MEMORANDUM

TO : Paul Hofmann, Bellaire City Manager

FROM : James Andrews, P.E. Bellaire City Engineer

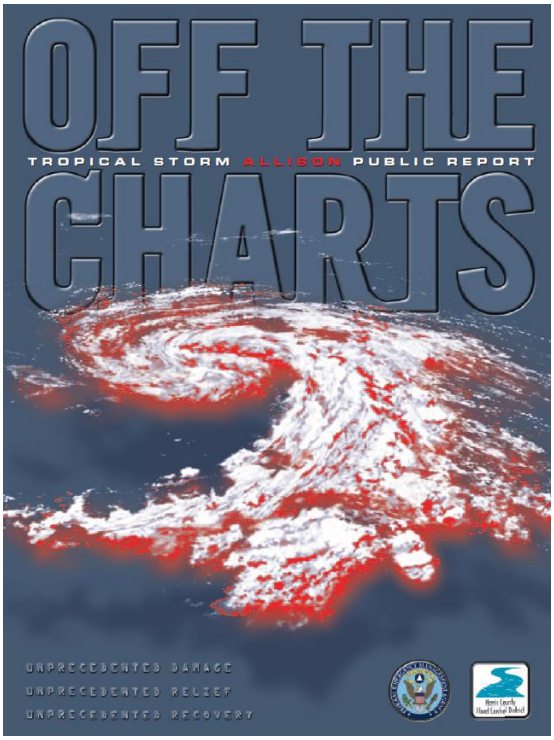
DATE : September 27, 2017

SUBJECT : Hurricane Harvey Storm Event

Homes in the City of Bellaire have flooded on numerous occasions over many decades. There are many factors that contribute to structures flooding in the area. Some of those include:

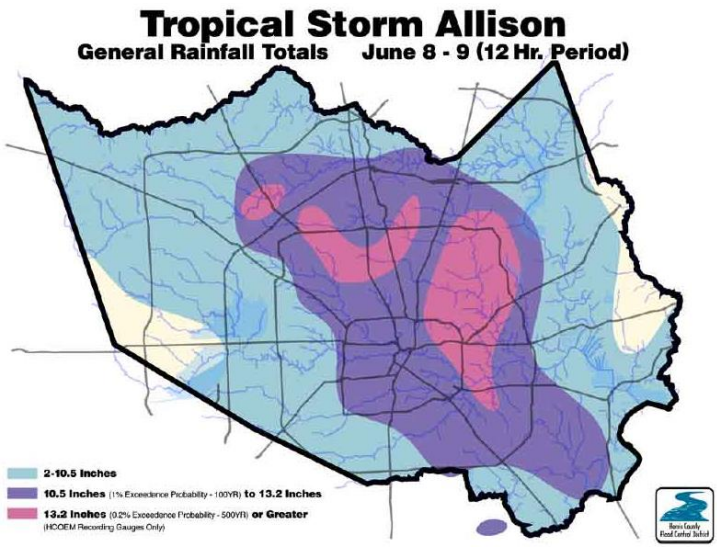
- very high annual rainfall of about 50 inches
- very flat topography with poor sheet flow characteristics
- clay soils that do not absorb water very well
- close proximity to an undersized Brays Bayou
- Low finished floor elevations of older homes
- Extreme storm events

Before Hurricane Harvey, the most devastating storm to flood Bellaire in recent times was Tropical Storm Allison in June of 2001. The Harris County Flood Control District (HCFCD) described Tropical Storm Allison as “Off the Charts” in terms of unprecedented rainfall amounts.



When the local rains finally eased, Allison had left Harris County, with 22 fatalities, 95,000 damaged automobiles and trucks, 73,000 damaged residences, 30,000 residents in shelters, and more than $5 billion in property damage in its wake.

At the time, the rainfall amounts were truly off the charts.



That is until Harvey…if TSA was off the chart, then Harvey broke the chart.

HCFCD provided a good description of the path Harvey followed that is worth repeating. The tropical wave that would eventually develop into Hurricane Harvey moved off the west coast of Africa on August 11th and tracked westward across the tropical Atlantic becoming a tropical storm on August 17th and then moved into the Caribbean Sea where Harvey become disorganized and was downgraded to a tropical wave. The tropical wave entered the Gulf of Mexico on the afternoon of the 22nd and was upgraded again to tropical depression Harvey on the morning of the 23rd. Over the next 48 hours Harvey would undergo a period of rapid intensification from a tropical depression to a category 4 hurricane and make landfall along the Texas coast near Port Aransas around 10:00 p.m. on August 25th. The upper air steering patterns that moved Harvey toward the Texas coast weakened and Harvey's forward motion slowed to near 5mph after landfall and then to a meander just north of Victoria, TX on the 26th. Rain bands on the eastern side of the circulation of Harvey moved into southeast Texas and Harris County on the morning of the 25th and continued through much of the night and into the 26th. A strong rain band developed over Fort Bend and Brazoria Counties during the evening hours of the 26th and spread into Harris County and slowed while training from south to north. Flash flooding developed rapidly between 10:00 p.m. and 1:00 a.m. as tremendous rainfall rates occurred across much of Harris County. Additional rain bands continued to develop into the morning hours of the 27th producing additional excessive rainfall amounts.

As the center of Harvey slowly moved east-southeast and back offshore heavy rainfall continued to spread across Harris County through much of the 29th and the 30th exacerbating the ongoing widespread and devastating flooding. Harvey maintained tropical storm intensity the entire time while inland over the Texas coastal bend and southeast Texas. After moving offshore, Harvey made a third landfall just west of Cameron, Louisiana on the morning of the 30th.
Total rainfall amounts ranged from 25 to 47 inches across the county for the 4 days. The 2 day amount ranged from 20 to 35 inches.

Rainfall was less than a 4% (25-yr) event for the 15-min to 6-hr time periods for most areas except southeast Harris County and Brays Bayou where 2% (50-yr) to 0.2% (500-yr) and greater rainfall occurred. Rainfall for the 12-hr to 4-day time periods ranged from 2% (50-yr) to 0.2% (500-yr) and greater for all watersheds.

Time	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr	2-day	4-day
Peak Rainfall (inches)	6.8	11.9	14.8	18.9	20.9	25.6	34.5	47.4

The Harris County Flood Control District (HCFCD) approximated the magnitude of the Hurricane Harvey storm event as follows:

Duration	**Rainfall Amount**	**Return Interval – years (exceedance probability)**
1-Hour		
Maximum	6.8”	1,500 (0.0667%)
Weighted Range	4-5”	50-500 (2.0% - 0.2%)
24-Hour		
Maximum	28.6”	8,000 (0.0125%)
Weighted Range	16-20”	200-1,000 (0.5%-0.1%)
2-Day		
Maximum	35.2”	9,000 (0.011%)
Weighted Range	27-33”	2,500-6,000 (0.04%-0.0167%)
4-Day		
Maximum	47.4”	40,000 (0.0025%)
Weighted Range	35-43”	500-20,000 (0.2%-0.005%)

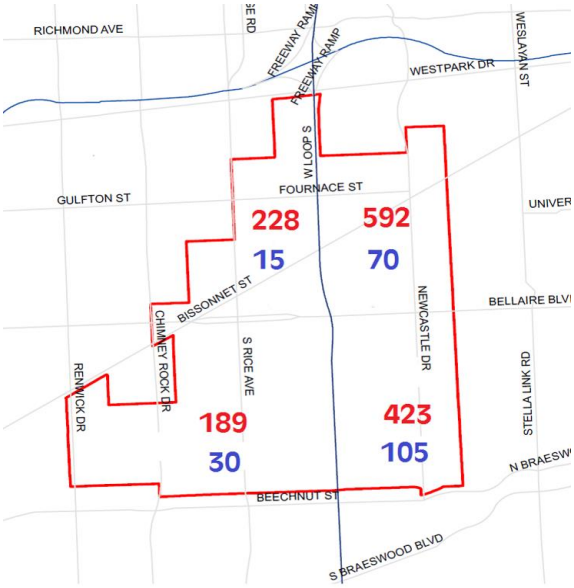
The next table compares the extraordinary rainfall associated with Harvey against Tropical Storm Allison in June 2001 and the Tax Day Flood of April 2016 for various time periods. It is interesting that Tropical Storm Allison exceeds Harvey's rainfall in the 12 and 24-hr periods. In the 2 day period Harvey dropped 6.0 inches more than Allison and 8.9 inches more over 4 days.

Duration	**Harvey**	**Allison June 2001**	**"Tax Day" 2016**
1-hr	6.8	5.7	4.7
2-hr	11.9	9.9	7.3
3-hr	14.8	13.5	8.3
6-hr	18.9	21.2	13.9
12-hr	20.9	28.3	16.7
1 day	25.6	28.4	17.4
2 days	34.5	28.5	17.5
4 days	47.4	38.5	N/A

A total of 1 trillion gallons of water fell across Harris County over the 4 day period which would fill the Houston Astrodome 3200 times and cover Harris County's 1800 square miles with an average of 33 inches of water. This volume of water would also run Niagara Falls for 15 days.

Disastrous flooding occurred on nearly every watershed in Harris County with many creeks and bayous rising to record or near record levels. Historical records held by the October 1994 flood and Tropical Storm Allison were exceeded by Harvey at many locations. Field work continues to collect high water marks and document the flooding extents and depth.

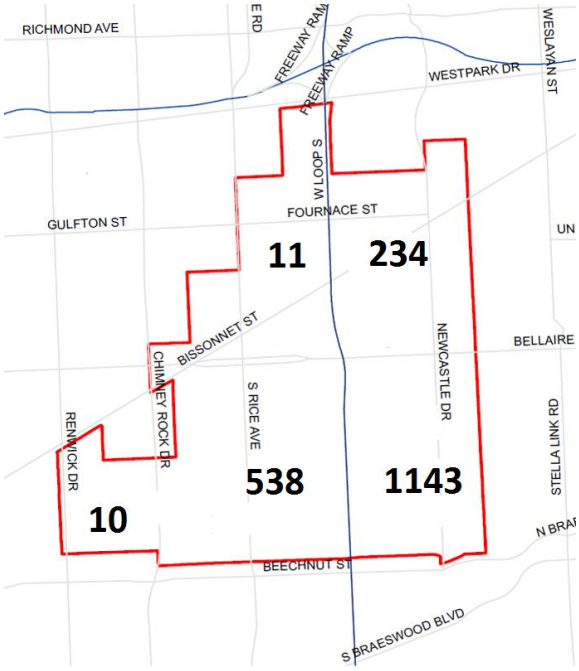
A review of the Tropical Storm Allison flood event documentation for the City of Bellaire showed approximately 1,432 homes were flooded in Bellaire with 1,015 of those homes located east of 610. The largest number of homes flooded were located in the northeast quadrant of the City away from the bayou.



Reported Structures Flooded

Allison 1432 JUNE 9, 2001 May 2015 220

ARKK ENGINEERS



Homes Flooded not including garages

Hurricane Harvey flooded approximately 2318 structures including garages. We estimated approximately 1936 homes had water damage to the main house structure. The areas with the most structures flooded were located in the southeast quadrant of the city followed by the south central area. Both of these areas close to Brays Bayou.

Two independent sets of structural flooding data were collected, one by the fire department and the other by ARKK Engineers. The number of flooded structures is our best guess at the time of inspection determined by identifying water surface elevation debris lines immediately after the storm and debris piles in the front yards a few days after the flood.

Types of Floods in Bellaire

As we have discussed in the past, flooding occurs in the Bellaire area because of shallow floodplain flooding and ponding/overland flow problems or some combination of both. Harvey was an extreme combination of both types of flooding events.

Shallow Floodplain Flooding

Shallow floodplains exist throughout much of Harris County. Bellaire is located very near Brays Bayou and is in the shallow floodplain of Brays Bayou.

When the Bayou capacity is exceeded and flood waters overtop the bayou banks, flooding occurs in the land areas near the bayou that are located at lower elevations. Land areas can remain flooded for hours until water surface elevations drop in the bayou.

As Brays Bayou comes out of its banks, the City drainage is adversely and directly affected.

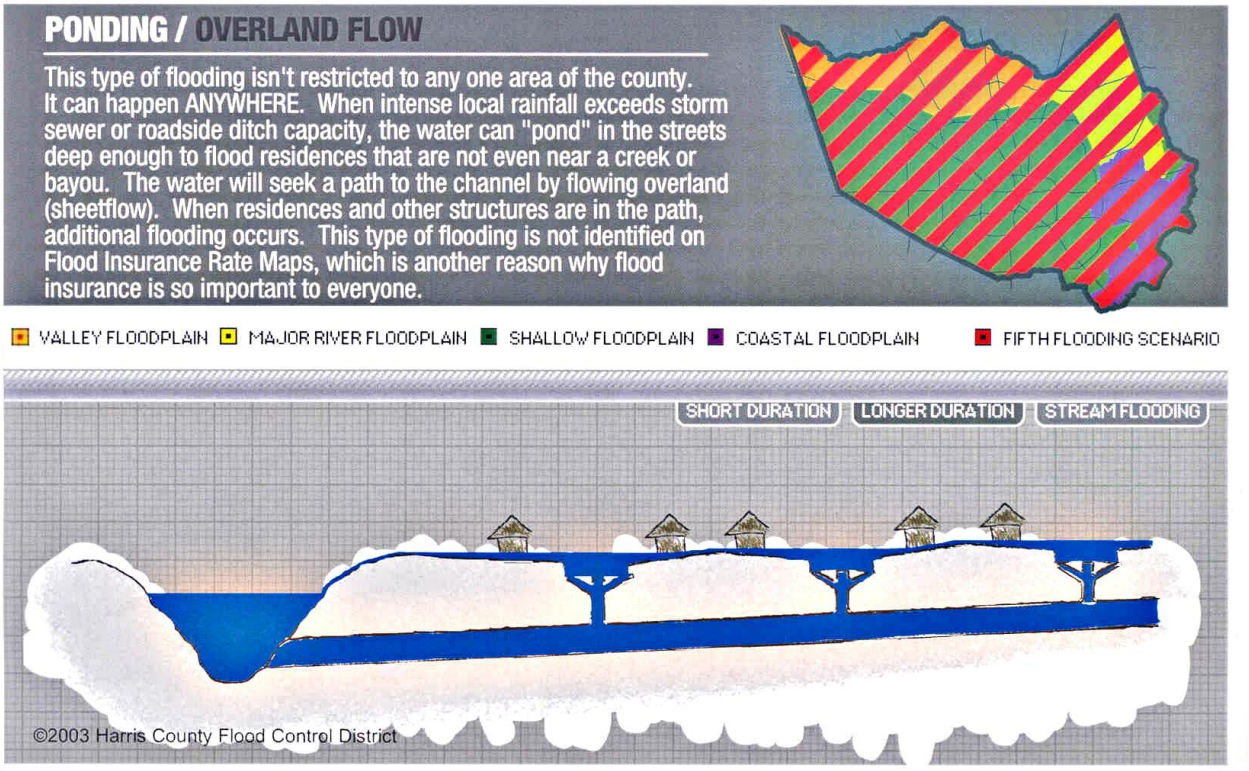
Ponding/Overland Flow Flooding

Ponding or overland flow flooding occurs when intense local rainfall exceeds the storm sewer capacity, the water can “pond” in the streets deep enough to flood residences that are away from the bayou.

This type of flood is not restricted to any one area. It can happen anywhere. The storm water ponds until it eventually seeks a path to the outfall by flowing

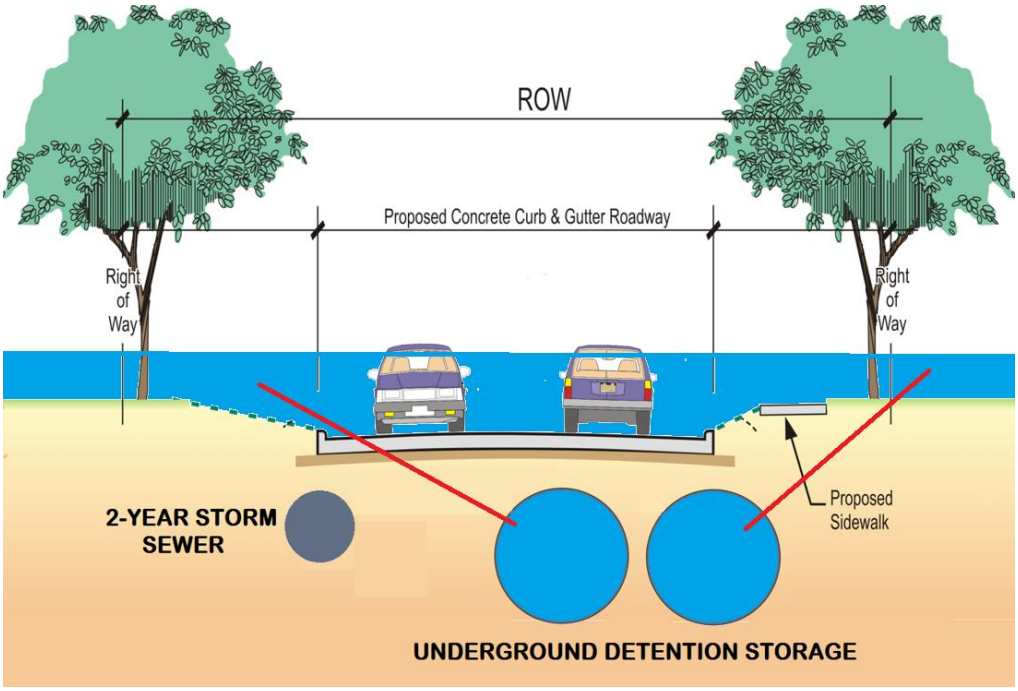
overland. When residences and other structures are below the surrounding land elevation or in the path of the overland flow, flooding may occur. The probability of this type of flooding is not shown as a floodplain on the Flood Insurance Rate Maps. This type of flooding condition is something that Bellaire is addressing during the current Bonds for a Better Bellaire 2016 program.

As you know, our current Bonds for a Better Bellaire Street reconstruction program focuses on the street condition and drainage needs based on local heavy rainfall problem areas. In other words, trying to lower ponding heights when the

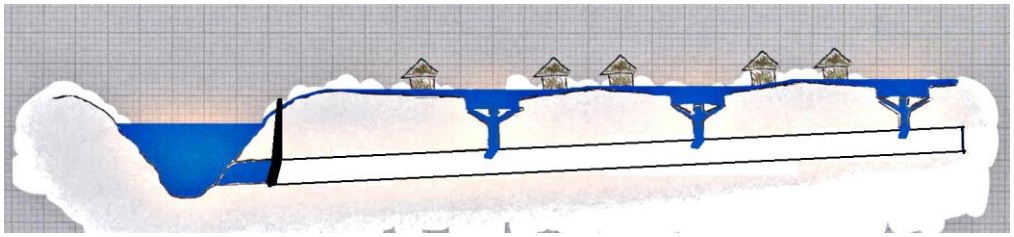


City of Bellaire is hit with a localized 100 year event and water ponds to a height that begins to flood structures before it can flow away from the area overland.

The Bonds for a Better Bellaire 2016 program does two things to improve the drainage during this type of rain event. First, the underground system for these streets with major localized drainage problems will be upsized above the typical two year to the 100-year capacity. The idea being to improve the underground storage capacity under the pavement, thus decreasing the height of ponding during a major local rainfall.



We are also in the preliminary design stage of developing backflow devices in certain locations to prevent storm water from the bayou during high water surface conditions from coming back into the City's underground system. This backflow can take up capacity in the underground system even when there is no local rainfall, so the idea is to restrict stormwater from Brays Bayou from back flowing into the City's underground system, thus allowing local storm water to use the City's underground system capacity

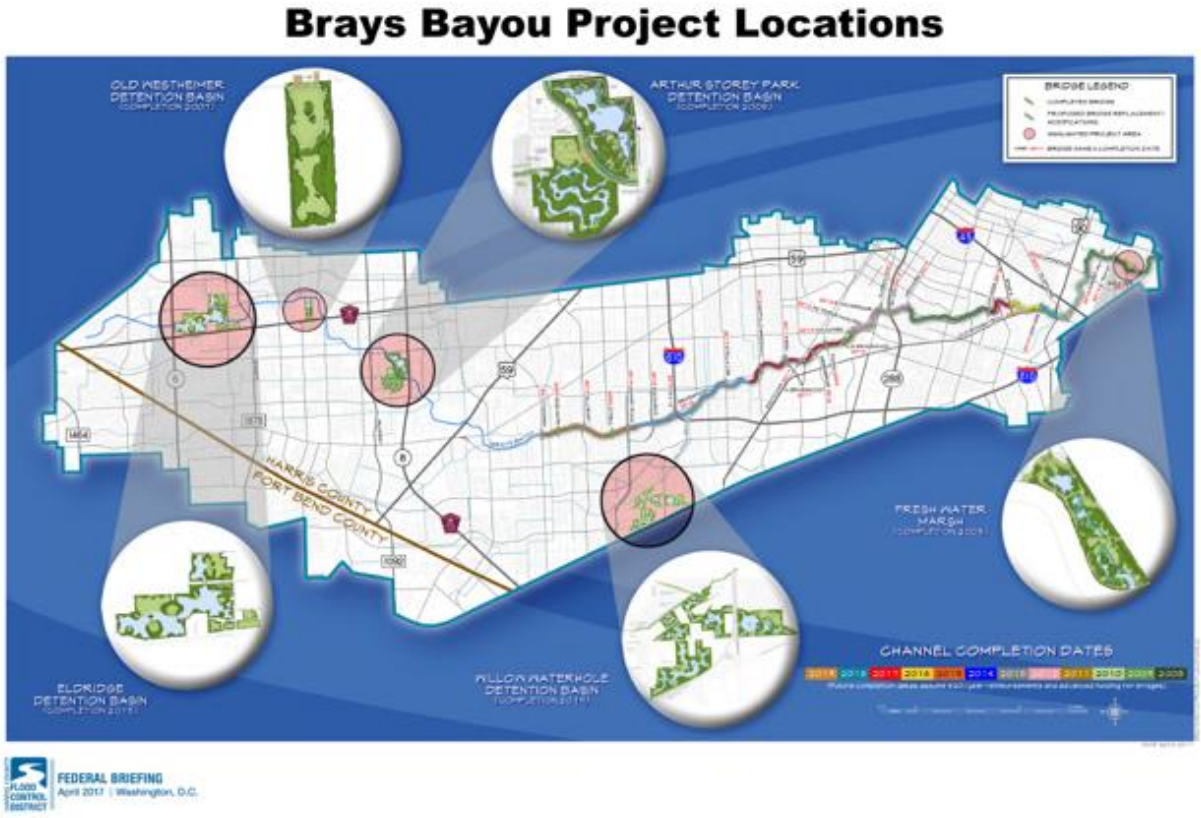


The majority of the first phases of the Bonds for a Better Bellaire program has focused on these local drainage improvements that the City of Bellaire can improve without outside agency approval.

In some cases, the backflow devices require approval from other entities like TxDOT and the City of Houston because they affect their drainage systems as well. The City of Bellaire continues to explore ways to leverage bond dollars to construct projects with other entities that will benefit the citizens of Bellaire. For example, the City took advantage of the current plans TxDOT has for reconstructing the I69/IH610 interchange by contributing a third of the cost for upsizing storm sewers in the vicinity of the new construction.

Project Brays

The single most significant flood control improvement project for our area has been under construction for many years and is outside the control of the City of Bellaire and under control of the HCFCD and Army Corps of Engineers. That is Project Brays.



The Brays Bayou Federal Flood Damage Reduction Project, known as Project Brays, is the largest flood damage reduction program undertaken by the Harris County Flood Control District to date.

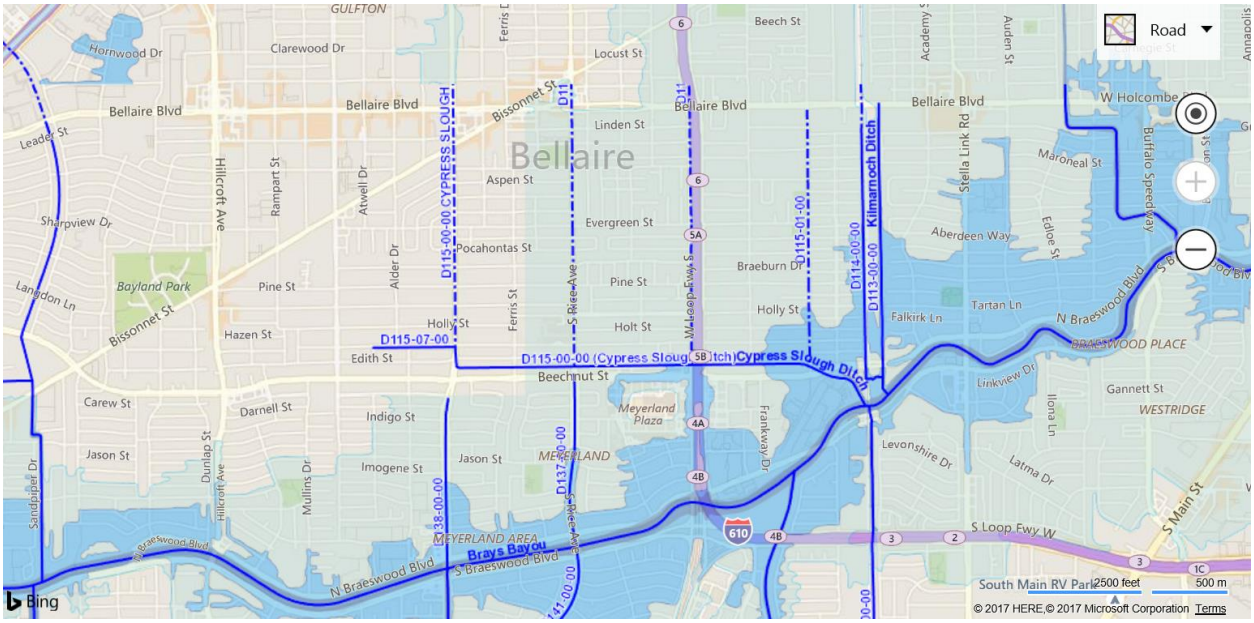
A cooperative effort between the Flood Control District and the U.S. Army Corps of Engineers (Corps), Project Brays is an active multi-year, $480 million project that substantially reduces flooding risks in the Brays Bayou watershed. It is the largest partnership project the Flood Control District and Corps have conducted to date.

Encompassing more than 75 individual project components, Project Brays will help to reduce flooding risks by widening 21 miles of Brays Bayou from the Houston Ship Channel to Fondren Road and from West Houston Center Boulevard to State Highway 6, replacing or modifying 32 bridges (including two pedestrian bridges) to accommodate channel modifications and excavating four storm water detention basins that will hold a collective 3.5 billion gallons of storm water.

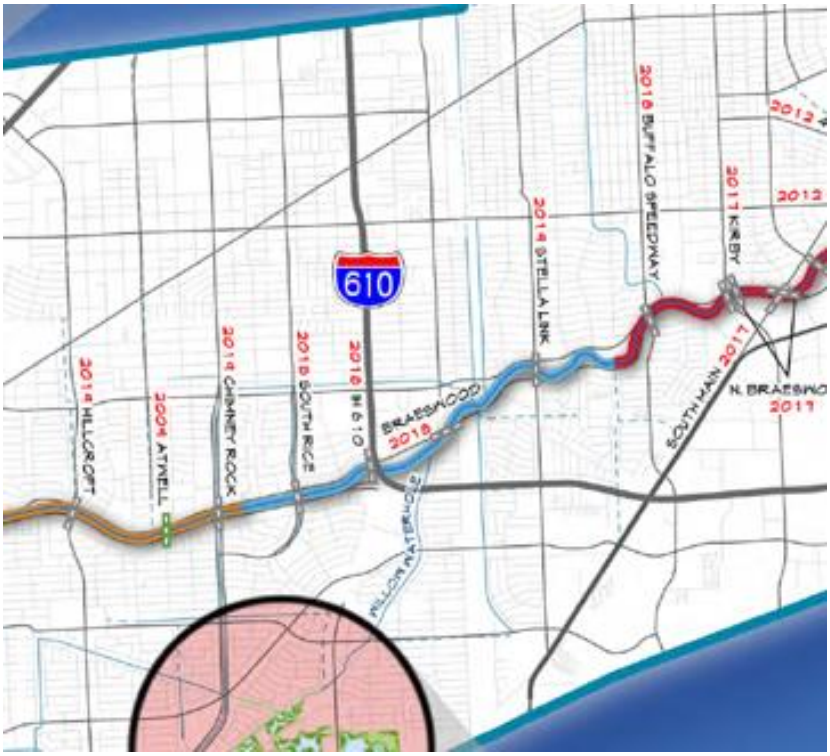
The map below shows the Conditional Letter of Map Revision (CLOMR) that was approved by FEMA for Project Brays. It represents an *estimate* of the revised 1% floodplain as a result of the proposed project and is *not to be used as an official map* for floodplain determinations or for setting insurance rates. The map is subject to change based on complete construction of the proposed Project Brays elements. The purpose of this map is to provide information to Brays Bayou residents about the potential flood risk reduction benefits of Project Brays.

Upon completion, Project Brays will provide a 1 percent (100-year) level of protection along the main stem of Brays Bayou upstream of Beltway 8. After the construction of all elements of Project Brays, the area downstream of Beltway 8 will see the removal of the 1 percent (100-year) floodplain from approximately 15,000 homes/businesses in the watershed according to the HCFCD.

The CLOMR map shows much of 100-year floodplain removed from the majority of Bellaire. It is important to keep in mind that it does not show flooding that may occur from extreme local rainfall events.



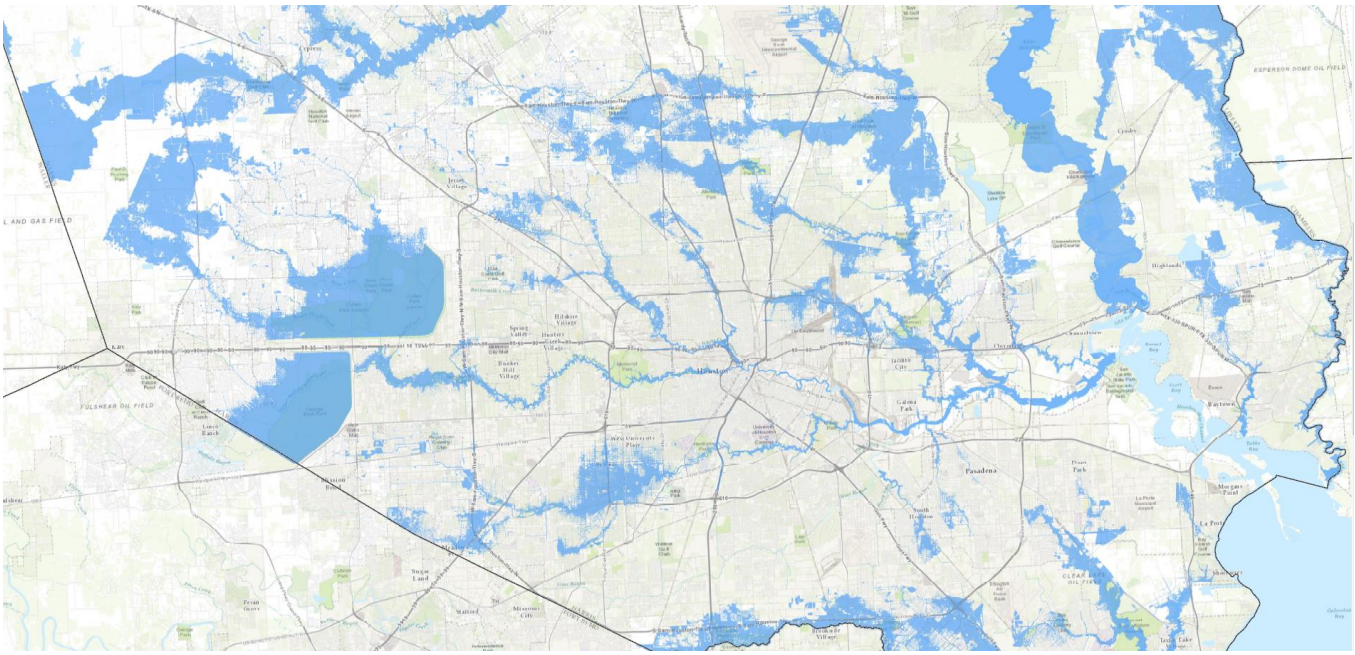
The portion of Project Brays that should benefit the City of Bellaire the most is channel widening and increasing capacity scheduled to be completed in 2021.



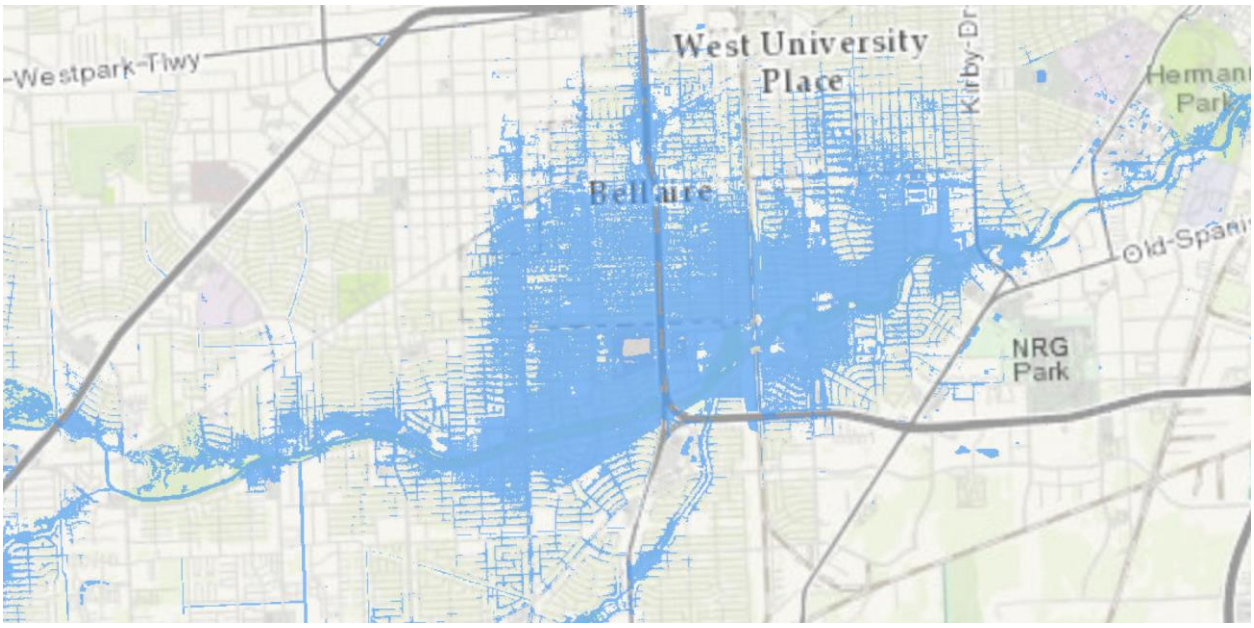
Because high water surface elevations within the banks of the bayou may still cause backflow into the city's storm sewers even after Project Brays is completed, the back flow prevention methods recommended in the City's Drainage Study and started under Bonds for a Better Bellaire 2016 should remain a priority.

Project Brays and the Bonds for a Better Bellaire 2016 program together still do not solve the catastrophic flooding problems caused by a storm like Hurricane Harvey.

As previously mentioned, Harvey broke the Charts for a severe storm. There appear to be several factors that caused the severe flooding in Bellaire during Harvey. This DRAFT inundation map prepared by the HCFCD shows the City of Bellaire as one of the, if not the, worst hit areas along the entire reach of the 128 square mile Brays Bayou watershed.



The large inundation area highlighted below is mostly Bellaire and Meyerland.



This shows the importance of expediting the improvements to Brays near the City of Bellaire.

During an event like Harvey, there appears to be other factors that contributed to flooding. The elevated railroad track to the east of the City and the elevated IH 610 roadway in the center of Bellaire combined with the inadequate capacity of Brays Bayou may have blocked the overland flow from the area creating excessive flood depths.

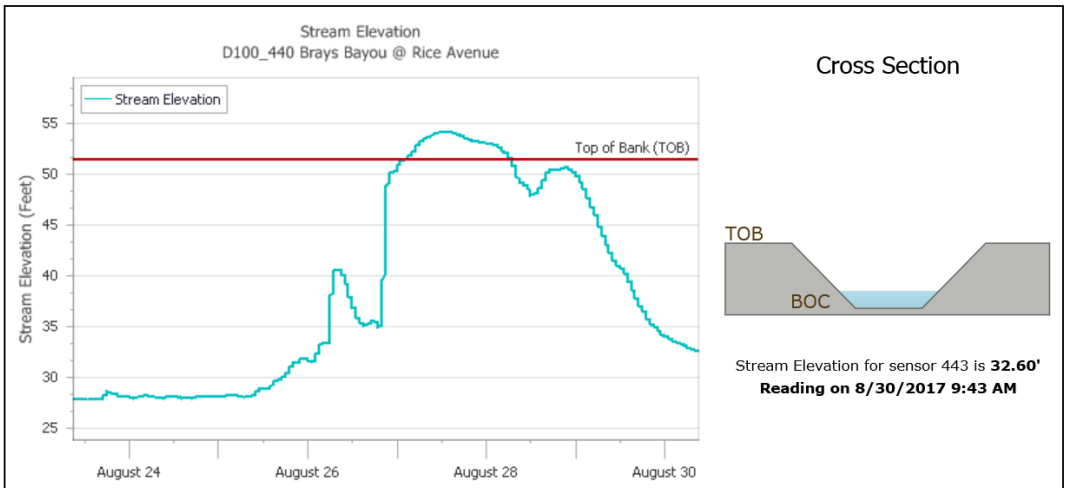
I reviewed the HCFCD Food Warning System information that shows both historical storm events and real time rainfall and flood stages in the Harris County bayou and stream system. A detailed look at rainfall amounts and flood stage elevations in Brays Bayou on August 27th through the 29th provides valuable insight as to why the southeast and south central portion of Bellaire flooded to such a depth.

Both the HCFCD rain gages on Brays Bayou near the City of Bellaire show the bayou out of or at the top of its banks for 2 days, August 27th and 28th.

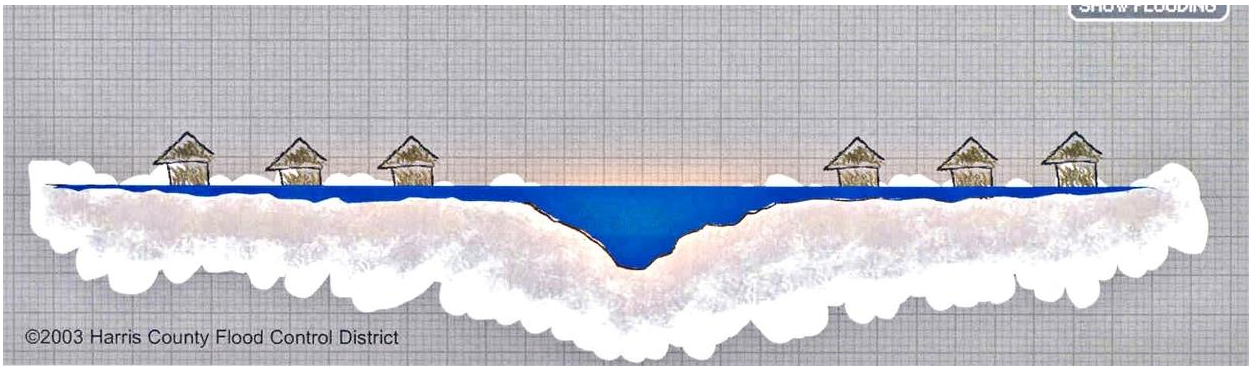
Stream Elevation Sensor **443**
D100_440 Brays Bayou @ Rice Avenue

Key Map 531U	
Sensor ID	**443**
Sensor Type	Bubbler
Installed	8/10/1984
Top of Bank (TOB)	51.30'
Bottom of Stream	25.97'
Tip of Orifice	27.45'
Measuring Plate	54.84'
Benchmark	53.81'

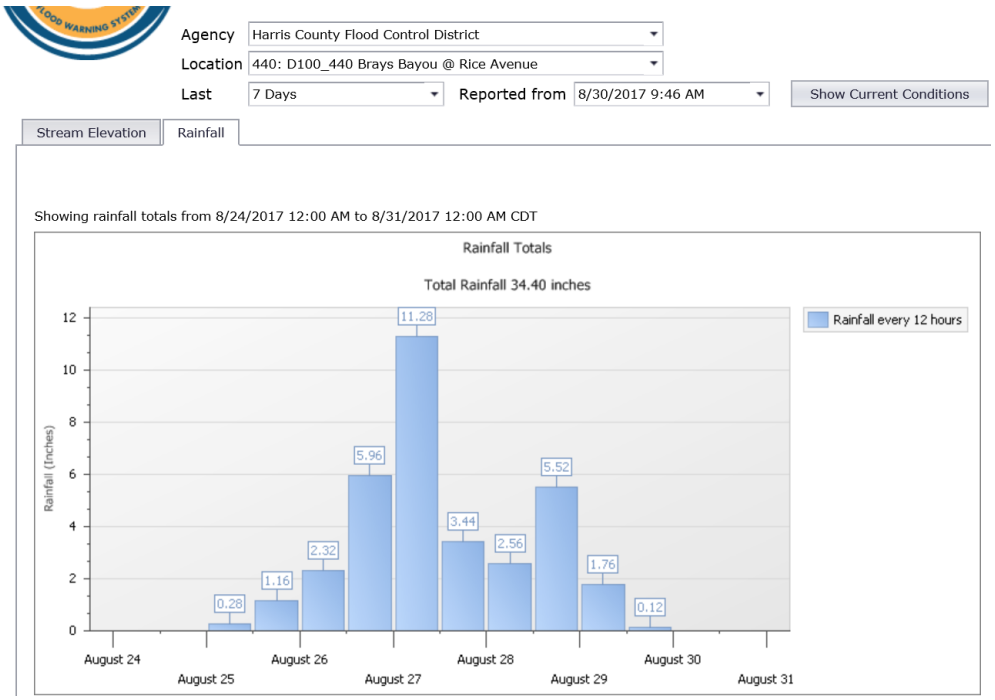
RM 040160 stamped D100 BM 20 located on the downstream sidewalk of northbound bridge at stream centerline, 1988 NAVD, 2001 adjustment. 78 to 01 Adjustment -1.99
As of July 1, 2007, the elevation datum was changed from 1929 NGVD, 1978 adjustment to the 1988 NAVD, 2001 adjustment.



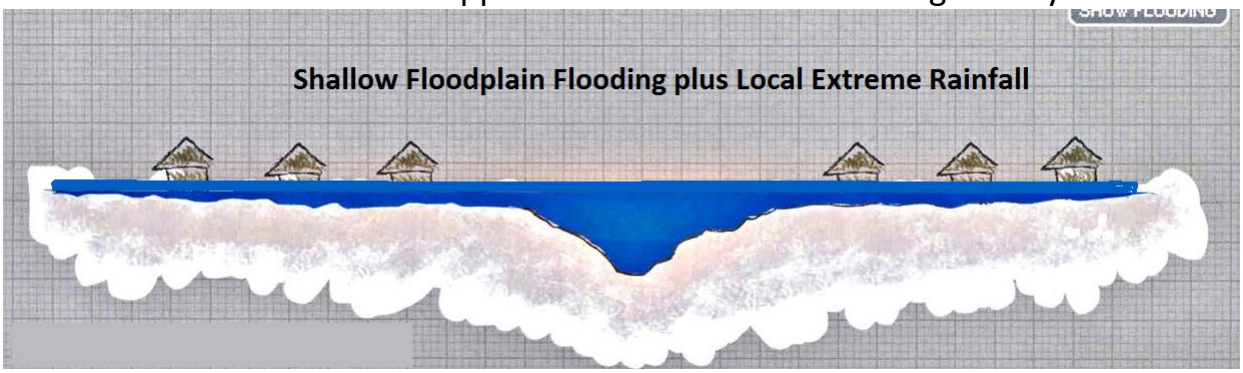
This illustration shows the bayou at flood stage during that 2 day period. This condition alone would flood the lower elevations of Bellaire.



At the same time this shallow floodplain flooding was occurring, the City of Bellaire received over 2 ½ feet of rainfall that simply put, added to the depth of the flooding.



These two flood conditions happened at the same time during Harvey.

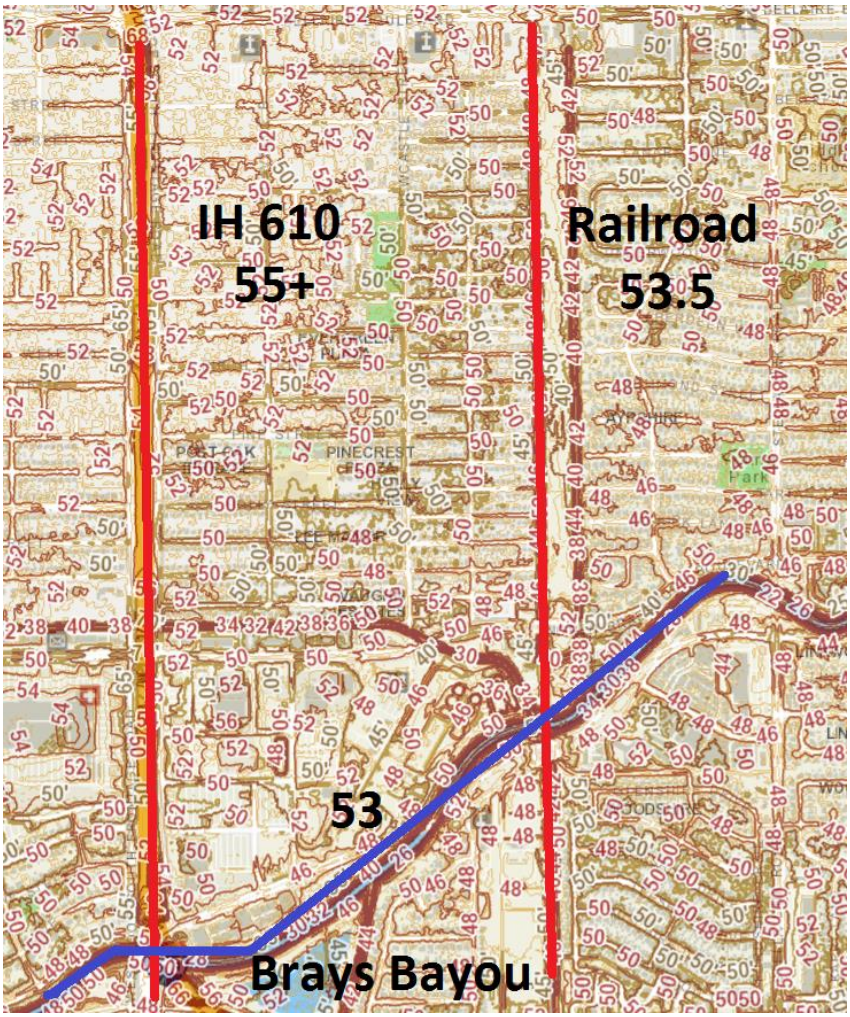


The bayou was at are over the banks creating a wall of water in which the local extreme event rainfall had nowhere to drain.

The elevated section of IH 610 and the railroad prevented the natural flow of the storm water from flowing to the southeast when the bayou was at flood stage.

The magnitude of rainfall that hit the Bellaire area at the same time the water surfaces in the bayou were at or above the 100 year levels was unprecedented. The HCFCD has estimated the 2.5 to 3 feet of rainfall over this two day period to be within the 2500 to 6000 year reoccurrence or return interval. Absolutely devastating amounts of rain.

What would have helped? More capacity in Brays Bayou as Project Brays will provide and perhaps flood relief structures through the elevated railroad and IH 610 structures.



We are still collecting data on homes that flooded in Bellaire, but preliminary indications are the current standard for building homes above the base flood elevation was a success. We found that the homes constructed under the newest National Flood Insurance and City of Bellaire standards performed well.

SUMMARY

Description		Existing Homes	May 2015 Flood		August 2017 Flood		Flooded in Both Storms
			Structural Flooding	% Flooded Homes	Structural Flooding	% Homes w/Structural Flooding	
Tier I	Pre 1980	2313	122	5%	1039	45%	80
Tier II	1980-1993	1087	32	3%	291	27%	12
Tier III	1994-2007	2348	56	2%	554	24%	30
Tier IV	2008-Present	739	16	2%	47	6%	5
	Year Build Unknown	201	2	1%	5	2%	0
	TOTAL	***6688***	***228***	***3%***	***1936***	***29%***	***127***

Our preliminary review of flood data and elevation certificate data, indicates that 47 homes or 6 % of the homes that flooded were constructed to today's finished floor height regulations. Consequently, building 1 foot above the current base flood elevation provided greater protection even during this catastrophic event.

In summary, Hurricane Harvey was an unprecented catastrophic storm that in my opinion cannot realistically be completely controlled. Furthermore, there is nothing the City of Bellaire can build on its own to remove flooding conditions during an event of this magnitude. Some have suggested buying perimeter properties around the city to construct levees and pump stations to protect the City of Bellaire. Not only would this be extremely costly, it would require approvals from surrounding agencies like the Harris County Flood Control District and the City of Houston for proof there would be no adverse impact to others outside Bellaire.

Hurricane Harvey did show us the need to work together with our state and federal government to expedite improvements to Brays Bayou to add capacity and lower the flood stage water surface elevations and to perhaps explore the benefits of removing the overland flow obstacles that the railroad and IH 610 may create.

Finally, there have been some citizens that have asked for information to help warn them about flooding during these extreme storms. The HCFCD's Flood Warning System previously metioned is a very useful site that anyone can use. It can be found at: https://www.harriscountyfws.org/

Again, you can review historical flood conditions and real time water surface elevations in the Bayou and real time rainfall amounts occuring at selected rain gages.