

HURRICANE HARVEY

Impact of Harvey on Houston MUDs

CONTACT INFORMATION

This market analysis was prepared by Meyers Research, a national market research and consulting firm specializing in the real estate industry, and Municipal Information Services, a firm specializing in the bond performance of municipal utility districts. It has been commissioned by the Association of Water Board Directors.

Scott Davis served as Project Director and oversaw all aspects of this assignment. Follow-up questions should be directed to Scott Davis at (832) 236-5486 or at sdavis@meyersllc.com.

OBJECTIVE

The objective of this analysis is to document the extent of flooding damage to properties located within utility districts in the Houston area compared to the area in general, to assess damage to utility district-owned infrastructure and the continuous delivery of utility services during and immediately after the storm, and to assess the likelihood of the ability of districts with damaged properties to meet debt service obligations on bonds issued by these districts. For the purposes of this analysis, we have assessed the status of districts with 200 or more flooded homes. Finally, the report assesses some of the identified and suspected causes of flooding.

LIMITING CONDITIONS

Meyers Research and Municipal Information Services have relied upon reports by district officials and operators for portions of this report, and government data sources including the US Census Bureau, the Federal Emergency Management Agency, the Texas General Land Office, the Texas Commission on Environmental Quality, the City of Houston, Harris County, and the Harris County Flood Control District. While we strive to verify the accuracy of this data where possible, we cannot warrant the accuracy of each of these data sources.

We have no responsibility to update our report for events and circumstances occurring after the date of our report.

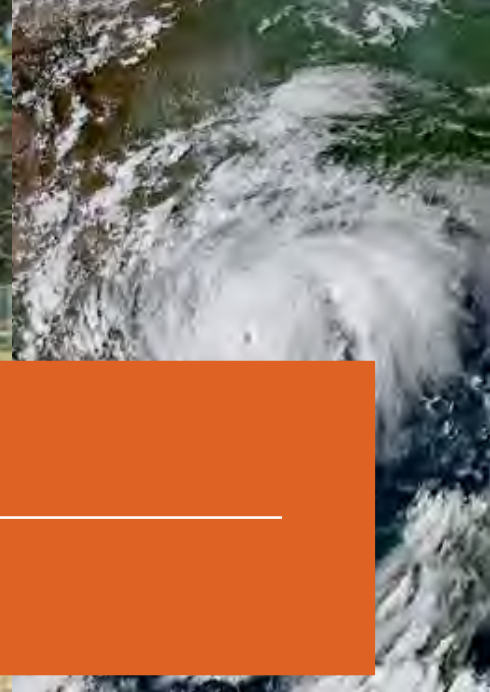
Payment of any and all of our fees and expenses is not in any way contingent upon any factor other than our providing services related to this report.

ASSOCIATION OF WATER BOARD DIRECTORS

The Association of Water Board Directors – Texas is a statewide educational and advocacy group for utility districts in Texas. Founded in the early 1970s, the membership includes MUD's (Municipal Utility Districts), FWSD's (Fresh Water Supply Districts), PUD's (Public Utility Districts), UD's (Utility Districts), and WCID's (Water Control & Improvement Districts), and Levee Improvement Districts (LID's). Each of these districts is governed a board of directors who typically live or own property in the district that they govern. AWBD member water districts provide water, sewer, and drainage service to millions of Texans. AWBD exists to educate these volunteer directors on the latest technology, laws and rules that will affect their daily operations of their districts.

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KEY FINDINGS

Impact of Harvey on Houston MUDs

Key Findings: Hurricane Harvey and MUDs

Few disasters figure as prominently in history and the human imagination as a flood. Ancient cultures including the Mayans, the ancient Greeks, the Sumerians, the Chinese and the Indians, all have flood myths. *The Bible* records the history of Noah's survival of the flood. We use the phrase antediluvian ("before the flood") to describe something very old. This kind of disaster has such a strong hold on our imagination because of its powerfully destructive nature. For many people across the nation, Harvey was a compelling news story on television. For Texans, many of whom lost their lives, or their homes or property, Harvey was a tragedy. Meyers Research and AWBD are truly aware of the great devastation of Harvey. Every Texan knows friends and family who were directly impacted by this powerful storm.

Harvey created many challenges and generally Houston area utility districts rose to those challenges. As detailed in this report, Harvey was a storm of unprecedented size and scope. Houston (and other areas on the Gulf Coast) has experienced severe storms and heavy rainfall intensities many times in the past. The difference with Harvey was that no other storm has brought so much rainfall so quickly over so large an area. Portions of the Houston MSA received more rain in four days than the region's annual average rainfall. According to Jeff Lindner, chief meteorologist with the Harris County Flood Control District, Harvey produced almost 50% more rainfall over a 1,000 square mile area than the previous record storm. Almost all of the Houston area experienced a 1,000-year storm with some areas receiving rain equivalent to a 40,000-year storm event. GPS calculations showed that the weight of the water covering the Houston area was sufficient to cause the very land beneath the city to subside by a quarter inch.

But the Houston area and the utility districts which service much of the region proved remarkably resilient in response to this epic storm. As many as 190,000 houses – 9% of the Houston MSA's housing stock – experienced flooding. Our research shows that less than 20% of those flooded units were located within the utility districts that provide water, wastewater and storm water services to Houston's fastest growing areas (MUDs). Our research shows:

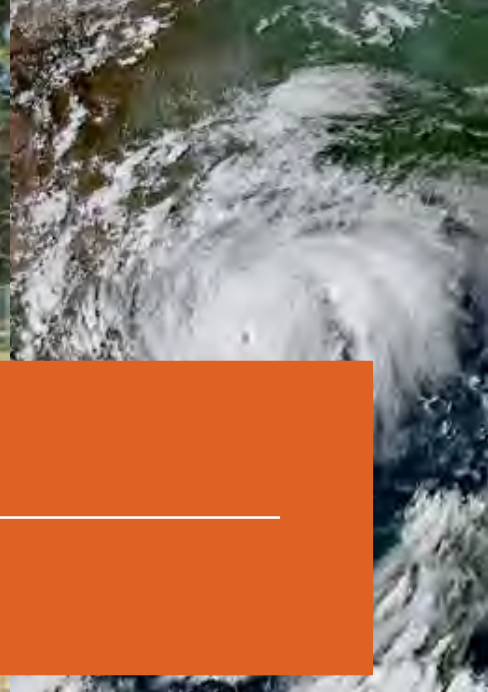
- Of the 945 MUDs servicing the Houston MSA, only 253 experienced home flooding – and only 53 had more than 200 homes flooded. Nearly every subdivision within those 53 MUDs was platted before 1981 – the first year FEMA made flood plain maps available for Harris County.
- 37,211 flooded homes are located within MUDs.
- 65% of flooded homes located within MUDs are located in districts platted before 1981 – the first year FEMA made flood plain maps available for Harris County.

Most of the flooding is in areas developed prior to the current understanding of flood potential and prior to regulations restricting construction in flood-prone areas.
-Harris County Flood Control District

Key Findings: Hurricane Harvey and MUDs

- 213 utility systems of all types – municipal, private water companies, and utility districts – were compelled by the TCEQ to issue Boil Water Notices during the storm because of damage to water facilities – and only 12 of those systems were operated by MUDs.
- The TCEQ tracks 1,096 wastewater treatment plants in the Houston MSA – only 3 of those were destroyed by the storm, and none of those were operated by MUDs.
- Flooding in these 253 MUDs is concentrated into five separate categories – overflow from the Addicks and Barker Reservoirs operated by the US Army Corps of Engineers; channel flooding from overflow in Cypress and Spring Creeks; overflow flooding from the San Jacinto River; flooding in Fort Bend County along the Brazos River, where communities experienced an 800-year storm event after the river floodgates had closed; and flooding in the Clear Creek watershed, where more than 56” of rainfall was received – a level of rainfall greater than the “possible maximum precipitation” believed possible for a storm in the Houston area. Meyers Research also identified 139 bridges on Houston’s bayous whose elevations were below the 500-year flood plain, a significant potential contributor to flooding.
- The 53 MUDs which flooded 200 homes or more have a combined bonded indebtedness of \$996 million, and another \$195 million collectively in cash reserves. Collectively these MUDs could pay three years of debt service without collecting a single dollar of tax revenue if necessary and have sufficient remaining authorizations to make significant repairs or improvements if needed.
- Meyers Research reviewed over 97,000 transactions in the Houston Association of Realtors Multiple Listing Service, specifically at transactions in the 12 months prior and 90 days following Harvey in the 253 MUDs which experienced flooding during Harvey. There were 19,226 sales in 230 of these MUDs before and about 5,553 after the storm. The average MUD experienced a decline of just under \$10,000, or about 4% from the pre-storm sales price.
- One of the most severely impacted MUDs saw the largest decline in sales at 38%. After an investor purchase and repairs, the value of that average home would be closer to a 7-10% decline – well within the range of financial sustainability for most of these MUDs.

Overall this research shows that Houston’s network of MUDs was extremely resilient in the face of Harvey, largely provided utility service without interruption during the storm, and has a very low risk of default on bonds.



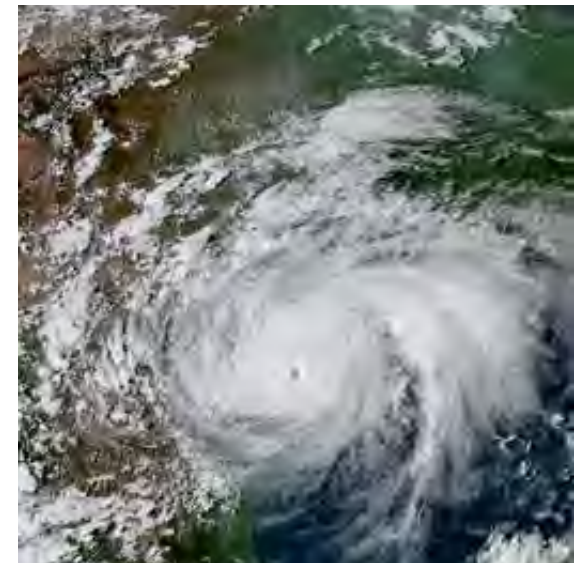
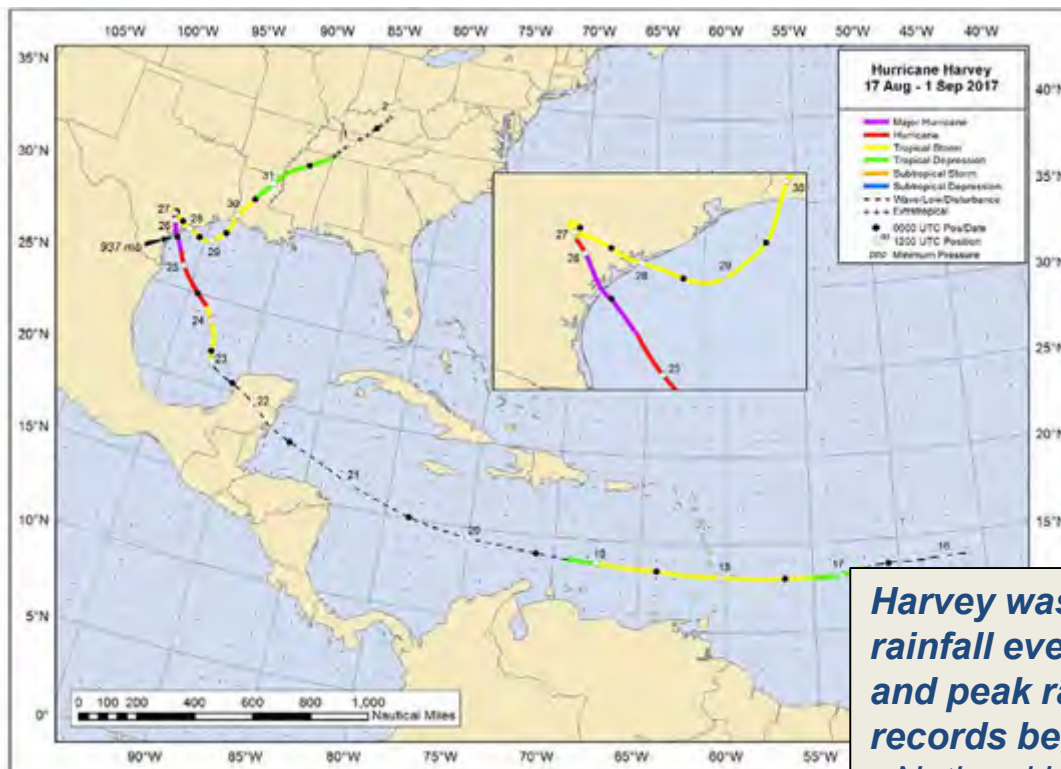
AN UNPRECEDENTED STORM

Impact of Harvey on Houston MUDs

Hurricane Harvey

Hurricane Harvey formed east of the Lesser Antilles, becoming a tropical storm on August 17, 2017. Harvey crossed the Yucatan Peninsula on August 22, was upgraded to a hurricane on August 24 and reached category 4 on August 25 shortly before making landfall at Rockport, Texas. The storm slowly crawled up the coast and returned to the Gulf of Mexico on August 28 and made a third landfall west of Cameron, LA.

Harvey was the first major storm to make landfall in the US since 2005, and dropped more than 35" of rain across the Houston metropolitan area. Damage estimates from the storm range from \$73 billion to \$125 billion. Harvey is the most significant and at least the second costliest tropical cyclone to hit the US in recorded history.



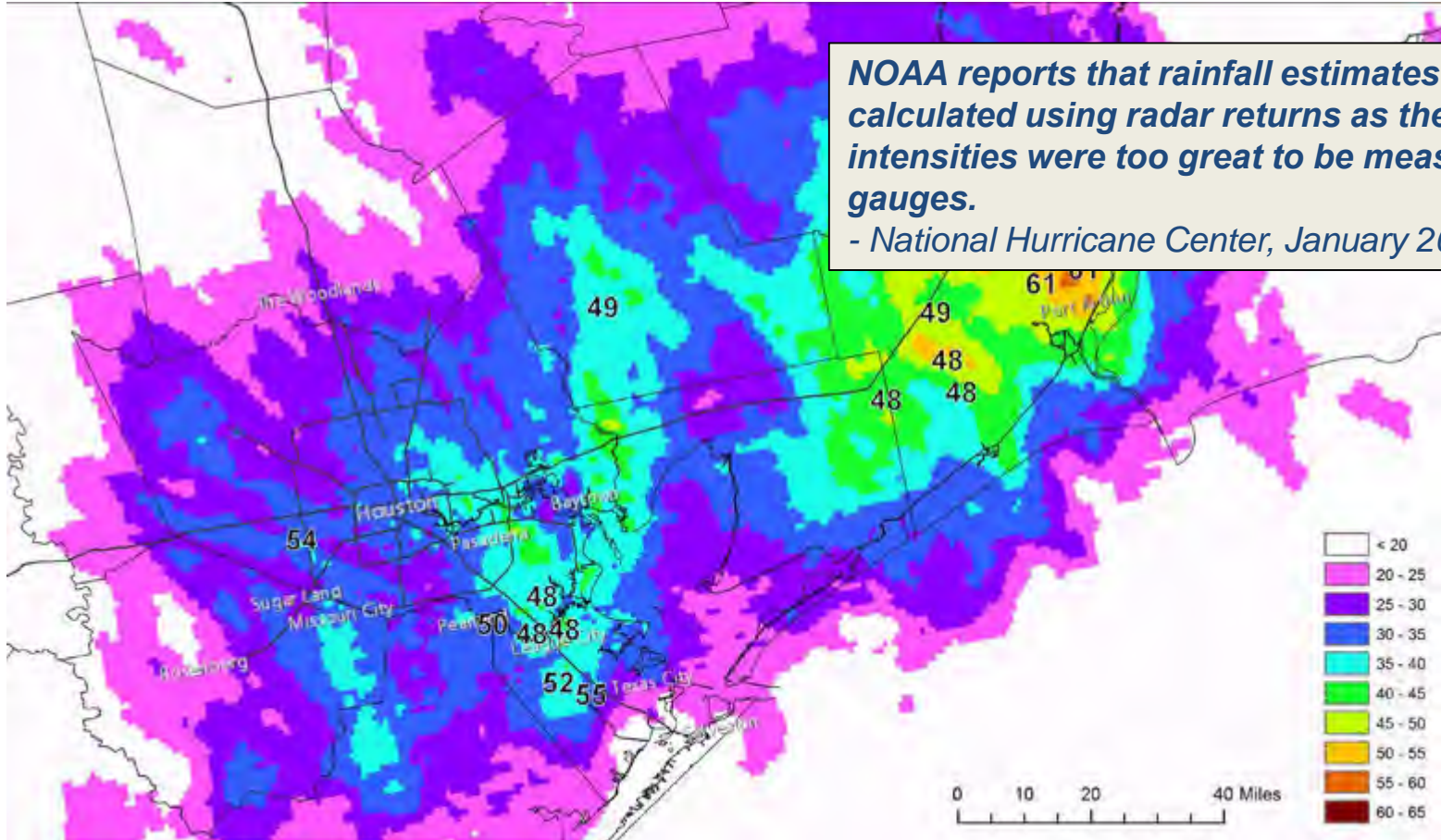
Harvey was the most significant tropical cyclone rainfall event in United States history, both in scope and peak rainfall amounts, since reliable rainfall records began around the 1880s.

- National Hurricane Center, January 2018

Source: NOAA, NHC, NASA

Harvey: An Unprecedented Storm

In January 2018, the National Hurricane Center released a report on Hurricane Harvey. The NHC had to use a combination of radar returns and rain gauges to estimate the storm's rainfall totals; rainfall was so intense in many places that rain gauge measurements were inaccurate because the gauges were either damaged or overflowed too quickly to accurately register rainfall totals.

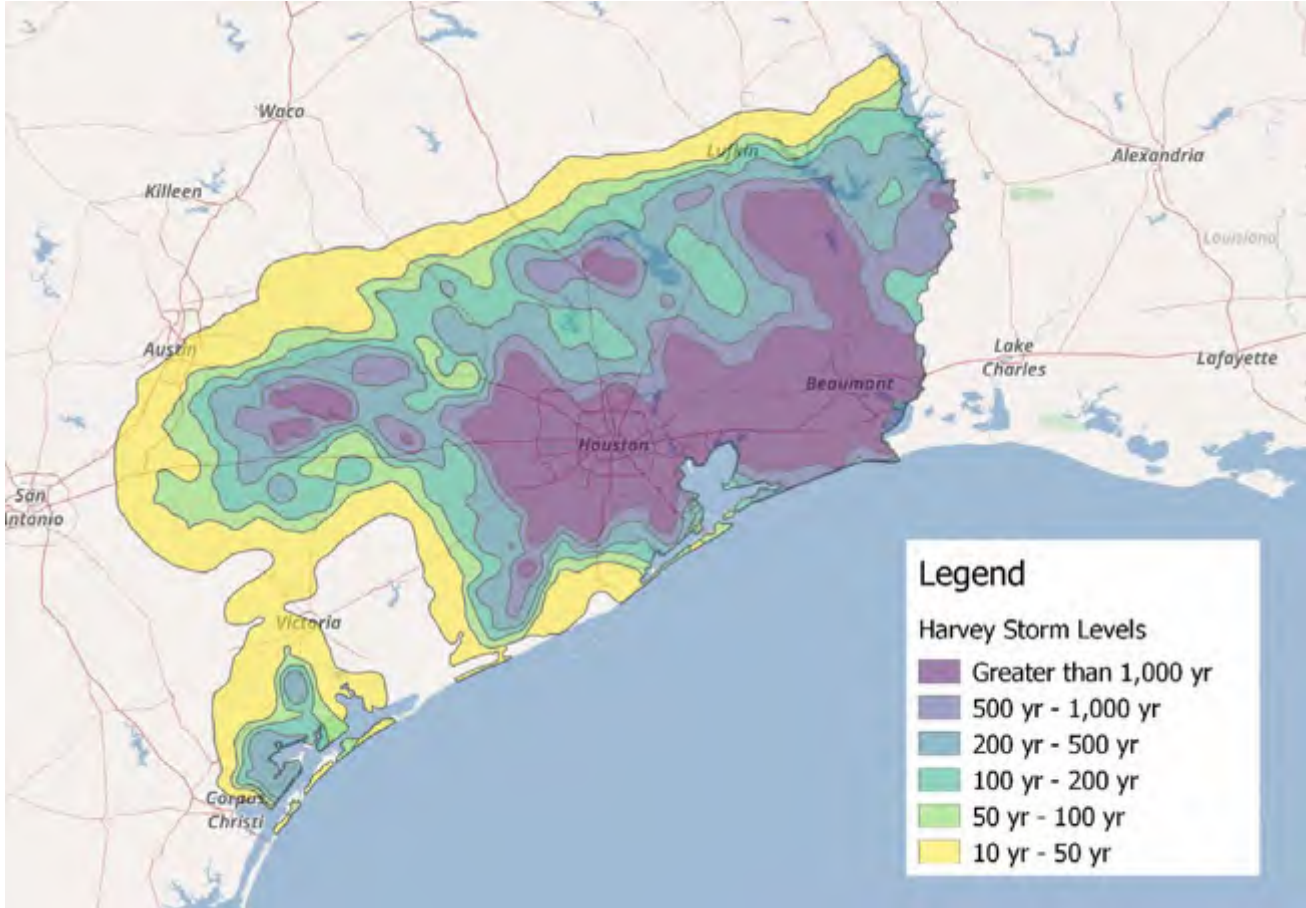


NOAA reports that rainfall estimates had to be calculated using radar returns as the rainfall intensities were too great to be measured by rain gauges.
- National Hurricane Center, January 2018

Source: National Hurricane Center

Harvey: An Unprecedented Storm

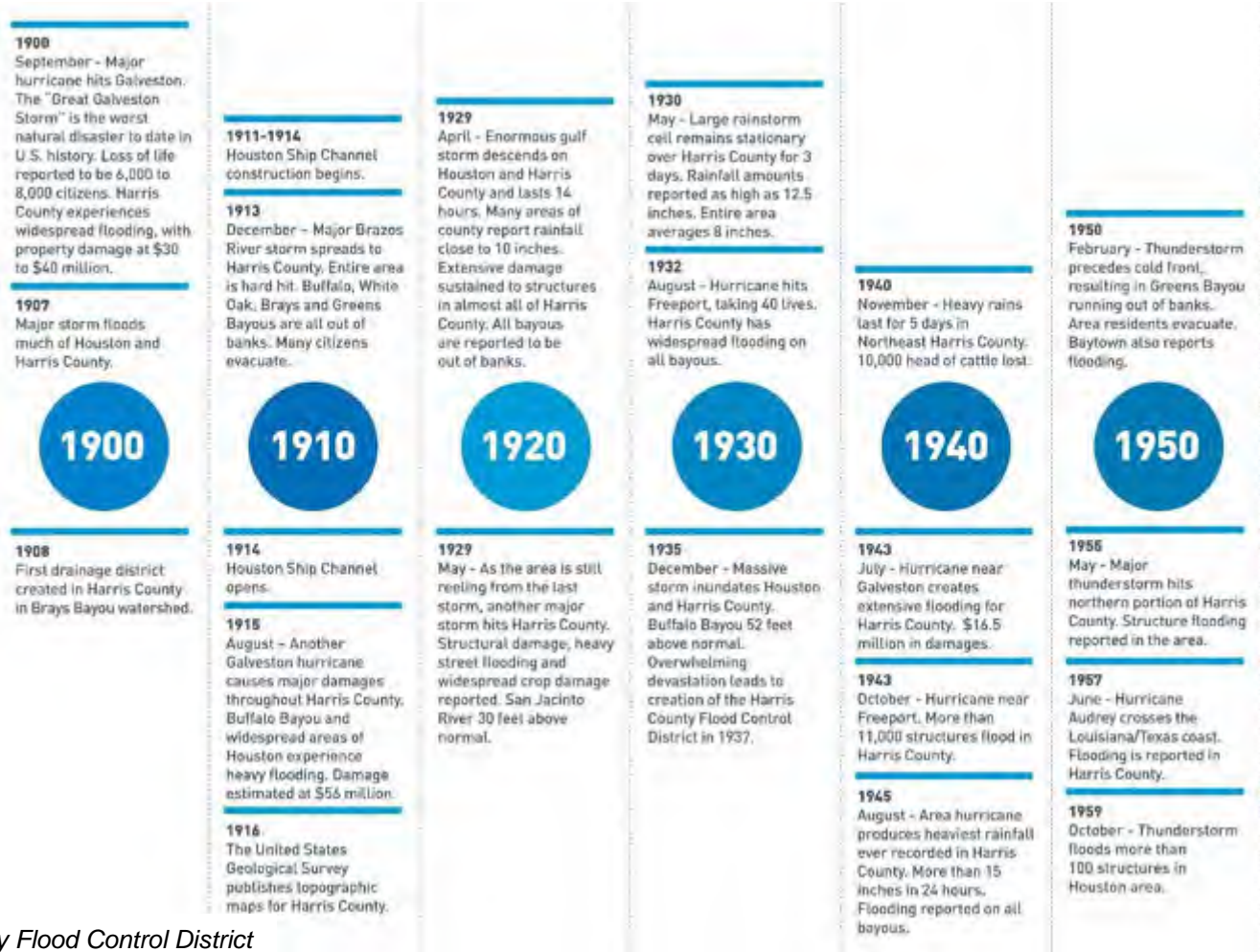
The map below shows the “annual exceedance probabilities” of Harvey – the level of design storm that rainfall levels reached. The dark purple areas covering most of the Houston MSA show that in these areas the level of rainfall was greater than a 1,000 year design storm – the kind of storm for which there is a less than 0.1% chance of happening in any given year.



Source: NOAA, Open Street Map

Houston's History of Flooding

This chart below shows a history of major flooding in the Houston area dating back to 1900. Harris County Flood Control District's website says "Harris County doesn't have earthquakes... doesn't have blizzards... doesn't have avalanches. We have flooding. A major flood still occurs somewhere in Harris County about every two years. Most of the flooding is in areas developed prior to the current understanding of flood potential and prior to regulations restricting construction in flood-prone areas."



Source: Harris County Flood Control District

Houston's History of Flooding, Continued

1960

June - Thunderstorm inundates many areas throughout Harris County. Cypress Creek, Spring Creek and San Jacinto River experience flooding. Over 200 families evacuate.

1961

September - Hurricane Carla pounds the Gulf Coast, taking 34 lives. It is the largest hurricane ever recorded, with property damages exceeding \$300 million. Heavy flooding reported in southern Harris County.

1960

1969

February - Thunderstorm precedes cold front, flooding more than 250 area structures. Damages exceed \$3.3 million.

1972

March - Thunderstorm precedes cold front and floods much of northern Harris County. More than 700 families evacuate.

1973

June - Major storm hits Harris County and brings 10-15 inches of rain. Sims and Greens baysou are reported out of banks. 10 lives are lost and damages exceed \$50 million.

1970

1979

July - Tropical Storm Claudette brings record rainfall amounts to the area. A U.S. record of 42 inches of rain in 24 hours falls in Alvin. Total damages exceed \$700 million.

1982

May - Large thunderstorm floods areas along several baysou. Damages exceed \$14 million.

1983

August - Hurricane Alicia strikes Galveston and Harris County. Damages approach \$1 billion, mostly due to wind.

1980

1983

September - Nine inches of rain falls south of downtown. More than 1,000 structures flood along Brays Bayou. Damages top \$38 million.

1984

October - Thunderstorm in northern Harris County floods more than 200 structures. Total damages exceed \$22 million.

1989

May & June - Two separate storms result in two back-to-back presidential disaster declarations.

1992

March - Major storm floods more than 1,500 structures and many baysous are out of banks. Much of I-10 is under water.

1994

October - Major storm hits Harris County. Twice as many structures flood than in the 1972 storm. Most baysous are out of banks.

1990

1998

September - Tropical Storm Frances causes extensive flooding along White Oak Bayou and other baysous. More than 1,300 structures flood.

1998

October & November - Adding insult to injury, two more major storms flood hundreds more structures, mainly in north Harris County.

2001

June - Tropical Storm Allison strikes first on June 5; returns three days later for a second round of storms. Texas Medical Center essentially shut down. North Downtown Houston decimated. Two million people impacted; 22 lives lost. More than 70,000 structures flood. Damages top \$5 billion.

2004

June 19 - Rainfall on already saturated ground floods 3,270 homes, 561 apartments and one nursing home, mostly along Berry and Sims baysous. Rainfall 8-10 inches in three hours.

2000

2008

September - Hurricane Ike, 3rd costliest in U.S. history, strikes Galveston Island. Eleven deaths in Harris County. Storm surge swamps 2,500 structures; rainfall causes 1,200 more structures to flood. More than \$28 billion in damage.

2009

April 17-28 brings extensive flooding; five children drown when a car goes into a Greens Bayou tributary. Some highways close; record high water on Bear, Langham, Mayde creeks. 2,305 structures flood on Langham Creek and Buffalo Bayou. HCFCO records one-hour rainfall of 6.7 inches at Clear Creek.

2012

July - High water rescues along Cypress, Little Cypress and Willow creeks after several days of heavy rainfall beginning July 9. More than 70 structures flood in northern Harris County.

2014

August - Slow-moving rains drench portions of Harris County with 3.5-4.5 inches. In the Greens Bayou watershed, 109 structures flood.

2015

May 25-27 - Memorial Day Flood. More than 4,000 structures flood. Seven fatalities. Highest rainfall recorded in Buffalo and Brays watersheds. Nearly 11 inches in 3 hours on Brays Bayou.

2010

2014

April 17-19 - Tax Day Flood. Historic flood over northern and western Harris County results in seven fatalities. Average 12-14 inches of rain in 12 hours; countywide record pool levels in Addicks and Barker reservoirs. Estimated 9,820 structures flood in Harris County.

2014

May 26-27 - Memorial Day Flood. North and northwest Harris County hit with 8-13 inches of rain. Overbank and structural flooding along Spring, Willow, Little Cypress and Cypress creeks, San Jacinto River. More than 400 structures flood in Harris County and more than 900 in the Spring Creek watershed in Montgomery County.

Source: Harris County Flood Control District

Houston's History of Flooding



Houston CBD, 1935



Buffalo Bayou & Franklin, 1935



Bellaire, Audrey 1957

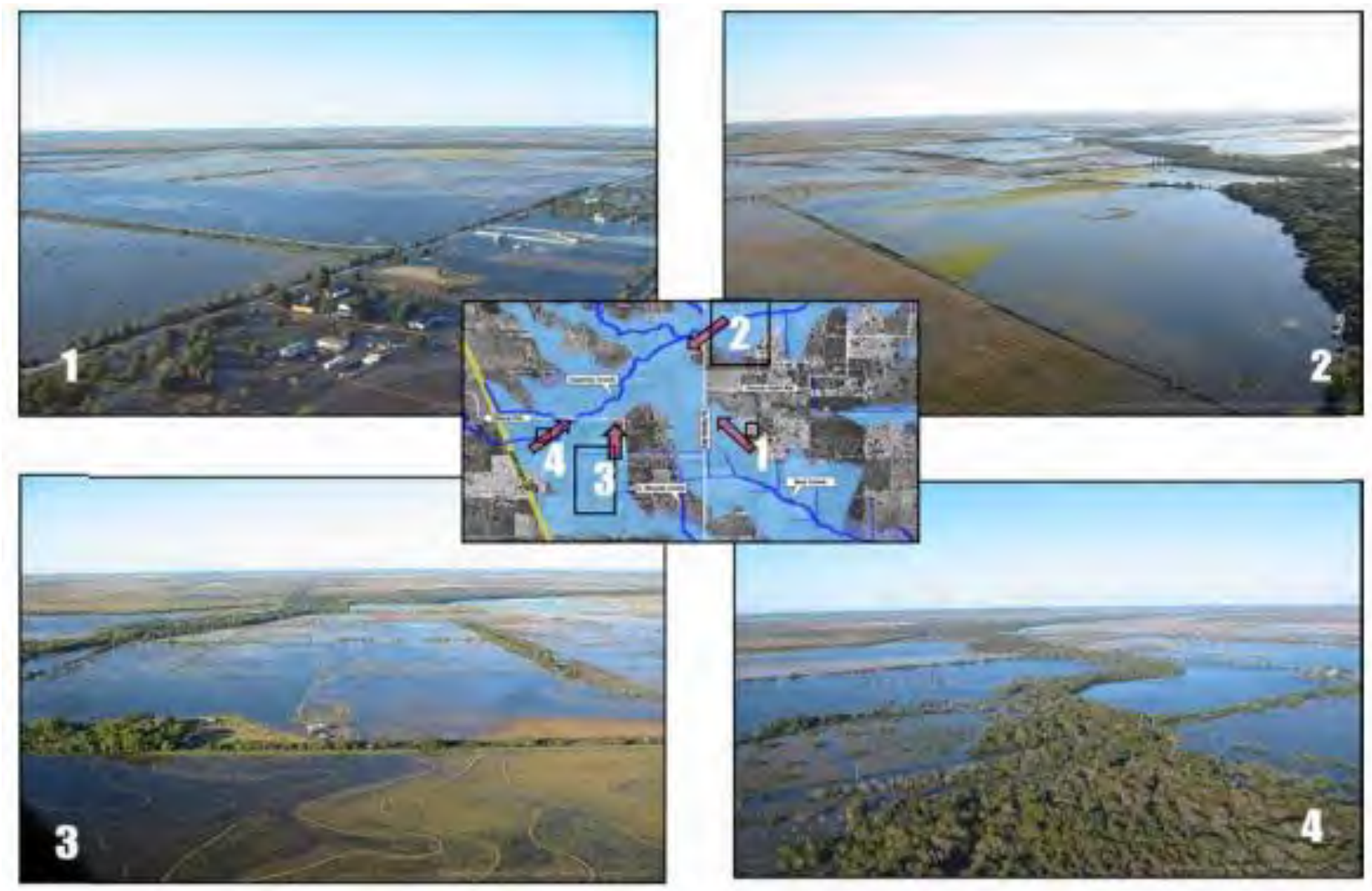
Source: Harris County Flood Control District



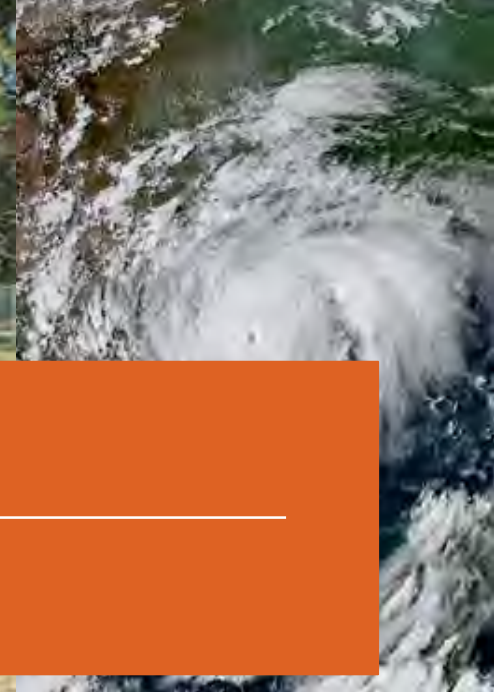
Preston Ave Bridge, 1929

Houston's History of Flooding

Katy Prairie flooding event, 2002



Source: Harris County Flood Control District



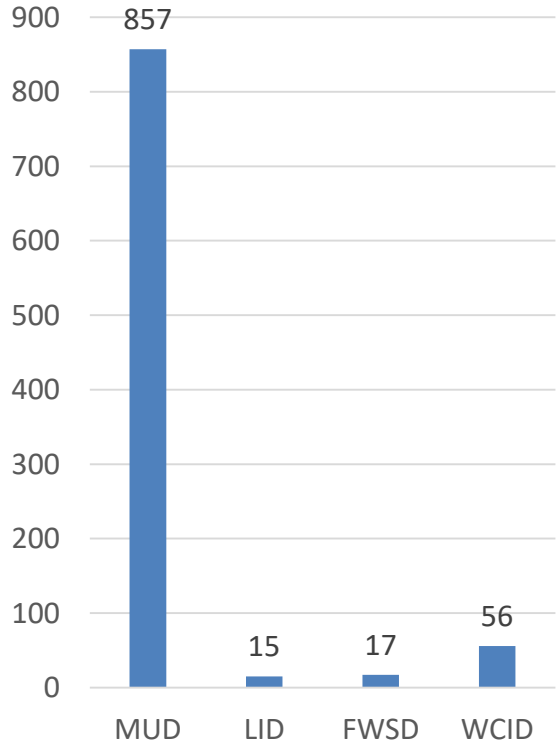
MUDs AND DEVELOPMENT

Impact of Harvey on Houston MUDs

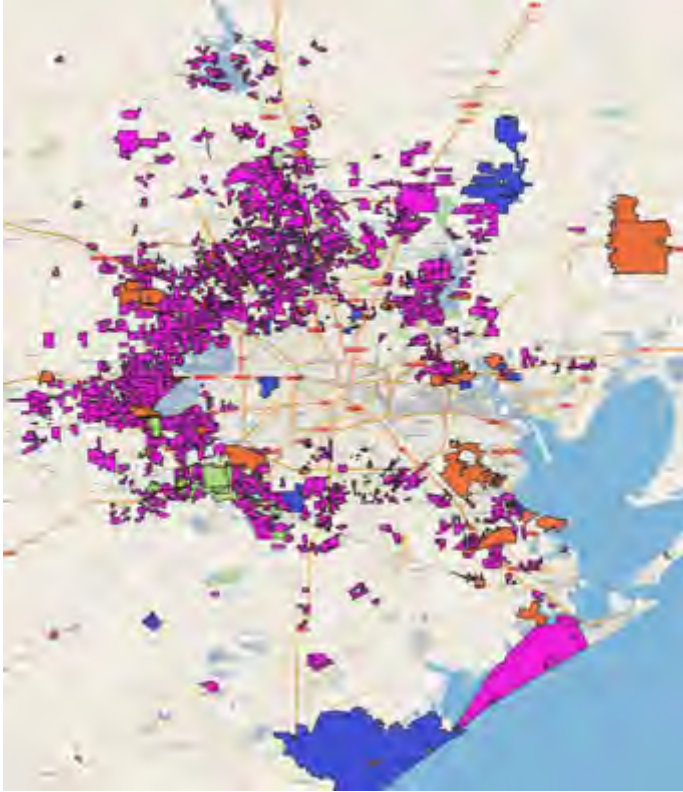
Types of MUDs

Districts are limited purpose political subdivisions of the State of Texas whose principal functions are to finance, construct, own, and operate waterworks, wastewater, and drainage facilities and to provide such facilities and services to its customers. Districts may also provide solid waste collection and disposal service; establish, operate, and maintain a fire department; construct and operate parks; build roads; supplement city and county policing; and perform a variety of other functions depending on the type of district.

Within the Houston MSA, there are 945 such districts, including 857 municipal utility districts (MUDs), 15 levee improvement districts (LIDs), 17 fresh water supply districts (FWSDs), and 56 water control and improvement districts (WCIDs). This report sometimes will refer to all of these types of districts collectively as “MUDs.”



Source; TCEQ



- MUD
- LID
- FWSD
- WCID

Although MUDs are used in jurisdictions around the state, they are most concentrated in the Houston area. The power to create these districts dates back to the 1920s, but MUDs and similar districts came into widespread use in the 1970s and 1980s to facilitate the Houston area's rapid growth during the oil boom of that era. The city and its development community turned to MUDs as a way to "make growth pay for itself" in providing utility service to new development in unincorporated areas.

Major Types of Districts

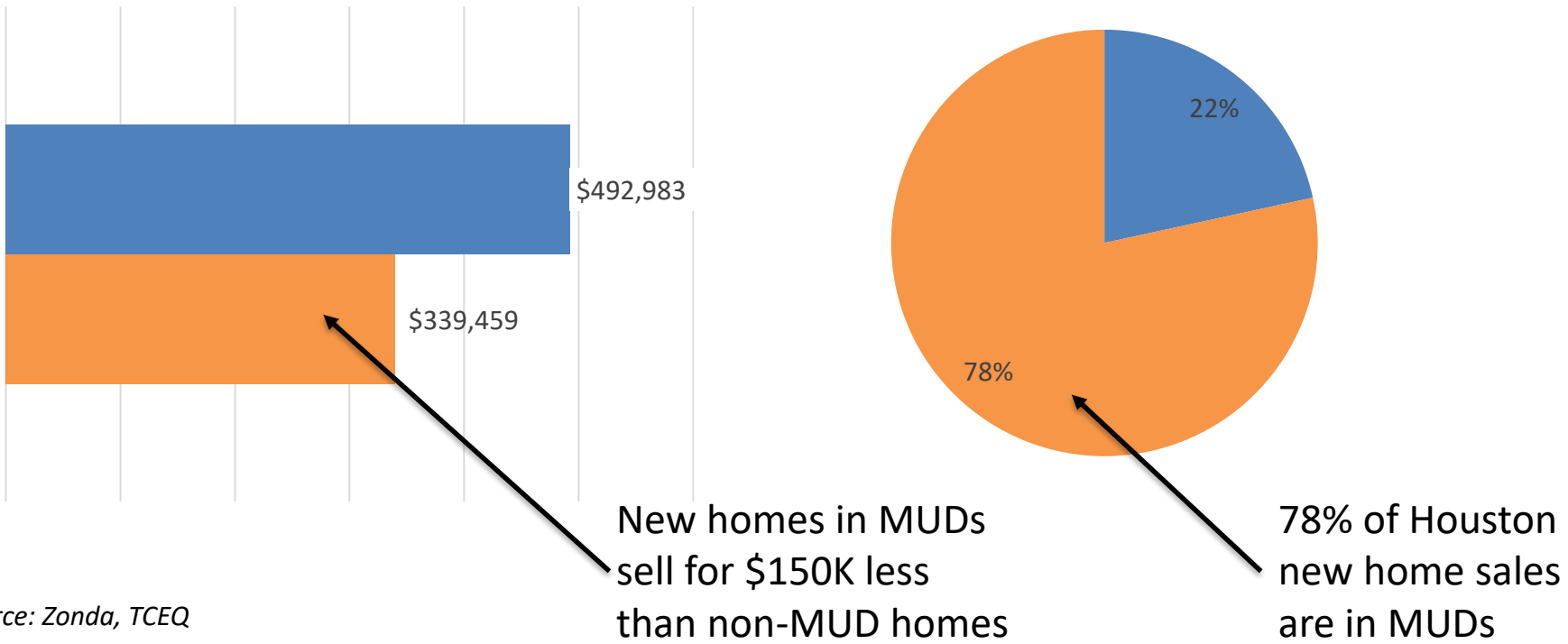
- **MUD – Municipal Utility Districts** are the most common form of district. A MUD is a political subdivision of the State of Texas created for the purposes of providing water, wastewater, drainage and other services. They are created for areas undergoing residential and commercial development where no utilities exist. MUDs are formed either by a special act of the Legislature, or by the TCEQ. The TCEQ may receive petitions to form MUDs from the owners of large plots of land that desire development. The MUD's elected board of directors oversees and manages the district's operations, which include overseeing the design, construction, financing and operation of the district's utilities. The primary duties of MUDs include the following:
 - Controlling, storing, preserving, and distributing water resources for municipal, commercial, and domestic uses
 - Managing any shortage or excess of water
 - Protecting, preserving, and restoring the purity and sanitary condition of Texas water
 - Overseeing the conservation and development of natural resources
 - Providing parks and recreational facilities for inhabitants within the district
 - Collecting, transporting, processing, and disposing of waste
- **WCID -- Water Control and Improvement Districts** can be created by petition of landowners or the county commissioner's court. A district may include all or part of one or more counties. They have an elected board of five members that oversee the district's activities. Some WCIDs have converted into and function just like a Municipal Utility District (MUD). WCIDs have the ability to:
 - Supply treated and untreated water
 - Provide wastewater service
 - Manage drainage and flood control
 - Oversee irrigation and navigation

Houston MUDs

- **LID – Levee Improvement Districts** may be established to build levees, straighten channels, and provide drainage. Legislative authorization for the establishment of levee improvement districts was first given in the early 1900s. LIDs are created by the county commissioners' court. The districts are typically governed by a board of three supervisors, typically appointed by the county commissioners' court.
- **FWSD – Fresh water supply districts** were originally established by the Texas Legislature in 1917 for the exclusive purpose of providing and distributing water for domestic and commercial use. The districts are organized similarly to WCIDs. FWSDs may be created through petitions, local commissioners' courts or requests of individuals property owners. The district is managed by a board of five elected supervisors. FWSDs have the ability to:
 - Supply treated and untreated water
 - Provide wastewater service
 - Manage drainage and flood control
 - Construct, operate and maintain pipelines, levees, sewer systems and bridges

MUDs Keep Houston Housing Affordable

Meyers Research studied the role of MUDs in Houston housing development in 2016. Of 945 districts, the average district was just over 1,000 acres. In 2016, 78% of new home sales in the Houston area were inside of MUDs – and on average these homes cost \$150,000 less than homes sold outside of MUDs. MUDs are key to maintaining housing affordability in the Houston market.



Source: Zonda, TCEQ

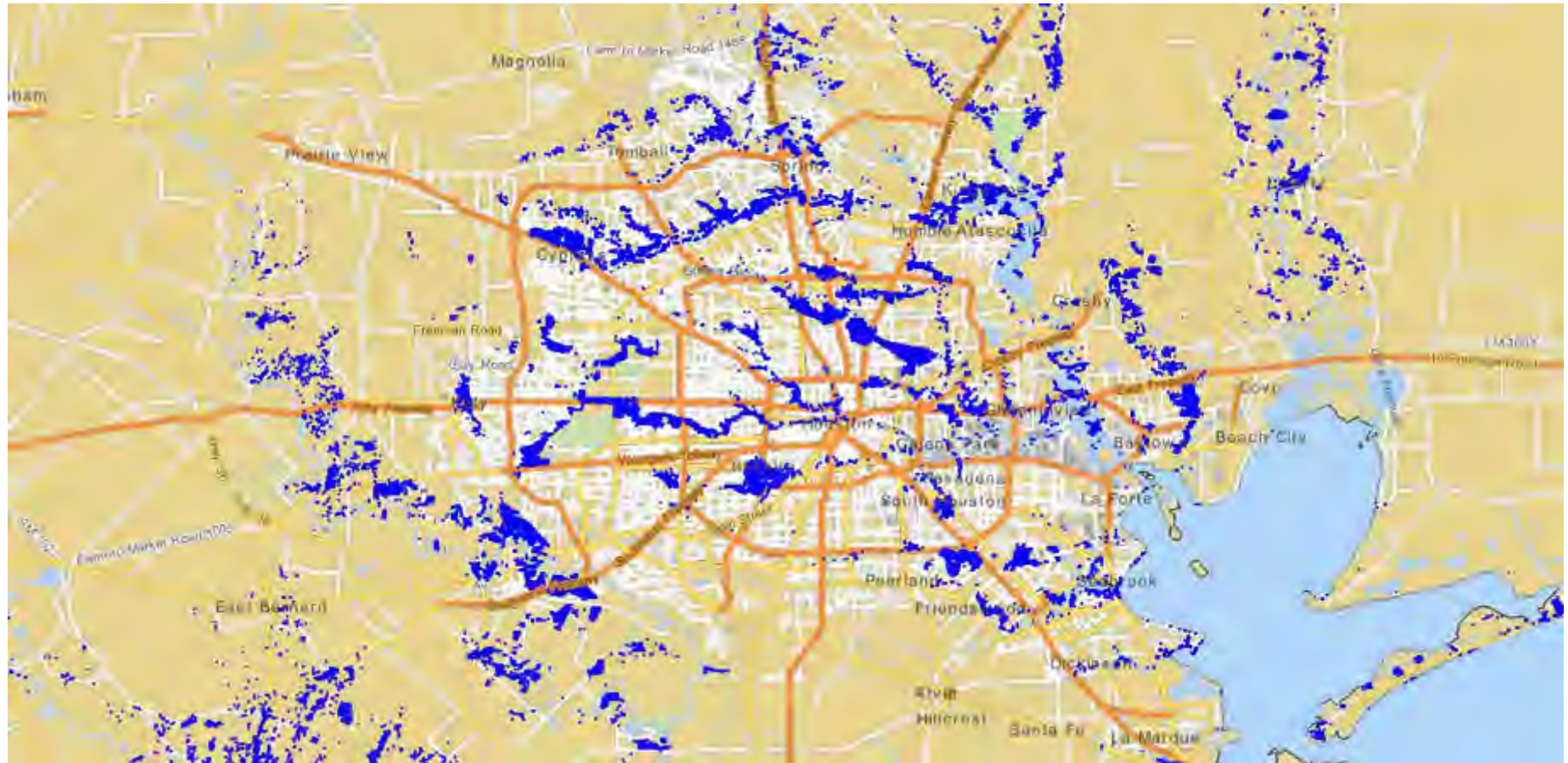


CALCULATING THE EXTENT OF DAMAGE

Impact of Harvey on Houston MUDs

How Many Homes Were Damaged in Harvey?

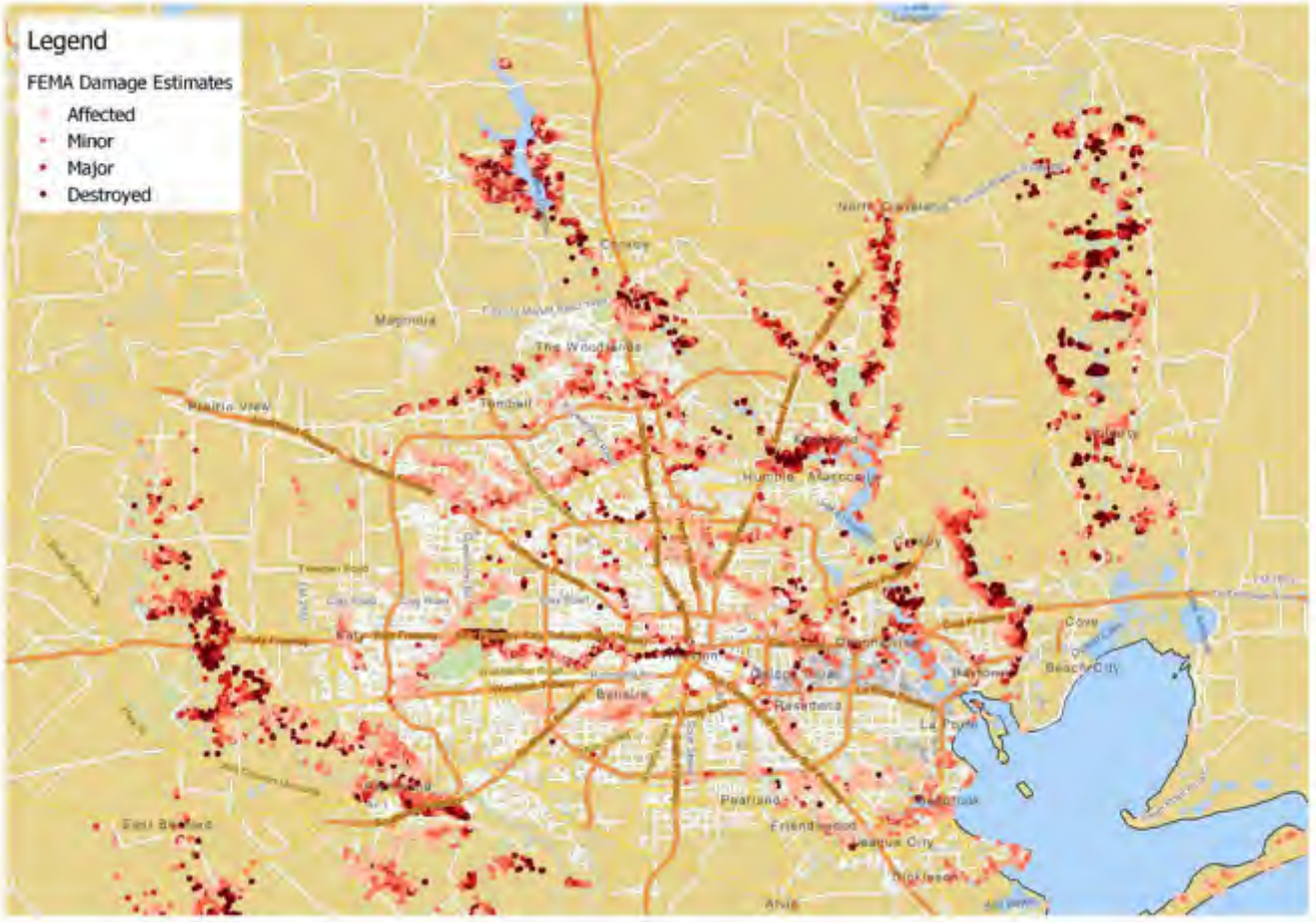
To begin the assessment of the extent of flooding damage in Houston area MUDs, Meyers Research first looked at the “FEMA Modeled Damage Layer,” described as “Modeled Building Level Damage Assessments for Hurricane Harvey” at https://gis.fema.gov/arcgis/rest/services/FEMA/FEMA_Damage_Assessments/MapServer. The data layer is mapped below.



Source: FEMA, US Census Bureau, Open Street Map

How Many Homes Were Damaged in Harvey?

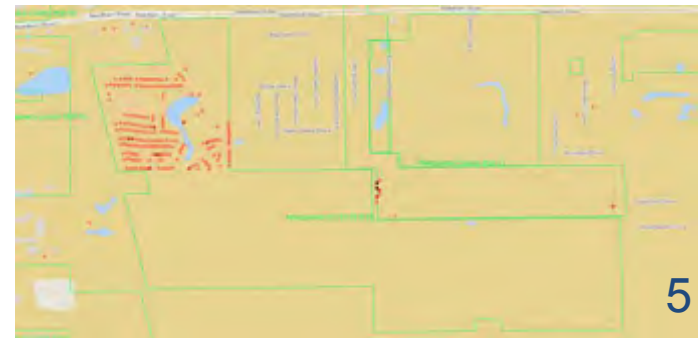
A number of data visualizations similar to the map below have been prepared by the media and non-profit organizations to demonstrate the extent of flooding damage during Harvey. One such graphic prepared by the *Texas Tribune* comes with the notation: “FEMA’s damage modeling is based on parcel data and coastal and river flood gauge levels, and does not account for damage that may have been caused by wind or levee breaks, nor does it take into account that structures on a property may be elevated.”



Source: FEMA, US Census Bureau, Open Street Map

How Many Homes Were Damaged in Harvey?

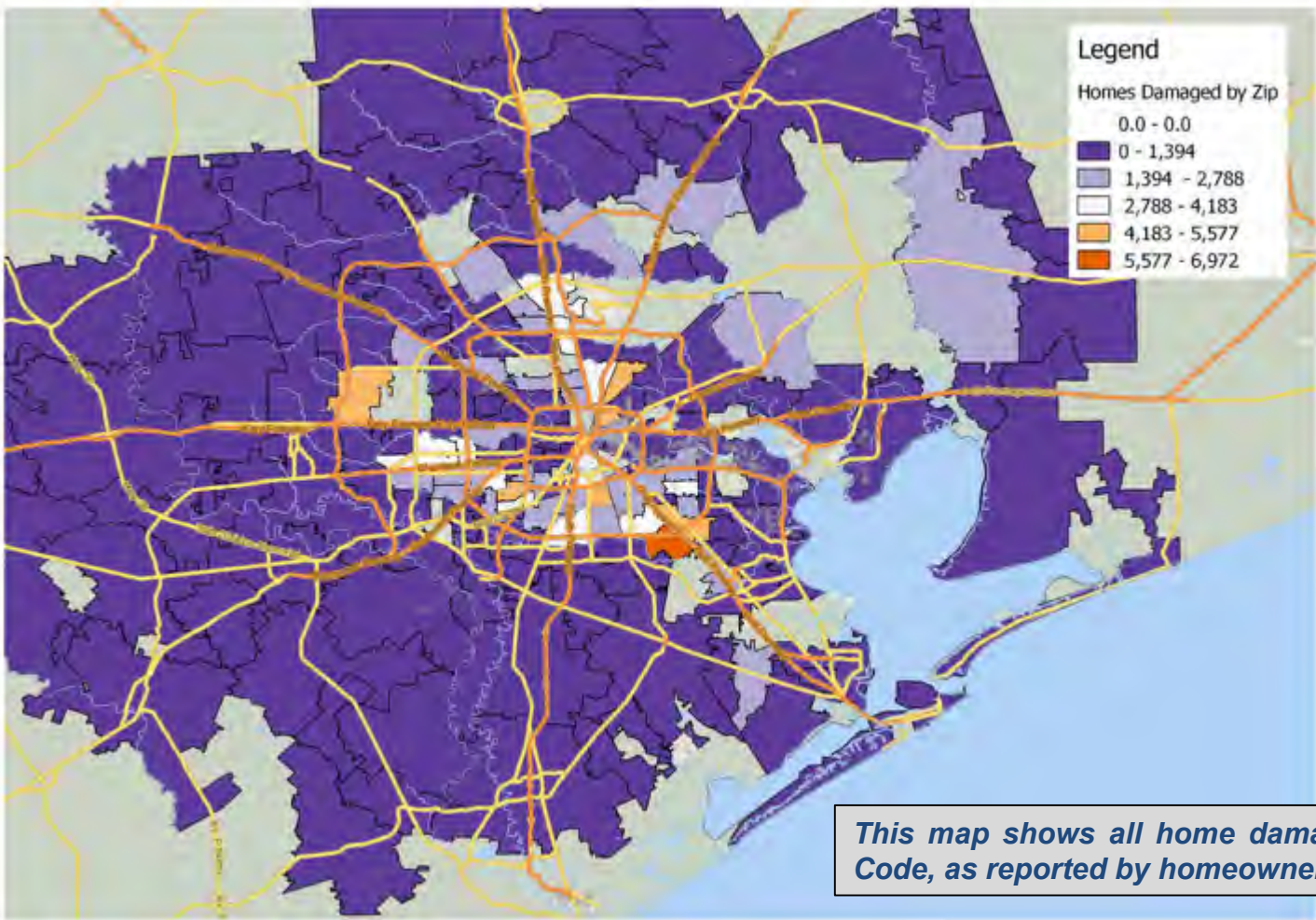
A quick spot check of the FEMA modeled damage layer quickly revealed, however, that the extent of flooding shown in that layer did not reflect the extent of flooding which actually took place.



1. MC MUDs 8 & 9: FEMA shows over 2,500 flooded homes in these districts – a very small number of homes along the lake's shore flooded
2. FB LID 2: FEMA shows 0 homes, City of Sugar Land reports 230 homes flooded
3. FB LID 11: FEMA shows 1,234 homes flooded – no homes actually flooded
4. FB LID 19: 0 FEMA reported, LID reports 570
5. MC MUD 95: 530 homes reported by FEMA, actual total reported by district is 0

How Many Homes Were Damaged in Harvey?

Meyers Research then obtained the FEMA assistance applications by zip code. The map below shows the applications made by zip code in the Houston area for damaged homes. This is approximately 190,000 applications. The highest concentrations are in Meyerland, along US 59, west of the Addicks Reservoir, and the Friendswood area.

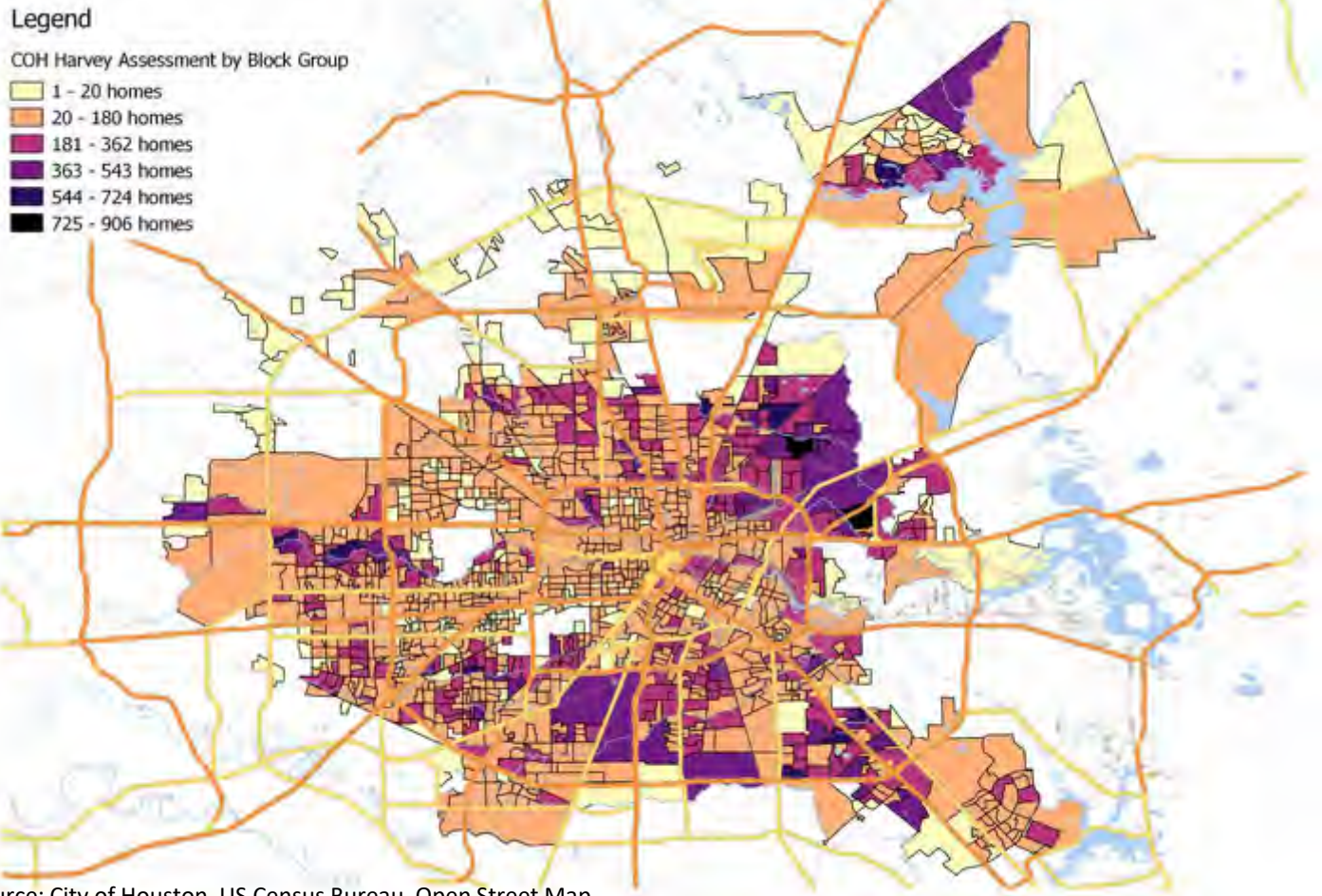


This map shows all home damage claims to FEMA by Zip Code, as reported by homeowners/residents.

Source: FEMA, US Census Bureau, Open Street Map

How Many Homes Were Damaged in Harvey?

Even the City of Houston's own data assessment shows the difficulty of obtaining an accurate count of flooded houses in Harvey. The City's damage assessment collected data from damage assessment surveys by Department of Neighborhood (DON), Department of Public Works and Engineering Floodplain Management Office (FMO), and National Flood Insurance Program (NFIP). The data show 158,000 flooded houses within the city limits; added to the suburban counts obtained in our survey, the combined counts roughly equal the Texas General Land Office estimates of 190,000 houses affected by flooding.



Source: City of Houston, US Census Bureau, Open Street Map



SURVEY OF FLOOD DAMAGE FROM HARVEY

Impact of Harvey on Houston MUDs

An Uncertain Number: Homes Damaged by Harvey

There are a variety of sources providing estimates of the extent of damage to residential structures by flooding. FEMA has provided a “model damage layer” but this is a calculated layer and has not been ground verified. FEMA has also just released a dataset by zip code and county of aid applications that includes reported housing damage, assistance with food or medicine, vehicle damage or shelter needs. This data also includes a count of NFIP (flood insurance) claims, which is almost 68,000 for the nine-county Houston MSA. Not every home that flooded is insured so this number represents a floor for the number of properties damaged. Reports in the media suggest that only 20% of flooded properties are insured through NFIP, but this ratio appears to derive from the percentage of Houston area households with flood insurance rather than as a result of ground verification. That share is likely too low, as it would result in almost 350,000 homes damaged.

The applications for individual assistance show over 400,000 reporting flood damage to homes without an assessment of the extent of that damage. This number is much higher than any other damage reports, and likely at least double counts NFIP claims – most who flooded reported to FEMA even if they were also insured. The “shelter needs” application number of 162,602 is probably the ceiling for flooded residential units in the Houston area. Apartment Data Services estimates that 18,000 multifamily units were flooded which would yield about 144,000 single family structures damaged by Harvey-related flooding in the Houston MSA. This would also suggest that 45-50% of the total houses flooded were insured, a much higher number than has been widely reported. Part of the variance between these filings and earlier flooding estimates may be variation in the definition – FEMA’s estimates include an “affected” category (damage levels defined on the following page) – which has an expansive definition of damage. The survey described here has focused on damage at the moderate – destroyed level, making it possible that the difference between Meyers and others estimates of flooding may be in this “affected” category.

County	FEMA Damage Claim	FEMA Assistance Approved	Shelter Need Claims	Flood Insurance (NFIP) Claims
Austin	724	320	273	85
Fort Bend	22,698	22,654	12,730	3,799
Chambers	4,782	3,186	1,683	702
Brazoria	35,353	18,618	15,028	4,794
Galveston	32,346	20,269	12,474	8,358
Harris	290,843	177,553	112,990	47,035
Liberty	7,948	4,868	2,447	548
Montgomery	13,357	7,550	4,532	2,320
Waller	1,775	878	445	311
Total	409,826	255,896	162,602	67,952

Source: FEMA

An Uncertain Number: Homes Damaged by Harvey

The City of Houston has also released a flooding assessment, based on calls to 311, heavy trash pickups, and data reported to FEMA. This number suggests almost 160,000 flooded homes within Houston's city limits. Any flooding is serious, but the level of flooding can cause widely differing amounts of damage – with widely differing costs for repairs. To address this, FEMA qualifies flooding into four different categories of damage:

- **Destroyed** – total loss of structure, structure is not economically feasible to repair, or complete failure to major structural components (e.g., collapse of basement walls/foundation, walls or roof);
- **Major Damage** – substantial failure to structural elements of residence (e.g., walls, floors, foundation), or damage that will take more than 30 days to repair;
- **Minor Damage** – home is damaged and uninhabitable, but may be made habitable in short period of time with repairs; and
- **Affected** – some damage to the structure and contents, but still habitable.

None of the available surveys quantify the degree of damage; for instance, a home that may have received ½” of water in a garage that may merely requiring sanitation and light cleaning and a home that was destroyed by more than 6’ of water both count as “flooded,” despite the varying needs and policy ramifications of both types of damage.

Based on Meyers Research surveys and a review of available data, it is very likely that 190,000+ houses were “affected by flooding” in the Houston area after Harvey. Our research also suggests that the number of homes that most people would consider to have “flooded” – e.g. sustained enough water to require significant repairs such as replacement of flooring, sheetrock, and mechanical systems, is probably closer to 130,000 – 140,000. We believe the lack of clarification around the “affected” category of flooding explains the difference between these two counts.

Meyers Research Field Survey of Flooding in MUDs

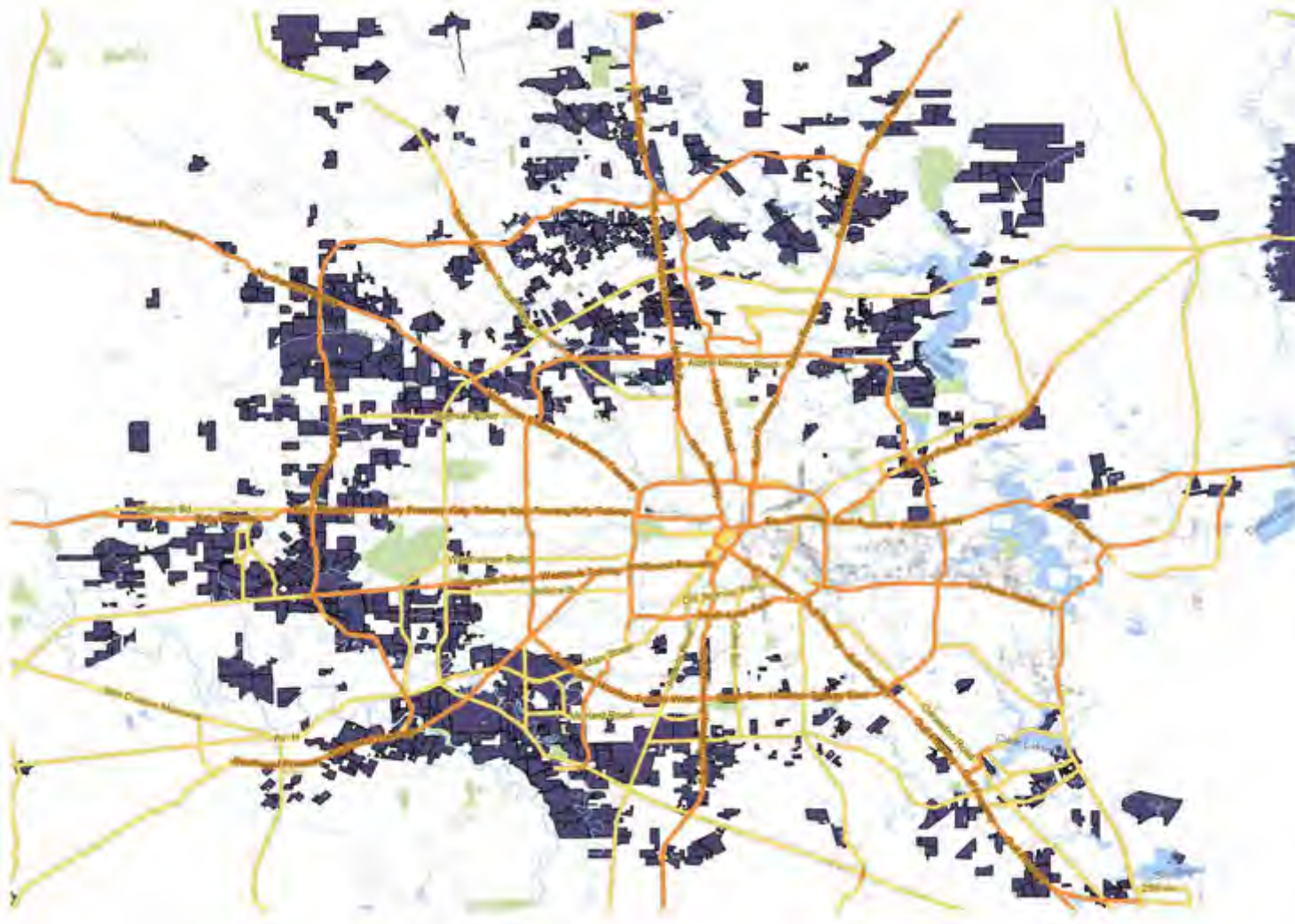
To get an accurate assessment of the extent of home flooding in utility districts, representatives of Meyers Research and Municipal Information Services surveyed districts in the Houston area using the following methodology:

- Review annual financial reports of utility districts where it is believed flooding took place
- Review official statements on new bond offerings that may reveal the extent of flooding
- Review event-based bond disclosures from districts reporting significant flooding
- Survey district operators to obtain numbers of flooded properties and damage to infrastructure
- Review aerial imagery from NOAA flown during the storm to identify the extent of flooding in districts
- Conduct field surveys to verify the extent of flooding when no other sources are available.

In the course of this research, Meyers Research and Municipal Information Services reviewed annual financial reports, event-based disclosures and official statements from over 500 utility districts, and conducted field surveys of flooding in over 200 additional districts. The results of this survey are the most accurate publicly available data on the extent of flooding in Houston area MUDs.

Vast Majority of Districts Experienced No Flooding

The vast majority of districts – 692 of the 945 utility districts in the Houston area – experienced no flooding whatsoever.



Source: Meyers Research, TCEQ, Open Street Map

Meyers Research Field Survey of Flooding in MUDs

- Utility districts are required to disclose certain events in official statements, annual reports or voluntary event notices that may be material to an investor’s decision on the bonds. An example of a possible disclosure is the extent of flooding. An official statement is the equivalent of an investment prospectus after bonds have been sold. Several hundred area districts have disclosed the extent of flooding, or lack thereof in these statements.
- NOAA conducted overflights of the Houston area from August 27 – September 2 to estimate the extent of flooding. The photos below are of Greatwood, described earlier as an area with very limited flooding, if any, and Grand Lakes, which suffered extensive home flooding.



Greatwood, Source: NOAA



Grand Lakes, Source: NOAA

Identifying a Flooded House After the Water is Gone

Where counts of flooded houses were not available, Meyers conducted a field survey. (1) The most obvious sign is the presence of debris outside the home. A surprising number of homes still have storm-related debris curbside even six months after the storm. Where debris has been cleared, there remains a residue of sheetrock and construction debris, and a sizeable area of dead grass in the front yard (2), sometimes even visible on aerial photography (3). In other cases evidence of construction like building permits (4) or construction dumpsters (5) indicate the home likely flooded.

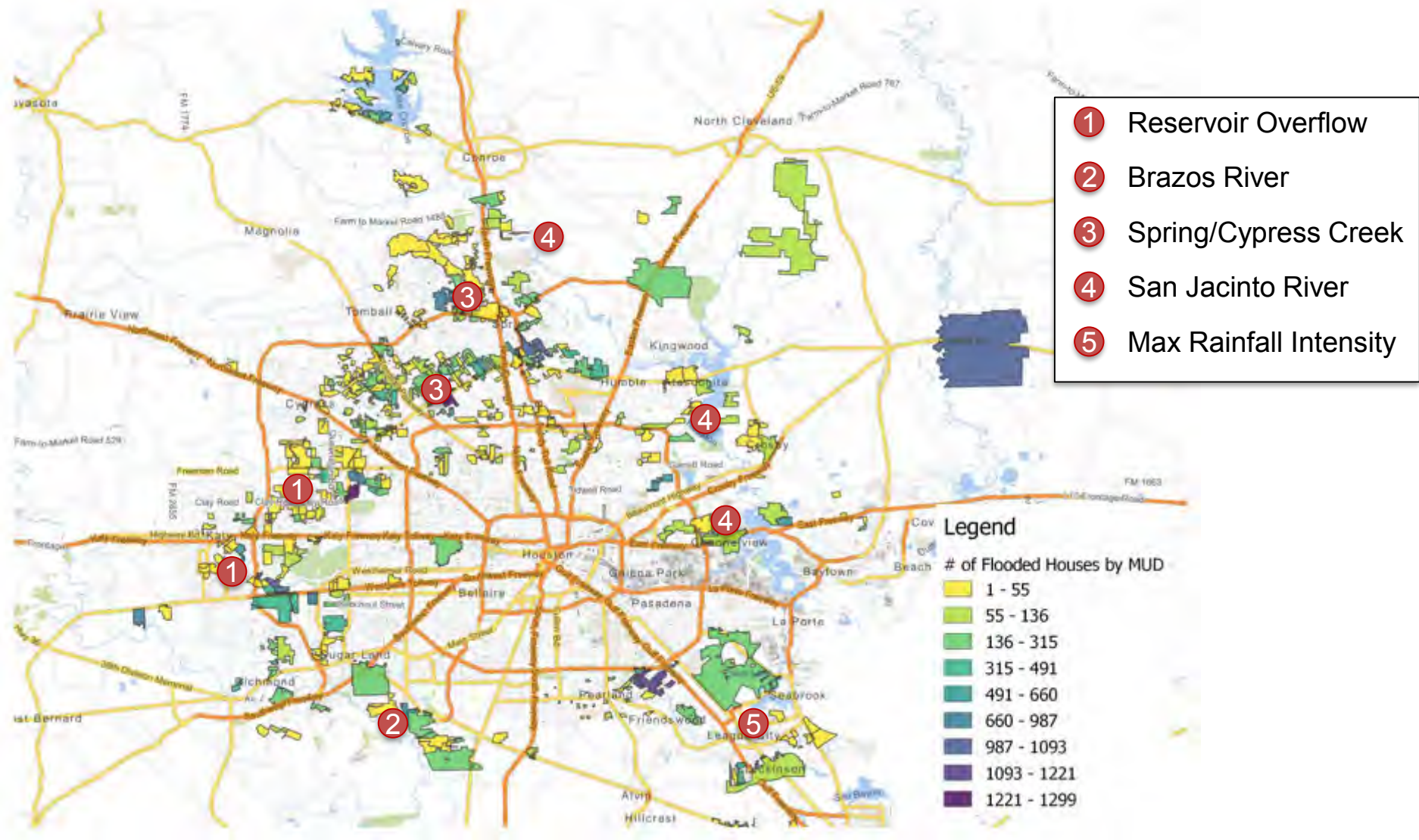


Survey Results: Flooding by District

The results of our survey show that roughly 37,211 homes within MUDs were flooded by Harvey. Of the 945 utility districts in the Houston MSA, 253 districts experienced flooding of one or more homes. In districts that experienced flooding, roughly 9% of the houses flooded, and in a total of 65 districts, more than 20% of the homes flooded. In terms of raw numbers, approximately 53 districts had more than 200 homes flooded. The average total number of flooded homes in all 253 districts with flooding was about 147 homes.

The map and tables on the following pages show the extent of flooding in utility districts in the Houston area. The flooding in suburban Houston can generally be grouped into five categories: overflow from the reservoirs; flooding along the Brazos River; flooding along Spring Creek and Cypress Creek; flooding along the San Jacinto River; and flooding around Clear Creek, the area of highest rainfall intensity. Additionally, Meyers Research has identified 139 bridge crossings across Houston's bayous where the bridge elevation is below the 500-year flood plain, potentially blocking stormwater drainage and contributing significantly to flooding conditions upstream.

Survey Results: Where Was the Flooding Concentrated?



Survey Results: Extent of Flooded Homes by District

After the completion of our survey, Meyers Research found 253 districts with at least one flooded home. These districts contained 411,483 homes and we estimate that 37,211 of homes were flooded. This is just over 9% of homes, roughly in line with the estimated percentage of homes that were flooded in the Houston MSA. Of these districts, just over 50% (129) experienced flooding in 5% or less of the homes. The largest number of flooded homes (9,087) were in the 59 districts that experienced flooding from 5% to 20% of the homes in those districts. Only 20 districts had flooding in more than 60% of homes, which represented a total of just over 7,600 homes.

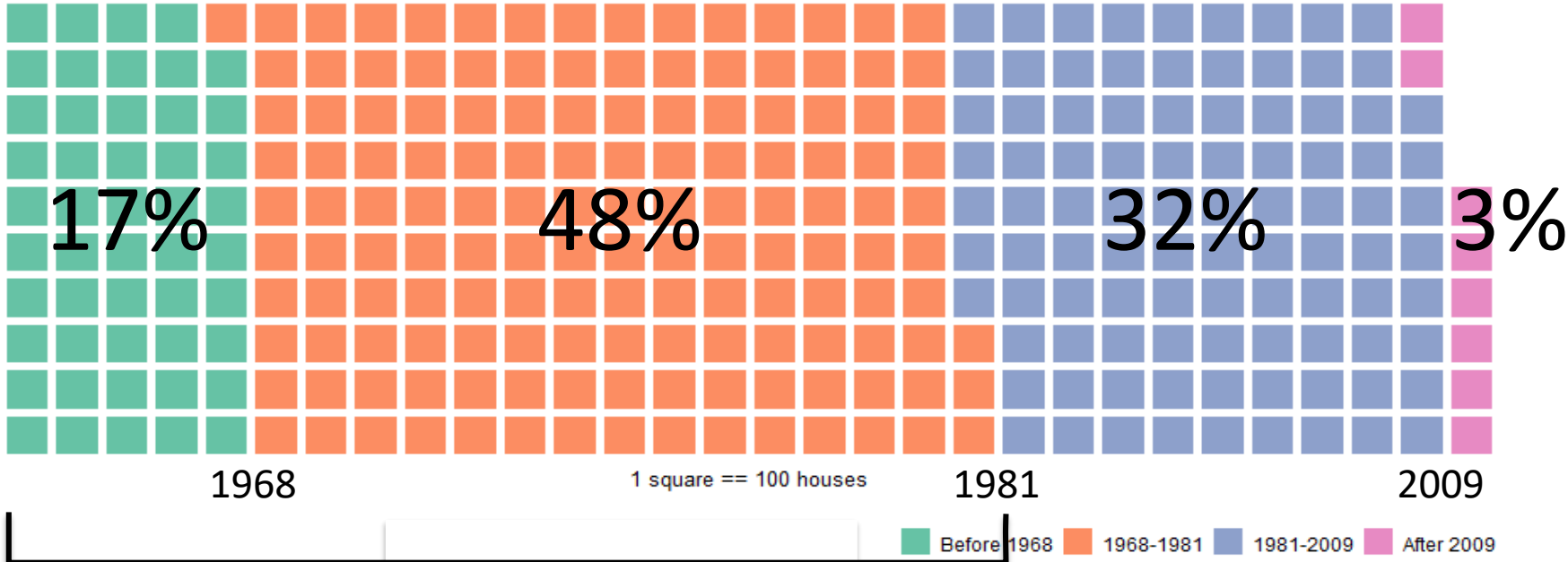
Percentage of Homes Flooded	No. of Districts	Total Homes	Homes Flooded
Less than 5%	129	271,189	4,163
5-20%	59	82,990	9,087
20-40%	30	31,907	8,660
40-60%	15	15,978	7,680
60-80%	9	4,085	2,869
80-100%	11	5,334	4,752
Grand Total	253	411,483	37,211

Survey Results: Flooding by Subdivision Plat Date

An accurate rendering of the date (and rules in place) of development is the date of the first subdivision plat filed within the utility district. Not all plats have dates readily available, and there are more than 22,000 subdivisions in Harris County alone.

The chart below shows the extent of flooding in our survey by the subdivision plat date, categorized by the state of floodplain regulation. The National Flood Insurance Program (NFIP) was not created until 1968; about 17% of houses which flooded are located in districts platted before the NFIP. More than 48% of houses which flooded are in districts with plats between 1968-1981; 1981 is the year that Flood Insurance Rate Maps (FIRM) were first available for Harris County. Prior to 1981 there were no FIRMs available for the area, and prior to 1984 Harris County did not require onsite stormwater detention. This was truly a watershed moment in development regulation. Another 32% were in districts platted between 1981-2009, when revised FIRMs and new regulations based on them were issued after the Tropical Storm Allison Project. Only 3% homes of the 37,211+ that flooded were in districts platted after 2009. The bottom-line is that as we learn more about flooding and implement stricter regulation, home flooding is reduced.

Flooding by Subdivision Plat Date



Survey Results: Compared to County Numbers

Meyers Research's survey shows that only about 3% of homes in areas developed after 2009 flooded as a result of Harvey. The 2009 date is significant because in that year Harris County adopted more stringent flood development regulations as well as new floodplain maps after Tropical Storm Allison.

Harris County recently conducted a similar survey of properties which flooded and concluded:

- *75,000+ homes were built in subdivisions developed in 2009 and later utilizing the current infrastructure requirements for drainage and extreme event flow analysis.*
- *Of those homes, only 467 flooded during Harvey, or 0.6%*
- *Zero homes were substantially damaged*

The survey results described here are slightly higher than those found by Harris County; the survey area here includes the entire MSA, not only Harris County and includes areas that experienced significant flooding along both the Brazos and Trinity Rivers, neither of which runs through Harris County.

Source: Harris County Engineering Dept



DISTRICT PERFORMANCE DURING THE STORM

Impact of Harvey on Houston MUDs

District Performance: Water Systems and Waste Water Plants

The TCEQ regulates the provision of water and waste water services and tracks the status of plant operations for all utility providers, including utility districts. The chart below is compiled from reports made to TCEQ by all utility providers regarding operations during and after Harvey. Some 213 utility providers issued “Boil Water Notices (BWN)” to their customers, indicating the water provided was not safe for consumption. Of these providers, only 12 were utility districts and all of them had the BWN orders rescinded. Of the almost 1,100 waste water treatment plants monitored by TCEQ, only 3 were completely destroyed, and one of those was operated by Cedar Bayou Utility District. The district is presently being serviced by the City of Baytown and will soon be annexed. There are also five WWTP operating with some issues, although it is uncertain that any of those are operated or owned by utility districts. This performance demonstrates the resilience of utility services provided by utility districts during this unprecedented storm.

County	Boil Water Notices	MUD BWN	Total WW Plants	Non-Operation/Destroyed	Operating WW with Issues
Austin	0	0	13	0	0
Brazoria	49	0	89	0	1
Chambers	9	0	29	0	0
Fort Bend	9	0	117	0	0
Galveston	1	1	47	0	0
Harris	76	6	627	3	3
Liberty	28	1	13	0	0
Montgomery	40	4	143	0	1
Waller	1	0	18	0	0
Total	213	12	1096	3	5

Source: TCEQ

District Performance: Water Systems and Waste Water Plants

The table below shows damages to utility district infrastructure reported during Meyers Research's survey of utility district operators. Of the 945 districts operating in the Houston MSA, only 23 reported damage to district facilities ranging from trivial to significant. Most of these districts had made repairs by early October and none still had interrupted service.

District	Facility Damage
Brazoria MUD 31	Stormwater infiltration in sewer system - rendered some toilets inoperable. Also 30 meter box tops floated away
Clear Lake City Water Authority	Sinkhole damage to drainage ditch. One of the authority's 30 lift stations was overcome by highwater and replaced with an auxiliary pump after the water had receded.
Cypress Creek Utility District	Water facilities undamaged. Lake Forest WWTP damaged - needs \$1.1 million in repairs
Cypress Forest PUD	Water plant #2 damaged. All electrical and chemical equipment, four booster pump motors, the NHCRWA surface water controls, generator transfer switch.
FB MUD 5	Approx. \$20,000 of damage to wastewater treatment plant
Fulshear MUD 1	2 City of Fulshear lift stations damaged. 4 days of interrupted sewer service due to City of Fulshear lift stations serving the district. No interruptions to water service
Galveston County MUD 30	Erosion damage around a drainage culvert, repaired for \$6,800
Greenwood Utility District	WWTP & admin building. Lost several electrical components
Harris County MUD 102	WWTP and several lift stations, also water well no 4. WW disrupted.
Harris County MUD 109	Flooded generator at lift station. Estimated \$23,750
Harris County MUD 18	Well motor at Oak Bluff water plant damaged. \$25,000 to replace motor.
Harris County MUD 238	Minor water line breaks.
Harris County MUD 286	5' of flooding at WWTP. Need to replace a 25 yo generator and four blowers. One lift station needs a new controller. Generator - 190K, Raise blowers \$275K, blowers \$300K
Harris County MUD 368	Pump station flooded. BNSF ROW inundated, no where for water to go. Pump later relocated to Northpointe Blvd where it was vandalized.
Harris County MUD 55	Leak in ladies' room at District Facility
Harris County MUD 71	Collapse of support column for District's water trunk lines.
Harris-Montgomery Counties MUD 386	Failure of water plant #2 and lift station #4. Damage also to lift stations #1 and #5, and the WWTP
Montgomery County MUD 137	WWTP damage to electrical system from flooding
New Caney MUD	Three lift stations & a well motor
Northwest Harris County MUD 5	District admin bldg flooded, blower needs replacement
Timber Lane Utility District	WWTP generator, electrical panels, UV disinfectant system. Estimated at \$300,000
Velasco Drainage District	West end pump station engine 3 blown. The River Flood over took the Clute-Lake Jackson Pump Station's Fresh Water Canal levee.
Westador MUD	District lift station completely underwater, along with a generator

Source: Meyers Research Survey



UTILITY DISTRICT FINANCIAL PERFORMANCE

Impact of Harvey on Houston MUDs

Ratings Outlook Positive

In September, Moody's indicated that 33 MUD bond ratings/outlooks were under review. To date, 20 of those ratings have been confirmed, and only 3 of the 33 districts were downgraded to a negative outlook.

Issuer Name	Rating/Outlook	County	Debt Outstanding 8/27/17	Status
Cnp Utility District	A1/NOO	Harris	\$15.94M	Confirmed
Corinthian Point Municipal Utility Dist 2	Baa3/STA	Harris	\$1.39M	Confirmed
Cypress-Klein Utility District	A1/NOO	Harris	\$355,000	Confirmed
Fort Bend Co MUD 144	Baa2/STA	Fort Bend	\$15.40M	Confirmed
Fort Bend Co. MUD 25	A2/NOO	Fort	\$100.39M	Confirmed
Fort Bend County MUD 116	A2/NOO	Fort Bend	\$26.34M	Confirmed
Fort Bend County MUD 117	A2/NOO	Fort	\$16.13M	Confirmed
Fort Bend County MUD 152	Baa3/STA	Fort Bend	\$8.40M	
Fort Bend County MUD No. 128	A2/NOO	Fort	\$67.47M	
Fulshear MUD 1	Baa2/STA	Fort Bend	\$13.29M	
Galveston County MUD 14	A3/NOO	Galveston	\$9.61M	Confirmed
Harris County MUD 109	A2/NOO	Harris	\$28.39M	Confirmed
Harris County MUD 132	A1/NOO	Harris	\$385,000	
Harris County MUD 153	A1/NOO	Harris	\$23.02M	Confirmed
Harris County WCID 132	Baa1/STA	Harris	\$3.80M	
Kleinwood MUD	A2/NOO	Harris	\$11.83M	Confirmed
Montgomery County MUD 46	Aa3/NOO	Montgomery	\$82.91M	
Montgomery County MUD 9	A1/NOO	Montgomery	\$12.11M	
Montgomery County MUD 94	A3/NOO	Montgomery	\$33.16M	Confirmed
Montgomery County MUD 95	Baa2/STA	Montgomery	\$20.93M	Confirmed
Montgomery County MUD 90	Baa2/STA	Montgomery	\$20.93M	Confirmed
Montgomery County WCID 1	A3/NOO	Montgomery	\$13.49M	
Montgomery MUD 90	Baa2/STA	Montgomery	\$8.09M	
New Caney MUD	A3/NOO	Montgomery	\$25.17M	
Northampton MUD	A2/NOO	Harris	\$28.90M	
Northeast Harris Co. MUD 1	Baa3/STA	Harris	\$8.51M	
Oakmont PUD	A2/NOO	Harris	\$30.05M	Confirmed
Pecan Grove MUD	A1/NOO	Fort Bend	\$53.34M	Confirmed
Southern Montgomery County MUD	A2/NOO	Montgomery	\$7.56M	
Spring Creek Utility District	A2/NOO	Montgomery	\$52.12M	
Timber Lane Utility District	A2/NOO	Harris	\$49.48M	Confirmed
Varner Creek Utility District	Baa1/NOO	Brazoria	\$7.46M	Confirmed

Source: S&P

Even with Flooding, Districts Have Strong Financial Performance

Meyers Research reviewed the financial performance of the districts which experienced the most severe flooding, which was defined as 200 or more homes with flood damage. The financial position of these districts is extremely strong. More than half (24) of these districts have enough operating reserves to cover between 2 and 5 years of debt service, and another third (16) have more than 5 years of debt service held in operating reserves. Only 7 districts had less than 1 year's debt service in operating reserves and collectively these seven districts are expected to cover 98% of 2018 debt service through estimated tax collections.

Category	Districts	Flooded Houses	Debt Outstanding (\$)	Operating Reserves (\$)	2018 Debt Service (\$)	2018 Estimated Tax Revenue (\$)
2- 5 year	24	11,809	517,228,046	76,760,358	36,621,074	42,142,744
Less than 1	7	3,476	276,750,000	27,508,212	22,368,842	22,141,632
More than 5	16	7,696	163,973,618	75,101,306	11,843,754	21,411,748
Grand Total	47	22,981	957,951,664	179,369,876	70,833,670	85,696,124

Source: Municipal Information Service

Home Sales: Even Flooded Districts Weathered the Storm

Meyers Research reviewed over 97,000 transactions in the Houston Association of Realtors Multiple Listing Service, specifically at transactions in the 12 months prior and 90 days following Harvey in the 253 districts which experienced flooding during Harvey. There were 19,226 sales in 230 of these districts before and about 5,553 after the storm. The average district experienced a decline of just under \$10,000, or about 4% from the pre-storm sales price.

The 230 districts were almost evenly split between those that saw average prices increase (116) and decrease (114). The average price increase was about 10% while the average decrease was about 15%. It's easy to understand why home prices would decrease after a storm – but some of the reasons why home prices would increase are less clear. The most logical explanation is that these are prices on properties which had never flooded and sellers were able to obtain a premium for perceived flood resilience. In other cases it may be the unit mix of properties for sale has changed; in a large district there will be a mix of new and older existing product for sale. Given the relatively small number of new properties which are reported to have flooded, it could be that the mix of properties for sale after the storm is more concentrated on new homes with fewer existing homes than before the flood which would result in a higher average price. One example of this is likely in Montgomery County MUD 2. Seven Coves and Harbor Town are communities with a mix of lots both on and off of Lake Conroe. A change in the mix of waterfront sales could easily explain a significant increase in average sales in this district.

There is also at least some anecdotal evidence that flooded houses may even experience price increases – there appears to be a divergence in pricing between single flooded and multiple flooded homes. In older communities, these first-time flooded homes may receive significant upgrades through remodeling. They also appear to receive some of the benefit of never-flooded homes given the uniqueness of an event like Harvey. Multiple flooded homes do not appear to receive this kind of benefit with the possible exception of homes in urban neighborhoods with significant teardown activity. None of these areas were included in this study because they aren't in MUDs.

Category	District Count	Pre-Storm Price	Post-Storm Price	Change	Change Pct
Price Decrease	114	273,056	243,643	-42,236	-15%
Price Increase	116	236,413	258,306	21,893	9%
Total	230	254,576	251,236	-9,893	-4%

Source: TCEQ, HAR MLS

Home Sales: Even Flooded Districts Weathered the Storm

What happens to homes in those districts who experienced significant flooding and have seen prices decline by thousands of dollars? In a recent interview with the *Houston Chronicle*, Brian Spitz of Big State Home Capital Buyers discussed the approach of investors to the flooded home market. In this interview, Spitz explained that investors will typically buy a home at 85% of pre-storm value less the cost of repairs.

The chart below shows an example of an investor purchase of an “average” flooded home in one of the more severely impacted districts. An estimate of \$30 per square foot is used as a repair cost. A home with this type of flooding damage is likely to include sheetrock and flooring replacement, new plumbing fixtures and a complete kitchen remodel.

Category	Amount
Average Pre-Storm	\$ 157,883
Average Post-Storm	\$ 94,954
Difference	\$ (62,928)
Percentage Change	-39.9%
Average Size	1,750
Repair Cost/SF	\$ 30.00
Repairs	\$ 52,500
Post-repair value	\$ 147,454
Difference	\$ (10,428)
Percentage Change	-6.6%

The estimate shows that after repairs, the post-storm value of the flooded house has only declined about 7% over pre-storm pricing. For the owners of this particular home this is still not an ideal result, but from a financial perspective of a district, a 7% reduction in value is a much healthier result than a decline of 30-40%. How likely are these sales to be taking place? In the first 90 days after the storm, there are roughly one-third the number of sales of the previous twelve months in districts which experienced flooding in 50% or more of their homes. That is the same ratio of pre- and post-storm sales in both districts with less than 50% of homes flooded, and in the general single family sales market over that same period. So it appears that buyers are active in heavily flooded districts, suggesting price support along the lines of this example.

Source: TCEQ, HAR MLS



WHY WAS THE FLOODING SO EXTENSIVE?

Impact of Harvey on Houston MUDs

What Caused Harvey's Flooding To Be So Extensive?

A full analysis of the causes of the extensive flooding due to Harvey would require an in-depth engineering study that is beyond the scope of this report. Some individual districts have engaged such studies, and where those results are publicly available, this report will include them here.

The most obvious cause of the extensive flooding during Harvey is the unusual nature of the storm itself. The introduction to this report references the National Hurricane Center's review of Harvey and the historic amounts of rainfall from the storm. The report elaborates on why the rainfall from Harvey was so much more intense than any storm ever recorded in the United States:

“The meteorological situation that caused Harvey to produce these extreme rains deserves additional explanation. While Harvey was very slow moving over Texas, not all drifting cyclones produce such torrential rain totals, and it is notable that the heaviest rainfall fell outside of the core of the cyclone. Harvey moved into a somewhat baroclinic environment over Texas, with slightly cooler and drier air over the southern United States behind a weak stationary front. The weak front was situated across the Houston metro area from 26-27 August, enhancing surface convergence and lift within the very warm and humid air on the eastern side of Harvey, leading to several episodes of heavy rain. Upper-level divergence was also occurring near the front, further contributing to large and intense rain bands. The rain rates observed in these bands were exceptional, with 6.8 inches of rain in just one hour documented in southeastern Houston from extremely heavy rain bands training over the same location. The front hardly moved from 27-28 August, leading to the extreme rainfall totals in the Houston metro area since the main inflow band originated over the very warm waters of the northwestern Gulf of Mexico, which provided multiple influxes of warm and humid air. It should be noted that while the magnitude of this event was unprecedented, the synoptic situation was not, and previously has been associated with other tropical cyclone flood events near the coast. “

Source: National Hurricane Center

What Caused Harvey's Flooding To Be So Extensive?

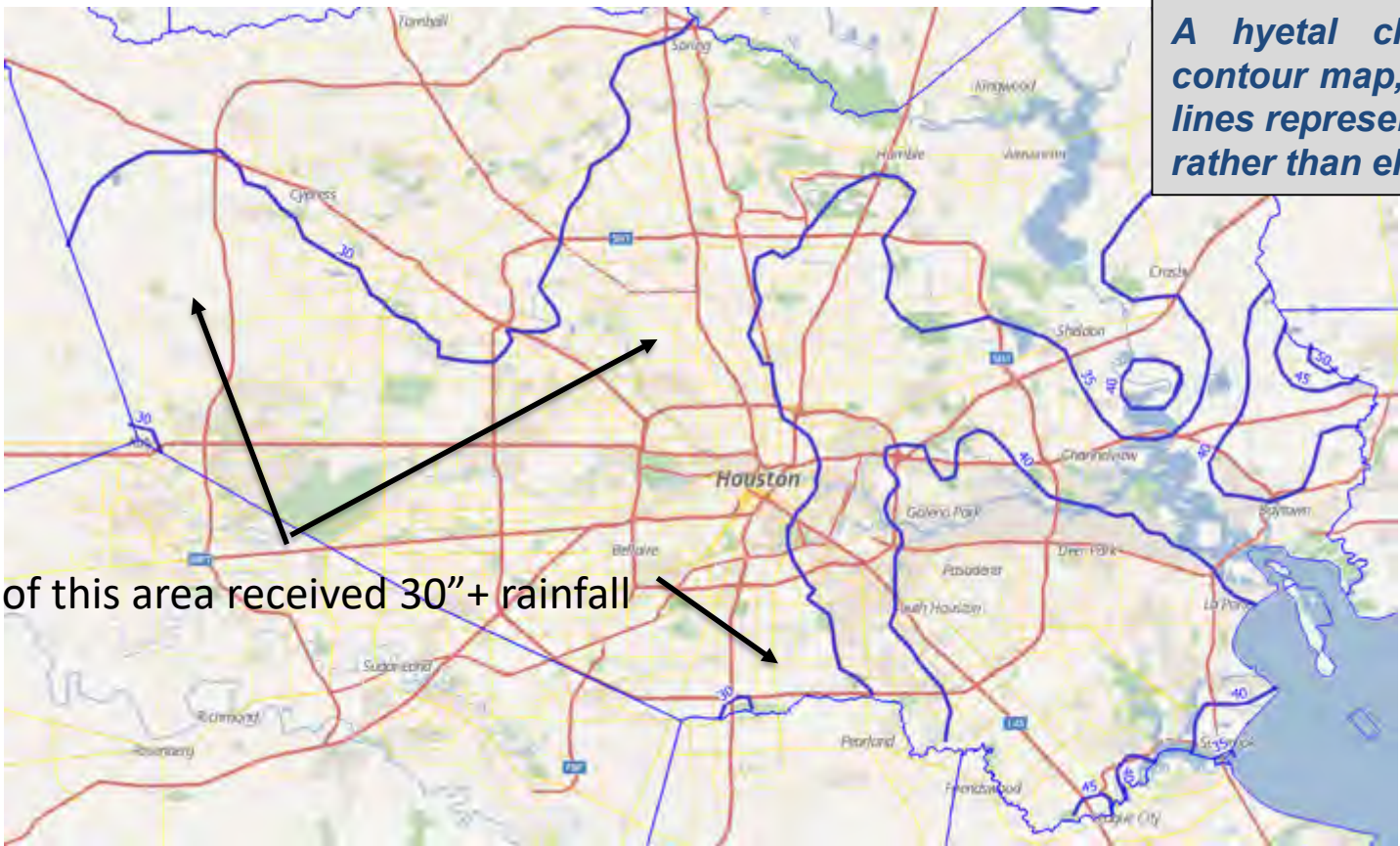
The question that recovery and mitigation efforts are trying to answer is the extent to which “development causes flooding.” There is some truth to the suggestion, which is why since 1985 developments, at least in Harris County, have been required to include detention to limit runoff rates to pre-development levels. Studies in this area are very limited, but one of the most recent was the Cypress Creek Overflow study, conducted by the Harris County Flood Control District in 2015. This study suggests that about 75% of the rainfall on undeveloped land in western Harris County is converted to runoff, and rises to 90% of rainfall converted to runoff on developed tracts, about a 15% increase. As the maps on the following pages will show, the vast majority of this area studied by HCFCD was developed before stormwater detention was required, and even before flood plain maps were available for Harris County.

What this section will show is:

- Although the Houston area has experienced rainfall intensities in the past that were similar to Harvey, the region has never experienced that intensity of rainfall over such a broad geographic area;
- After extensive flooding in 1935, the US Army Corps of Engineers (USACE) built the Barker and Addicks reservoir system – the rainfall produced by Harvey exceeded the design storm of these facilities;
- Harvey represented a 1,000-year rainfall event for most of the Houston region, and in most areas that experienced significant flooding; while there is no defined “1,000-year flood plain”, water levels in bayous and creeks in these areas exceeded the 500-year flood plain by 2-3 feet;
- Despite the suggestion that wetlands “lost” to development could have stored significant amounts of rainfall, in fact those “lost” wetlands would only have been able to hold a very small percentage of that rainfall;
- In addition to lacking the natural capacity to store Harvey’s rainfall in natural drainage features like wetlands, the areas which experienced the most significant flooding have soils which have extremely high runoff potential;
- There are more than 139 locations in the Houston area where bridges are below the 500 year flood plain elevation, and more than 100 that are below the 100-year flood plain elevation – these low bridges can often function like a damn and potentially worsen flooding conditions upstream of the bridge;
- Despite years of research into the dangers of upstream flooding around the reservoirs, a highly accurate rainfall forecast and days of intensive modeling, the USACE failed to provide property owners and residents notice of the dangers of flooding both upstream and downstream of the reservoirs;
- In reviewing the performance of district facilities during the storm, there was no evidence that a district drainage facility – or the absence of a district drainage facility was a cause or contributed to the flooding of homes or businesses.

Harvey's Rainfall Unlike Any Previous Storm

A common suggestion is that Houston should have been better prepared for the storm. Certainly more preparation is generally better; any loss of life or property in a disaster is a tragedy. Parts of Houston have experienced rainfall intensity like Harvey before, but not over such a broad geographic area. Harris County received on average 35" of rainfall over the four days of the storm – compared to about 47" of annual average rainfall. The hyetal chart below shows the extent of rainfall intensity from Harvey. The maps on the following pages show hyetal charts for historical storms versus that for Hurricane Harvey.



A *hyetal chart* is like a contour map, except that the lines represent rainfall totals, rather than elevation.

All of this area received 30" + rainfall

Source: Meyers Research analysis of data from LJA, Open Street Map

Harvey's Rainfall Far Exceeded the 1935 Storm

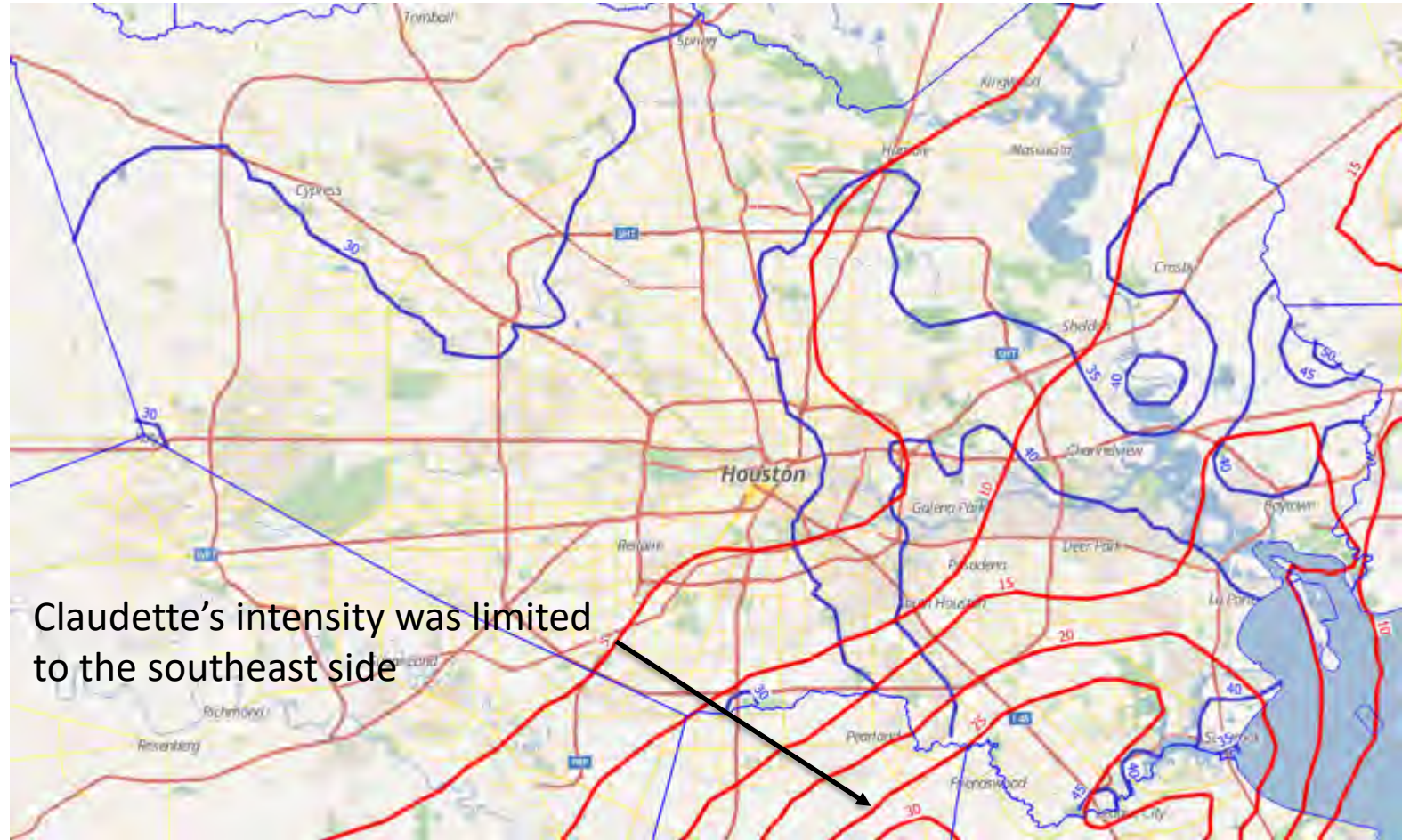
The hyetal chart below compares the Harvey rainfall intensity versus the 1935 storm that prompted creation of the Harris County Flood Control District and the reservoirs. Although we do not have the full level of rainfall across the entire county, it is clear from this storm that intensities were concentrated in the Katy Prairie.



Source: Meyers Research analysis of data from LJA, USACE, Open Street Map

Rainfall Intensity More Widespread than TS Claudette in 1979

The hyetal chart below compares the Harvey rainfall intensity to Tropical Storm Claudette which struck Houston in 1979. Alvin, Texas, 20 miles south of Houston still holds the US record for rainfall in a 24-hour period – 43". This storm also demonstrates a fairly tight pattern of high rainfall intensity.



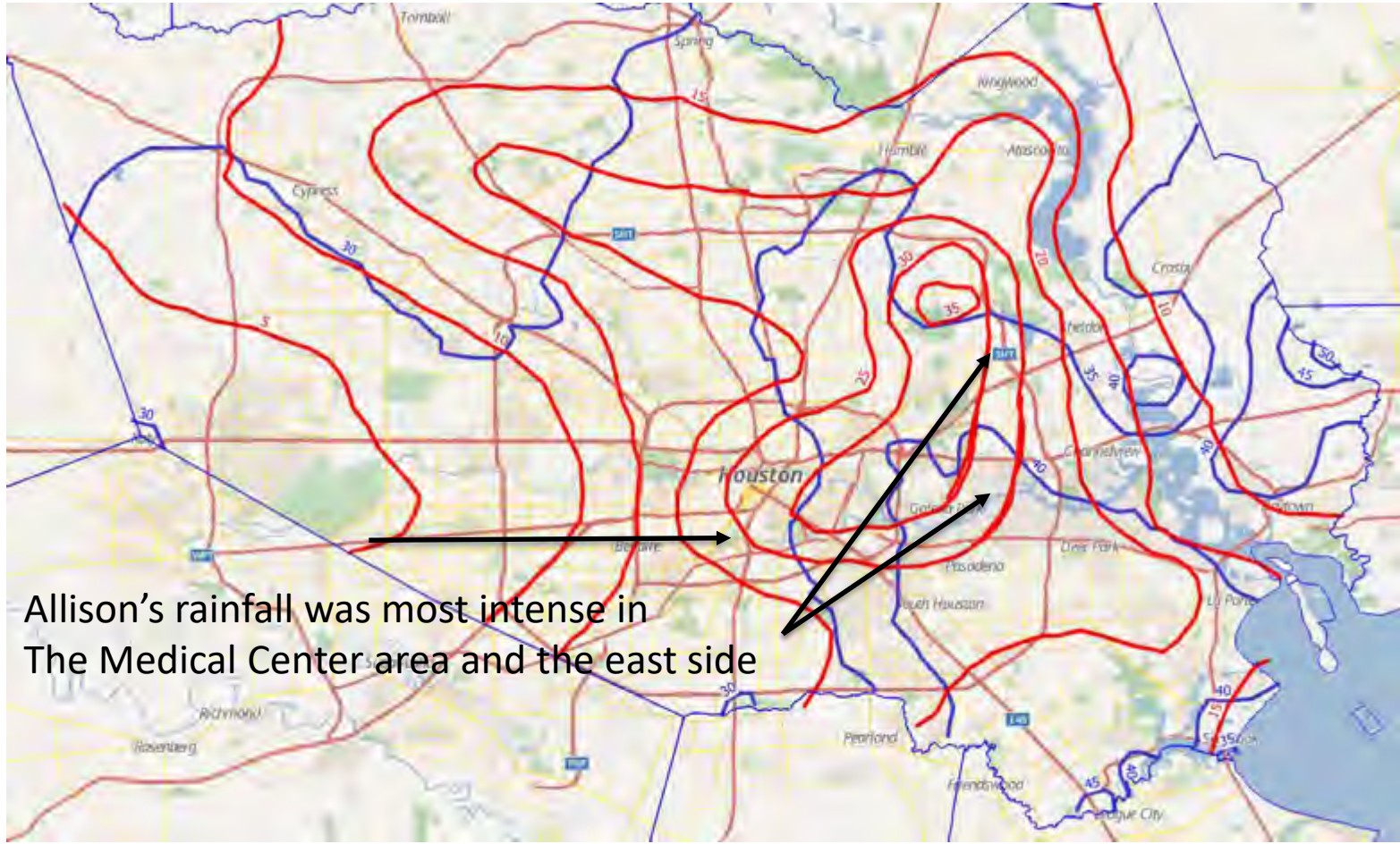
Claudette's intensity was limited to the southeast side

- Harvey
- Claudette

Source: Meyers Research analysis of data from LJA, USACE, Open Street Map

Harvey Matched Allison Intensity but over Larger Region

Prior to Harvey, Tropical Storm Allison was the “gold standard” for storm impacts, and the storm had higher 24 hour rainfall records than Harvey. Allison crippled the city and flooded thousands of homes. But even with Allison, high rainfall intensities were concentrated in much smaller areas ranging from the Texas Medical Center to the East Belt.

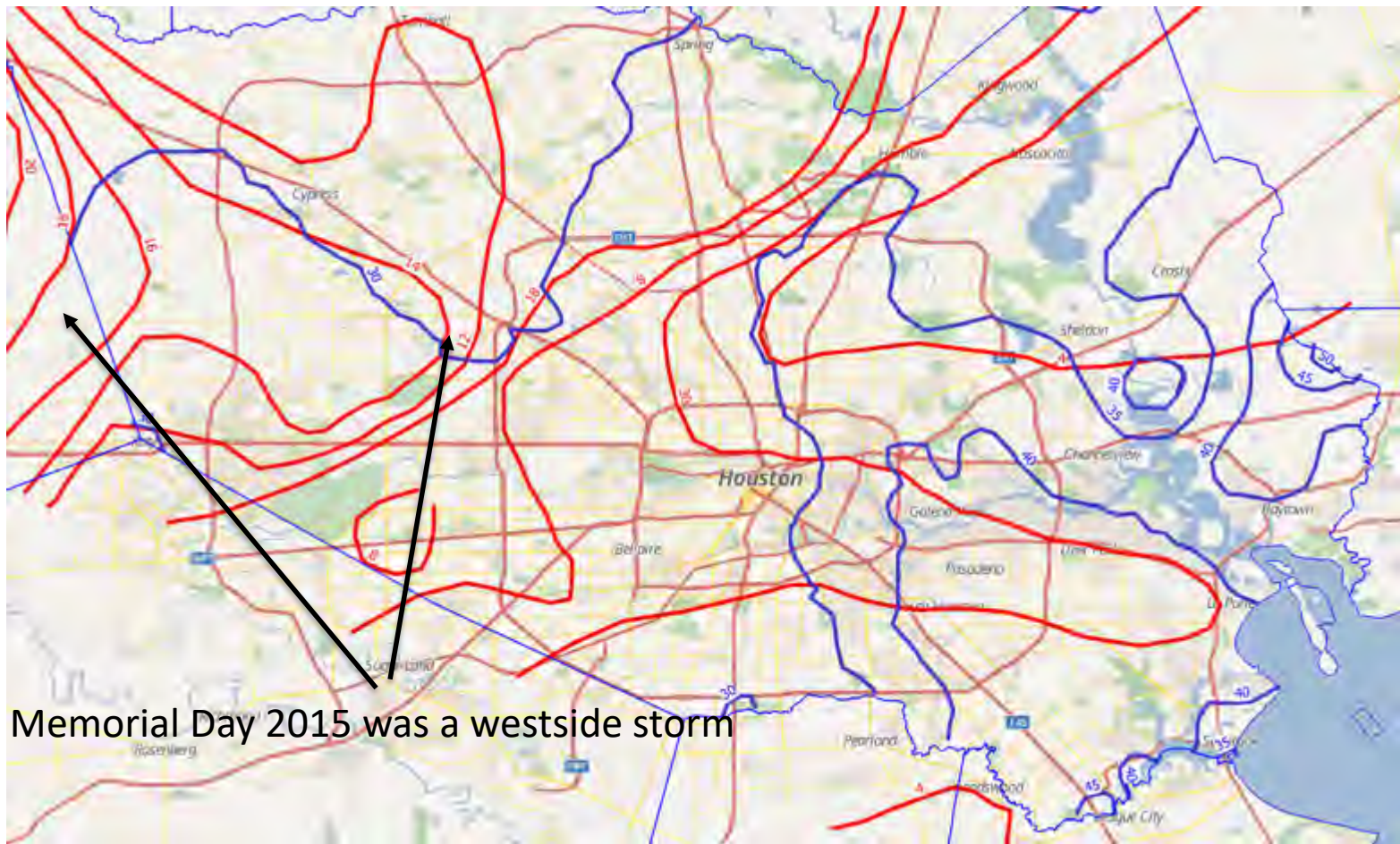


Allison’s rainfall was most intense in The Medical Center area and the east side

Source: Meyers Research analysis of data from LJA, USACE, Open Street Map

Harvey Surpassed Memorial Day Storm of 2015

The hyetal chart below shows the rainfall intensities of Harvey versus the Memorial Day storm of 2015. The intensity bands are only for a 12 hour period, but again show the intensity of rainfall concentrated in western Harris County, and even then the highest rainfall levels were in the 12 – 18” range.



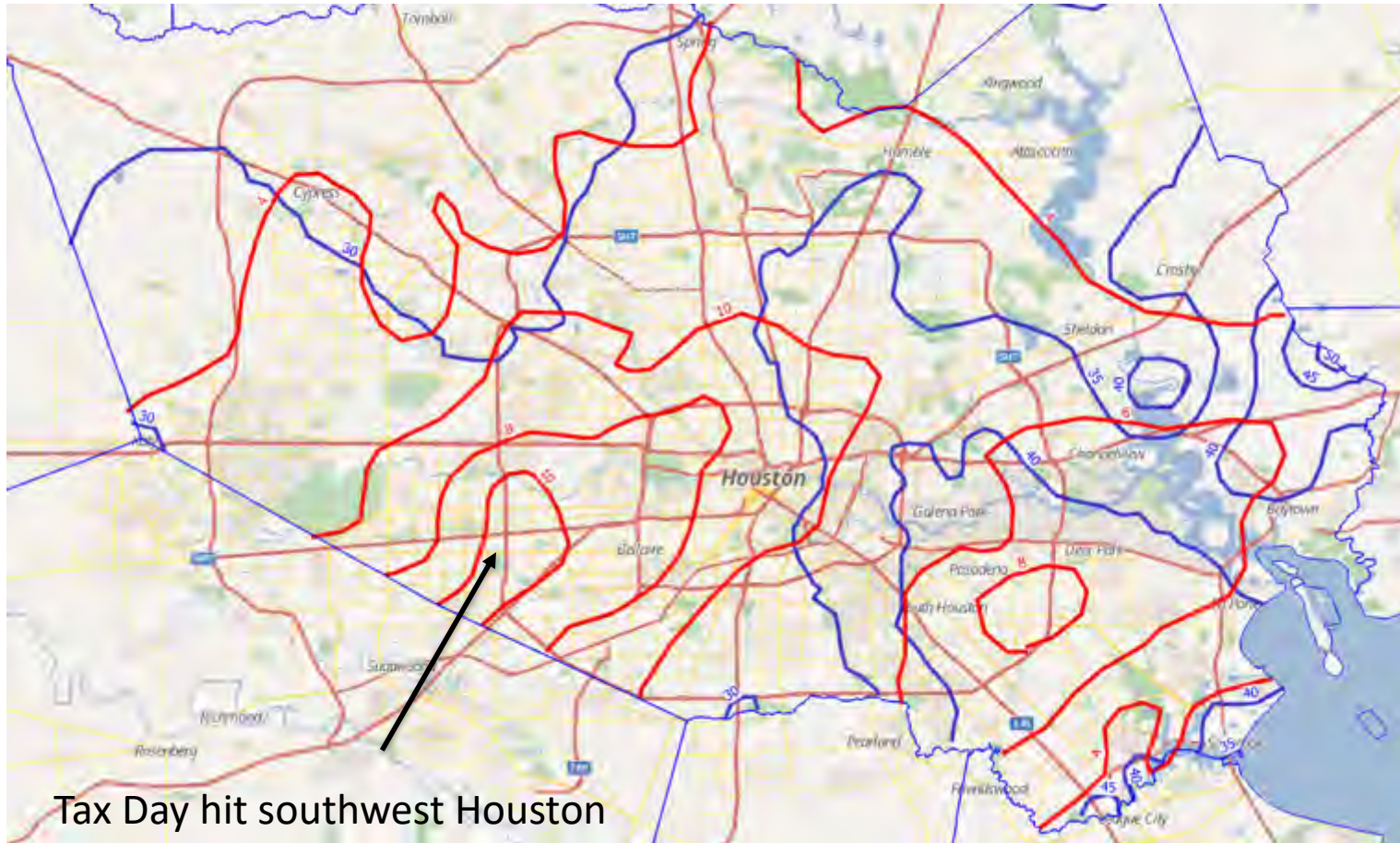
— Harvey
— Memorial

Memorial Day 2015 was a westside storm

Source: Meyers Research analysis of data from LJA, USACE, Open Street Map

Harvey Surpassed Tax Day Storm of 2016

This hyetal chart compares the 2016 Tax Day storm versus Harvey. Again these are 12-hour intensity curves for the 2016 storm, but here again the most intense rainfall took place in the West Belt/Westchase area, causing extensive flooding in areas like Meyerland.



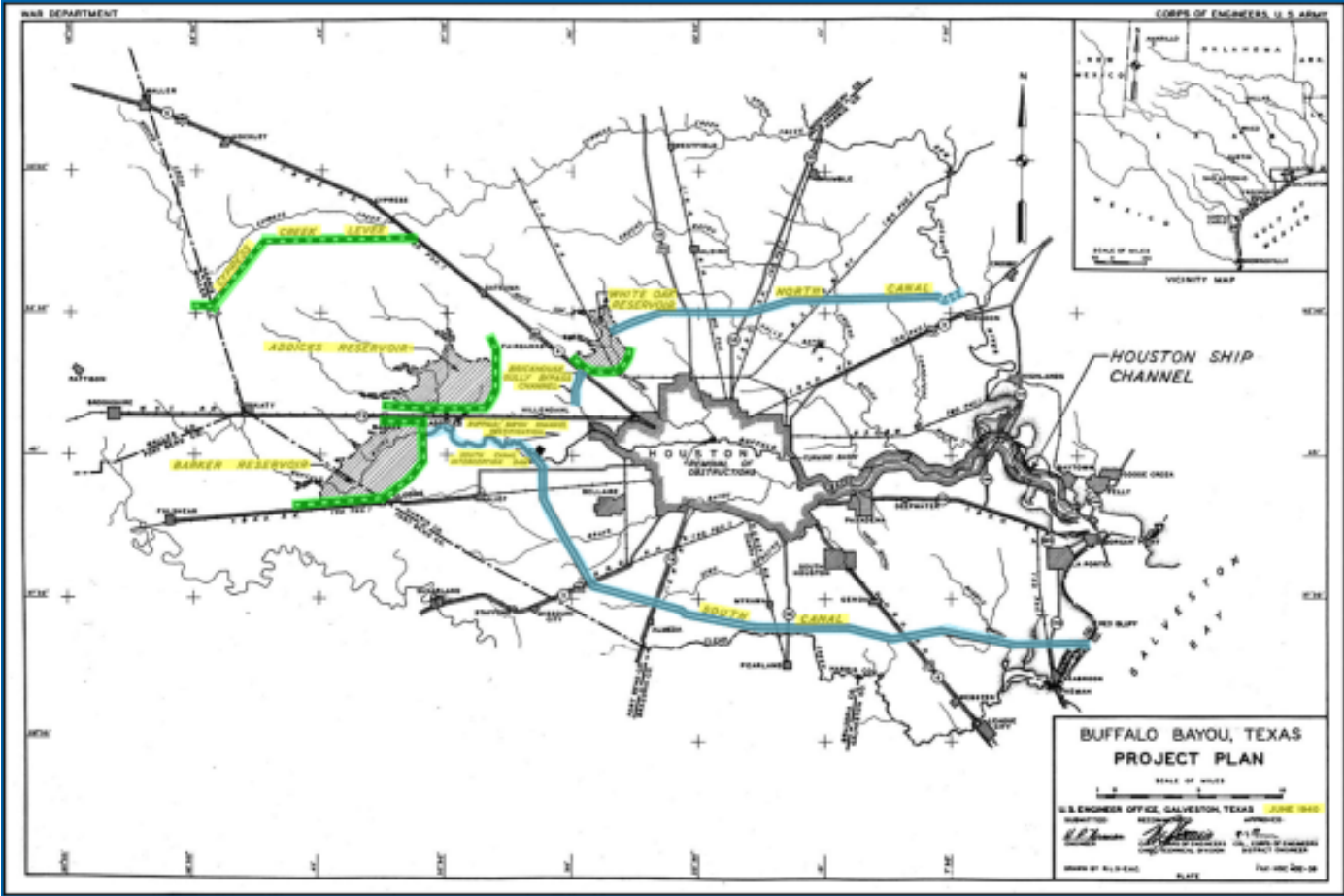
— Harvey
— Tax Day

Tax Day hit southwest Houston

Source: Meyers Research analysis of data from LJA, USACE, Open Street Map

The Original Reservoir Plan Was Never Completed

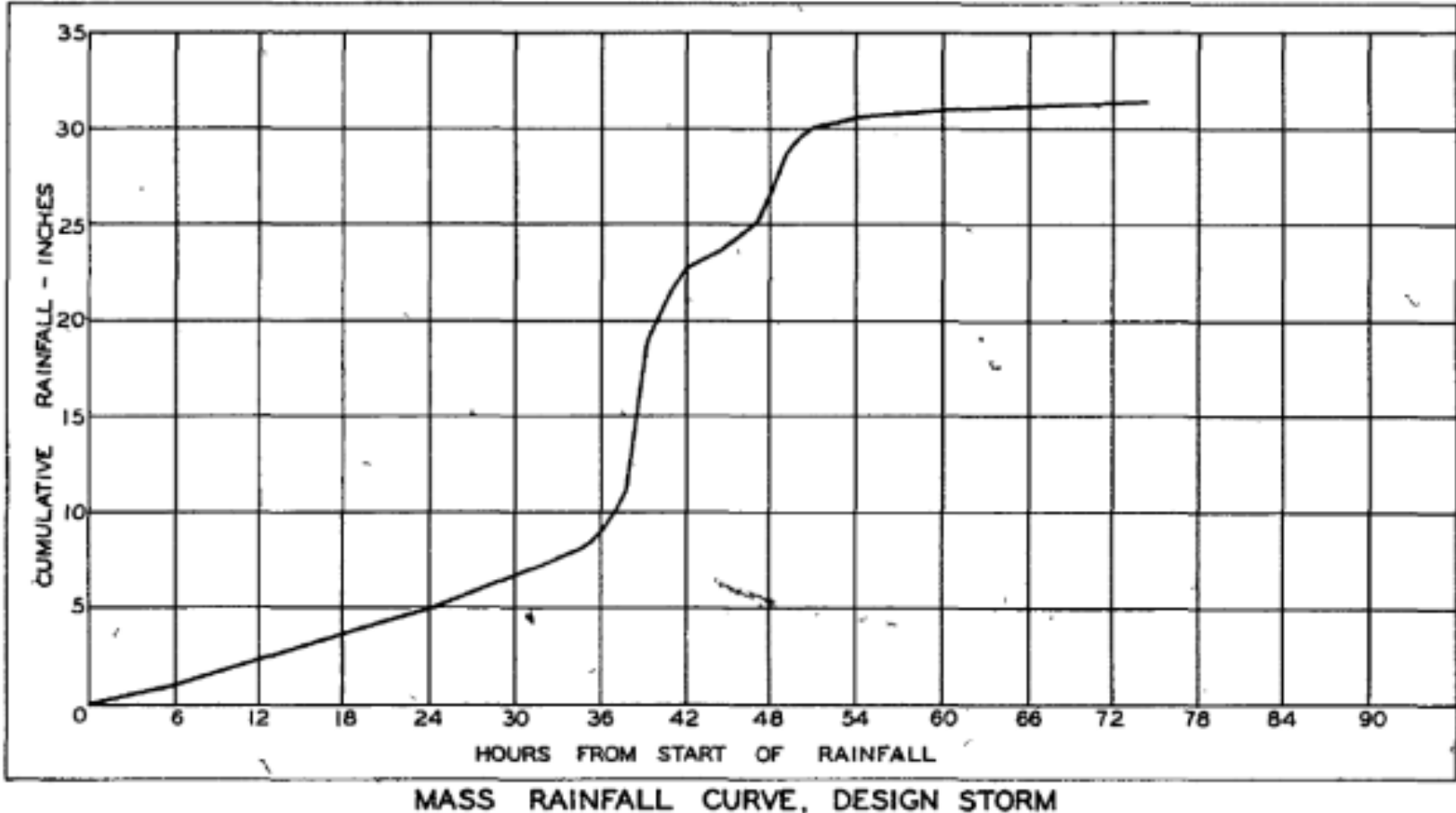
The map below shows the original plan prepared by the Army Corps of Engineers in 1940. The plan called for three reservoirs, a levee to prevent overland flow from Cypress Creek into the Addicks Reservoir, and a north and south drainage channel. Of these recommended improvements, only the Addicks and Barker Reservoirs were actually built.



Source: US Army Corps of Engineers

The 1940 Reservoir Design Storm Planned for 31" in 72 Hours ...

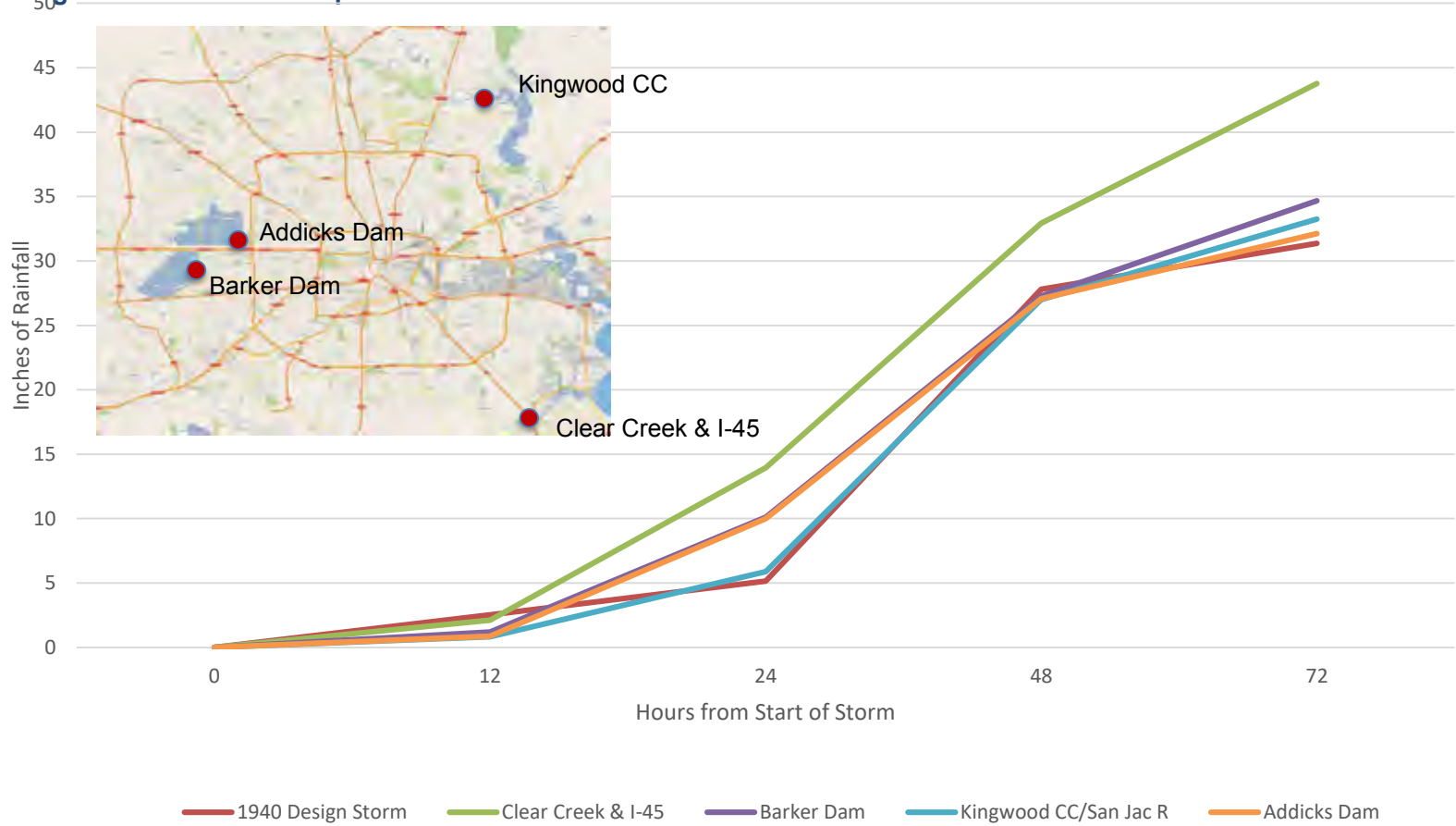
The US Army Corps of Engineers combined two storms, one from 1899 and another from 1918, to create the design storm for the 1940 reservoir plan. This storm showed the area receiving approximately 31" of rain in 72 hours.



Source: US Army Corps of Engineers

... And Was Exceeded by Harvey's Rainfall

The red line in the chart below shows the rainfall curve of the 1940 design storm. The chart also shows rainfall reported from Harris County Flood Control District gauges at locations at Barker Dam, the Addicks Dam, I-45 & Clear Creek and Kingwood Country Club at the San Jacinto River. All of these locations except Kingwood Country Club received rainfall that exceeded the design storm for the 1940 plan.



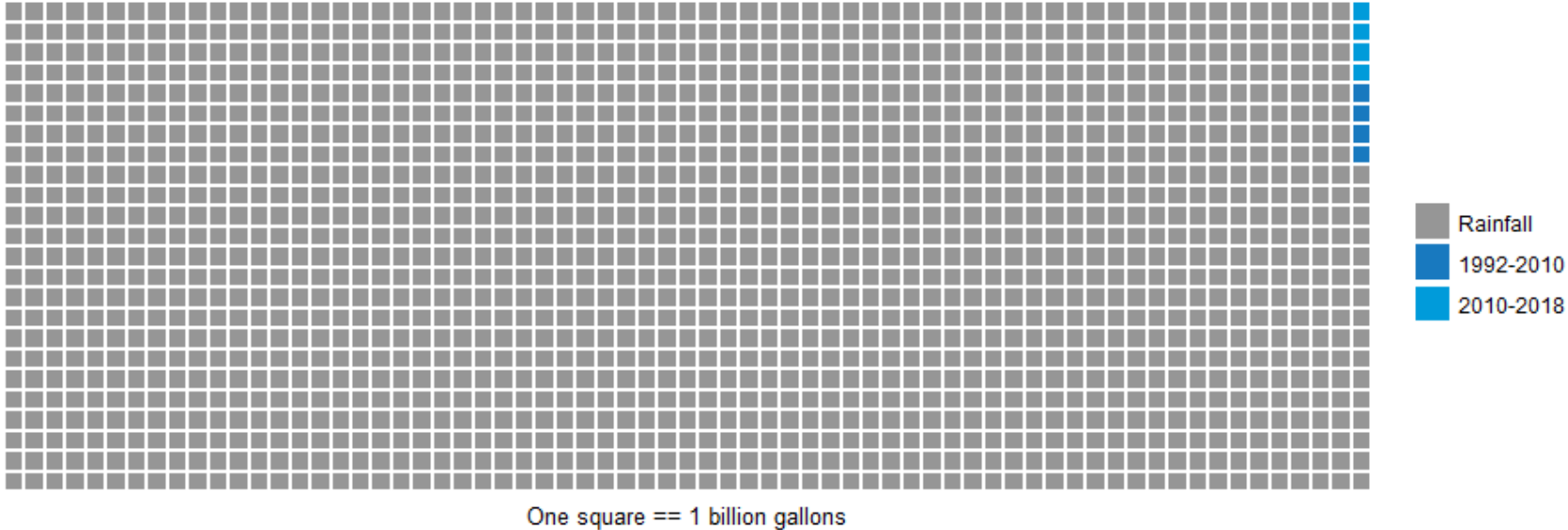
Source: Meyers Research analysis of data from HCFCD and USACE

Harvey's Rains Overwhelmed Even an Undeveloped Katy Prairie

John S. Jacob, in his study, *Houston Area Freshwater Wetland Loss, 1992 – 2010* (Texas A&M University System), suggests that the native wetlands in the Katy Prairie could have absorbed much of the floodwaters that overwhelmed west Houston. It states that west Houston wetlands loss "...in the study area is equivalent to at least 12,000 acre-feet, or nearly 4 billion gallons, of storm water detention." The study period ended in 2010 so there are no figures available for development over the last decade. Areas west of Houston have seen significant development but during this period wetlands and floodplain development have significantly changed; without a replication of the original study it is difficult to say how much water storage capacity could have changed.

Using the calculations shown on the following page, Harvey dumped 1.6 trillion gallons of rainfall on Harris County alone during its four days in the Houston area. The graph below shows the total amount of rainfall from Harvey, the 4 billion gallons potentially stored as defined by the Jacobs study, and an additional 4 billion gallons, assuming the wetlands loss defined in the study doubled from 2010-2017.

Harvey Rainfall

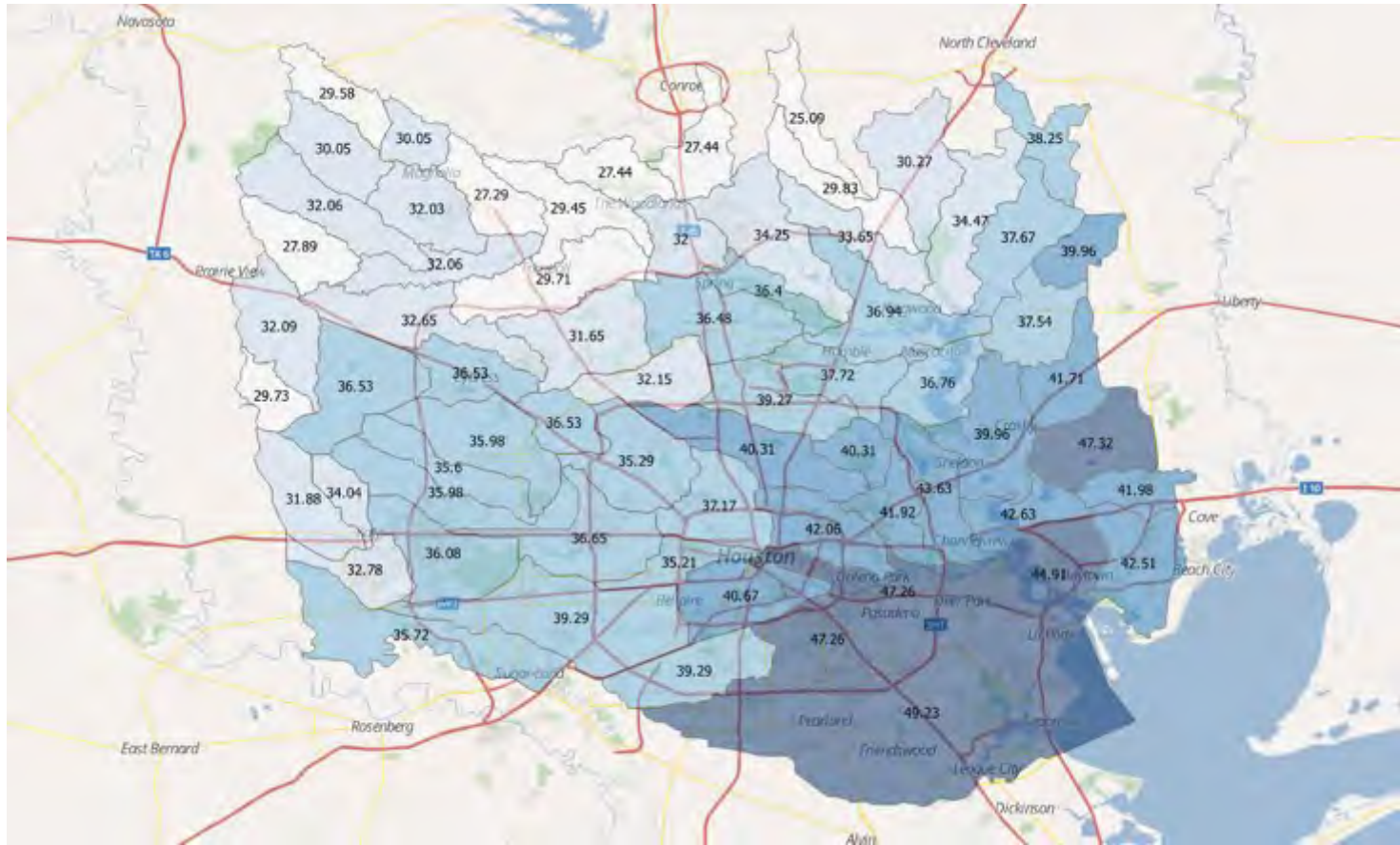


Harvey produced hundreds of billions of more gallons of rainfall than could have been absorbed by these “lost wetlands” – under even the most conservative analysis.

Harvey Dumped 1.6 Trillion Gallons of Water on Harris Co Alone

One inch of rainfall over one acre yields 27,154 gallons of water. The map below, from data compiled by NOAA and Harris County Flood Control District shows the average amount of rainfall over each watershed in Harris County.

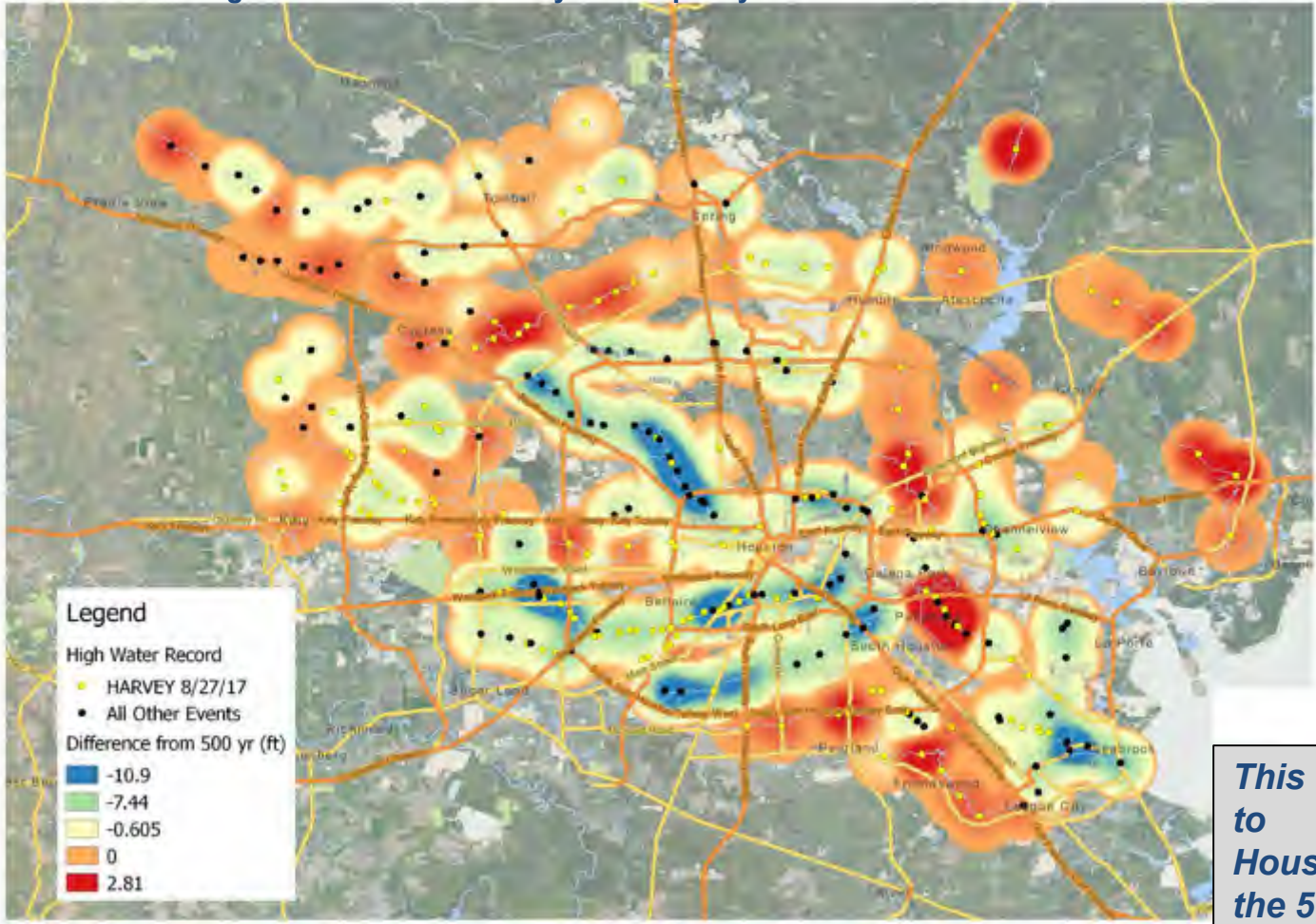
This data shows that Harris County alone received 1.6 trillion gallons of rainfall, 200x the capacity which could have been held by these “lost wetlands.”



Source: Meyers Research analysis of data from NOAA, HCFCFD, Houston Advanced Research Center, Open Street Map

Flood Levels at 500-Year Flood Plain or Higher Across Region

The heatmap below shows the areas where flooding exceeded the 500-year flood plain. Areas ranging from orange to red were at or as much as 3' above the 500-year flood plain level. Note the heat map compares intensity of water levels across the area and does not convey the geographic or spatial extent of floodwaters. This map shows the extent to which Harvey's rainfall overwhelmed the region's stormwater conveyance capacity.

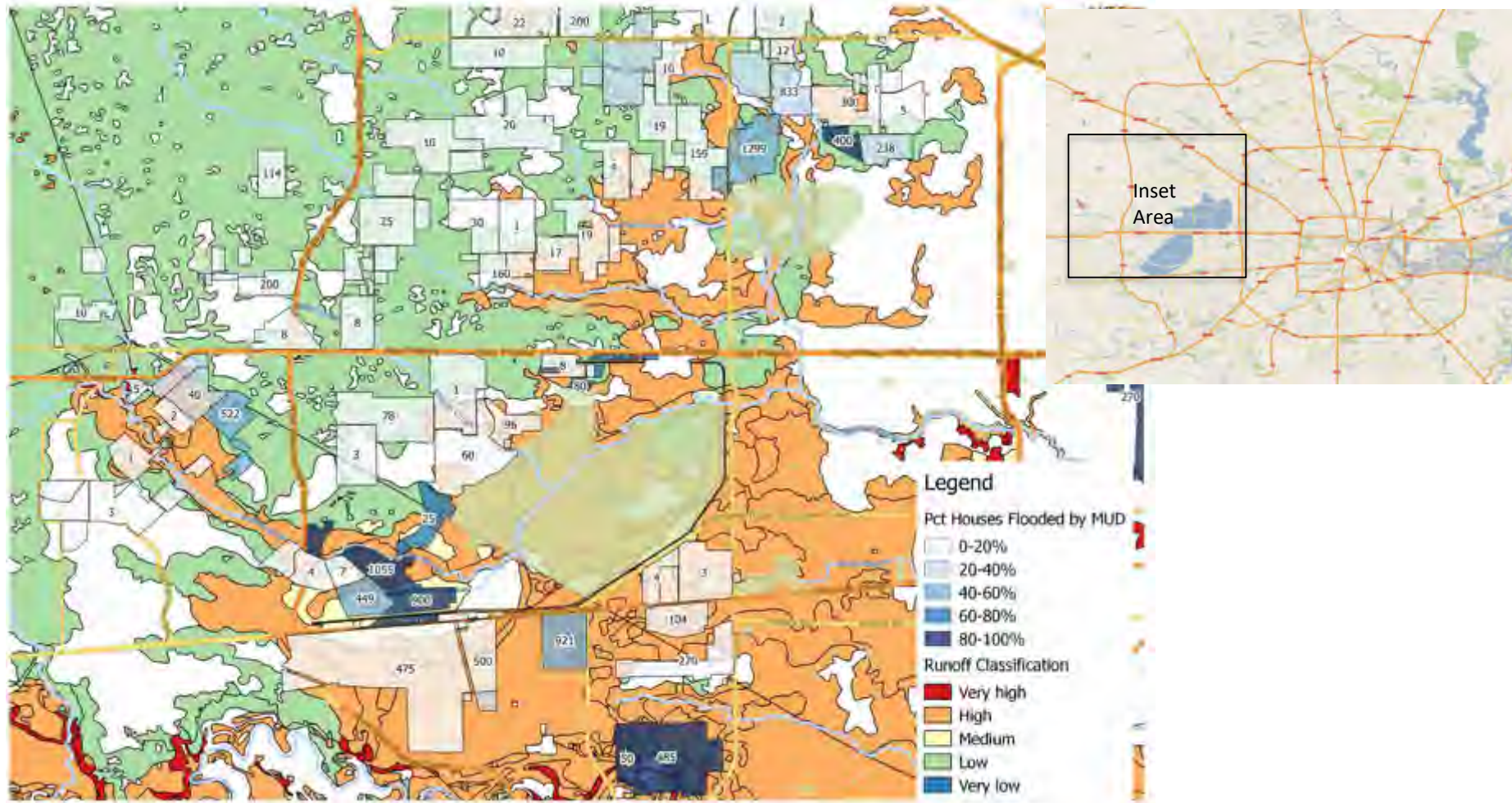


This map shows the extent to which flooding in Houston's bayous exceeded the 500 year flood plain.

Source: Meyers Research, TCEQ, HCFCD, Open Street Map

High Runoff Potential Soils Predominate Houston Area

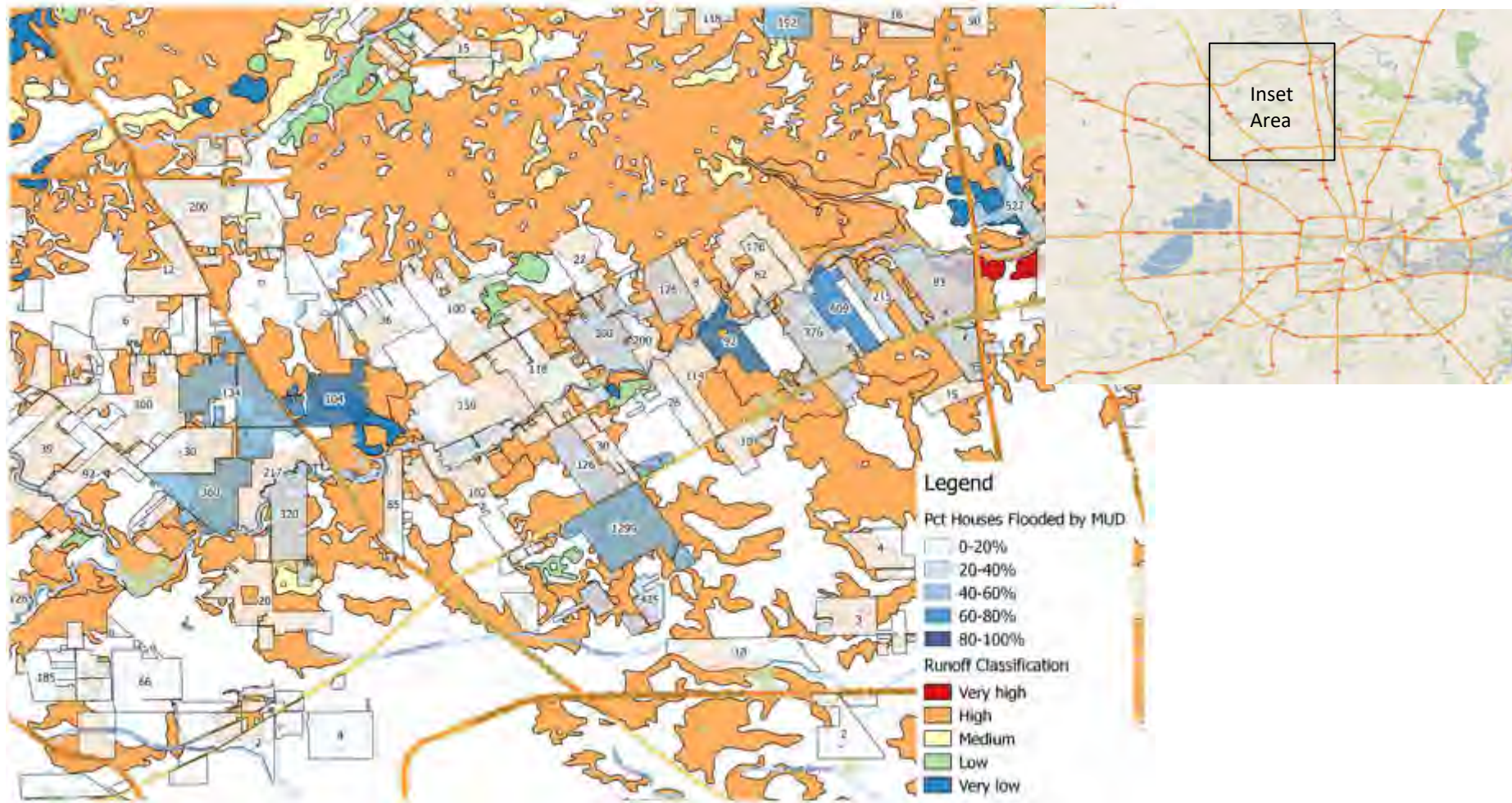
Soil surveys conducted by the US Department of Agriculture show the reservoirs and utility districts with most significant flooding to be located in soils with high or very high runoff potential – indicating that development would likely not significantly increase runoff. Utility districts are shaded by the percentage of houses which flooded and labelled with the actual number of homes flooded.



Source: USDA Soil Survey, Meyers Research, Open Street Map

High Runoff Potential Soils Predominate Houston Area

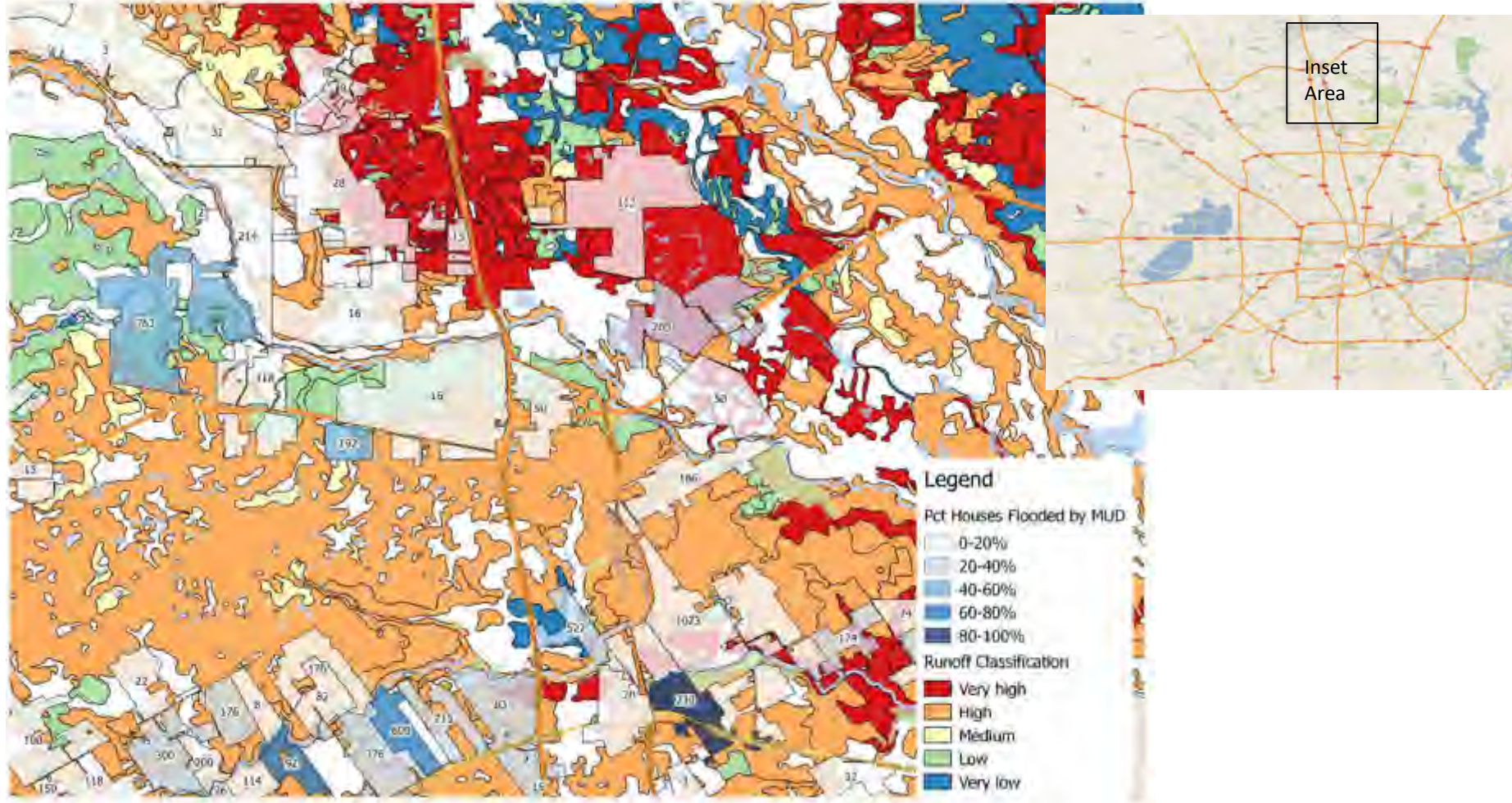
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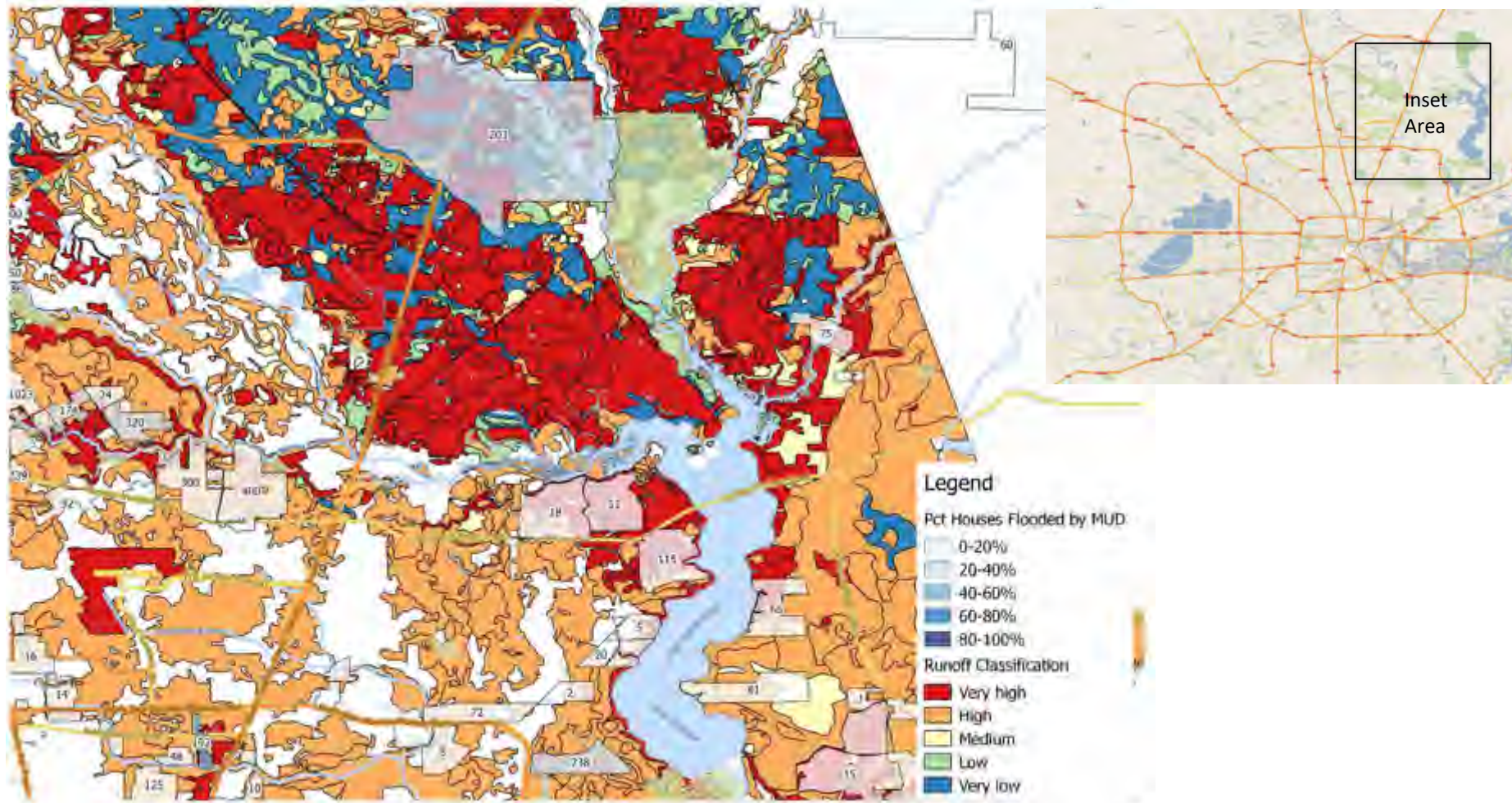
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High Runoff Potential Soils Predominate Houston Area

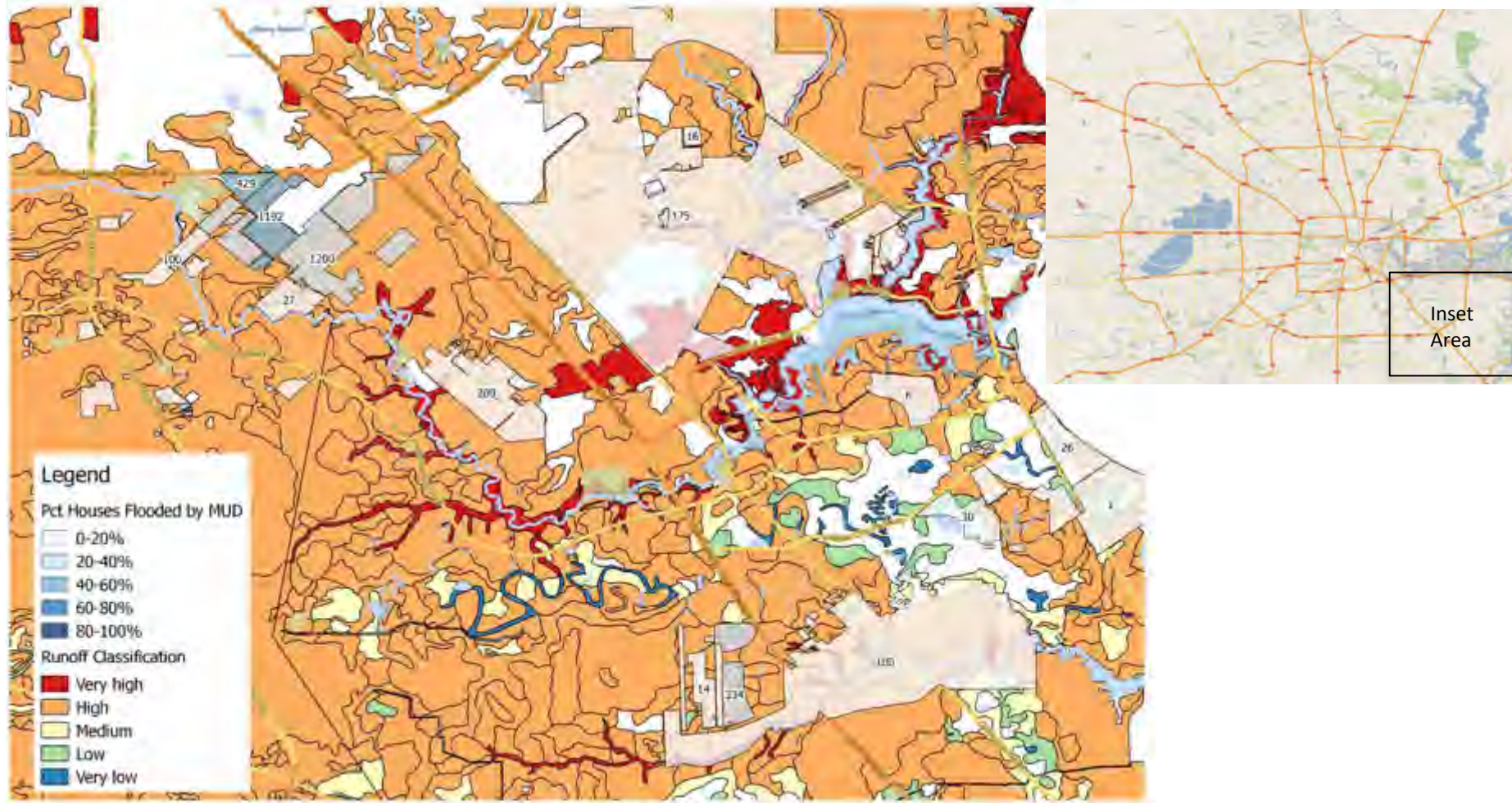
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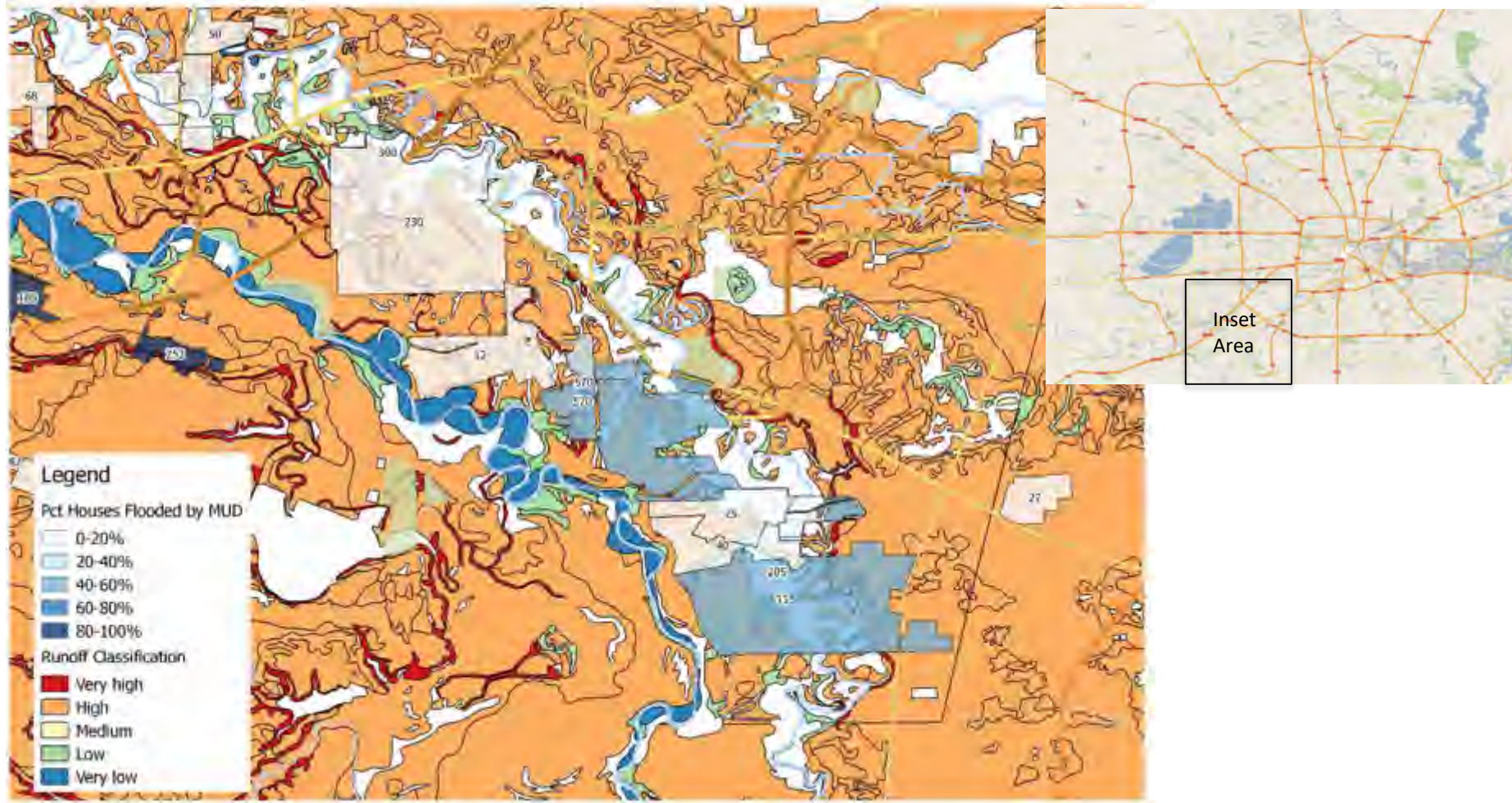
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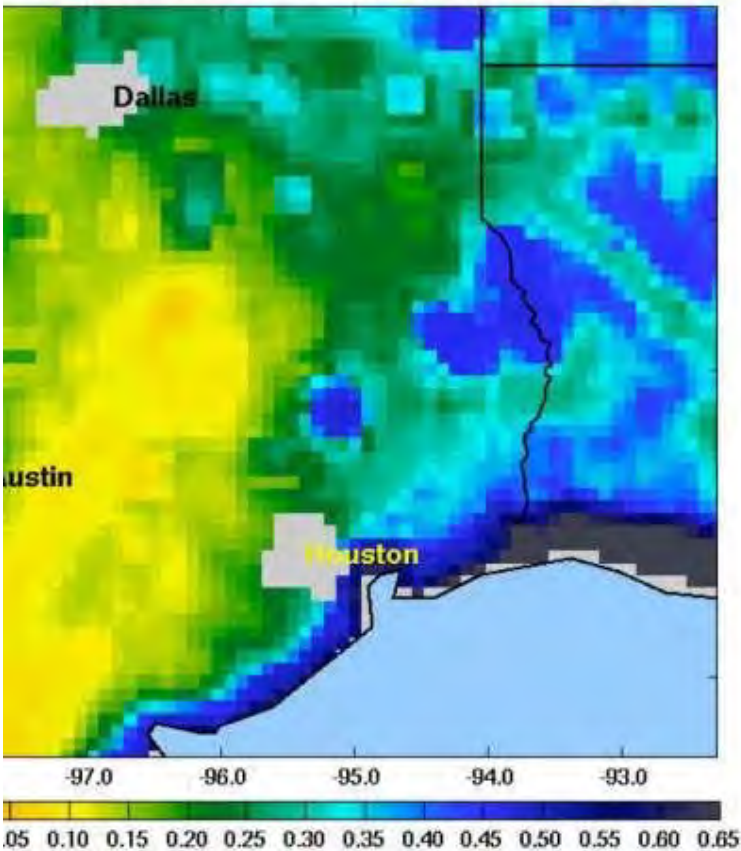


Source: USDA Soil Survey, Meyers Research, Open Street Map

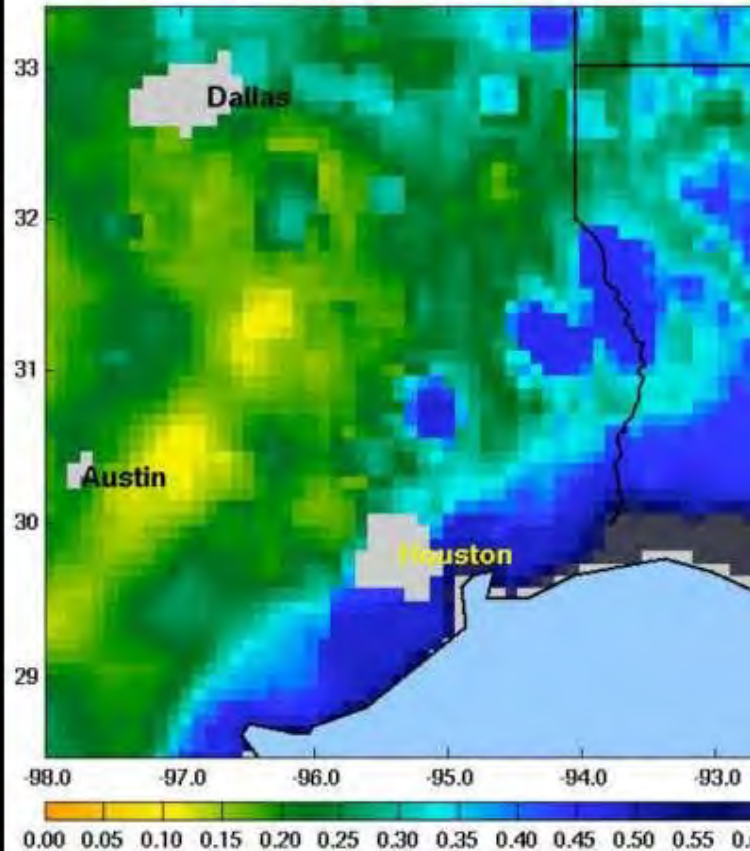
Houston Area Soils Saturated Before Harvey Landfall

In addition to the area's naturally poor drainage, Houston area soils were already saturated before the storm. The Jet Propulsion Laboratory reviewed soil moisture conditions in the Houston area from data obtained by NASA's Soil Moisture Active Passive (SMAP) satellite. The image on the left from August 21-22 shows that "soil surface conditions were already very wet a few days before the hurricane made landfall, with moisture levels in the 20 to 40 percent range. Such saturated soil surfaces contributed to the inability of water to infiltrate more deeply into soils, thereby increasing the likelihood of flooding." The image on the right shows the same area after Harvey's landfall, reflecting even more intense moisture concentration.

SMAP soil moisture retrieval 20170821 and 20170822 in m3/m3

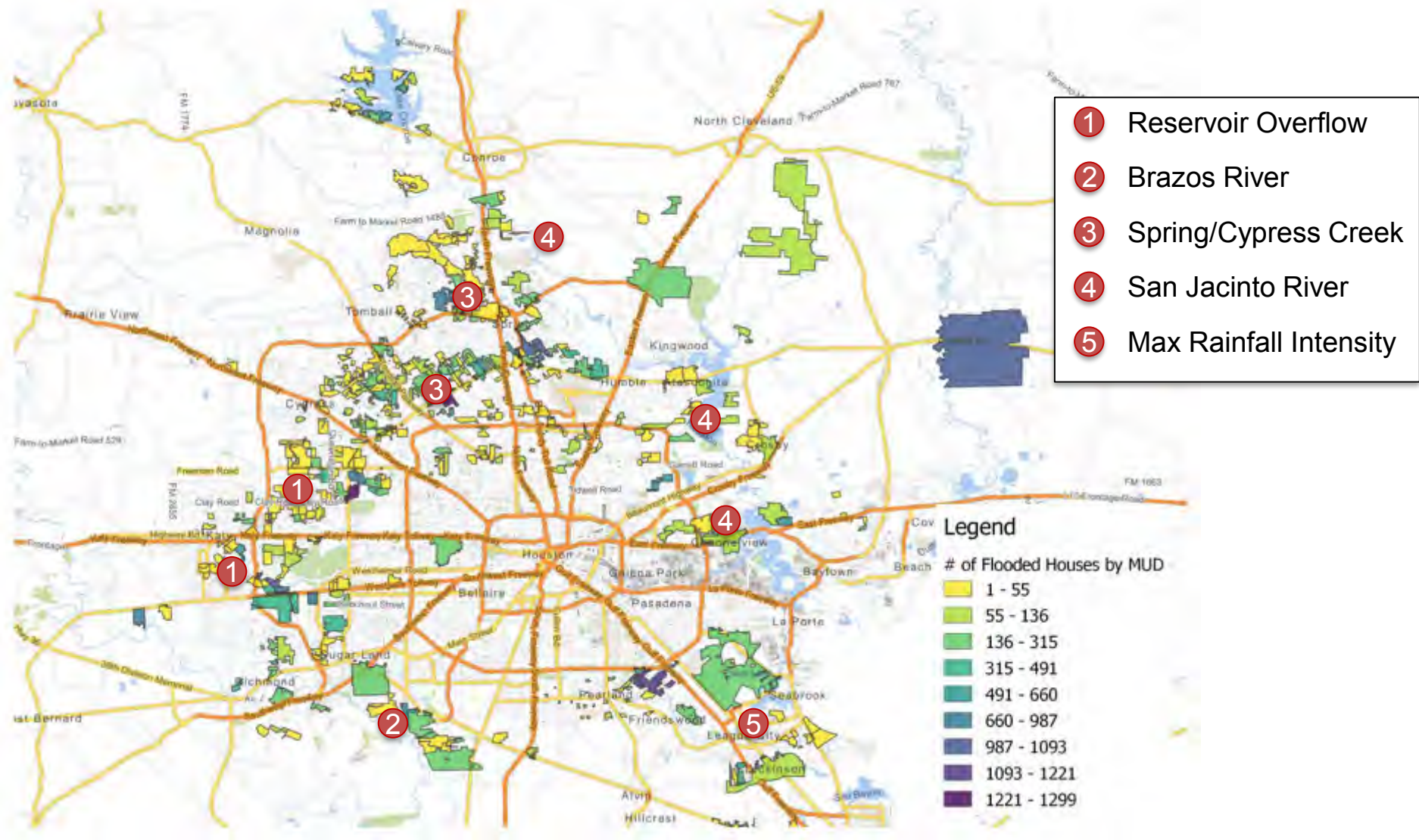


SMAP soil moisture retrieval 20170825 and 20170826 in m3/m3



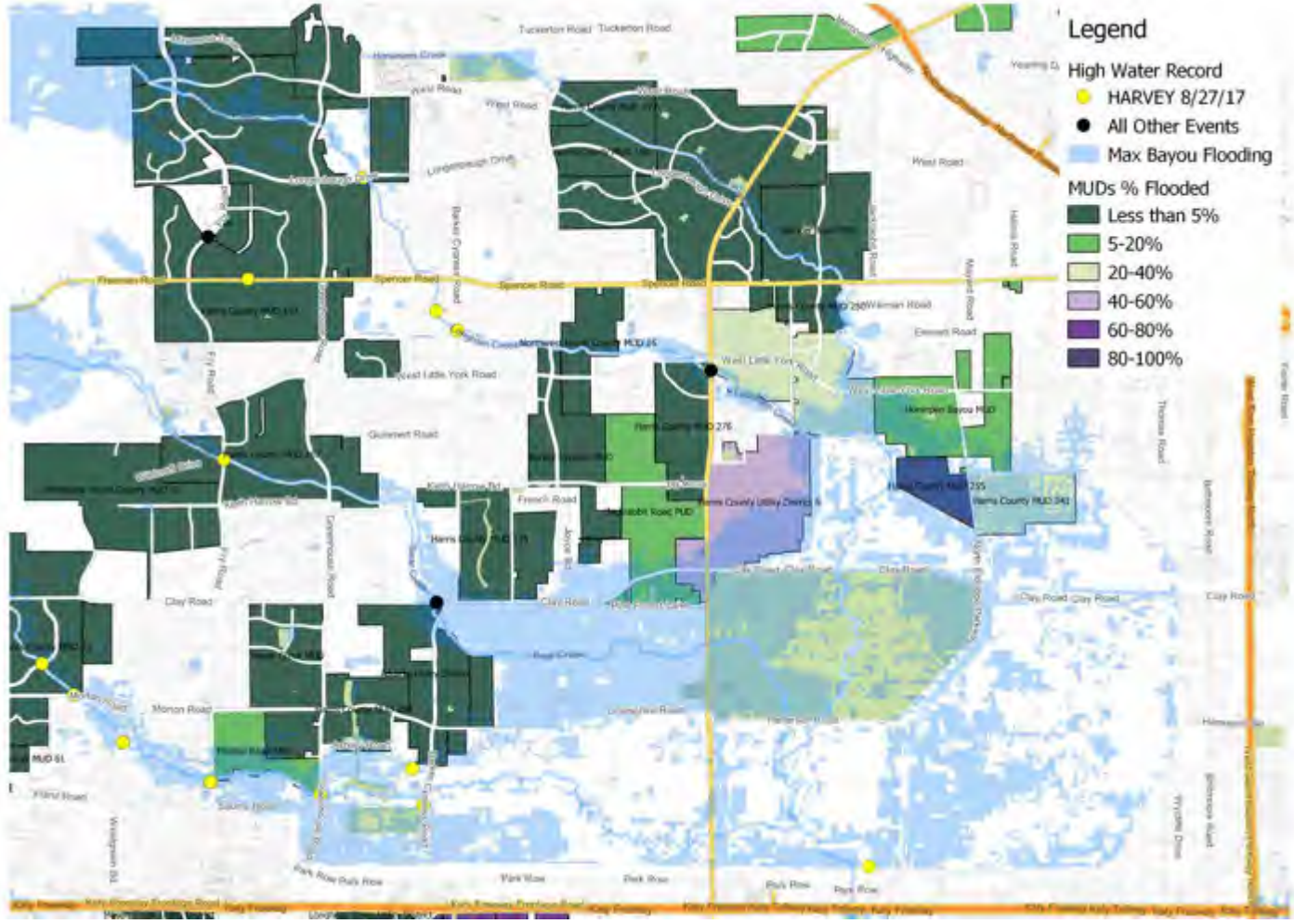
Source: NASA Jet Propulsion Laboratory

Survey Results: Where Was the Flooding Concentrated?



Addicks Reservoir Flooded Districts

The map below shows flooding as a result of overflow from Addicks Reservoir and the Addicks Reservoir spillway. Nearly all of these communities began developing before the first flood plain map of Harris County, and all before detention and drainage restrictions after Tropical Storm Allison. The yellow dots show points where Harvey was the channel's high water mark.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Addicks Reservoir Flooded Districts

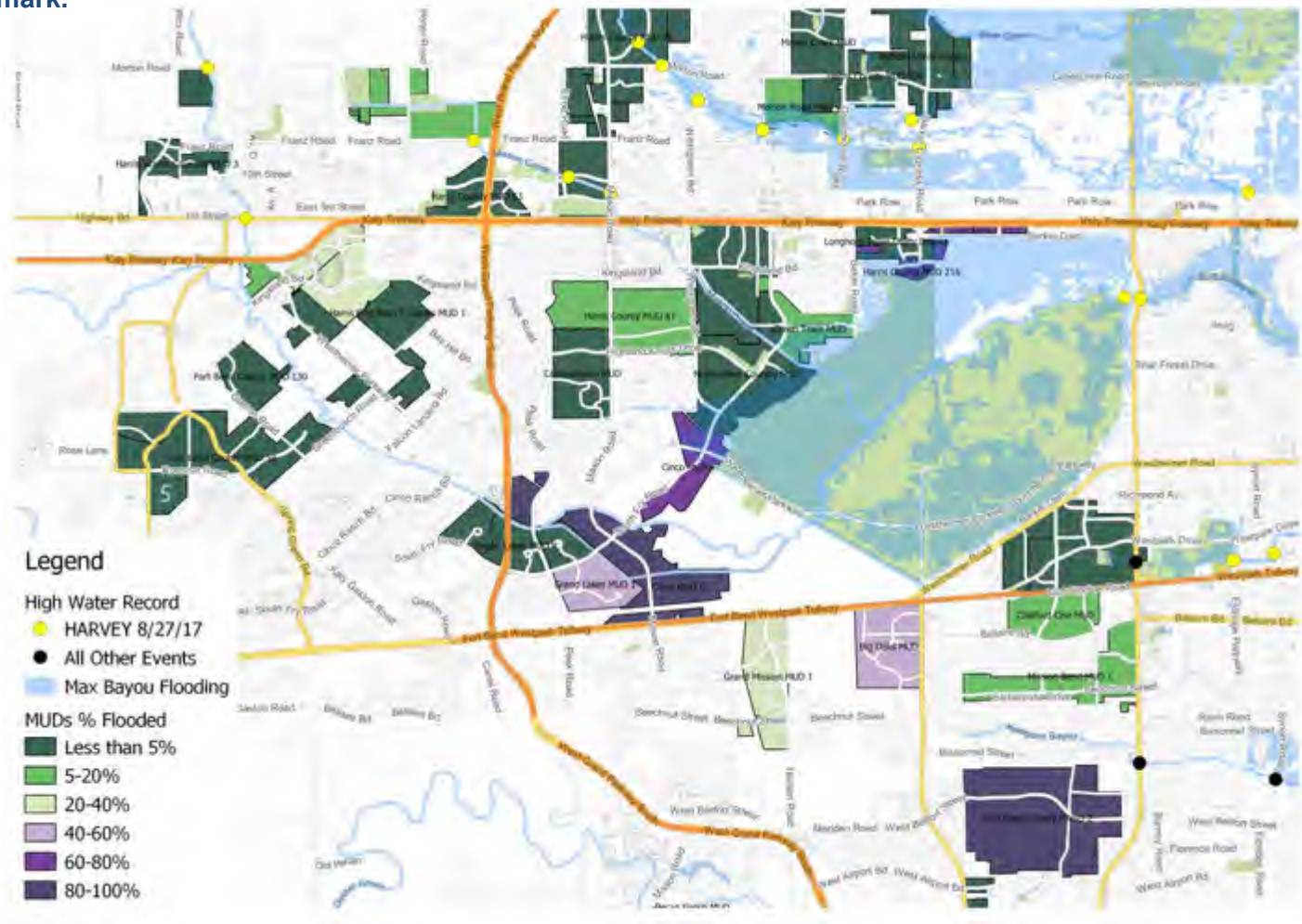
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Source: Meyers Research, TCEQ, HCFC, Open Street Map

Barker Reservoir Flooded Districts

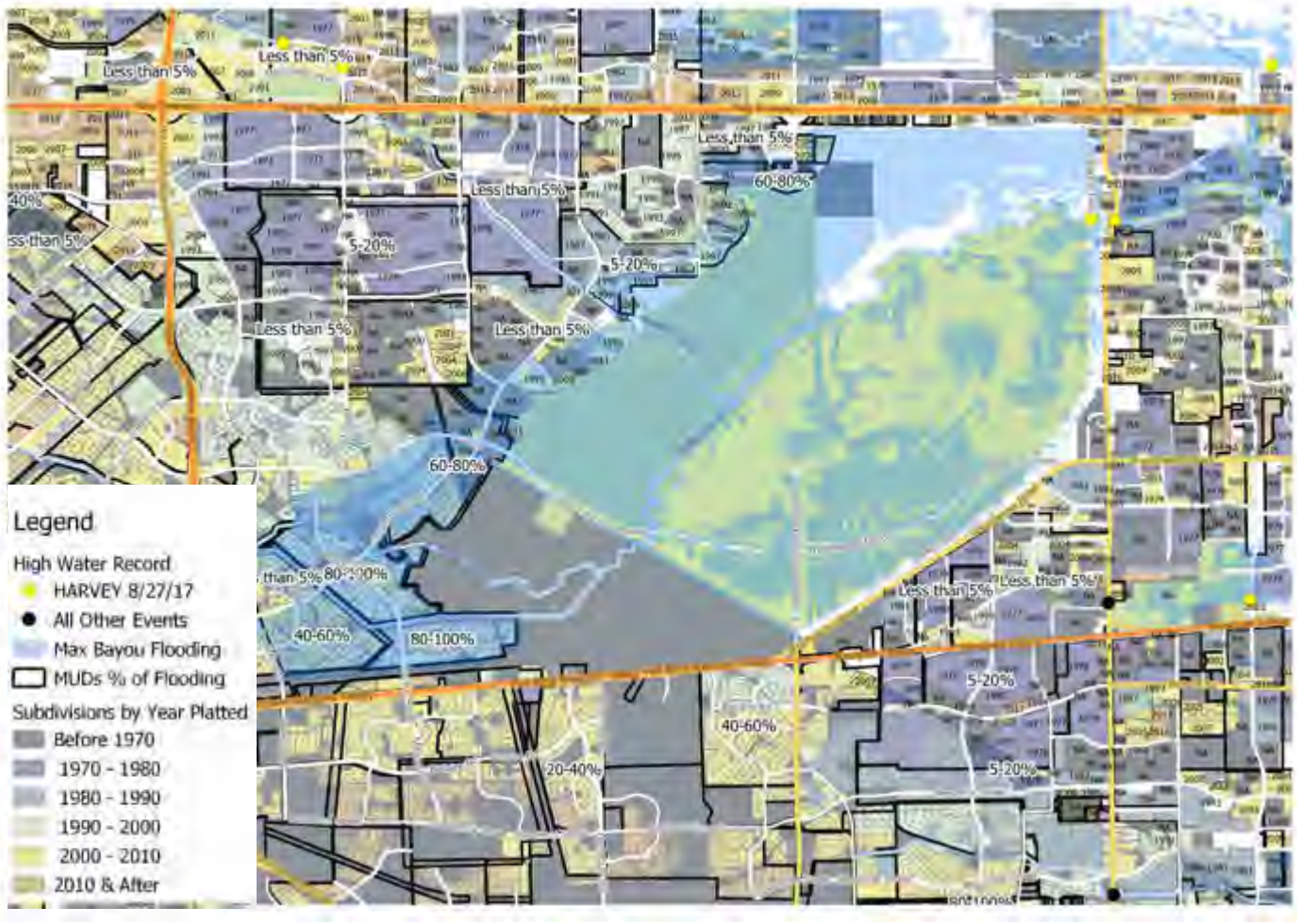
The map below shows flooding as a result of overflow from Barker Reservoir. The Corps of Engineers regulates the flow out of this reservoir. Many of these districts were developed before the first flood plain map of Harris County, and all before detention and drainage restrictions after Tropical Storm Allison. Yellow dots show locations where Harvey represented the channel's high water mark.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Barker Reservoir Flooded Districts

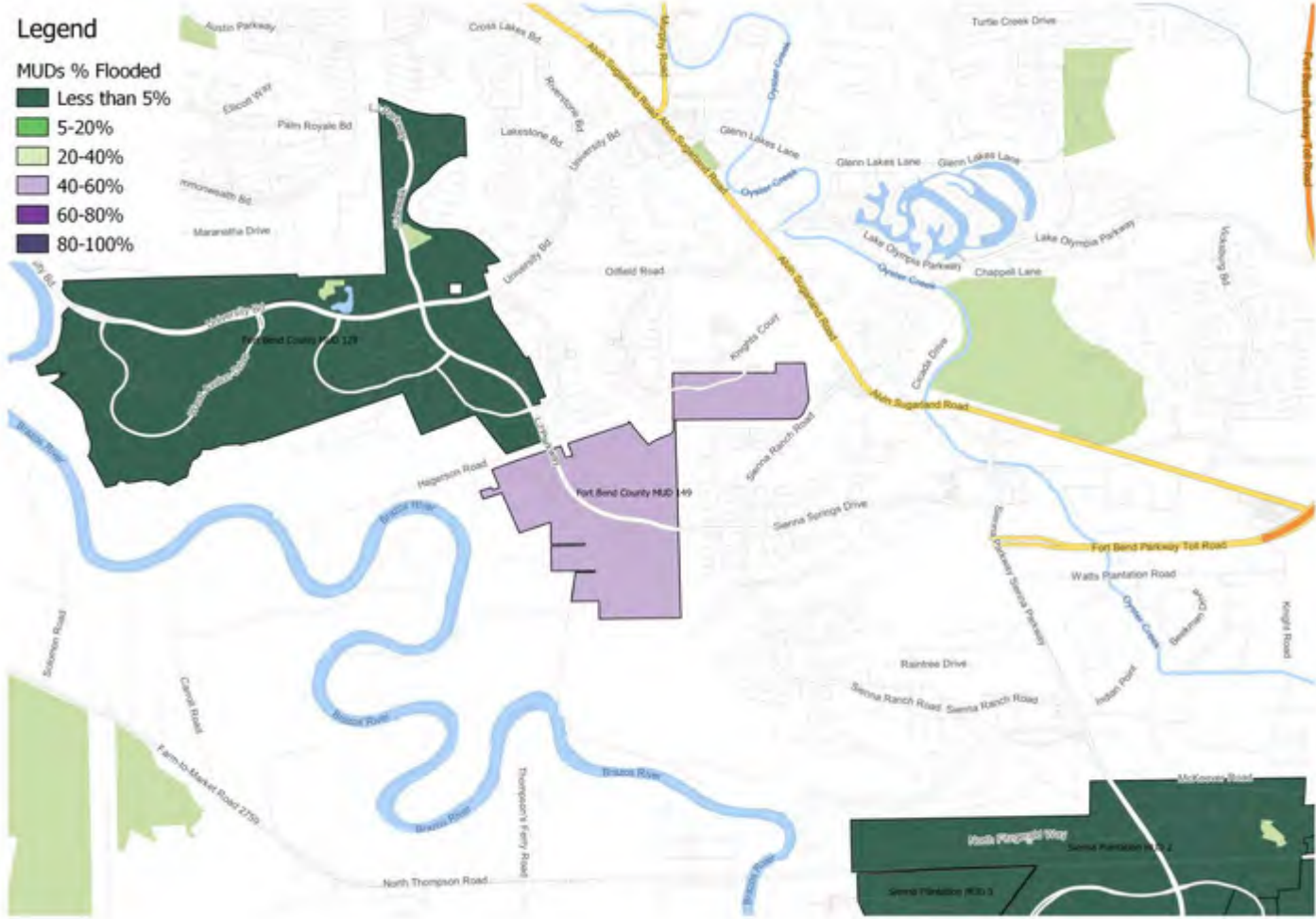
The map below shows flooding as a result of overflow from Barker Reservoir. The Corps of Engineers regulates the flow out of this reservoir. Many of these districts were created before the first flood plain map of Harris County, and all before detention and drainage restrictions after Tropical Storm Allison. Dates are indicated by shading, and yellow dots show locations where Harvey was the channel's high water mark.



Source: Meyers Research, TCEQ, HCFCF, Open Street Map

Brazos River Flooded Districts

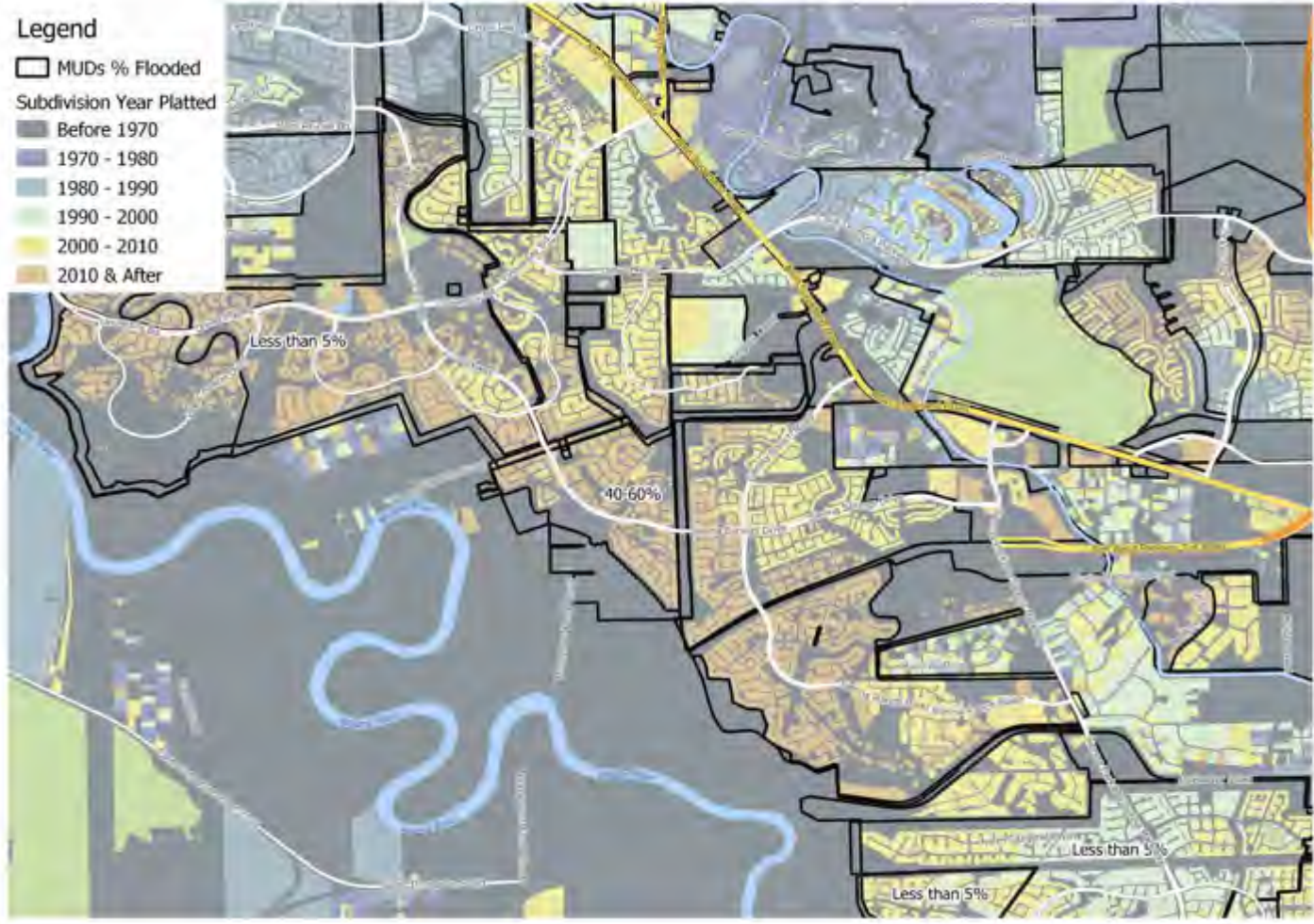
This map shows the districts that flooded from the Brazos River or its tributaries, or from severe rainfall after the floodgates closed. The City of Sugar Land estimates that this area received an 800-year storm event *after* the floodgates to the Brazos River had closed.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Brazos River Flooded Districts

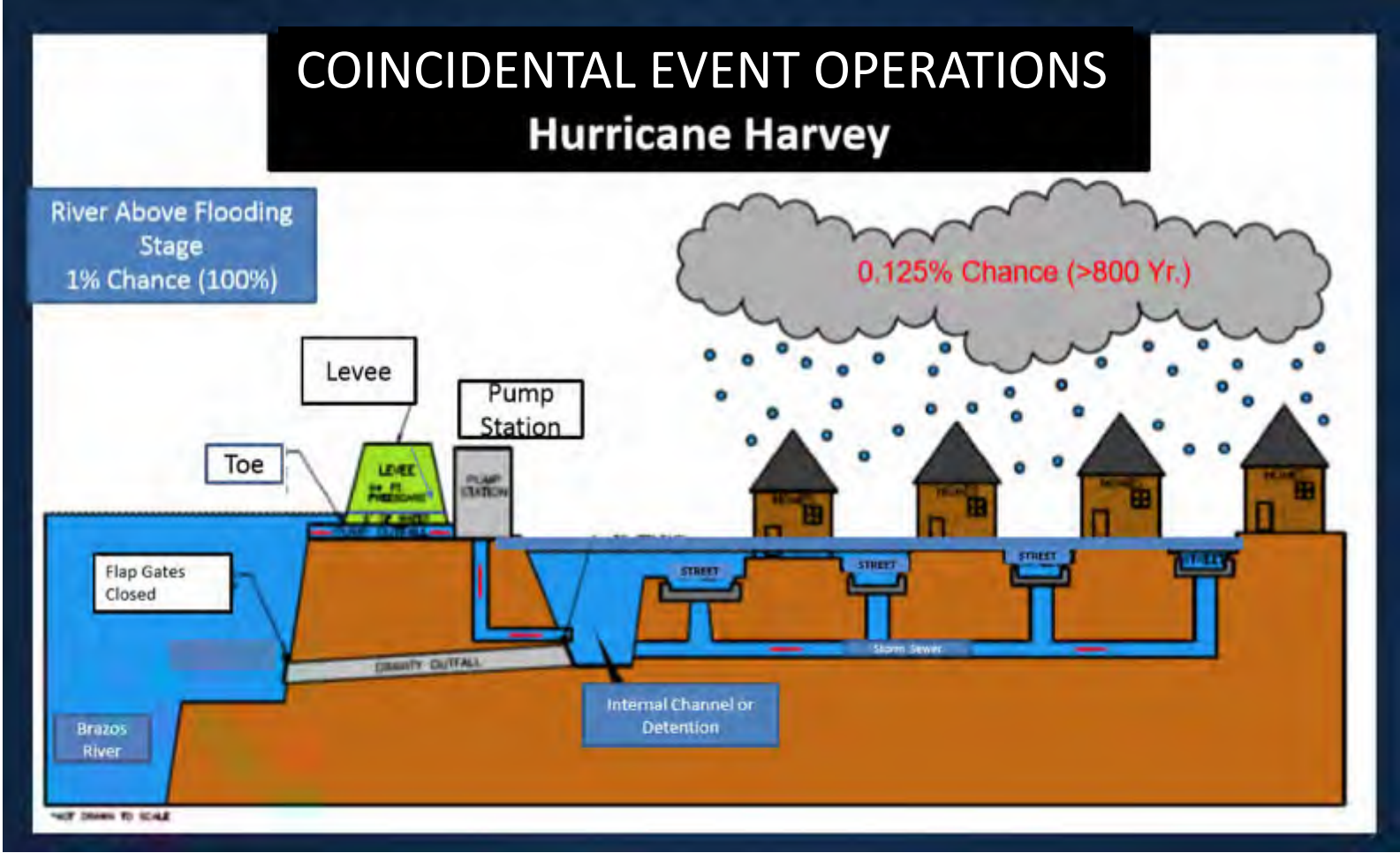
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Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Brazos River Flooded Districts

The graphic below shows the source of most flooding along the Brazos River in Fort Bend County. As river levels rose and shut the flap gates, the area inside the levees received an 800-year storm event.



Source: City of Sugar Land

The Corps of Engineers Failed to Warn Residents of Flooding Risk Upstream of the Reservoirs

The Houston Chronicle has reported despite modeling days prior to Hurricane Harvey that indicated there would be flooding upstream of Barker and Addicks Reservoirs, the Corps of Engineers failed to alert the emergency management officials of this prediction. Additionally, the Corps of Engineers failed to place any notice of special flood risk within the Barker and Addicks “Flood Pool” on the official FEMA floodplain maps. Despite being concerned about upstream flooding as early as 1992 when the Corps Right of Way Division prepared an appraisal of the upstream areas within the Flood Pool, no official notice of special flood risk was ever provided by the Corps to residents or regulatory officials charged with administering the floodplain maps.

The Corps of Engineers facilitated the development of homes and businesses upstream of Barker Reservoir by voluntarily granting easements for the construction of approximately 4 miles of channels within Barker Reservoir which the Corps at the time of granting the easements acknowledged that the easement “facilitated the development” of the upstream area. In granting the easements, there was no notice by the Corps of special flood risk to upstream property owners.

LID 19 – Rainfall Exceeded Design

The board of Fort Bend LID 19 – where 570 homes flooded – commissioned an “after action” report studying the causes of flooding damage within the district. Costello Engineering’s review indicates:

The structural flooding occurred due to internal rainfall well in excess of the design capacity of the drainage system. This condition was further exacerbated by the Brazos River level increasing to a point to where drainage via gravity was no longer possible. Due to the detention storage being over-capacity from rainfall occurring early during Harvey and the continuing rainfall, the pump station in the watershed was insufficient to deal with this level of a flood event.

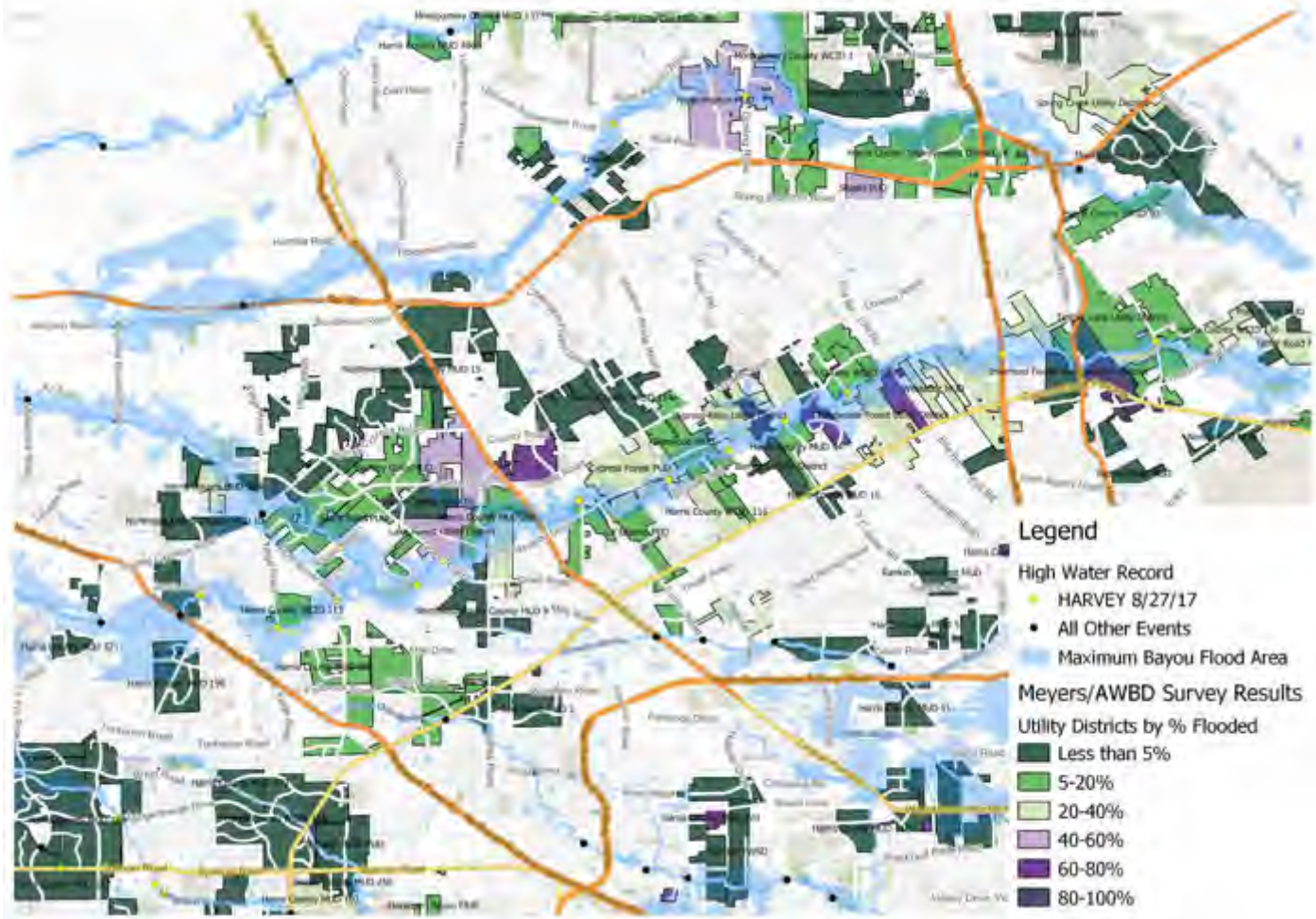


Levee Management Systems conducted an operational after action report as well; the picture on the left shows a section of levee undamaged by the storm. During the inspection LMS discovered superficial damaged caused by feral hogs to the levee in the photo on the right. There was no other visible damage to the levee.

Source: Fort Bend LID 19, Costello Engineering, Levee Management Services

Cypress Creek Flooded Districts

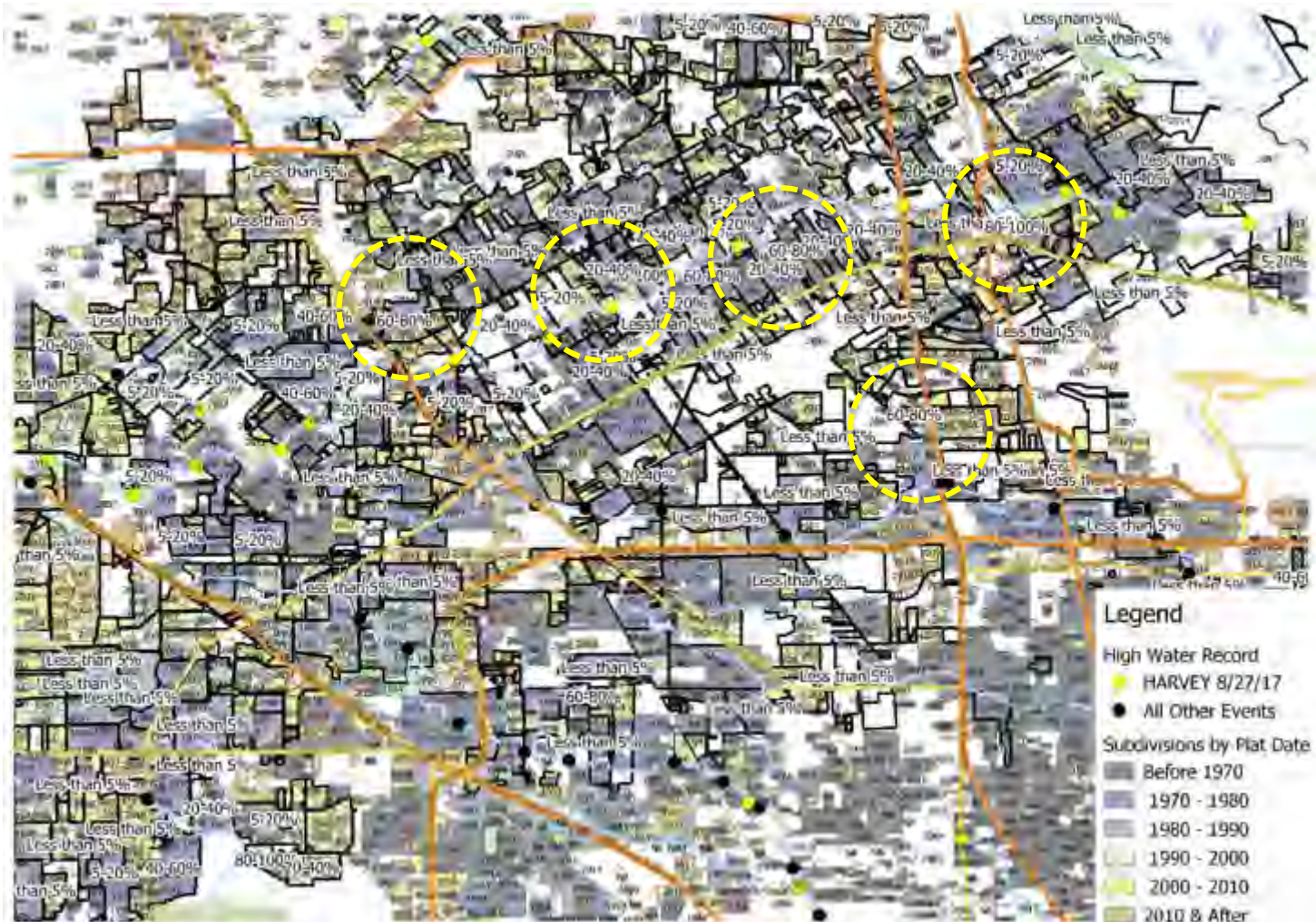
The map below shows flooding in the districts located along the route of Cypress Creek. Again, almost all of the subdivisions served by these districts were platted before the first flood plain map of Harris County was released, and all of them before the current drainage and detention regulations were adopted. The yellow dots mark locations where Harvey was the channel's high water mark.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Cypress Creek Flooding Most Intense in Older Subdivisions

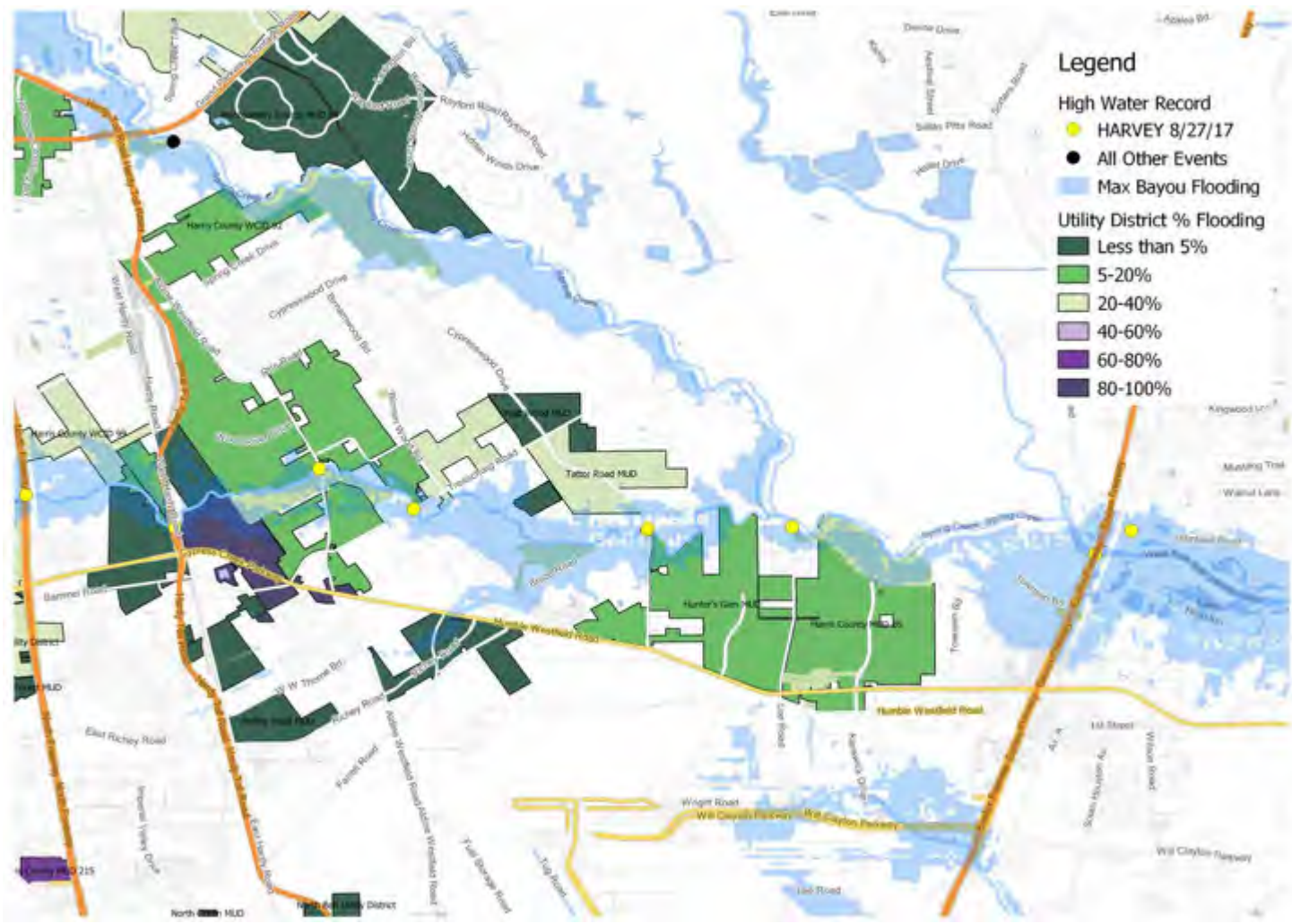
The map below shows the number of flooded houses by utility district, overlaid on subdivisions color coded by plat date. The areas of most significant flooding are in subdivisions platted before 1981. The yellow dots also indicate high-water marks along drainage channels – during Harvey, Cypress Creek saw the highest water levels ever recorded, a reflection of the rainfall intensity.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Spring Creek Flooded Districts

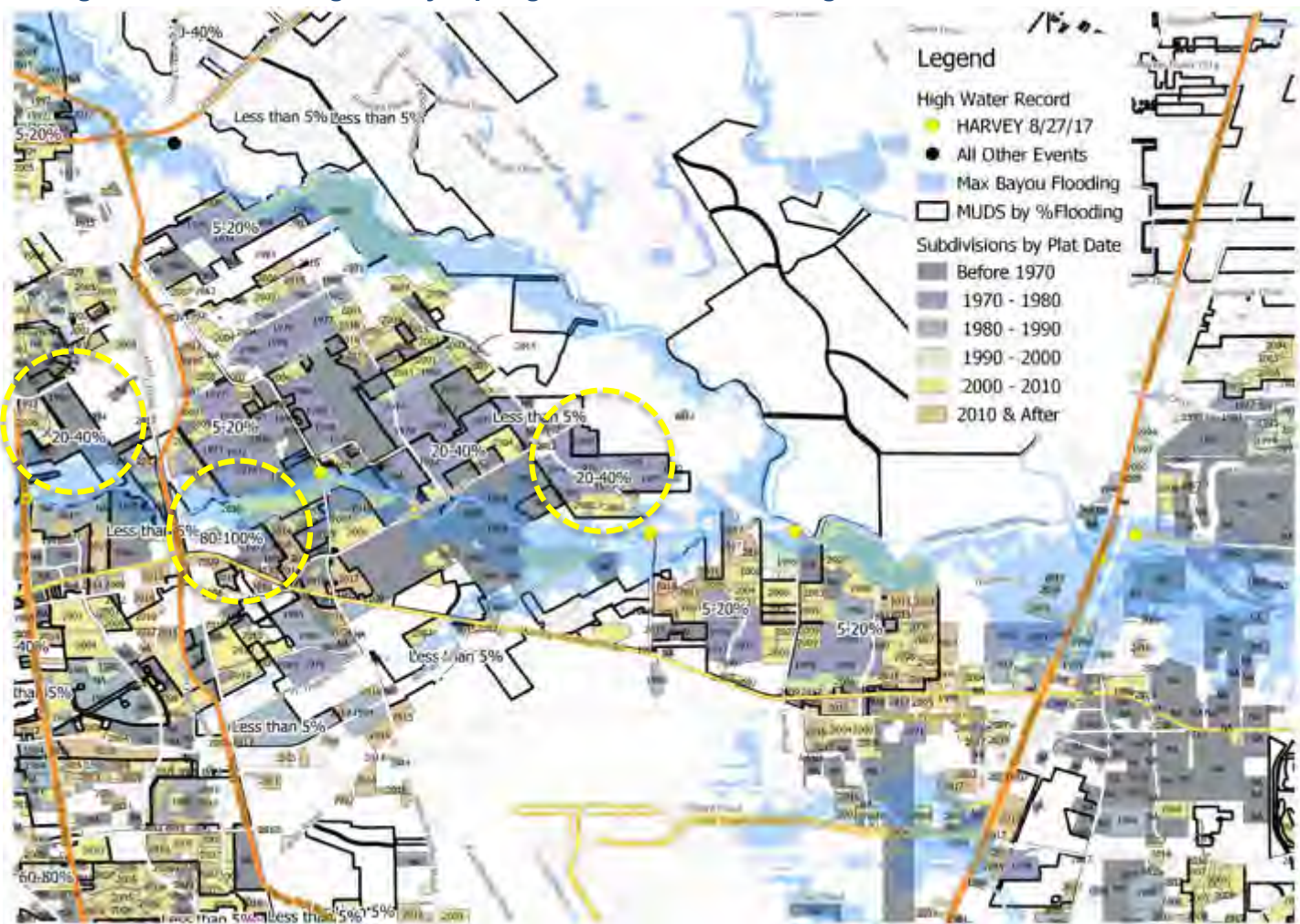
The map below shows flooding in the districts located along the route of Spring Creek. Yellow dots mark locations where Harvey represented the drainage channel's historical high water mark.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Spring Creek Flooding Most Intense in Older Subdivisions

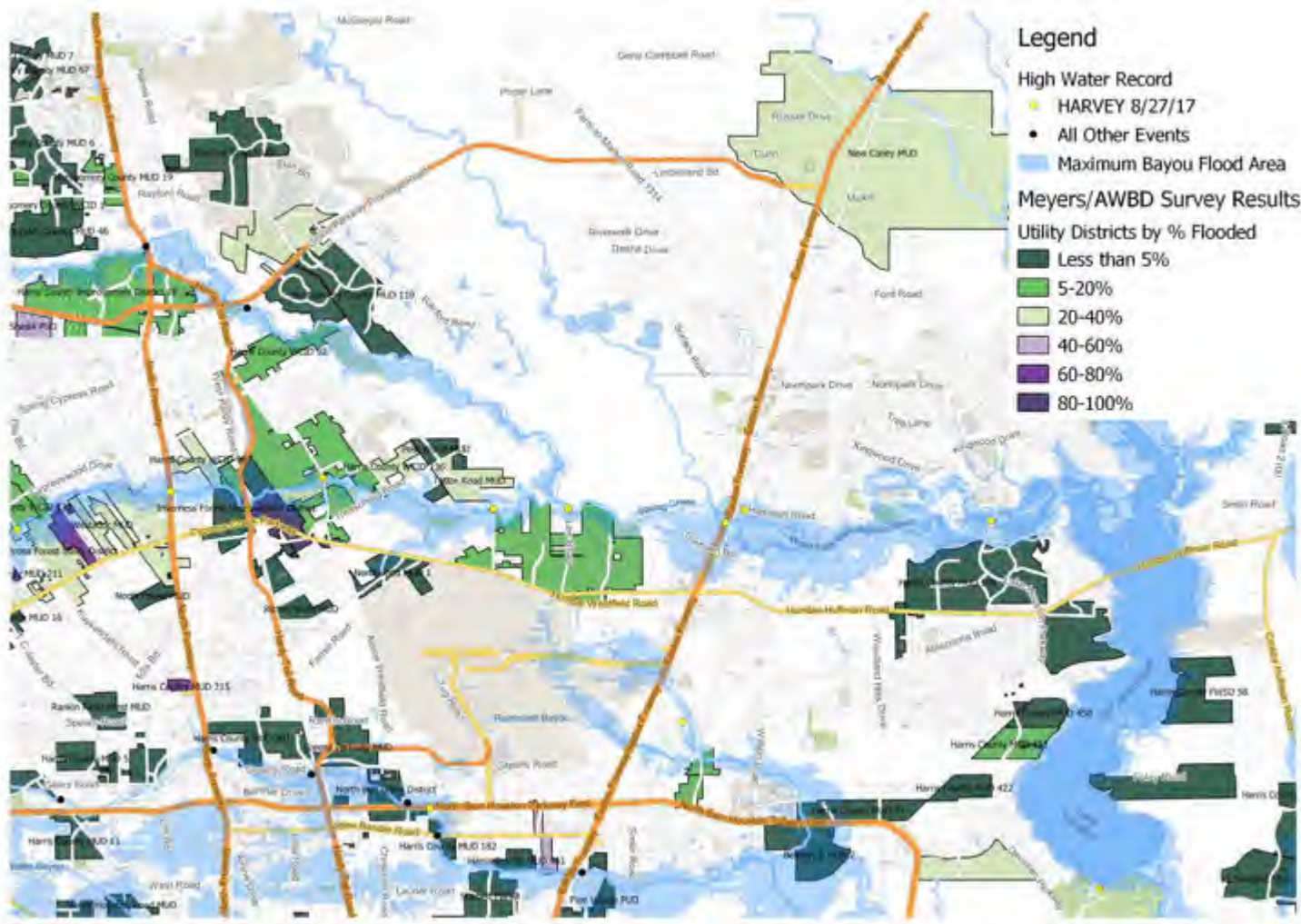
The map below shows the number of flooded houses by utility district, overlaid on subdivisions color coded by plat date. The areas of most significant flooding are in subdivisions platted before 1981. The yellow dots also indicate high-water marks along drainage channels – during Harvey, Spring Creek also saw the highest water levels ever recorded.



Source: Meyers Research, TCEQ, HCFC, Open Street Map

Spring Creek Flooded Districts

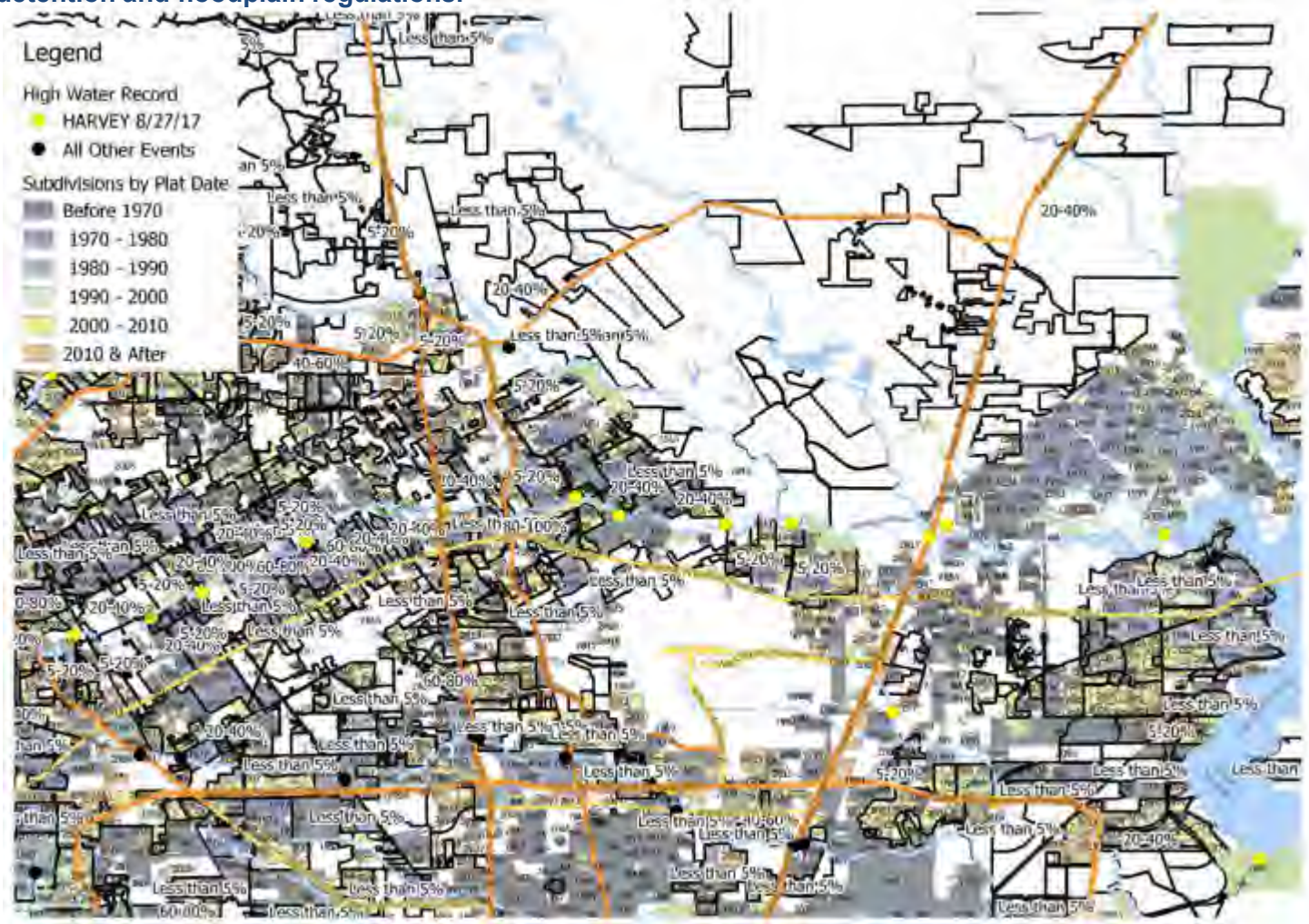
The map below shows flooding in the districts located along the route of Spring Creek. The yellow dots represent locations where Harvey represented the drainage channel's historical high water mark.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Spring Creek Flooded Districts

The map below shows flooding in the districts located along the route of Spring Creek. Yellow dots mark the locations where Harvey was the high water mark. As with most areas, the most intense flooding was in older subdivisions that pre-date modern detention and floodplain regulations.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map

San Jacinto River Flooded Districts

The map below shows flooding in the districts located along the route of the San Jacinto River. Again, almost all of these subdivisions were created before the first flood plain map of Harris County was released. At one point the flow over the spillway at Lake Houston was 425,000 cubic feet per minute – a flow rate almost twice that of Niagara Falls and enough water to supply the daily water need of Harris County every 3.5 minutes.

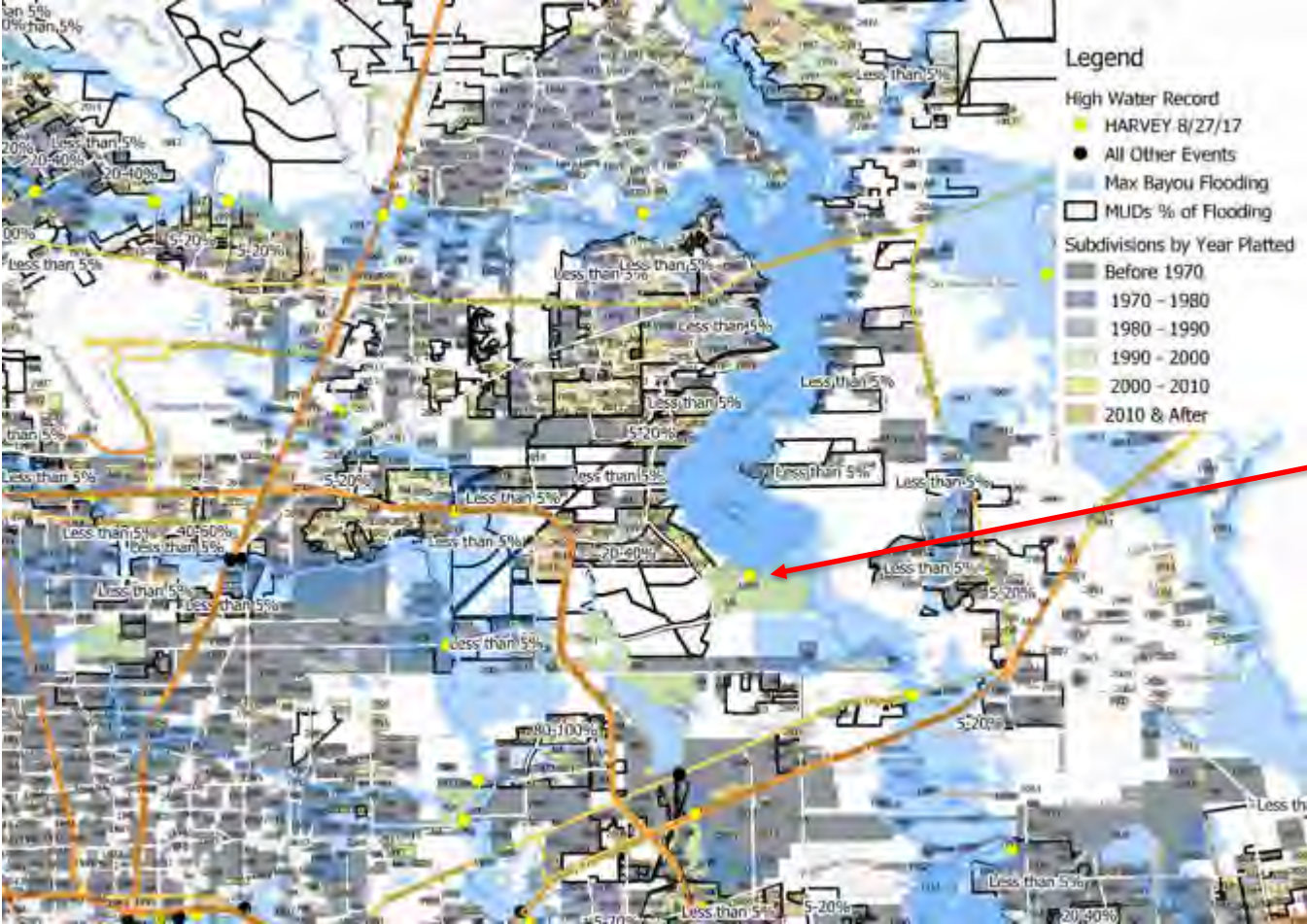


Lake Houston Dam

Source: Meyers Research, TCEQ, HCFCD, Open Street Map

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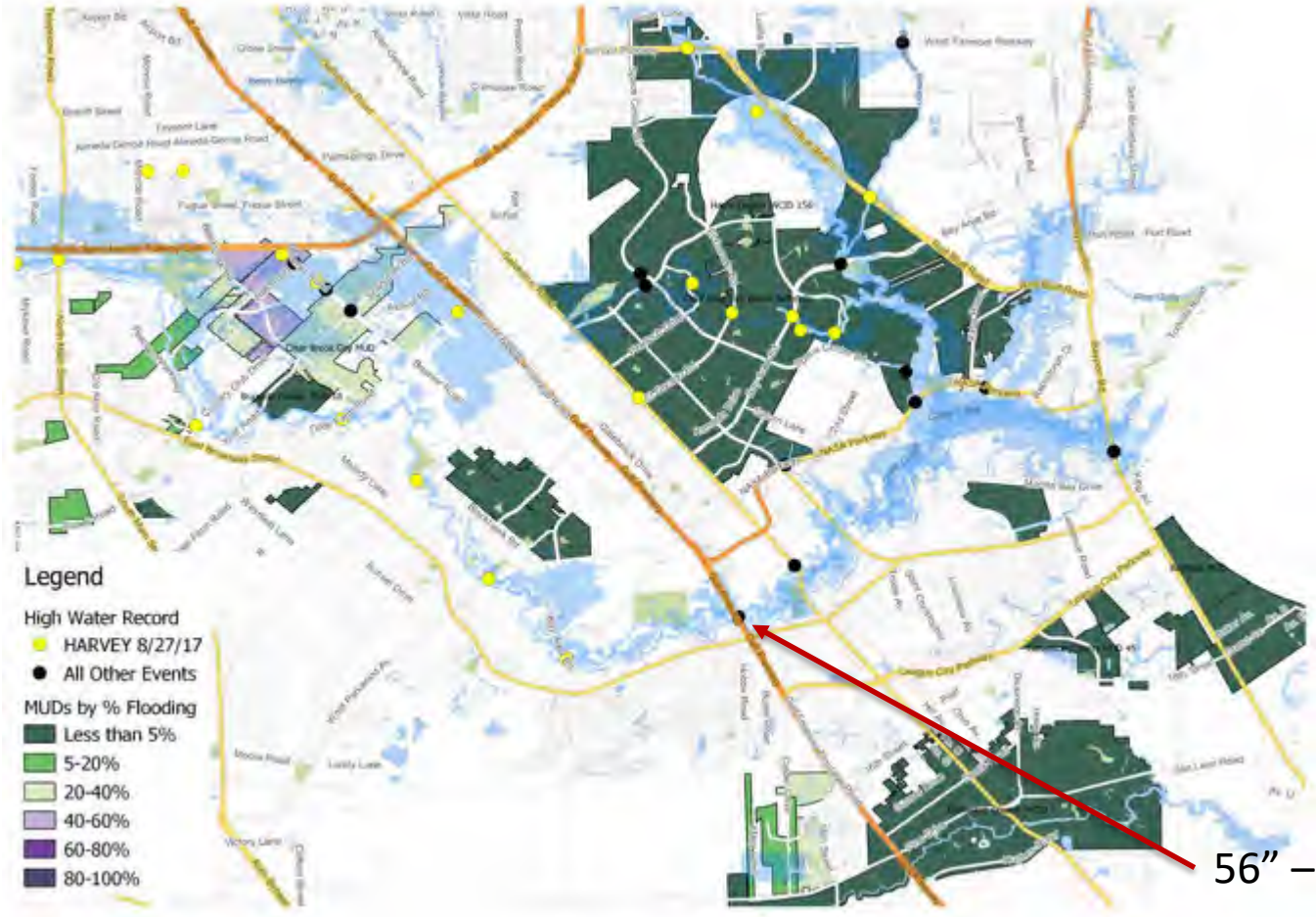


Lake Houston Dam

Source: Meyers Research, TCEQ, HCFCD, Open Street Map

Clear Creek Flooded Districts

The Clear Creek area received the maximum intensity of rainfall during Harvey. The 56”+ this area received was greater than the “potential maximum precipitation” meteorologists thought the atmosphere could produce. Most of the heavily flooded areas were in subdivisions in the 1960s and early 1970s. The Clear Lake City Water Authority, one of the area’s largest districts, reported that 90% of the homes which flooded were built before 1980.

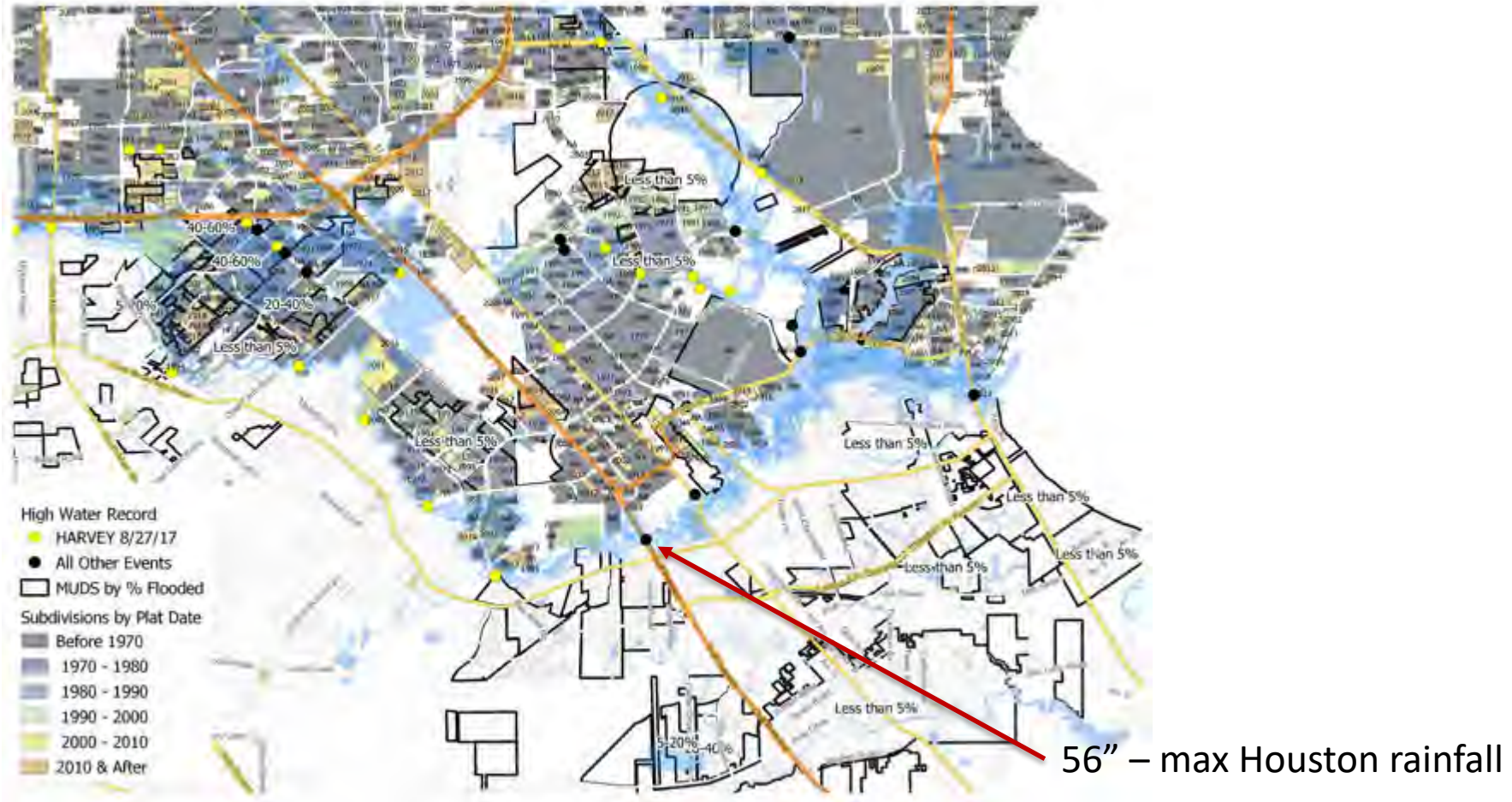


56” – max Houston rainfall

Source: Meyers Research, TCEQ, HCFCD, Open Street Map

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Source: Meyers Research, TCEQ, HCFCD, Open Street Map

139 Harris County Bridges are Below the 500 Year Flood Plain

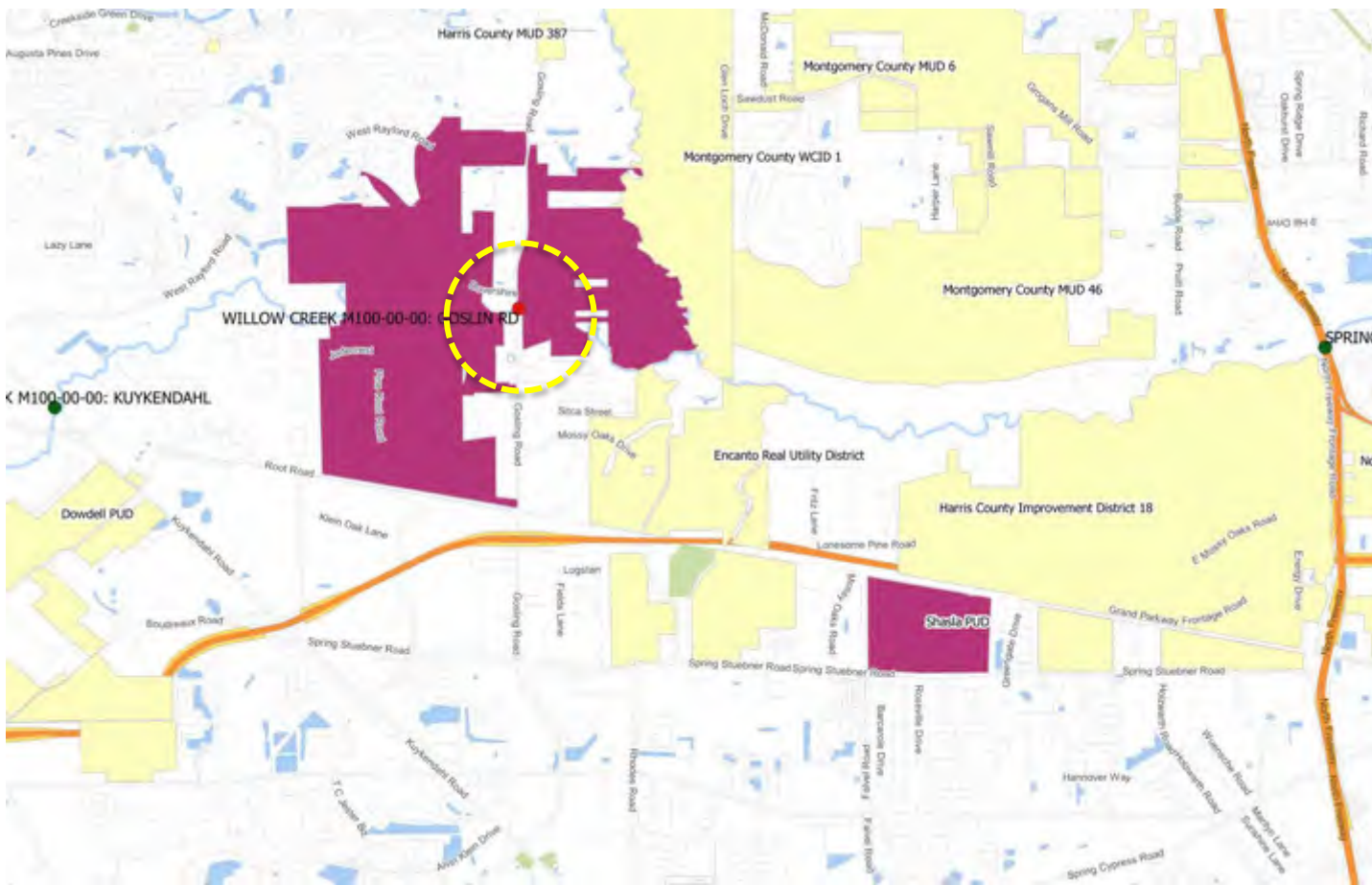
In the course of this project, Meyers Research uncovered data from Harris County Flood Control District that shows 139 bridges with levels below the 500 year flood plain, and 110 below the 100 year flood plain elevation. This map shows our flood count by district (purple) along with the City of Houston's flood data (red). The low bridges are shown as yellow dots – their elevation is important because low bridges over drainage channels can dam the flow of stormwater.



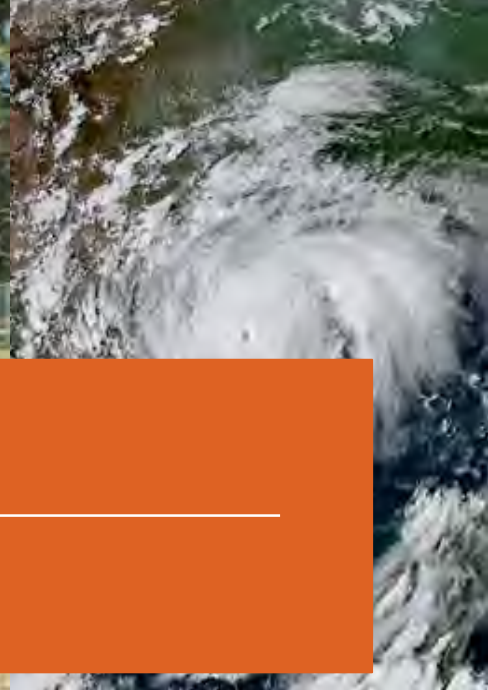
Source: FEMA, US Census Bureau, Open Street Map

Northampton MUD: Bridge Height on Willow Creek

Northampton MUD was one of the most heavily impacted utility districts in northern Harris County, with 147 homes reported flooded. Willow Creek, a tributary of Spring Creek is the major drainage through this district. The Harris County Flood Control District flood gauge shows a bridge height at Gosling Rd over Willow Creek at 113' -- about 9' below the Harvey water mark reported at 122'. Meyers Research has identified 139 bridges across the region whose elevation is below the 500 year floodplain.



Source: Meyers Research, TCEQ, HCFCD, Open Street Map



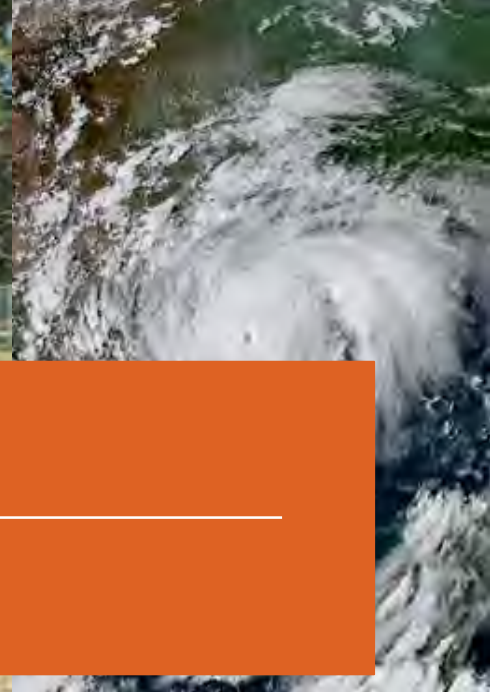
CONCLUSIONS

Impact of Harvey on Houston MUDs

MUDs Were Resilient During the Storm

Harvey was a devastating storm that brought unprecedented amounts of rainfall to the Houston area. Any loss of life or property in a storm is a tragedy. Our study of the impact of Harvey shows:

- The current system of detention regulations work. Less than 3% of the houses that were identified as flooded were built after 2009 and complied with the drainage and detention regulations adopted after Allison.
- The most extensive flooding was in districts with subdivisions that were developed before the adoption of modern detention regulations, and most even before FEMA had ever released a flood plain map of the region.
- MUDs were resilient and prepared for the storm. Only 12 MUDs (statewide) had to issue “boil water notices” in the storm’s aftermath. MUD directors and operators responded quickly to deploy back-up systems and additional pumps powered by generators to keep water and wastewater services operating.
- MUDs endured the storm. Less than two dozen MUDs reported damage to district-owned infrastructure and the vast majority of that damage was almost immediately repaired. As of the date of this report, only 3 districts (statewide) sustained damage that has left them inoperable.
- MUDs are financially healthy. MUDs are conservatively managed, and only 7 districts which experienced significant flooding have less than one year’s debt service payment in cash reserves. Collectively those districts are expected to have adequate tax revenues to cover that debt service. MUDs have reserves to cover operating costs, debt service and capital improvements and provide roads, water and wastewater services, and other amenities like parks without the pension liabilities of a city or county government.



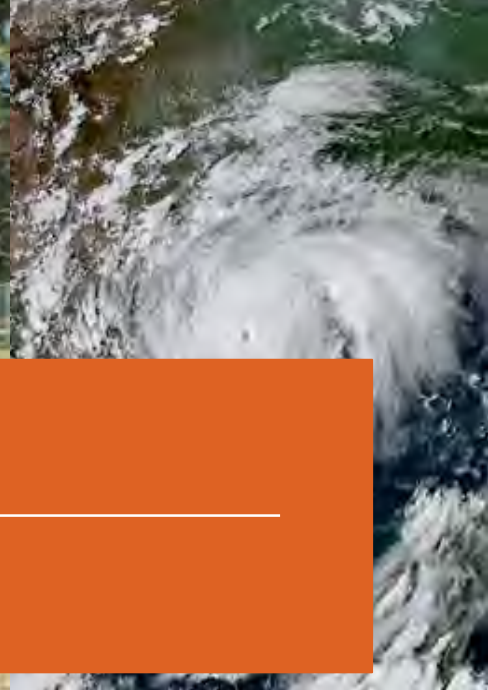
STUDY AUTHOR

Impact of Harvey on Houston MUDs

STUDY AUTHOR

Scott Davis is a Senior Vice President for Meyers Research, and is responsible for the company's single family advisory work in Texas. Prior to joining Meyers, Mr. Davis was the Houston Region Director for Metrostudy. In his 20 year real estate career, he has sold more than 2,900 acres for single family and retail development, been recognized as a top producer in the Houston and Eastern US Regions at CBRE, received the "Land Deal of the Year" award from the Houston Business Journal, and was nominated as Global Business Director of the Year by NAI Global for his leadership in commercial real estate. He has also written two books about the role of the Millennial generation in changing the workplace and faith communities.

Mr. Davis is a graduate of the University of Texas, where he received a BA in liberal arts/geography and an MS in community and regional planning, and is a licensed Texas real estate broker. Like thousands of other Texans, Mr. Davis lost his home to flooding in Harvey.



HURRICANE HARVEY

Impact of Harvey on Houston MUDs