high in Galveston Bay. However, at its highest, Hurricane Harvey produced a storm surge level of more than 12 feet, near Aransas Wildlife Refuge. Port Lavaca experienced over 10 feet of storm surge, and Port Aransas at least 6 feet. While the Houston area has seen multiple extreme rainfall flooding events in recent years, the heart of Houston has not had a bad storm surge event in decades. Hurricane Ike in 2008 produced a 20 foot storm surge and caused catastrophic damage in the Galveston area, particularly around Bolivar Peninsula (see Figure 4), and this was still not the worst possible scenario.

How to Find Storm Surge Information?

In anticipation of a storm event, the National Weather Service (NWS) releases warnings and statements about storm surge. This information is relayed by news outlets via internet, television and radio. The NWS has two designations for a surge warning:

Storm Surge Watch which is the possibility of life-threatening surges in specified areas, generally within 48 hours.

Storm Surge Warning which is the danger of life-threatening surges in specified areas, generally within 36 hours.

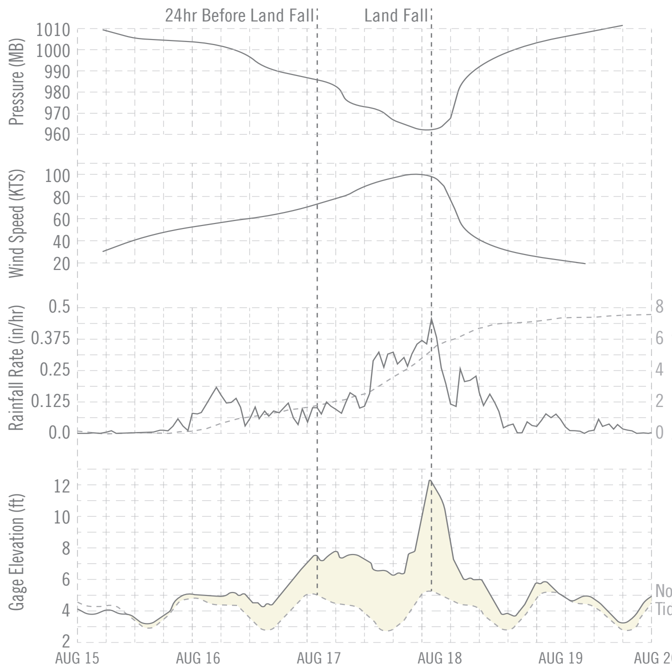


Figure 3 Sample Graphs of Pressure, Rainfall & Surge Data

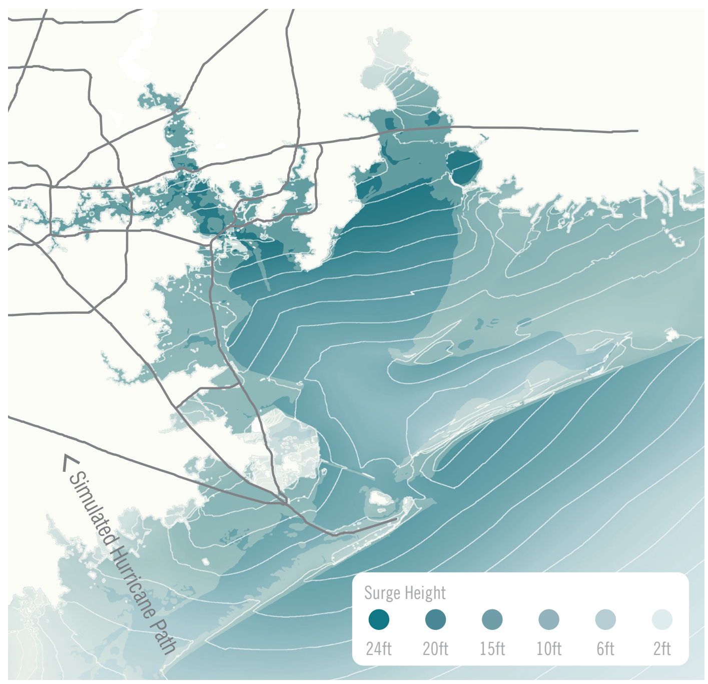


Figure 4 Category 3 Simulated Storm Surge by SSPEED Center

For More Information Visit

National Weather Service
Weather.gov

NOAA National Hurricane Center Info
NHC.NOAA.gov/Surge

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

KEY POLICY QUESTIONS

How much should be invested in major infrastructure to resist surge?

To what extent should new development in surge prone areas be limited?

How can critical infrastructure located in surge areas be protected?

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

7 Fact Sheet WHAT IS RESILIENCE?

Resilience is minimizing human and economic impact from disasters and recovering quickly, recognizing that disruption, displacement, and damages cannot be completely eliminated. Resilience is not preventing damages, but it is the ability of our economic, social and ecological systems to withstand and quickly recover from disaster, and the ability of these systems to anticipate and plan for future disruptions. Resilient communities manage their natural habitats in a manner that enables ecosystems to better tolerate disturbances and allows people, businesses, and neighborhoods to maintain essential functions and rebound quickly. Identifying and investing in ways for communities to enhance the resilience of their ecosystems will provide for swifter recovery and adaptation after severe weather events.

Resilience & the Houston-Galveston Region

The Houston-Galveston metropolitan region has the fifth largest population in the U.S., and is a significant economic contributor to the global economy. The region, located on the Upper Texas Gulf Coast, has suffered from a number of severe weather events in the last twenty years. Recurring cycles of disaster, disruption, and recovery, culminating most recently with Hurricane Harvey in August 2017, result in detrimental economic and environmental impacts on community, economic, and ecosystem well-being.

Resilience Planning

Planning for the uncertainties of future events is vital for promoting sustainable and livable Gulf Coast communities. Communities face growing challenges as aging infrastructure is under pressure from growing population, increasing development, increasing water prices, and extreme weather events. Communities need to contend with these increasing pressures and address risk in a manner that protects public health and the environment, enhances community vitality for current and future generations, and grows the economy. Communities must understand their assets and vulnerabilities and use risk-informed decision-making in order to create a resilient community.

Regional resilience collaboration allows community leaders, scientific and policy experts, and citizens to come together to talk through the tradeoffs associated with policies that may support a host of large and small adaptation strategies. This enables the formulation of practical solutions to overcome financial and institutional barriers to implementing local adaptation strategies.

Extreme weather, such as hurricanes or droughts, and man-made events, such as oil spills, have exposed vulnerabilities of energy and water infrastructure and subsequently the fragility of Gulf Coast communities. The vulnerability comes from the lack of effective tools to help coastal communities plan for both slow-burn (i.e., longer lasting or persistent) disasters, such as drought, heat waves, and extended wildfire seasons, or more rapidly occurring events such as hurricanes or flash floods. Water quantity and quality along with energy resources could be significantly impacted by climate variability and hazards. Reducing vulnerability in energy and water infrastructure is essential to support growing coastal communities and the development of industries that are vital to our nation's economy. The more resilient a community is, the better the community is positioned to support future economic development in ways that grow the economy, protect the environment and public health, and enhance community vitality to meet the needs of current and future generations.

"Hurricanes Harvey, Irma and Maria combined with devastating Western wildfires and other natural catastrophes to make 2017 the most expensive year on record for disasters, the National Oceanic and Atmospheric Administration reported Monday. The disasters caused $306 billion in total damage in 2017, with 16 separate events that caused more than $1 billion in damage each."

Washington Post, Chris Mooney

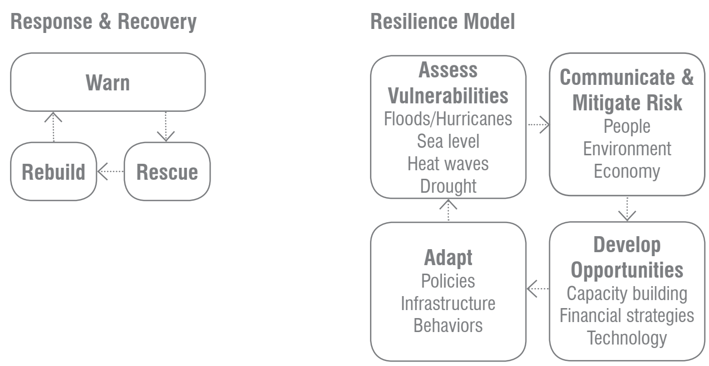


Figure 1 Traditional Disaster & Recovery Cycle & Proposed Resiliency Model (HARC).

KEY POLICY QUESTIONS

How can we implement resilience planning in our region?

What criteria should we use to determine and assess regional resilience?

How can we achieve resilience equitably across the region?

What funding strategies exist to support the development of community resilience across the Greater Houston Region?

For More Information Visit

Houston Advanced Research Center (HARC)
harcresearch.org/focus/resilience

Gulf Coast Resilient Communities
iscvt.org/program/gulf-coast-resilient-communities/

Coastal Resilience
coastalresilience.tamu.edu/

Gulf of Mexico Coastal Resilience
gulfofmexicoalliance.org

U.S. Climate Resilience Toolkit
toolkit.climate.gov/

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

8 Fact Sheet
HOW ARE BUYOUT PROGRAMS USED?

Introduction

This fact sheet is a summary of a report written by Kinder Institute for Urban Research. Refer to *Case Studies in Floodplain Buyouts* for the full report.

Buyouts are a non-structural flood mitigation strategy that involves buying properties that are deep within floodplains and where the cost of acquisition and demolition is less than the cost of repeatedly repairing and rebuilding in areas that are flood prone. Other non-structural mitigation strategies include floodproofing buildings and land use planning, while structural strategies include channel widening or building new detention basins and dams.

Cities depend on federal grant programs from the Federal Emergency Management Agency (FEMA) and from the Department of Housing and Urban Development (HUD) to finance flood mitigation efforts. As disasters increase in frequency, home buyout programs are growing in popularity as a mitigation investment because they can be a cost-effective alternative to larger flood control infrastructure and can help reduce repetitive flood losses.

Advantages of Buyout Programs

Structural flood mitigation strategies alone are sometimes not adequate or most economical in removing people from harm's way and minimizing flood related losses. Where engineering solutions cannot mitigate the risk, buyouts allow families to be permanently removed from harm's way and on to higher ground. This eliminates the possibility of future flood related damages and costs to owners and to insurance.

Additionally, once the property is acquired, the structures can be demolished and the land must be used as open space detention or other flood mitigation projects in perpetuity. HCFCD enforces this through deed restrictions, and various mechanisms, depending on local regulation. This can amplify future savings by protecting even more properties around the bought out land. The creation of open space can also improve quality of life around it by offering more outdoor recreational space.

Challenges with Buyout Programs

While buyout programs continue to gain popularity among some circles, this mechanism still faces perception and buy-in issues in many communities. Incentivizing homeowners can be particularly challenging, partly because the process takes a long time. The amount of time it takes to get funding approved is reliant on the Federal Government, and the time frame can vary widely. Jurisdictions typically start the process (which can take over two years) of applying for and implementing those funds after they know the funding will be there. Indeed, the vast majority of buyouts cannot receive funding until after the president declares a major disaster, according to current policy.

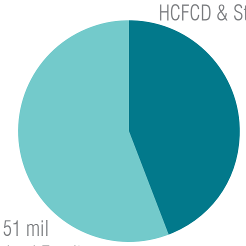
In other situations, residents may not want to volunteer for buyouts because of the economic cost of relocation and the social costs of breaking up a community or uprooting a family from a long-time owned home.

Compounding these challenges, many officials still prefer engineered solutions. This, along with other factors in county / state politics, could explain why between 1989 and 2016, only 41% of post-disaster mitigation funds were spent on buyouts by Harris County. Meanwhile, the Houston's Flood Czar, Stephen Costello, intends to use federal buyout funds to rebuild and elevate homes in the floodplain. This would require major deviations from the current policy, which intends to permanently remove homeowners from harm's way.

Case Study Quick Facts

Harris County Since 1985

(total $341 million)



2,075 structures purchased with FEMA grants

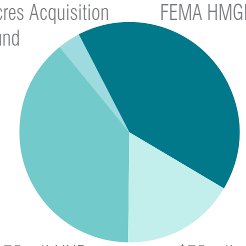
960 properties purchased with HCFCD funds

30 structures purchased with Corp of Engineers funds

Total 1,060 acres restored to floodplain

New Jersey Blue Acres Since 2013

(total $585 million)



Offers made to 900 homes

678 families accepted offer

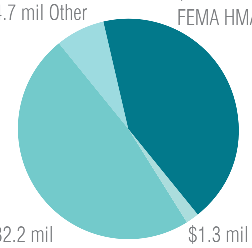
Recently completed 600th Blue Acres Closing

460 homes have been demolished so far

Completion of short sales or lender payoff approvals for 64 properties of owners underwater - total $4.5 million debt forgiveness

Charlotte-Mecklenburg Since 1999

(total $67 million)



400 properties acquired

185 acres restored to floodplain

Estimated $25 million in flood losses and $300 million in future losses avoided

Key Policy Questions

How can we support families in need during buyout and relocation?

How can we minimize social and emotional impact on families?

How can we reduce the length of time the buyout process takes?

How can we approach buyouts strategically to acquire contiguous land and provide the optimum use for future flood mitigation?

How can we raise more funds locally to respond more quickly with buyouts following floods?

How can we improve consolidation of county and city buyout efforts?

Hazard Mitigation Assistance Program (HMA)

FEMA administers five subprograms through the HMA that help fund eligible mitigation projects. States are generally the eligible applicants. They solicit subapplications and provide subgrants to lower jurisdictions such as cities, counties, or metropolitan planning organizations. While the local jurisdictions ultimately manage the subgrants, states ensure accountability, administer subgrants, maintain program compliance and oversee financial and project management. The five subprograms include:

- **Hazard Mitigation Grant Program (HMGP)** is the largest and longest running program. It is applied for by States to distribute to local jurisdictions.
- **Pre-Disaster Mitigation (PDM)** is intended for use prior to a disaster. It is funded by annual Congressional appropriations.
- **Flood Mitigation Assistance (FMA)** is the most competitive program, aimed at reducing National Flood Insurance Program (NFIP) claims. It is funded by NFIP proceeds.
- **Repetitive Flood Claims (RPC)** is offered to NFIP participants whose property has flooded 2 or more times with a cost of more than $1,000 each time in a rolling period of 10 years. A key difference with this program is it can fund 100% (rather than 75% in other programs) of buyouts for jurisdictions which cannot provide the 25% contribution
- **Severe Repetitive Loss (SRL)** is offered to NFIP participants whose property has flooded 4 or more times with damages worth more than $5,000, or 2 or more times with damages worth more than the post-disaster property value.

Funds from all of these programs may be used for the costs associated with acquisition and demolition of properties in the floodplains. HUD also offers funds through the Community Development Block Grant - Disaster Recovery (CDBG-DR) program to support similar flood mitigation projects.

Communities across the US generally prioritize spending funds on non-buyout projects over buyout projects.

Requirements for HMGP Eligibility

FEMA requirements for property buyout eligibility are as follows:

- Property must be in an NFIP participating community with a FEMA-approved Hazard Mitigation Action Plan.
- Buyout program must undergo a benefit-cost analysis showing the estimated future cost of flood damage surpasses the cost of purchasing and demolishing the properties' improvements.
- Properties must have current flood insurance policies.

HMGP funds can pay for up to 75% (except for RFL, which can fund up to 100%) of hazard mitigation projects, including costs associated with the value of the improvements on the property, land, relocation assistance, demolition, and other costs associated with the project. The other 25% of funding must come from non-federal sources, including philanthropic or non-profit investment. In 2013, the benefits analysis was changed to include *ecosystem-based management,* meaning the program would integrate not just the economic benefit in flood hazard areas, but also ecological and environmental benefits.

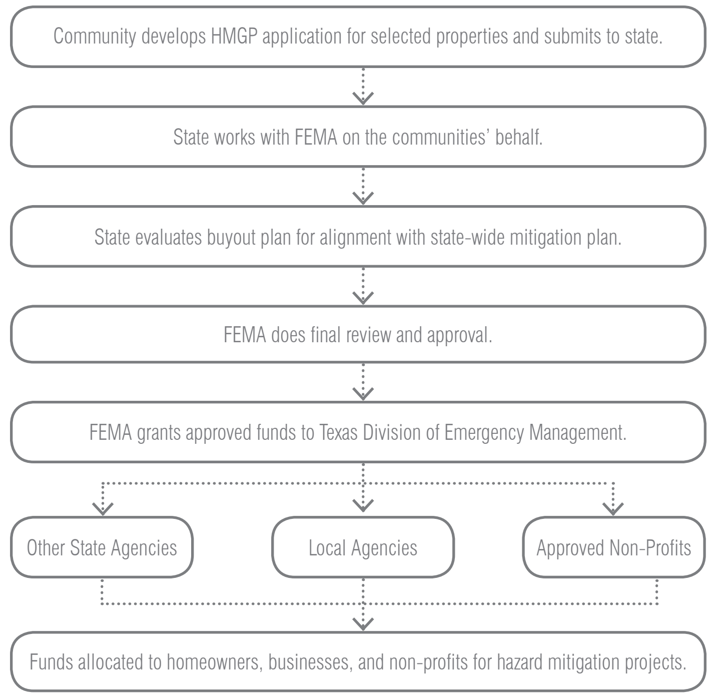


Figure 1 Basic Outline for Communities to Secure HMGP Funds

	Non-Buyout		Buyout	
	Median FEMA Contribution	Total FEMA Contribution	Median FEMA Contribution	Total FEMA Contribution
Harris County	N/A	N/A N/A	$6,679,388	$149,575,348 100%
New Jersey	$2,747,200	$57,879,305 29%	$9,157,506	$143,683,764 71%
Charlotte-Mecklenburg	$140,076	$391,568 2%	$1,668,728	$22,105,061 98%
US Totals	$545,970	$1,376,394,390 51%	$1,516,038	$1,302,666,099 49%

Table 1 FEMA Buyout Funds from PDM, FMA, RFC, SRL

For More Information Visit

Kinder Institute for Urban Research
Kinder.Rice.edu

HCFCD Home Buyout Program
hcfcd.org/homebuyout

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

9 Fact Sheet
HOW DO FLOODS IMPACT ENVIRONMENT?

Flooding leads to devastation at personal and regional scales. Immediate impacts can include loss of life and damage to property and infrastructure. Damage to infrastructure causes disruptions to supplies of clean water, wastewater treatment, electricity, transport, education, and health care. Flooding also brings many long term challenges including environmental impacts, deterioration of human health in affected areas, and economic hardship. Water quality, air quality, and energy supply are three areas significantly impacted by Hurricane Harvey.

Water Quality

Flood waters carry enormous amounts of debris, sediments, and hazardous pollutants. Toxins and pathogens such as viruses and bacteria are transported along with contaminated sediments and floating debris. During Hurricane Harvey, tons of sediment were carried and deposited downstream in water bodies such as Spring Creek, Buffalo Bayou, the Houston Ship Channel, and Galveston Bay. Sediment accumulations in some portions of the Houston Ship Channel reduced water depths by three feet. Sediments were deposited on city streets and in residential neighborhoods and parks, causing potential health concerns related to lead, arsenic, and other pollutants stored in the sediments.

Flooding can also cause hazardous spills and toxic releases. Water from flooded refineries and superfund sites, commercial and industrial facilities, storage tanks, grounded vessels, and common household chemicals from under the kitchen sink are swept up and spread with the flood waters. Superfund sites are legacy hazardous waste sites identified by the federal government as requiring cleanup and remediation. The EPA identified 13 out of the 34 Superfund sites in the path of Hurricane Harvey as being impacted by flood waters.

Flooding can often cause sewage treatment systems to fail. Millions of gallons of untreated sewage overflows occurred throughout the region as a result of Hurricane Harvey. Intestinal bacteria such as E. coli, Salmonella, Shigella; Hepatitis A Virus; and agents of typhoid, paratyphoid and tetanus are often found in floodwaters. People exposed to these infectious agents can develop intestinal distress and debilitating disease symptoms. Other floodwater-borne pathogens such as Vibrio vulnificus (also known as flesh-eating bacteria) can cause severe forms of illness, such as necrotizing fasciitis and sepsis.

Floodwaters can also have large impacts on ecosystems. Harvey resulted in vast amounts of freshwater inflows to Galveston Bay, decreasing salinity levels to near zero (the salinity of freshwater) near Bolivar Roads, the major inlet connecting Galveston Bay to the Gulf of Mexico. While freshwater inflows are an important component of the bay system, such long-term decreases in salinity for weeks on end can kill oysters. The Texas Parks and Wildlife Department estimates that it could take more than two years for oysters to repopulate areas of Galveston Bay. A massive flood also results in changes to and loss of nesting and feeding habitat for bird, reptile and mammal species. Scientists are awaiting data that inform us about the long term impacts of Hurricane Harvey on regional fish and wildlife populations.

Air Quality

Hurricanes and related flooding also impact air quality. To limit damage to refineries and petrochemical facilities, plants are typically shut down in preparation for the storm. However, depending on the intensity of the storm, spills may still occur resulting in increased site emissions. Further, after the storm has passed, the startup and malfunctions that may happen during startup can result in the release of large amounts of pollutants. During and after Harvey, the Houston region

CDC GUIDELINES FOR CLEANING AFTER FLOODING

- Wash hands thoroughly with soap and water after contact with floodwaters.
- Don't allow children or pets in or near floodwaters.
- Don't bathe in water that may be contaminated by sewage or toxic chemicals.
- Avoid exposure to floodwaters if you have an open wound.
- Clean open wounds and cover them with waterproof bandage to reduce chances of infection.
- If a wound develops any redness, swelling, or oozing, seek immediate medical attention.
- Wear protective equipment including rubber boots, gloves and goggles during cleanup. Respirator for cleaning mold.
- To help speed up the drying process, use fans, air conditioning, and dehumidifiers after the cleanup.

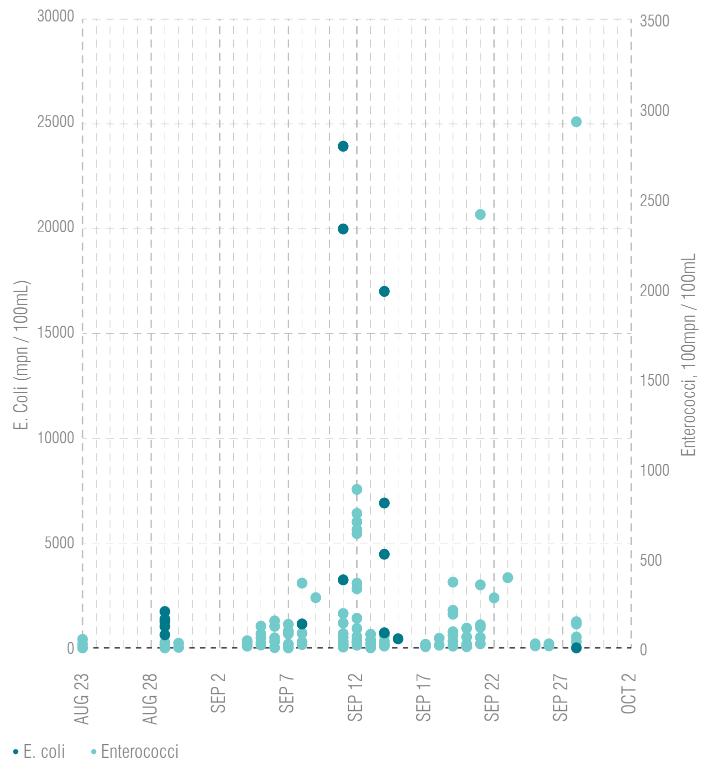


Figure 1 Modified Graph of Bacteria Sampling Results Before & After Harvey.(HARC)

KEY POLICY QUESTIONS

What regional strategies should be employed to reduce environmental impacts of flooding?

How can monitoring entities better coordinate to gather environmental data during & after future floods? What resources are required?

How can information on storm-related environmental impacts & risks to health be more quickly & transparently relayed to impacted communities?

experienced many storm-related releases and spills of air pollutants including volatile organic compounds (VOCs) and sulfur dioxide.

Two air pollutants were significantly elevated after Harvey, ozone and BTEX. Ozone is a respiratory irritant that can lead to coughing, breathing difficulty and shortness of breath, asthma attacks, throat irritation, and lung infections. The Houston region experienced four consecutive ozone action days after the storm (August 30 – September 2).

BTEX is an air pollutant whose primary sources are refineries, petrochemical plants, vehicle emissions, and evaporative losses from fuel storage tanks. Exposure can lead to headaches, eye and nose irritation, and nervous system, liver, and kidney damage. Benzene, a component of BTEX, is a known carcinogen (cancer causing). Elevated levels of these hazardous air pollutants were seen after Hurricane Harvey, and are likely due to storm-related spills and releases at industrial facilities, shutdowns and startups at refineries and petrochemical facilities, as well as increased numbers of small, gasoline-powered engines in portable generators, chainsaws, and leaf blowers operating in the region after the hurricane.

Electricity& Energy

Power outages are common during hurricanes and large flooding events. Due to wind and flooding, a hurricane is capable of damaging multiple components of the electric power system, from power generation to the distribution system. Hurricane Harvey cut the power to over 2 million customers across the Gulf Coast. Upon landfall much of the power outages were from wind damage to transmission and distribution lines. In utility territories that had implemented smart grid technologies, power was quickly restored. As Harvey moved up the Gulf Coast, power outages were due more to flooding of substations and transformers and less from wind. Because of the long duration of Harvey, it took several weeks to gain access to and repair damaged equipment. Fortunately, lessons learned from Tropical Storm Allison resulted in flood resilient infrastructure in parts of the region. The Grant Substation that feeds a portion of the Texas Medical Center was elevated after Allison and was not affected by Harvey.

Large central power stations were also impacted by Harvey. Heavy rains saturated the coal piles at the W.A. Parish Power Plant, one of the largest power plants in the region, forcing it to curtail operations and switch to natural gas. To improve resilience of our power generation system, the deployment of distributed generation systems, particularly combined heat and power (CHP), has increased across the region. At UTMB-Galveston during Harvey, two electrical feeders that provide power to the campus went down. However, the CHP system that was implemented after Ike maintained power, as well as continued to provide cooling for the hospital campus during and after the storm.

Planning & Monitoring

The environmental impacts of flooding can be wide-ranging. The Greater Houston region has a large transportation infrastructure and a long history of industrial activity that sits alongside ecologically diverse landscapes and coastal ecosystems. Many of these ecosystems are the subject of regular monitoring programs by federal, state and local agencies that provide information regarding their health and function. However, information gaps exist, especially relating to pollutants released into air and water. Storm events such as Harvey exacerbate existing environmental issues and call attention to the need for additional monitoring resources. Coordination of storm-related monitoring and data acquisition efforts should be a topic of regional planners in preparation for the next storm event.

Flood mitigation planning should also incorporate activities to avoid impacts to the greatest extent possible. For instance, the removal of fuel tanks and attention to hazardous wastes prior to landfall would eliminate some of the contaminated pollutant problems. Development of outreach material on the hazards of wading, playing or swimming in floodwaters would reduce direct contact.

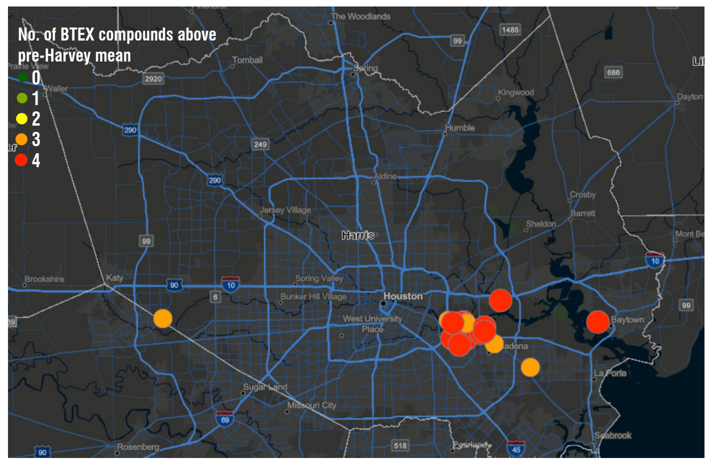


Figure 2 BTEX levels in Harris County on September 5, 2017. (HARC)

Figure 3 Hurricane Ike at UTMB-Galveston. Image from Affiliated Engineers presentation.

For More Information Visit

HARC Summarizing Hurricane Harvey's Environmental Impact
harveyimpacts.harcresearch.org

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

10 Fact Sheet
WHAT ARE INNOVATIVE FUNDING SOURCES?

Innovative Funding for Flood Mitigation Infrastructure

The availability of federal recovery funds necessary to rebuild infrastructure and communities in the wake of Hurricane Harvey is limited due to the active hurricane and western fire season in 2017. Strategies to increase regional resilience differ from recovery needs; and the development and implementation of resilience policies and programs will require additional financial resources. Traditional federal funds have strict limitations as to what they may be used for and therefore are not always adequate for the needs of a community. To overcome this lack of funding from traditional federal, state, and local sources, communities should begin to look toward newer, more innovative approaches to funding. Three funding approaches that are receiving greater attention by communities around the United States include green bonds, environmental impact bonds, and resilience bonds.

State and local governments issue bonds as a way to borrow money to pay for large infrastructure and long-term capital projects such as roads, schools, and water treatment facilities. Investors buy bonds or sell them on secondary financial markets as a means to earn tax-exempt income. Future users of the infrastructure project typically service the government debt through taxes or tolls.

Green Bonds

Green bonds are similar to other infrastructure-related bonds with one difference—they must demonstrate some type of environmental benefit, i.e. a qualified green investment as defined by the Climate Bonds Standard Board. The structure, risk, and return associated with green bonds are identical to those of traditional bonds.

Proceeds can be used for climate adaptation activity, which includes information support systems and early-warning systems; watershed conservation projects; and flood mitigation such as sustainable urban drainage systems. To date, most of these bonds have been focused on renewable energy, low-carbon buildings and transportation. However, the Climate Bonds Standard Board has approved certification criteria for water infrastructure projects. Certification criteria are under review for a variety of green infrastructure projects, such as coastal conservation infrastructure. A relevant example for regional post-Harvey efforts is the green water bond issued by the San Francisco Public Utility Commission to develop storm water management infrastructure.

Environmental Impact Bonds

An Environmental Impact Bond (EIB) is another option for green infrastructure, storm water management and other forms of resilient infrastructure. An EIB is a tax-exempt municipal bond that utilizes a pay-for-success approach to financing infrastructure. The bond provides upfront capital for innovative resilience projects and shifts downside risk from government agencies to private sector investors. The public sector repays investors based on whether the agreed-upon environmental outcomes are achieved, as evaluated by a third party. If the agreed upon performance is not achieved, the investor covers the loss. However, if the project performs better than anticipated, returns for investors are higher.

The first EIB was closed in September 2016 with the DC Water and Sewer Authority. This is a 30-year, $25 million bond with a mandatory tender after five years. In Louisiana, a state with a $50-billion need for implementation of its Coastal Master Plan, the Environmental Defense Fund is working with the Louisiana Coastal Protection and Restoration Authority and other partners to design the first ever EIB for wetland restoration.

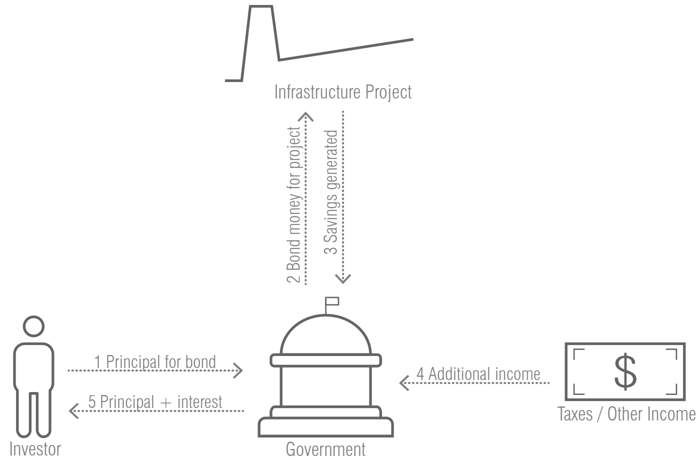


Figure 1 Bonds are a loan, paid back with tax-exempt interest at a predetermined date

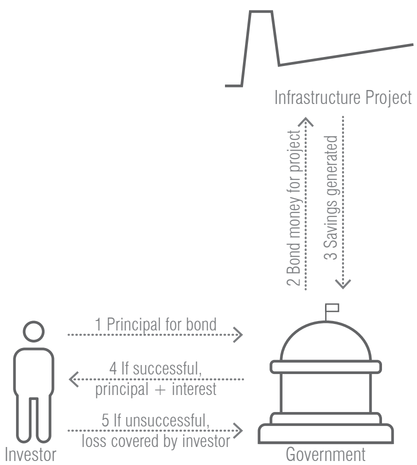


Figure 2 EIBs are paid back proportionately to the success of the project

KEY TERMS

Bond

A loan from the investor (eg. individual) to the issuer (eg. government or company) to be paid back with interest over a pre-determined time period.

Principal

Initial amount of loan given by an investor to an issuer. Used to purchase a bond that will be paid back with interest.

Interest

A percentage of a borrowed amount charged by a lender as a fee.

Maturity

The final date of payment on a loan.

Resilience Bonds

The modern finance industry has invented complex systems to transfer risk and give investors a chance to make higher than average returns. These methods can be used to reduce risk for public agencies and to help finance flood mitigation projects. Resilience bonds are bonds that fund infrastructure that will reduce the likelihood of losses during a natural disaster. These bonds can be used for coastal protection such as sea walls and stormwater-mitigating green infrastructure. Refer to Figures 3 and 4.

Resilience bonds build on catastrophe bonds, known as cat bonds. Cat bonds pair an investor with an insurance policy holder. Investors pay the issuer (eg. banks) a principal for a bond and earn interest on this bond until it reaches maturity (usually 3 to 5 years). However, in the event of a catastrophe during this time period, investors may lose some or all of their principal. The money that would have paid back the investor is used to pay the sponsor instead. Due to the higher risk of cat bonds compared to conventional bonds, investors earn higher than average interest rates. The sponsor (eg. a public agency or government) is the party that pays a premium to the issuer, similar to paying a premium for a car insurance policy. If no catastrophe occurs, the sponsor continues to pay this premium and the money is used to pay back cat bond investors. However, if a natural disaster does occur, similar to a car accident, the issuer will pay the sponsor to cover recovery costs using the principal and interest they do not pay the investors. Effectively, the investor in this equation buys a higher risk bond for a higher interest rate (paid for by the sponsor's premium payments), and the sponsor pays a premium to add to their insurance portfolio (paid for by the savings on the investor's principal in the event of a natural disaster).

A resilience bond issuer utilizes a catastrophe model to determine baseline risk, or cost, of natural disasters. This modeling establishes the size of the catastrophe bond issued for the project. The issuer then calculates how the implementation of a project that increases resilience to natural disasters would reduce future loss in comparison to the baseline. A resilience rebate is set based on the value of the anticipated loss reduction. The reduced risk of principal to the investor and the reduced premium expense to the sponsor is captured and provided to the sponsor as a rebate. This rebate can be used for financing resilient infrastructure or risk reduction investment.

The insurance linked securities (ILS) sector, which is primarily made up of catastrophe bonds, is a $25.5 billion market. To date, no resilience bonds have been issued but there is increasing interest and effort to better quantify risk and uncertainty with regards to resilient projects that might be backed by these types of bonds.

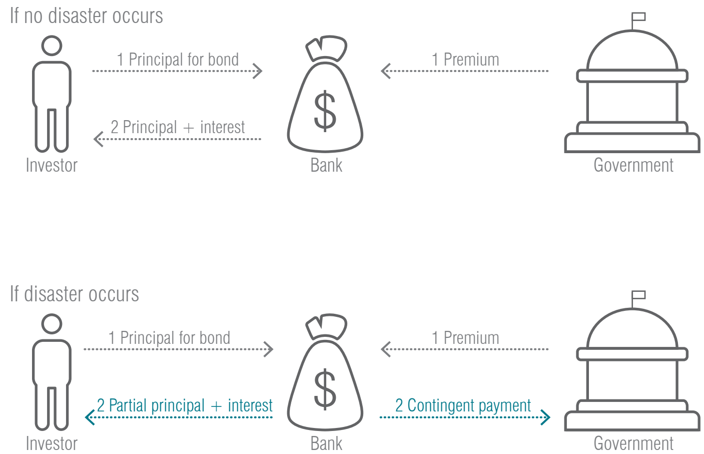


Figure 3 Catastrophe Bond

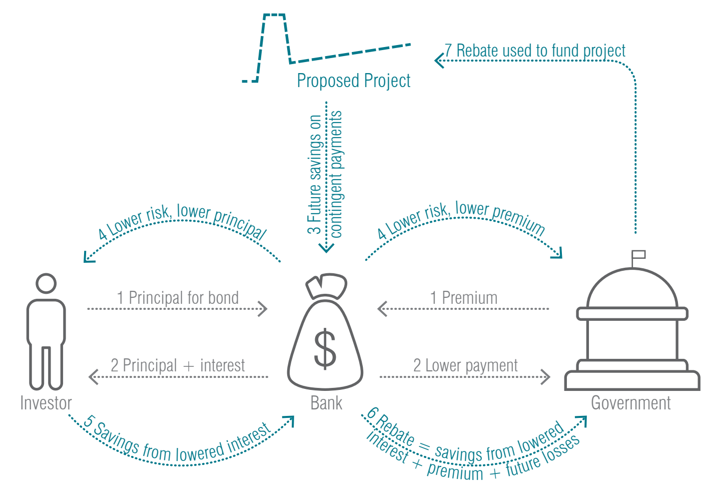


Figure 4 Resilience Bond

KEY POLICY QUESTIONS

What regulatory and policy changes must be made to facilitate the introduction of innovative funding mechanisms to invest in resilient infrastructure for our region?

How do we utilize innovative funding mechanisms, such as environmental impact bonds, to leverage federal and state recovery dollars?

For More Information Visit

Climate Bonds
climatebonds.net/standards

Environmental Impact Bonds
eesi.org/articles/view/environmental-impact-bonds-could-they-help-save-americas-aging-infrastructure

Green Bonds
icmagroup.org/assets/documents/Regulatory/Green-Bonds/

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

1 Briefing Document
FLOOD WARNING SYSTEMS

Definitions

A Flood Warning System (FWS) provides accurate information to allow individuals and decision-makers to make informed decisions about whether to take emergency action (e.g., evacuation) during a flood event. Some flood warning systems simply provide real-time data on flood conditions, but others use real-time data to predict future flood conditions several hours in advance.

A Flood Alert System (FAS) notifies individuals and decision-makers when predefined actions need to be taken. These alerts are targeted to specific locations, and are pushed out, rather than requiring someone to monitor a website. A flood alert system driven by a predictive flood warning system can give individuals notice of future flooding in their specific neighborhood with enough time to evacuate or move possessions outs of harm's way.

National Weather Service (NWS) provides flash flood and other warnings via text message and local media. However, these warnings are typically for broad, city-wide or regional, weather patterns or large river systems.

Advanced Hydrologic Prediction Service (AHPS) is used by the NWS to predict water levels and provide flood and other hydrologic warnings every 6 hours at locations where USGS river gages are available (14 in all of Harris County, neighboring counties have 0-6 per county). This information is provided in the form of hydrographs making it difficult for the general public to understand, and the system lacks the spatial and temporal resolution needed to provide detailed information about water levels in all 22 watersheds in Harris County.

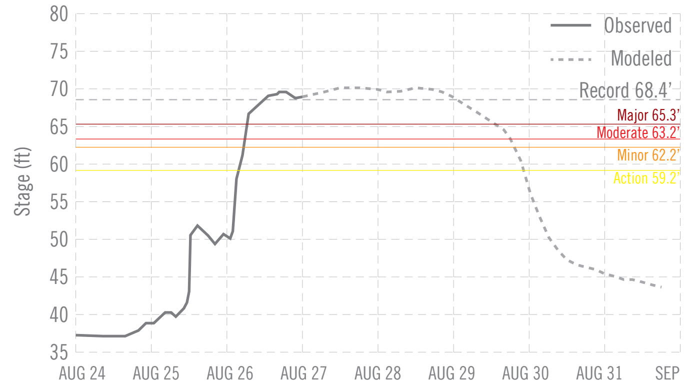


Figure 1 Example of the AHPS Prediction During Harvey

Current Harris County Flood Warning System

Harris County Flood Control District (HCFCD) has strategically placed 133 gages to monitor rainfall and water levels in the bayous and their tributaries. This real-time information is available to the public online and is updated every 15 minutes. However, the system does not predict future water levels in the bayous; it tells the public what is flooded right now, rather than what will flood.

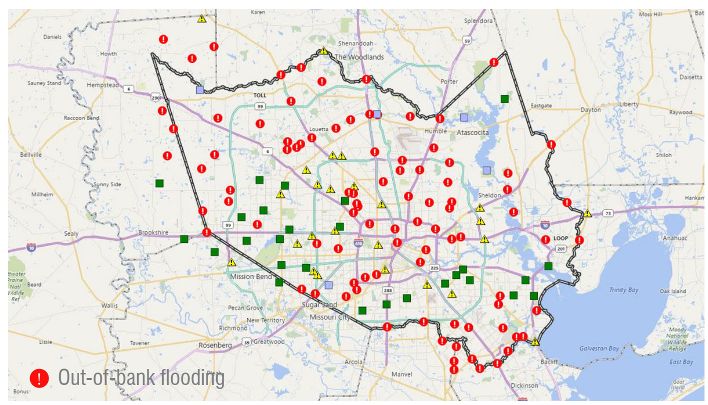


Figure 2 Stream Gage Map on HCFCD Website on 08/28/17

Advanced SSPEED Flood Alert Systems

The Severe Storm Prediction, Education, and Evacuation from Disasters (SSPEED) Center at Rice University has built localized Flood Alert Systems for the Texas Medical Center (TMC FAS4), Sugar Land, and the Texas Department of Transportation (TxDOT). These systems use real-time radar rainfall data to predict flood levels at critical locations. For example, the TMC uses FAS4 to determine when to implement emergency protocols regarding the placement and/or closing of gates and doors that prevent damages to the TMC from flooding. These systems are designed for use by specific end-users, but the real-time predictions and flood warnings are also available to the public online.

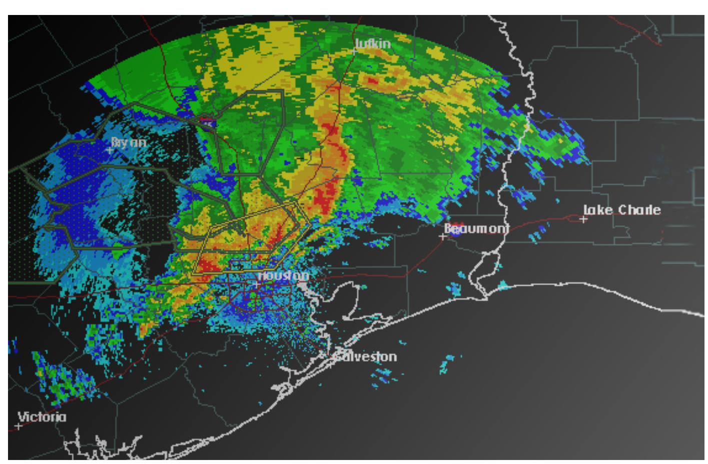


Figure 3 SSPEED Center

Success & Limitations of FAS4

The system provides real-time predictions of water levels in the Texas Medical Center, supporting mitigative action ahead of imminent flooding. The FAS system has been validated for accuracy over dozens of events dating back to 1997. Annual training of TMC personnel on how to utilize the system has helped reduce vulnerabilities at the TMC during the event, and increased performance in real-time. However, it is important to note that all flood alert systems are non-structural and must be implemented in combination with other measures to prevent structural or property damage.

What Is Needed to Implement a FAS in Harris County?

In Harris County, gages and NEXRAD rainfall are already in place from HCFCD and the NWS. However, funding is needed to update and build real-time models for all 22 watersheds and to maintain servers which can run the models every 15 minutes. The physical elements for the system are in place, however the model development and additional computing capability is required to implement a FAS4 or similar system in Harris County.

How Does the FAS4 Work?

Data - Collected on live rainfall information using Radar rainfall (NEXRAD), flow and stage gage data, and water levels via cams.

Modeling - Used to predict flood extents, these data are overlaid with models and maps, such as, Hydrologic Engineering Center's HEC-HMS, HEC-RAS, and floodplain mapping.

Prediction - Together, these produce, real-time rainfall, flow hydrographs, and floodplain map library (FPML).

Communication - With established warning thresholds, warnings are sent out via, text, email, FAS website, digital roadside warnings, news, and radio.

Case Studies

City of Austin Flood Early Warning System (ATXfloods)

ATXfloods has existed since 1985 and is maintained by the City of Austin Flood Early Warning System (FEWS) team. It was built in large part to monitor flooded roadways in Austin's surrounding 8-county area. The system uses 130 gages and cameras to monitor water levels in the creeks and at low-water crossings. Individuals can sign-up online to receive flood alerts via email, text message, and/or phone call. In addition, Austin has placed flashing lights and automated barricades at fifteen low water crossings to prevent motorists from driving into high water.

Lower Colorado River Authority Flood Operations Notification Service (LCRA FONS)

Because releases from flood control dams on Highland Lakes or Bastrop Dam in Central Texas can cause flash flooding, the Lower Colorado River Authority (LCRA) operates a flood alert system to warn residents living below Lake Austin when flood releases are occurring. Individuals can sign-up online to receive flood alerts via email, text message, and/or phone call when flood operations begin. LCRA FONS is intended to supplement NWS warnings and prompts individuals and businesses to take mitigative action in advance of flooding (e.g., evacuation).

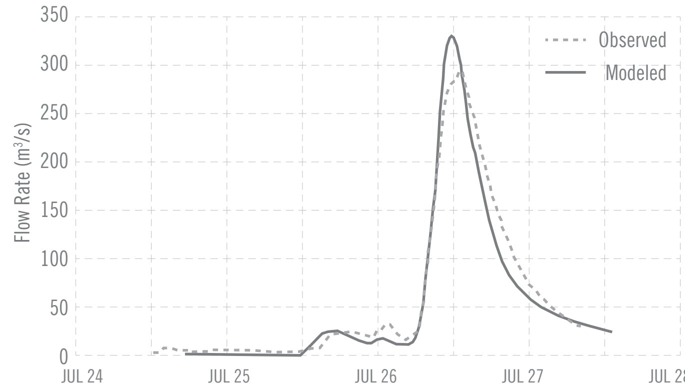


Figure 4 FAS2 HEC-1 Modeled Hydrograph vs USGS Observed at Main St. (July 2006)

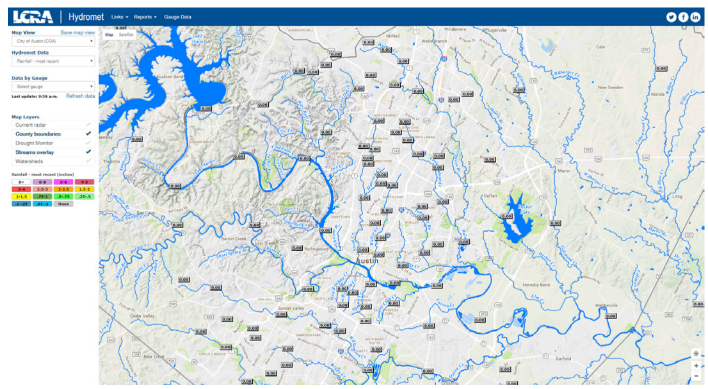


Figure 5 Rainfall gage map in Austin, TX

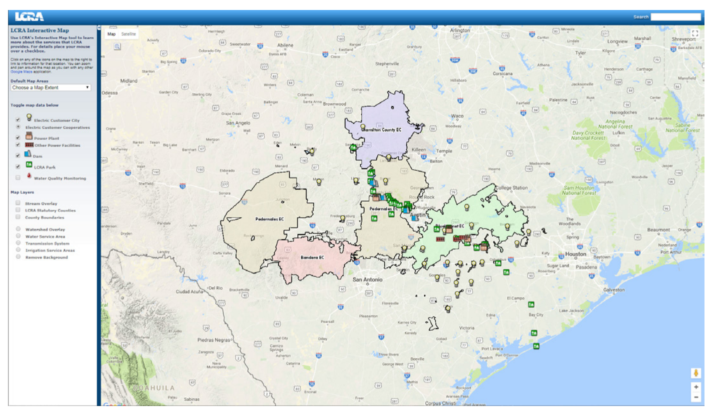


Figure 6 Real-time road closure information

For More Information Visit

SSPEED
sspeed.rice.edu

HCFCD Real-Time Gages
HarrisCountyFWS.org

Austin Real-Time Information
ATXFloods.com

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

KEY POLICY QUESTIONS

Could localized flood mitigation strategies be developed behind accurate flood warning systems to prevent flood damages?

Could a regional flood alert system be used to quickly allocate emergency services and personnel during a storm?

2 Briefing Document
ADDICKS & BARKER RESERVOIRS

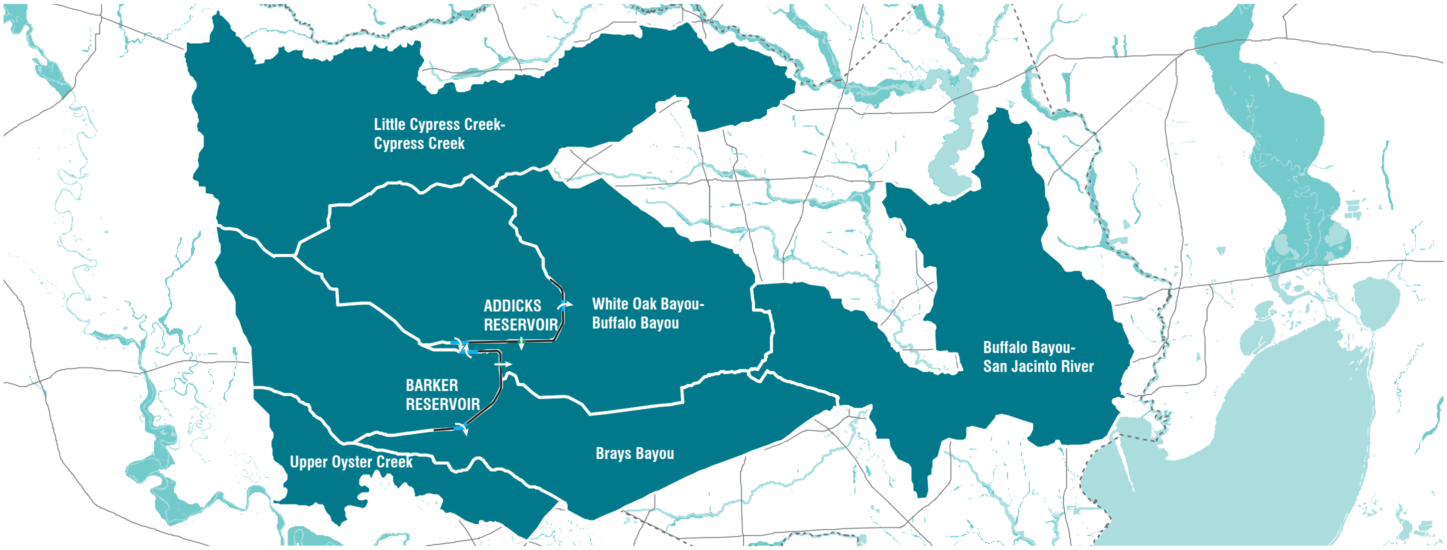


Figure 1 Watersheds impacting or impacted by Addicks and Barker

History of Addicks & Barker

Addicks Dam/Reservoir and Barker Dam/Reservoir are two federal flood control projects located in western Harris County that are designed to store water during large rainfalls to reduce downstream flooding along Buffalo Bayou within the City of Houston.

Addicks and Barker Dams were constructed between 1942 and 1948 as part of a larger U.S. Army Corps of Engineers 1940 flood protection plan for the City of Houston. At the time, around $4 million were spent on construction of these two dams, including land acquisition for the dams and for some of the land area behind the dams within the design flood pool of the reservoirs. The reservoirs were intended as part of a larger system that was never implemented:

1. A levee to prevent flood water from Cypress Creek watershed from overflowing into the Addicks Reservoir.
2. A reservoir on upper White Oak Bayou.
3. Bypass channels to direct high volumes of water being released from the dams out of Buffalo Bayou and around Houston.

The two dams were redesigned and reconstructed in the 1980s to meet updated safety criteria for federal dams.

Initially, these two dams and reservoirs were far from developed areas of Houston; however, today, development has occurred in and around both, including thousands of single-family homes built within the reservoirs' design flood pool for each dam, and within the pathway of floodwater releases from these dams along and outside the banks of Buffalo Bayou.

The reservoirs are designed to hold more rainfall than a 1% event, so land upstream of the reservoir is considered "safe" because it is protected from flooding due to rainfall in a 100-year event. Therefore, FEMA does not map these areas within the 1% floodplain, but in an event larger than the 100-year, they will flood. Similarly, during events larger than the 1%, dam releases can occur, flooding areas downstream, along Buffalo Bayou, that are not mapped in the FEMA 100-year floodplain. This scenario occurred during Harvey.

Benefits of Addicks & Barker Reservoirs

Addicks and Barker Reservoirs and Dams hold water during large rainfall events, reducing the flow of water into Buffalo Bayou and mitigating the risk of flooding along the bayou. This protects areas of significant economic impact in Houston, including Downtown, Memorial, River Oaks, Washington Avenue, Montrose, Fourth Ward, and the East End. Without the reservoirs, Harvey would likely have caused significantly more flooding in these areas.

Figure 2 Congress & Milam Intersection During a Flood (1929)

Figure 3 Congress & Milam Intersection During Harvey (2017)

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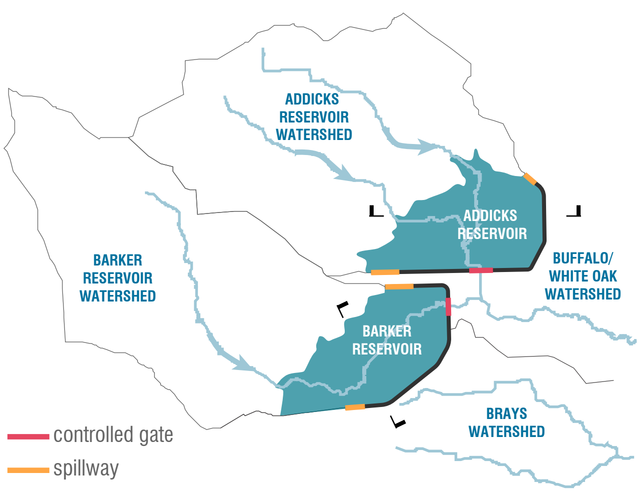
How Do the Dams/Reservoirs Work?

Addicks and Barker capture and store excess rainwater that runs off of the land upstream from the dams, creating a flood control reservoir, or pool, of water for an extended period of time until the stored water can be released through outlet pipes or conduits located at the bottom of each dam. Where Buffalo Bayou starts, both dams have **Controlled Outlet Gates** that allow outflow to be released at a desired rate. The flood control reservoirs hold floodwater and then slowly release through gated outlet pipes. The gates at the ends of the pipes can be incrementally opened to regulate the amount of water released from these dams so as to mitigate flooding downstream. **Emergency Spillways** are located at the far ends of both dams. Emergency spillways are built to allow water to flow out of reservoirs during extreme conditions in order to prevent dam failures, similar to an emergency overflow drain on a bathtub or sink.

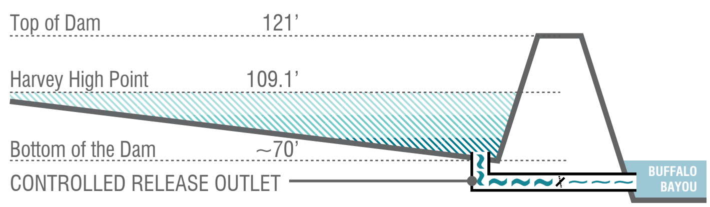
Thus, as the reservoirs start filling up, at a certain level some of the water stored behind the dams can begin to flow over the spillways. The spillways all have neighborhoods and commercial developments downstream of them. The reservoir levels have reached high enough to spill over, and it is not known what flooding might result from an overflow.

At its highest point near the outlet structure, Addicks Dam is 121 feet above mean sea level, while Barker Dam is about 115 feet. The top of the dams slope downward to a ground level approximately 70 feet above mean sea level, making the dams about 45-50 feet tall. For Addicks Dam, the spillways are at elevation 112 feet to 115 feet; for Barker, the spillways are at elevation 106 feet. Large areas behind each of the dams and within the reservoirs' footprints are inundated when the dams are filling up.

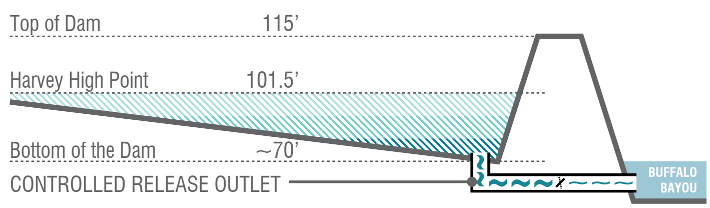
Normal Flow



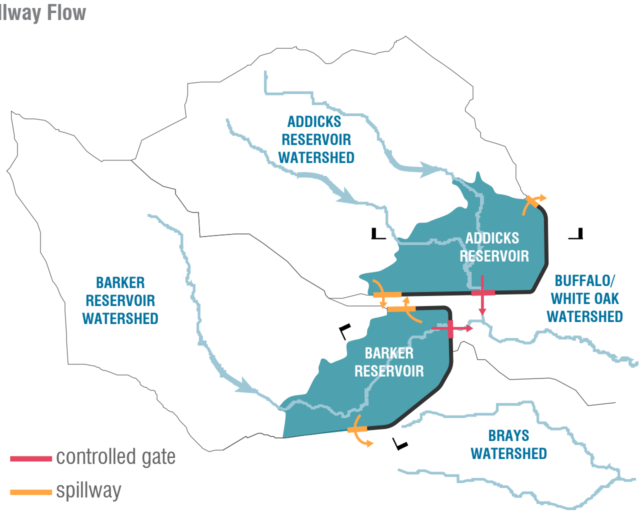
ADDICKS RESERVOIR OUTLET (controlled)



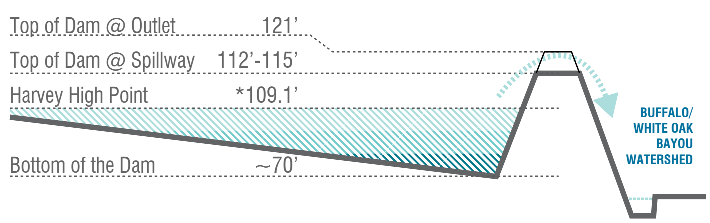
BARKER RESERVOIR OUTLET (controlled)



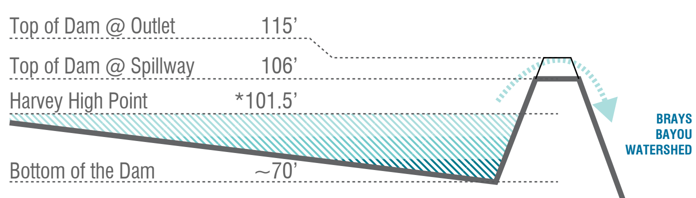
Spillway Flow



ADDICKS RESERVOIR SPILLWAY (uncontrolled)



BARKER RESERVOIR SPILLWAY (uncontrolled)



*Harvey did not exceed emergency spillway levels

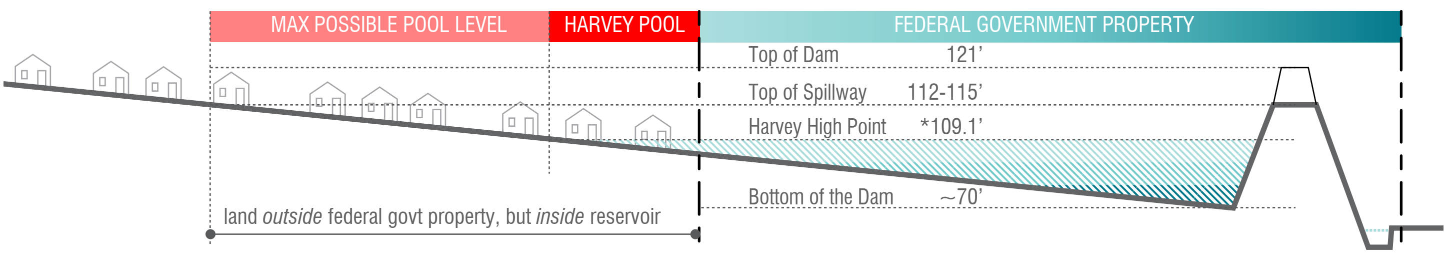
Figure 4 North Addicks Before Harvey

Figure 5 North Addicks After Harvey

Upstream Flooding Within the Reservoir Pool

During Harvey, unprecedented amounts of rainfall caused water levels to reach 109.1 feet above mean sea level inside Addicks Reservoir and 101.5 feet inside Barker Reservoir, both of which were record pool levels. In Addicks, the water level was high enough to flow out of the reservoir, going around the northern spillway that meets up with the natural ground at 108 feet elevation.

More than 10,000 homes located inside of these two reservoirs are estimated to have experienced some level of flooding during Hurricane Harvey. As the water level in these reservoirs began to rise significantly, water was released through the gated flood control structures at the outlets of each dam.



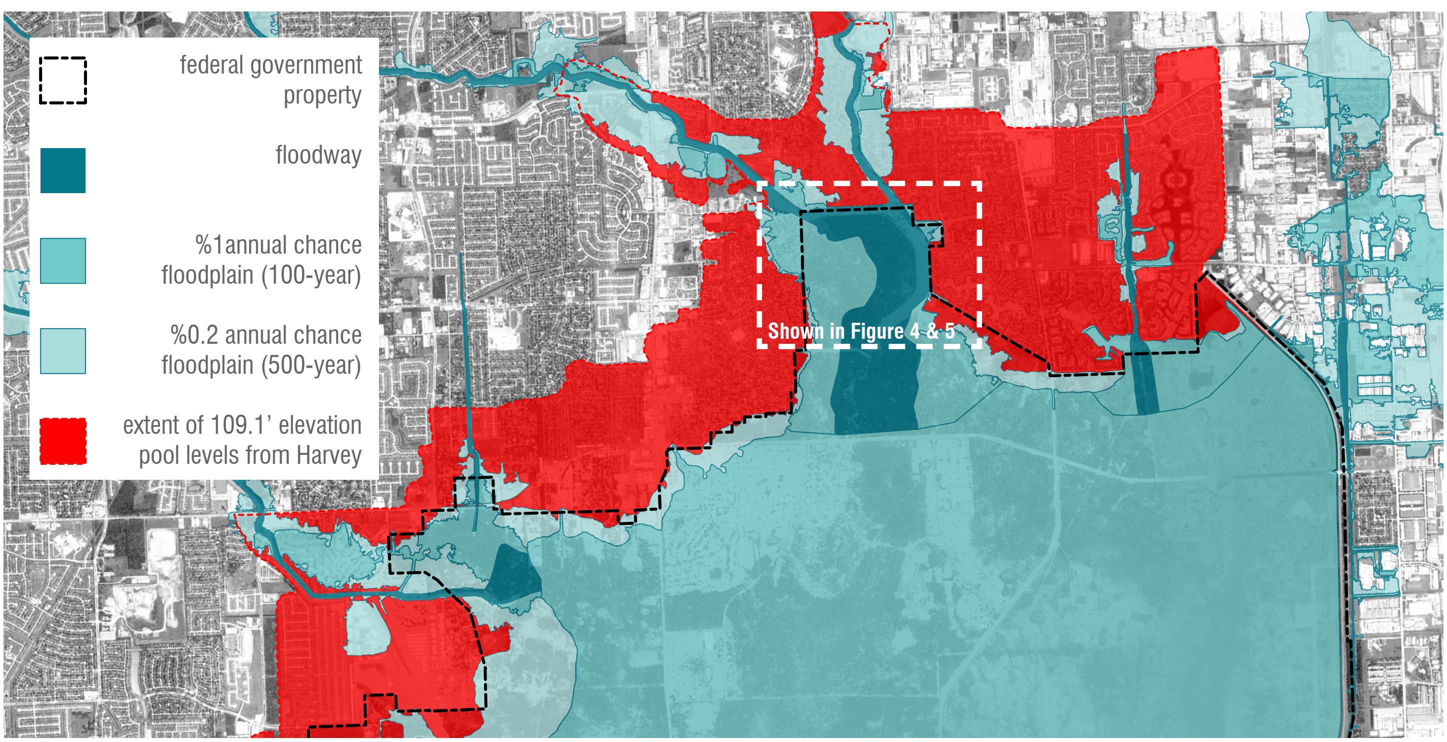


Figure 6 Diagram of Addicks as a Result of Harvey Rainfall

ADDICKS & BARKER DURING HARVEY

Figure 6 South Dairy Ashford Road @ Buffalo Bayou - Before Controlled Release

Figure 7 South Dairy Ashford Road @ Buffalo Bayou - During Controlled Release

Downstream Flooding Due to Dam Releases

In order to minimize upstream flooding, risks of spillway overflows from the reservoirs, and the risk of further rainfall exceeding the reservoir capacity, the Army Corps of Engineers released water at a controlled rate through the outlet gates during and after Harvey. The combined amount of water released through the gates of both dams exceeded 15,000 cubic feet per second (cfs), well above the capacity of Buffalo Bayou, resulting in flooding in neighborhoods downstream of the dams. Such reservoir releases have never happened before. Typically, combined reservoir releases have not exceeded 2,000 cfs. Neighborhoods between State Highway 6 and Beltway 8 were especially affected by the releases and an estimated 4,000 homes were flooded.

What Is the Status of the Reservoir Projects?

New outlet gate structures will replace the existing ones at both Addicks and Barker Dams, expected completion in 2019. Like all dams, Addicks and Barker are at some risk of failing, and failure could be catastrophic. More information about this can be found in later fact sheets.

Risk of Future Dam Releases

Addicks and Barker Dams could again release large amounts of water downstream or flood homes upstream during extreme rain events like Harvey, or as a result of a number of smaller rains occurring over a short period of time.

Some solutions that have been suggested to avoid future releases include excavating and/or clearing vegetation in the reservoirs' storage areas to increase their volumes, expanding Buffalo Bayou to increase its capacity and allow more flow, adding more flood control structures upstream, and additional regulations for upstream development to reduce the amount of water entering these reservoirs.

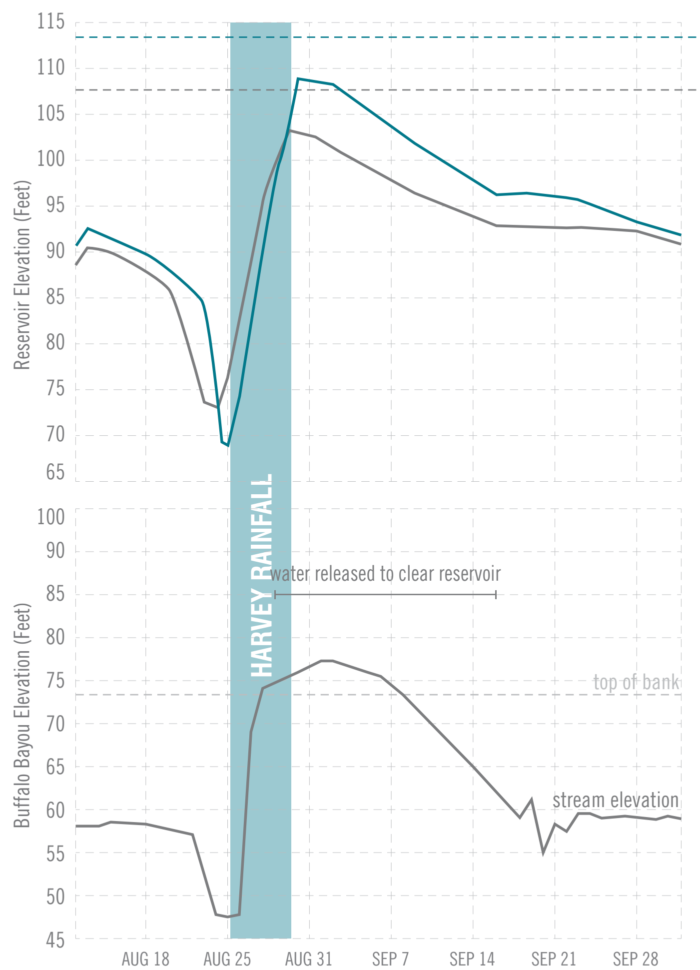


Figure 8 Stream Gages 08/12/17-09/30/17

KEY POLICY QUESTIONS

Could a new regional flood management strategy help use our current structures to their full ability and help target future funds for improvements?

Could regional policy restricting development inside the reservoir pool or overflow path help prevent damages in future events?

Could a policy requiring better water storage for developments lessen the demand for new storage structures in the future, or even prevent flooding in areas not near the reservoirs?

For More Information Visit

HCFCD
hcfcd.org

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

3 Briefing Document
FLOOD REGULATIONS

Regulations in Floodplains

Every community has the authority to enact floodplain regulations to protect the health and safety of its residents under its jurisdiction. In addition, any community that participates in the National Flood Insurance Program (NFIP) has to meet minimum standards set by the NFIP. These minimum standards apply to every new development, substantially improved, or substantially damaged buildings in a community; structures that were built before floodplain regulations were adopted in a community do not need to be retrofitted to meet new NFIP standards.

Flood regulations are enforced by cities, counties, or third party flood control authorities. Different jurisdictions adopt different regulations and sometimes implement stricter standards than the NFIP. Regulations are not only enforced by several different jurisdictional authorities, they are enforced by several different departments within those authorities. The process of complying and acquiring permitting is often difficult to navigate. Refer to the diagram on the right for a general overview of the process in the City of Houston. This process varies by jurisdiction and type or scale of project.

Floodplain regulations set by the NFIP and participating jurisdictions are aimed at protecting the structures and neighboring properties. Jurisdictions will also regulate water drainage and storage at each site.

Mechanics of Development Regulations in Floodplains

There are several layers to flood regulations geared toward three main goals, protecting structures, storing water, and conveying water. Balancing these is tricky because while water must be drained away from structures quickly, it must also be drained slowly enough to keep from overloading drainage channels.

By **Protecting a Structure**, regulations try to ensure habitable spaces within buildings are safe from flooding. This is often achieved by requirements to raise the **Finish Floor** of structure a certain amount above the base flood elevation (BFE), or to floodproof the building below that BFE, designated by FEMA. For more information on how floodplains and BFEs are determined, refer to Fact Sheet 4: *How are floodplains designated?*

By **Storing Water**, regulations try to hold water on site to prevent channels from overflowing due to the impact from development. Channels can overflow if the rate of inflow of water exceeds their capacity to drain into a larger body of water. Loss of vegetation or large amounts of impervious surfaces increases rate of stormwater flow into channels. Using **Detention** ponds to hold water away from the channels helps to maintain the rate of flow to match the capacity of a channel, which can mitigate flooding. Refer to Fact Sheet 3: *What is a Detention Basin?* Additionally, if part of a site is elevated through adding soil, the developer must **Balance Fill** by removing soil from other parts of the site.

By **Conveying Water**, regulations address development of altered drainage paths. A structure in a floodway or floodplain can displace water or block the flow of water in a flood event, increasing flooding elsewhere. To avoid this, **Foundations** and structures below the lowest floor of buildings should be designed to allow water to flow. Additionally, **Site Drainage** should be designed in such a way that new development does not alter the flow of water onto a neighboring property and increase their chance of flooding.

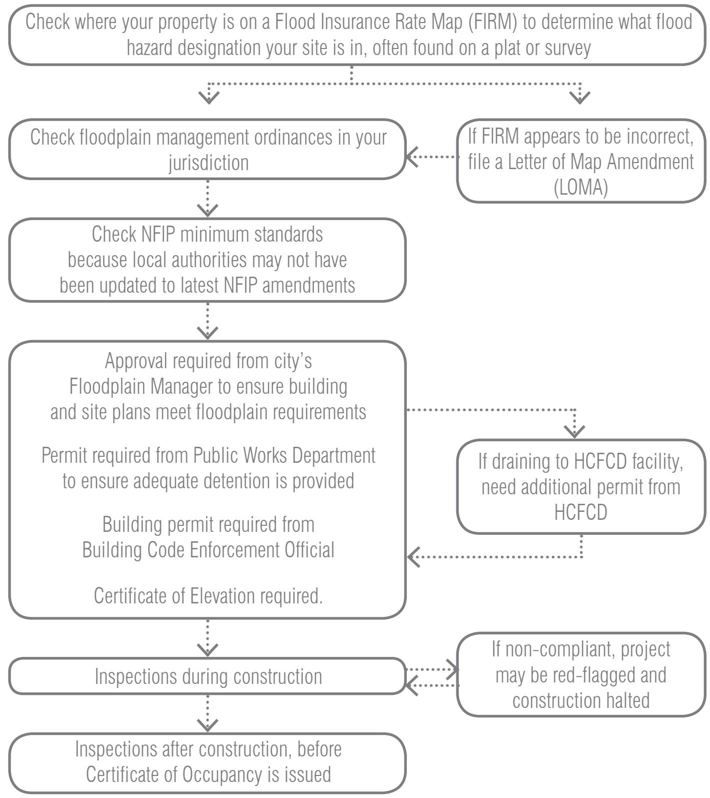


Figure 1 Permitting Process for New Development in Houston

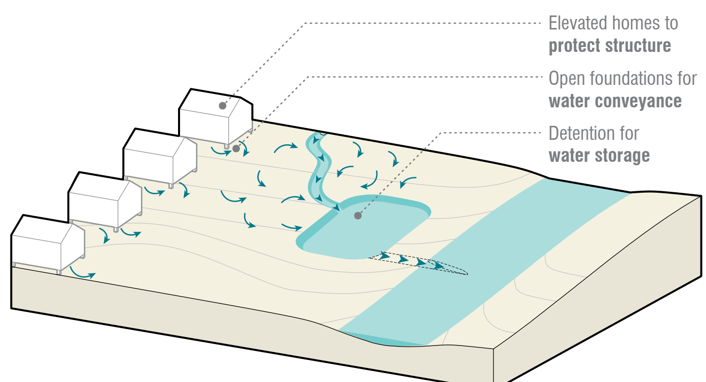


Figure 2 Mechanics of Flood Regulations

Key Terms

Finish Floor
Refers to the height of the top of a floor inside a building.

Detention
Is holding water and releasing it slowly into a channel.

Cut and Fill
Is the process of depressing and elevating the ground on parts of a site.

Foundation
Refers to the structural system beneath a building.

Site Drainage
Refers to the movement of water othrough a site.

ROLE OF FEDERAL EMERGENCY MANAGEMENT AGENCY

Mechanics of Insurance Regulations

The **National Flood Insurance Program (NFIP)** was established by Congress through the National Flood Insurance Act of 1968. If a community, city, or other governing entity chooses to participate in the NFIP, property owners in those communities have the option to purchase flood insurance, administered by the federal government. Participating communities agree to adopt and enforce a floodplain management ordinance that aims to reduce future flood risks in Special Hazard Flood Areas (SHFA).

All mortgages and loans for new construction, substantial improvements to existing buildings, and manufactured homes require flood insurance. The rate of flood insurance is based on where the property is located on a **Flood Insurance Rate Map (FIRM)**. If the property is located in an area of high flood risk, premiums are higher.

When floodplain maps change, the **Grandfathering Rule** allows a lower-cost insurance premium for buildings that already own flood insurance, or buildings that were built in compliance with the FIRM in effect at the time of construction.

If a building has been substantially damaged or improved, it is not eligible to be grandfathered. FEMA's definition of **Substantial Damage or Improvement** is that the cost of repairs or improvement of the structure due to a disaster is 50% or more of the structure's market value before the disaster occurs.

Letters of Map Amendment (LOMAs) and **Letters of Map Revision (LOTRs)** may be used by a property owner to remove their flood insurance requirement. The property owner must show that the property is incorrectly mapped or has been raised by fill out of the SFHA floodplain.

Community Rating System (CRS) is an incentive program to reward and encourage communities who take substantive steps to limit flood risk by providing discounted insurance rates. The CRS program benefits local and state governments as well as homeowners. If measures are implemented in accordance with CRS, floods damage fewer insurable properties, homeowners file fewer claims, and the NFIP pool remains stable. The CRS passes savings on to property owners in the form of lower premiums, all while encouraging more comprehensive approaches to mitigating flood hazard.

FEMA reviews each community against 19 criteria and gives each community a class rating from 1 to 10. Class 1 communities earn a 45% discount on NFIP premiums, while class 7, 8, and 9 earn 15, 10, and 5% discounts, respectively. Harris County, class 7, has earned residents in the SHFA outside cities a 15% discount. Houston, a class 5 community, passes on 25% savings to residents.

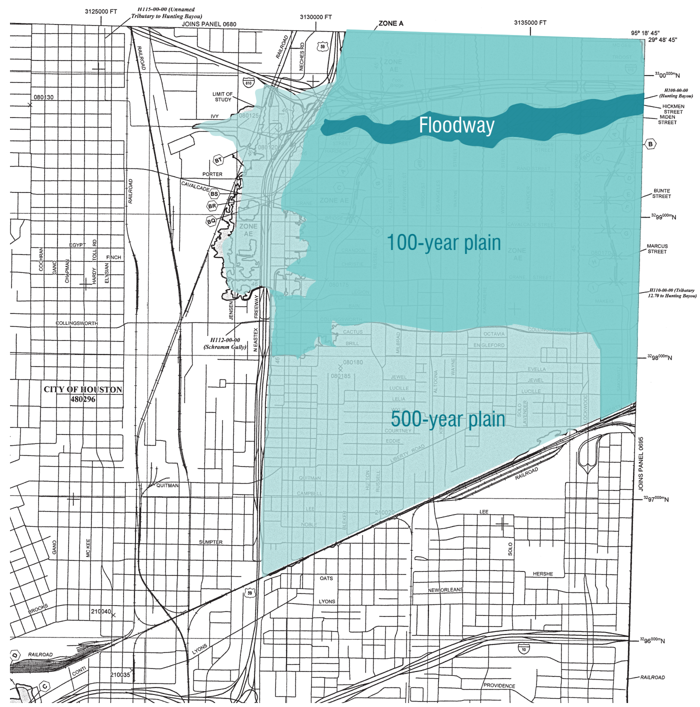


Figure 2 Typical Flood Insurance Rate Map (FIRM) overlaid with floodplain colors

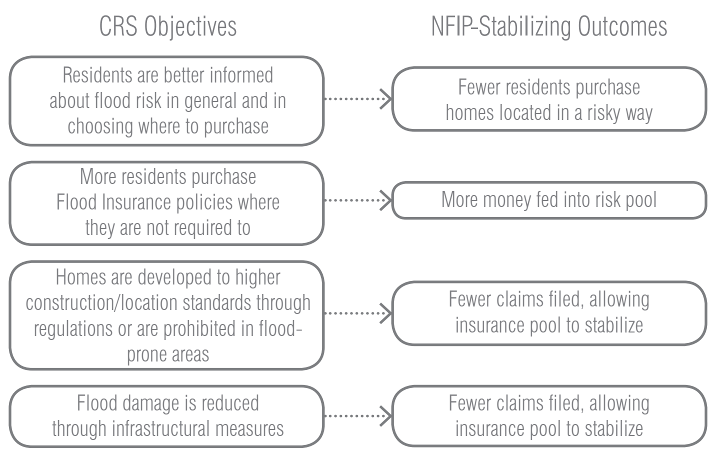


Figure 3 Objectives vs Outcomes

Key Policy Questions

What information should sellers be required to disclose transparently to property buyers?

Are we regulating the correct aspects of development?

Are there ways to retrofit buildings built before current regulations for greater flood mitigation?

Would it be useful to implement regulations across watersheds rather than political jurisdictions?

How can we balance implementing stricter regulations for flood mitigation with economic development and affordability?

For More Information Visit

National Weather Service
Weather.gov

NOAA National Hurricane Center Info
NHC.NOAA.gov/Surge

Greater Houston Flood Mitigation Consortium
HoustonConsortium.com

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

ROLE OF JURISDICTIONAL AUTHORITIES

Which Authorities Do You Need Approvals from at Each Site?

Jurisdictions implement and enforce a variety of different regulations that pertain to flooding. Some of these regulations are enforced by the jurisdiction whose political boundaries the site is located within. This is complicated by the establishment of Zones of Extraterritorial Jurisdiction (ETJs), which give cities some power outside their city limits. Other regulations are not set by political boundaries at all; the governing authority for detention and runoff is determined by the facility into which a development drains. Storm drains under local streets may be owned by the city or county, and those may feed into a drainage pipe owned and maintained by Harris County Flood Control District (HCFCD) or Texas Department of Transportation (TxDOT). The properties that connect directly to the HCFCD or TxDOT drainage facility must comply with their respective regulations.

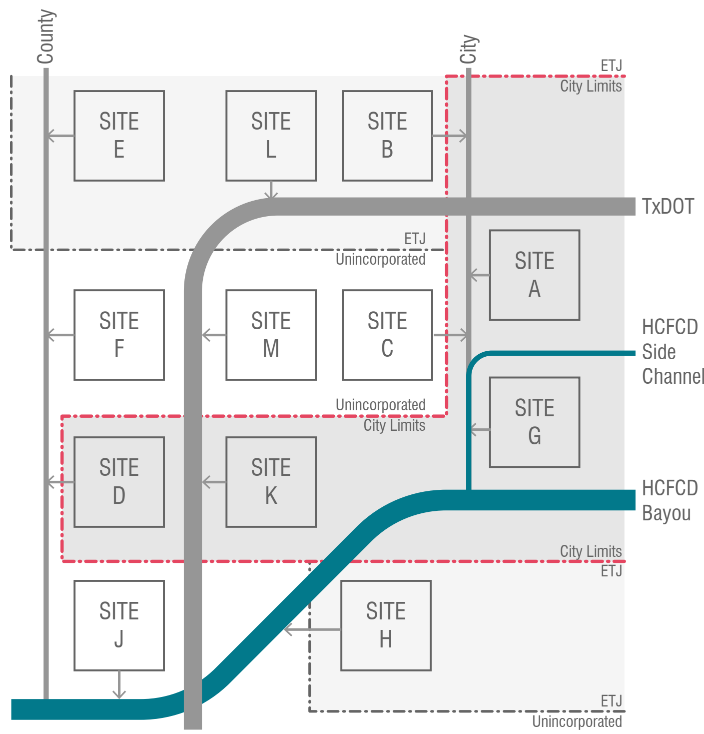


Figure 4 Jurisdiction boundaries and drainage facilities

DRAINS TO FACILITY OPERATED BY	REGULATION TYPE	SITE LOCATED IN: Houston City Limits	Extraterritorial Jurisdiction	Unincorporated Harris County
City of Houston		A	B	C
	Detention & Outflow	City of Houston	Harris County	Harris County
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code & Other Permits	City of Houston	City of Houston	Harris County
Harris County		D	E	F
	Detention & Outflow	Harris County	Harris County	Harris County
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code & Other Permits	City of Houston	City of Houston	Harris County
HCFCD		G	H	J
	Detention & Outflow	HCFCD	HCFCD	HCFCD
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code & Other Permits	City of Houston	City of Houston	Harris County
TxDOT		K	L	M
	Detention & Outflow	TxDOT	TxDOT	TxDOT
	All Other Flood Regulations	City of Houston	Harris County	Harris County
	Platting, Code & Other Permits	City of Houston	City of Houston	Harris County

Table 1 Who enforces various regulations at each site

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

WHAT TOOLS ARE USED FOR FLOODPLAIN REGULATIONS?

Protect Structure

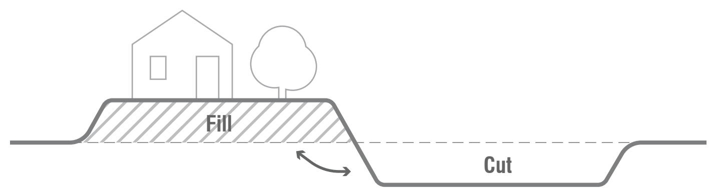
Finish Floor Elevation

The purpose of this is to ensure that habitable spaces in buildings are high enough to not be in danger of flooding. Several regulations require structures and/or utilities to be elevated relative to a Base Flood Elevation (BFE). The BFE is set by Flood Insurance Rate Maps (FIRMs). There are BFEs for both 1% (100-year) and 0.2% (500-year) events; the 0.2% BFE is always higher than the 1%, but the difference between the two can vary from inches to feet. Other regulations affecting the elevation of a structure are based on the closest sanitary sewer manhole and crowns of adjacent roads. Elevating the lowest floor of a structure attempts to mitigate water damage inside enclosed spaces.

Water Storage

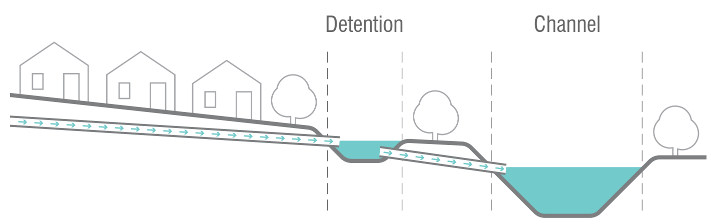
Balancing Fill

The purpose of balancing fill on a site is to ensure that the capacity of drainage systems and bayous are not reduced. While elevating a structure to meet the finish floor elevation requirement, or while grading a site, developers will often "fill" soil to raise part of the property. One flood mitigation strategy is to require developers to balance the "fill" with an equal amount of "cut" so the average elevation within the property remains the same and the developer is not inadvertently flooding neighboring properties. The "cut" creates room for water storage on-site.



Detention

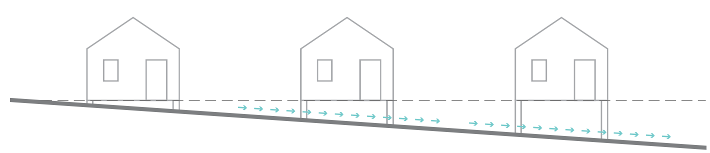
On-site or regional detention may be required to mitigate potential additional runoff from a new development and ensure drainage channels are not overloaded. Detention basins allow a large volume and rate of water to flow in, and a smaller volume and rate to flow out, reducing the chance of the channel overflowing. For more information on detention ponds, refer to *Fact Sheet 3: What is a Detention Basin?*



Water Conveyance

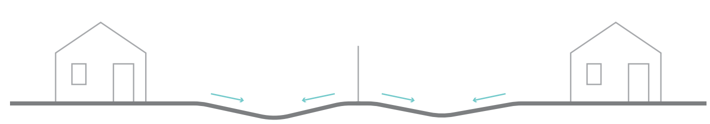
Foundation Types

Enclosures below the lowest floor and foundation types may be specified to ensure the path of water is not impeded. Flood regulations may require a structure to be elevated on a pier and beam foundation system. This lifts the structures off the ground, allowing water to flow beneath them. A pier and beam system is sometimes confused with a structural slab on piles, which does not mitigate flooding. A structural slab sits on-grade; so while the soils do not carry any loads, there is still no room for water to flow. Pier and beam systems ensure the flow of water is not impeded.



Site Drainage

Site drainage requirements are geared toward directing the flow of water within property limits to the proper drainage facility without altering drainage patterns and volumes on neighboring sites. This may require on-site swales or otherwise sloping the ground around a structure.



GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

PROTECT STRUCTURE

Finish Floor Elevation

Minimum finish floor elevations vary significantly by jurisdiction. Everyone requires it to be at least as high as the 1% Base Flood Elevation, but most jurisdictions add to this. Most floodways restrict development in floodways unless they demonstrate that the development will not increase flood levels. In this case, developments in floodways must match those in the SFHA. In the AO/AH zones where the FIRM provides a depth number, finish floors must be at least that high. Where there is no depth number, finish floors must be a specified elevation higher than adjacent grade. The International Building Code (IBC) requires finish floors to be built at 12 inches higher than the closest sanitary sewer or 4 inches higher than the crown of the street, whichever is stricter.

	1% Floodplain (SFHA)				
	Floodway	Zones A1-30, A99	Zones AO / AH (shallow flooding)	0.2% Floodplain	Everywhere
City of Houston	If demonstrated no increase in flood levels, 1% BFE + 1.5 ft	1% BFE + 1 ft	Depth Number + 1 ft Adjacent Grade + 3 ft	Critical Buildings = 0.2% BFE + 12 in	Nearest Sanitary Sewer + 12 in or Crown of Street + 4 in
City of Pasadena	Prohibited	1% BFE + 2 ft No Critical Facilities	Depth Number + 1 ft Adjacent Grade + 2 ft		Nearest Sanitary Sewer + 12 in or Crown of Street + 4 in
City of Baytown	If demonstrated no increase in flood levels, 1% BFE + 2 ft	1% BFE + 2 ft	Depth Number + 1 ft Adjacent Grade + 2 ft		Nearest Sanitary Sewer + 12 in or Crown of Street + 4 in
City of Conroe	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft	Depth Number + 0 ft Adjacent Grade + 2 ft		Nearest Sanitary Sewer + 12 in or Crown of Street + 4 in
City of Sugar Land	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft	Depth Number + 0 ft Adjacent Grade + 2 ft		Nearest Sanitary Sewer + 12 in or Crown of Street + 4 in
Missouri City	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft	Depth Number + 1 ft Adjacent Grade + 3 ft	Adjacent Grade + 1.5 ft 1% BFE @ Nearest Drain + 1 ft	Nearest Sanitary Sewer + 12 in or Crown of Street + 4 in
League City	If demonstrated no increase in flood levels, 1% BFE + 1.5 ft	1% BFE + 1.5 ft	1% BFE + 8 in Adjacent Grade + 2 ft		Crown of Street or Adjacent Grade + 1.5 ft
Harris County (new)	Prohibited unless no increase in base levels, 0.2% BFE + 2 ft	0.2% BFE + 2 ft	Depth Number + 3 ft Adjacent Grade + 6 ft	Res. = adjacent grade + 1 ft* Non-Res. = adj. grade + 6 in*	Res. = adjacent grade + 1 ft* Non-Res. = adj. grade + 6 in*
Fort Bend County	If demonstrated no increase in flood levels, 1% BFE + 1.5 ft	Natural Ground + 2 ft 1% BFE + 1.5 ft	Depth number + 1 ft Adjacent grade + 2 ft		
Montgomery County	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft	Depth Number + 1 ft Adjacent Grade + 3 ft		
San Jacinto County	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft	Consider establishing a minimum finish floor		
Liberty County	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft	Depth Number + 0 ft Adjacent Grade + 2 ft		
Galveston County	If demonstrated no increase in flood levels, 1% BFE + 0 ft	1% BFE + 0 ft or Natural Ground + 1.5 ft	Depth Number + 0 ft Adjacent Grade + 2 ft		
Brazoria County	If demonstrated no increase in flood levels, 1 % BFE or natural ground + 2 ft	1 % BFE or Natural Ground + 2 ft	Depth Number + 0 ft Adjacent Grade + 2 ft		
Grimes County	If demonstrated no increase in flood levels, 1% BFE + 0 ft	1% BFE + 0 ft	1% BFE + 0 ft Adjacent Grade + 2 ft		
Waller County	If demonstrated no increase in flood levels, 1% BFE + 1.5 ft	1% BFE + 1.5 ft	1% BFE + 0 ft Adjacent Grade + 2 ft		
Walker County	If demonstrated no increase in flood levels, 1% BFE + 1 ft	1% BFE + 1 ft			

* Harris County does not apply these regulations to conforming subdivisions.

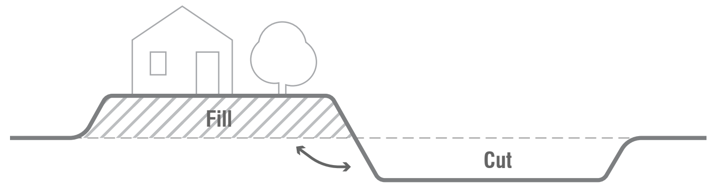
Strictest Regulation — No Regulation

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

WATER STORAGE

Balancing Fill

Fill on a site can impede or redirect water flow. To prevent this, most jurisdictions do not allow any fill in the floodway, unless the developer can demonstrate that flood levels will not increase. In the 1% floodplain, fill may be allowed but often jurisdictions will require fill to be balanced with a "cut" within the site or some small distance away from the site so no water storage capacity in the floodplain is lost.



		1% Floodplain (SFHA)		
	Floodway	Zones A1-30, A99	Zones AO / AH (shallow flooding)	**0.2% Floodplain**
City of Houston	Fill conveyance offset volume requirement	Fill mitigation required		
City of Pasadena	Prohibited unless no increase in flood levels	Mitigated so no loss of flood storage capacity		
City of Baytown	Prohibited unless no increase in flood levels			
City of Conroe	Prohibited unless no increase in flood levels			
City of Sugar Land	Prohibited unless no increase in flood levels	Compensate capacity reduction		
Missouri City	Prohibited unless no increase in flood levels			
League City	Prohibited unless no increase in flood levels	Storage volume equal to amount of encroachment		
Harris County (new)	Prohibited	No fill allowed Offset capacity reduction		
Fort Bend County	Prohibited unless no increase in flood levels	Compacted fill if more than 40 loads per acre		Mitigate alteration of natural flow
Montgomery County	Prohibited unless no increase in flood levels	Compensate capacity reduction		
San Jacinto County	Prohibited			
Liberty County	Prohibited unless no increase in flood levels			
Galveston County	Prohibited unless no increase in flood levels	Compensate capacity reduction	Permitted if increase in BFE is less than 1 ft	
Brazoria County	Offset capacity reduction	Mitigate alteration of natural flow	Mitigate alteration of natural flow	Mitigate alteration of natural flow if >20 loads
Grimes County			Permitted if increase in BFE is less than 1 ft	
Waller County	Prohibited unless no increase in flood levels	If increase in BFE is more than 1 ft, comply with FEMA 44 CFR 65.12	Permitted if increase in BFE is less than 1 ft	
Walker County	Prohibited unless no increase in flood levels	Compensate capacity reduction	Permitted if increase in BFE is less than 1 ft	

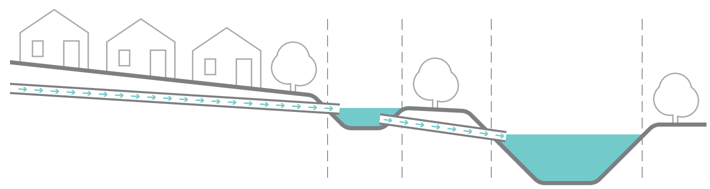
Strictest Regulation — No Regulation

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

WATER STORAGE

Detention

Detention requirements are governed by the authority that owns and maintains the outfall from each site, so these regulations do not vary by floodplain, but are based on the design capacity of the drainage facility. Design capacities and formulae for calculating runoff and drainage vary significantly across jurisdictions. The capacity of a drainage facility may be based on the estimated rainfall amount in a given storm at a specified duration of time.



Requirements

City of Houston	Design rainfall duration for area less than 200 acres of drainage area must be greater than 3 hours. Design rainfall duration for area greater than 200 acres must be greater than 6 hours.
City of Pasadena	Runoff rates computed by Director of Public Works. All runoff rates computed on the basis of ultimate development of entire watershed contributing runoff to proposed subdivision.
City of Baytown	Design storm based on rainfall intensity-frequency data used by county flood district.
City of Conroe	
City of Sugar Land	
Missouri City	Design storm runoff will be calculated in accordance with Fort Bend County or Harris County, as applicable.
League City	Stormwater runoff calculated based on whether or nor stormwater management techniques have been utilized. For non-platted land, calculated as if land was developed according to existing zoning and as if stormwater management techniques have been utilized.
Harris County (new)	Maximum discharge rate based on capacity of receiving storm sewer or pro-rata share of existing capacity of roadside ditch.
Fort Bend County	Runoff based on analysis of rural areas.
Montgomery County	Flow rates calculated case-by-case, working closely with County Drainage Administrator.
San Jacinto County	Calculations based on fully developed upstream conditions.
Liberty County	
Galveston County	Peak outflow rate at undeveloped conditions.
Brazoria County	Design for 24-hour storm duration. Assume average 40% impervious cover on average for developed areas.
Grimes County	Outfall ditches sized to 100-year rainfall frequency.
Waller County	Runoff to match pre-development flows for 100-year, 25-year, and 10-year at a 24-hour storm duration.
Walker County	
HCFCD	Design for 1% and 10% chance rain events at a 24-hour duration, and not exceeding pre-development outfall amounts.

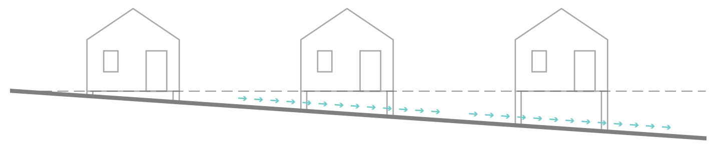
Strictest Regulation — No Regulation

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

WATER CONVEYANCE

Foundation Types

Enclosures and foundation structures below the lowest floor of a building are regulated so that water is able to flow in its intended path. Most new homes in the Houston area are slab-on-grade on top of fill. This blocks water flow. Pier and beam foundations or perimeter walls with openings, on the other hand, permit water conveyance minimizing negative impact. To achieve this in the floodway, City of Houston and Harris County require open foundation systems with a minimum elevation for the lowest structural member. However, note that foundations are also subject to balancing fill regulations. For most jurisdictions, this means whatever the foundation type is, the development must demonstrate no increase in flood levels. Within the 1% floodplain, a majority of jurisdictions require some percentage of any enclosure below the lowest floor to have a minimum amount of openings.



		1% Floodplain (SFHA)		
	Floodway	Zones A1-30, A99	Zones AO / AH (shallow flooding)	**0.2% Floodplain**
City of Houston	Pier and beam structural members = 1% BFE + 18 in	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
City of Pasadena	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
City of Baytown	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
City of Conroe	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
City of Sugar Land	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Missouri City	Enclosures prohibited below 1% BFE	Enclosures prohibited below 1% BFE		
League City	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Harris County (new)	Lowest structural member = 0.2% BFE + 3 ft.	Open foundations No basement in residential	No basement in residential	
Fort Bend County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2	Watertight structure below BFE or flood depth number	
Montgomery County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2	Watertight structure below BFE or flood depth number	
San Jacinto County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Liberty County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Galveston County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Brazoria County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Grimes County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Waller County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		
Walker County	Prohibited unless no increase in flood levels - then follow SFHA requirements	If enclosed below lowest floor with 2 openings 1' above grade at 1 in^2 / 1 ft^2		

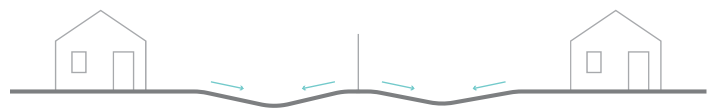
Strictest Regulation — No Regulation

GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

WATER CONVEYANCE

Site Drainage

Site drainage requirements are very generic but where regulated, they have three common underlying goals: to drain away from structures, minimally affect drainage patterns over the site, and cause absolutely no change in drainage patterns on adjacent sites. This can be controlled by sloping away from structures and creating swales on-site to direct water.



	1% Floodplain (SFHA)		
	Zones A1-30, A99	Zones AO / AH (shallow flooding)	**Everywhere**
City of Houston	Floodway Conveyance Offset Volume at rate by City Engineer		No sheet flow from developed property to adjacent property
City of Pasadena			
City of Baytown		Adequate drainage paths to guide floodwaters away from structures	
City of Conroe			
City of Sugar Land			
Missouri City		Adequate drainage paths to guide floodwaters away from structures	Adequate drainage paths away from structures No alteration of flow on adjacent sites
League City		Adequate drainage paths to guide floodwaters away from structures	
Harris County (new)			Drainage swales permitted for off-site sheetflow only
Fort Bend County			Drainage swales permitted along lot line
Montgomery County			
San Jacinto County			
Liberty County		Adequate drainage paths to guide floodwaters away from structures	
Galveston County			Adequate drainage paths to guide floodwaters away from structures
Brazoria County			Drainage swales permitted along lot line
Grimes County			
Waller County			
Walker County			Adequate drainage paths to direct floodwaters to streets or drainage

Strictest Regulation — No Regulation