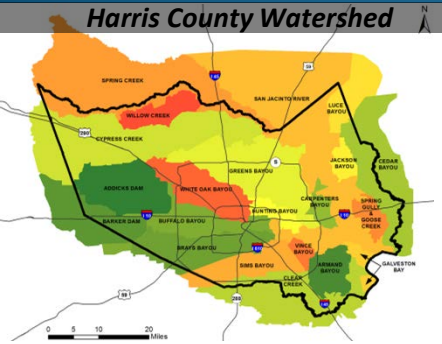
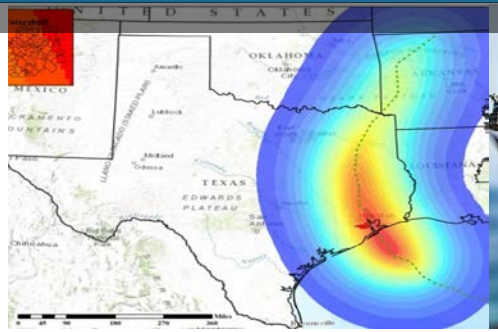
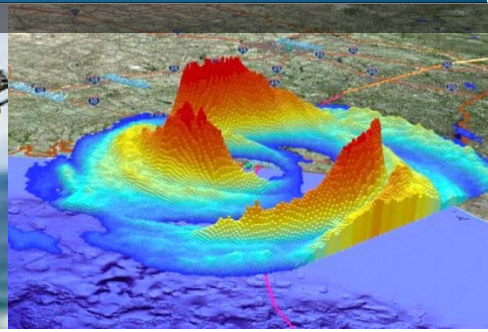
What We Learned from *Hurricane Harvey* for *Smart Cities*?







Presented at 18th Annual SAME Infrastructure Forum

February 2nd, 2018

Nick Z. Fang, Ph.D., P.E. Assistant Professor

Water Resources Engineering
Civil Engineering Department
The University of Texas at Arlington

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—WATER RESOURCES
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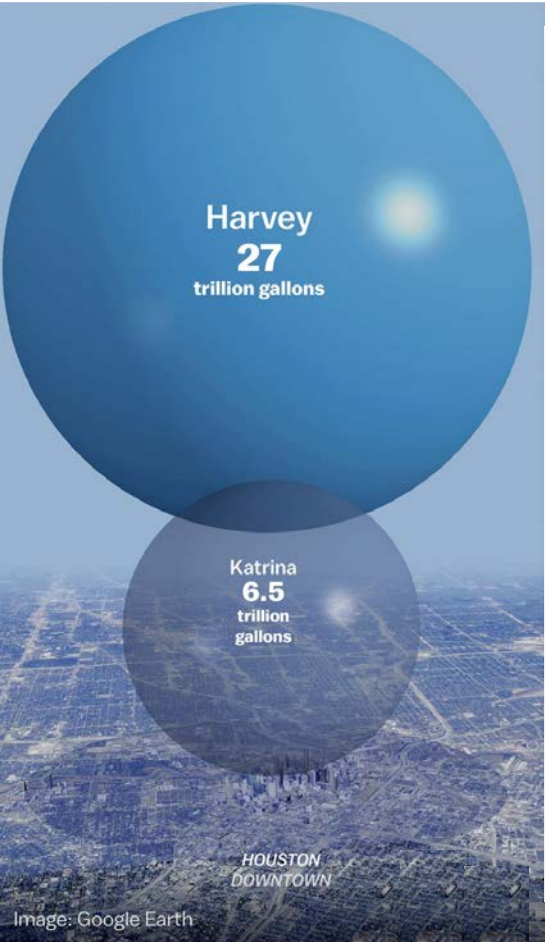
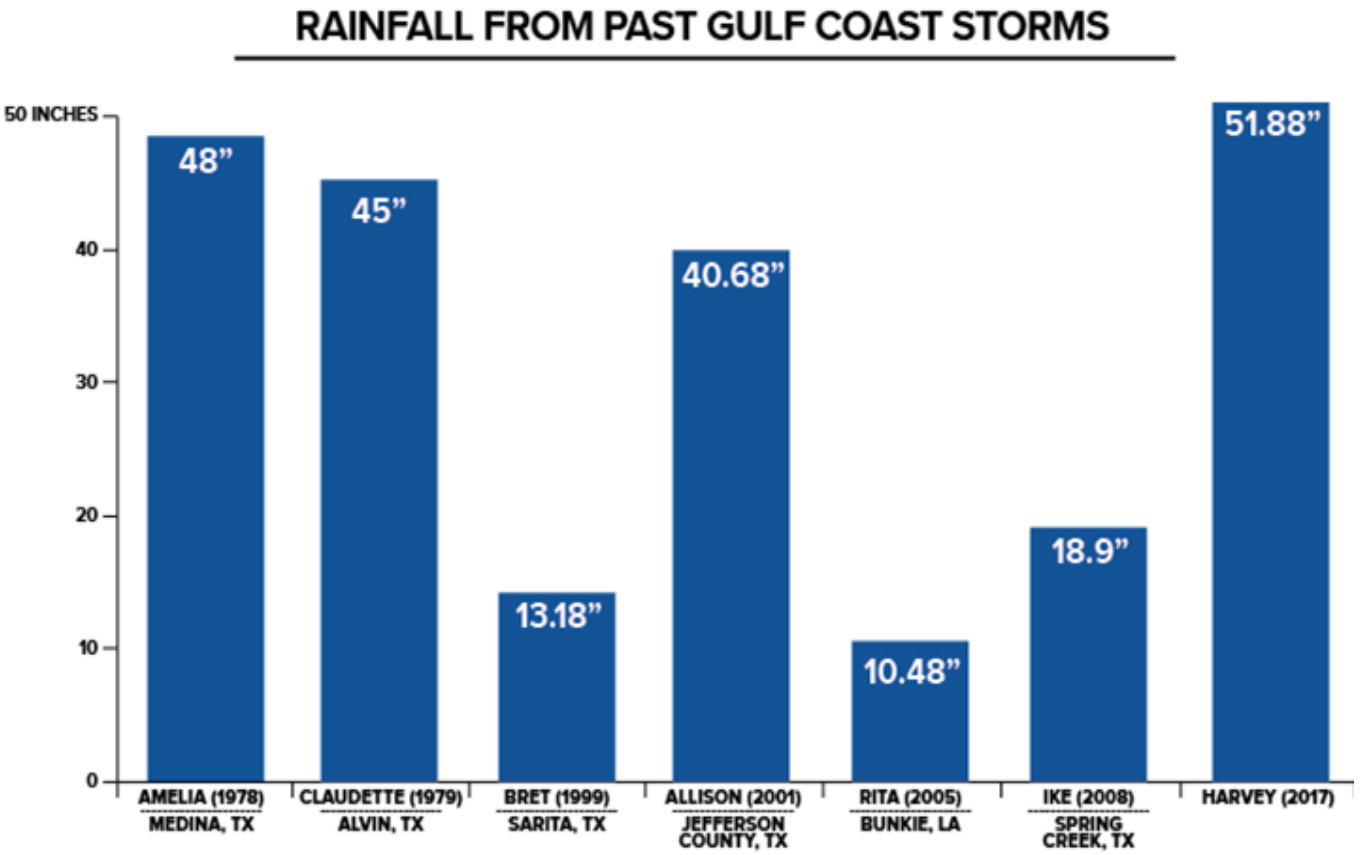
Society of SAME American Military Engineers
Sustaining Member since 1958

UNIVERSITY OF TEXAS ARLINGTON

THE POTENTIAL ESTIMATED
DAMAGE IN HOUSTON
ALONE: $97 BILLION

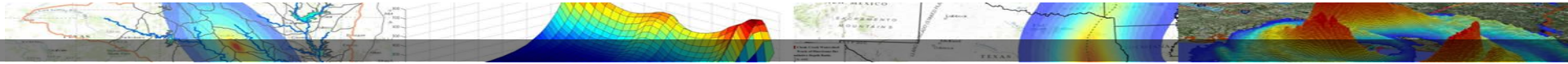

Harvey
27
trillion gallons
Katrina
6.5
trillion
gallons
HOUSTON
DOWNTOWN
Image: Google Earth


RAINFALL FROM PAST GULF COAST STORMS
50 INCHES
40
30
20
10
0
48"
45"
13.18"
40.68"
10.48"
18.9"
51.88"
AMELIA (1978)
MEDINA, TX
CLAUDETTE (1979)
ALVIN, TX
BRET (1999)
SARITA, TX
ALLISON (2001)
JEFFERSON COUNTY, TX
RITA (2005)
BUNKIE, LA
IKE (2008)
SPRING CREEK, TX
HARVEY (2017)

Source: NOAA

Hurricane Harvey Flood Damages

Image Source: Houston Chronicle

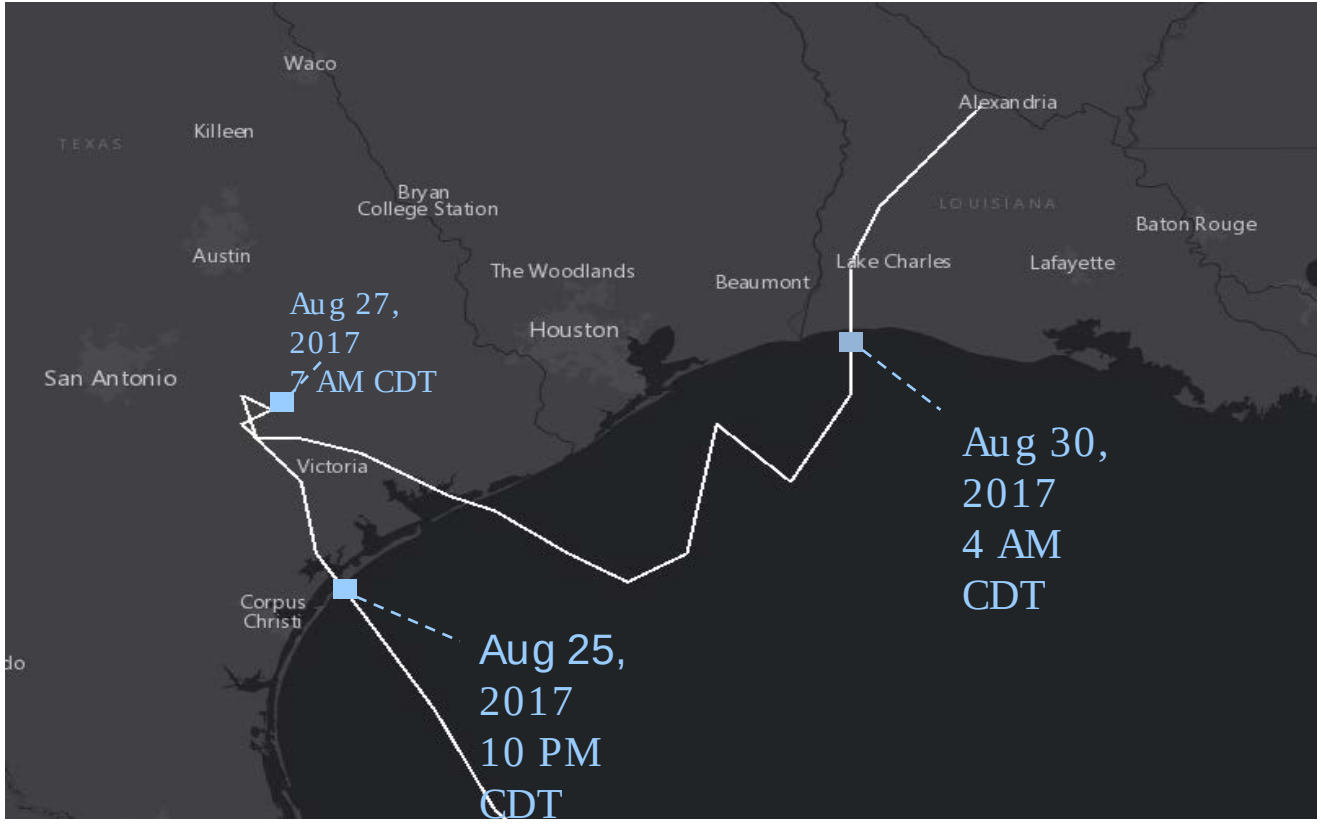


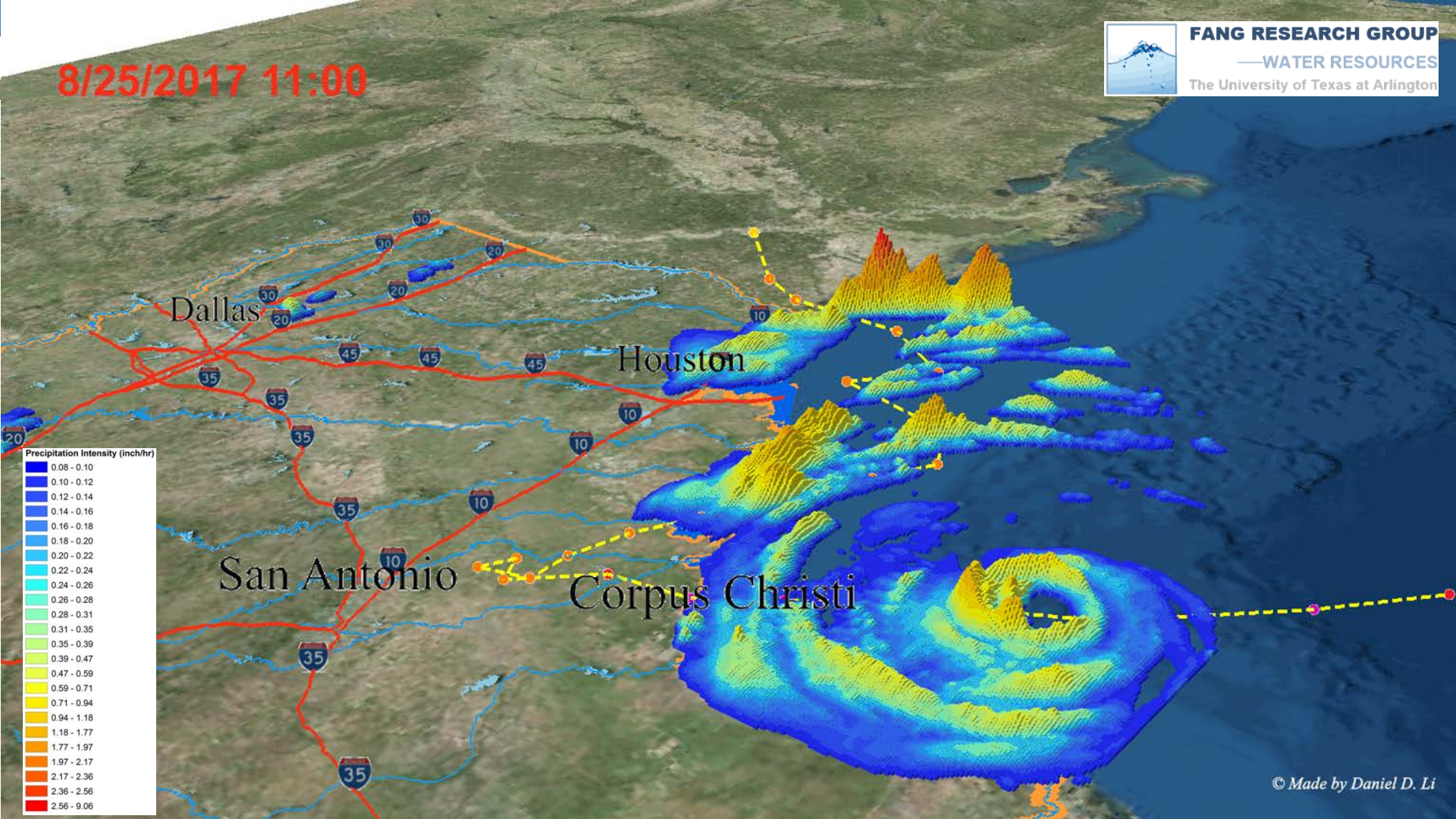
Notable Gulf Coast Hurricanes

Hurricane	Year	Date of Landfall	Landfall Location	Saffir-Simpson Category	Max. sustained winds (mph)	Max. Storm tide (ft)	Max. Total rainfall (in)
Katrina	2005	29-Aug	LA	3	127	27.9	15.0
Rita	2005	24-Sep	TX	3	115	15.1	16.1
Ivan	2004	16-Sep	AL/FL	3	121	15.1	16.9
Ike	2008	13-Sep	TX	2	109	12.8	18.9
Gustav	2008	1-Sep	LA	2	104	13.1	20.9
Isaac	2012	29-Aug	LA	1	81	11.2	26.8
Harvey	**2017**	**25-Aug**	**TX**	**4**	**130**	**12.0**	**51.9**

Adapted From: Torres, J. M., Bass, B., Irza, N., Fang, Z., Proft, J., Dawson, C., . . . Bedient, P. (2015). Characterizing the hydraulic interactions of hurricane storm surge and rainfall–runoff for the Houston–Galveston region. Coastal Engineering, 106, 7-19. doi:10.1016/j.coastaleng.2015.09.004

Hurricane Harvey Track (August 2017)




8/25/2017 11:00
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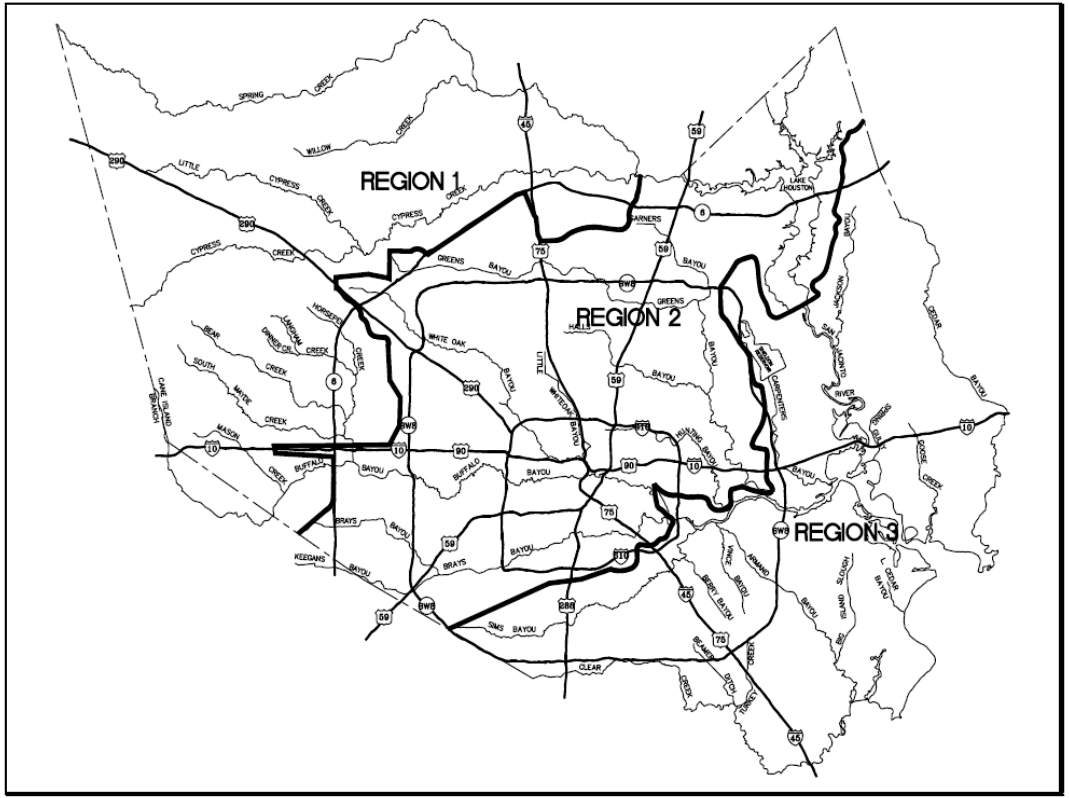
WATER RESOURCES
The University of Texas at Arlington
Dallas
Houston
San Antonio
Corpus Christi
Precipitation Intensity (inch/hr)
0.08 - 0.10
0.10 - 0.12
0.12 - 0.14
0.14 - 0.16
0.16 - 0.18
0.18 - 0.20
0.20 - 0.22
0.22 - 0.24
0.24 - 0.26
0.26 - 0.28
0.28 - 0.31
0.31 - 0.35
0.35 - 0.39
0.39 - 0.47
0.47 - 0.59
0.59 - 0.71
0.71 - 0.94
0.94 - 1.18
1.18 - 1.77
1.77 - 1.97
1.97 - 2.17
2.17 - 2.36
2.36 - 2.56
2.56 - 9.06
© Made by Daniel D. Li

Harris County Hydrologic Regions

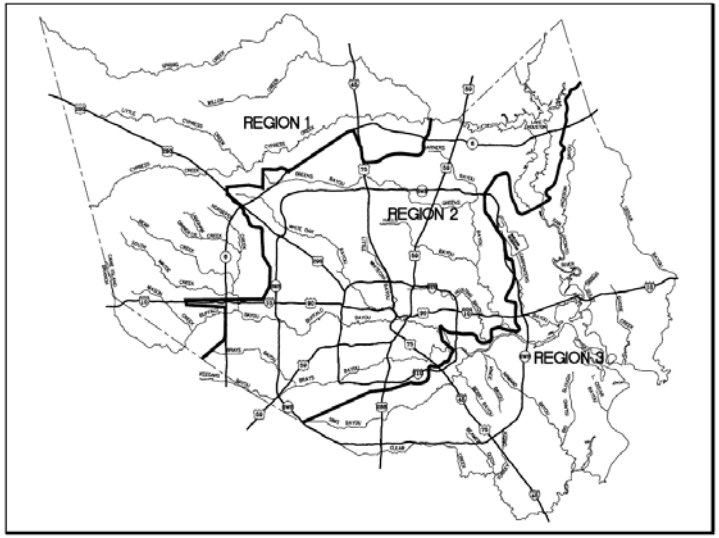
Hydrologic Regions	Region 1	Region 2	Region 3
100-yr 24 hr	12.4	13.2	13.5
100-hr 4 days	14.9	15.9	16.9
500-hr 24 hr	17.7	18.9	19.3
500-hr 4 days	19.8	21.1	22.3

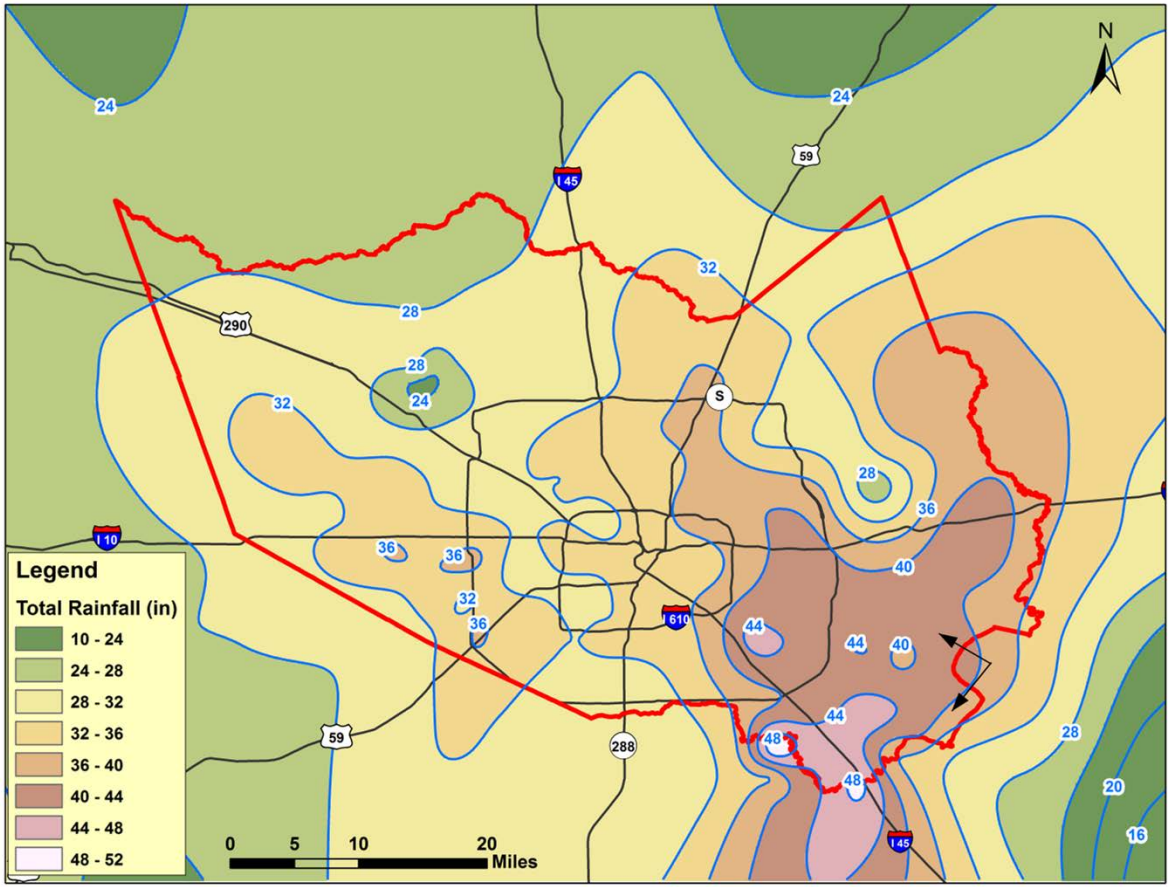


Source: TSARP

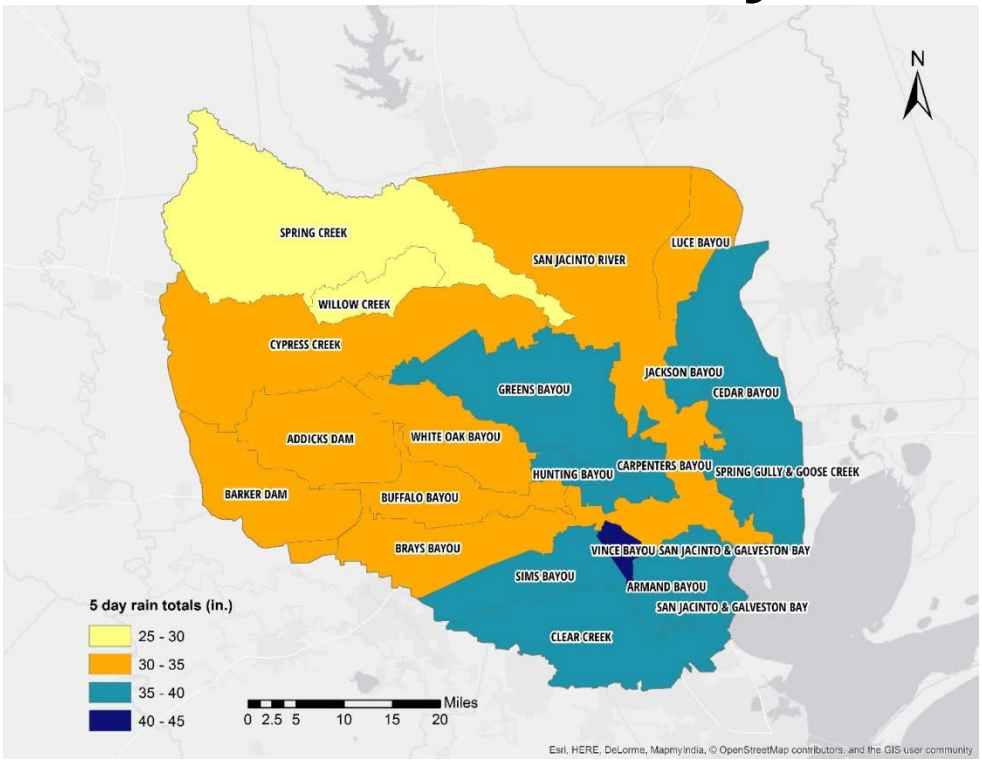
Rainfall Contours

Period: 120 hours
From Aug 25th 12:00 AM
to Aug 30th 12:00 AM





Hurricane Harvey Rainfall

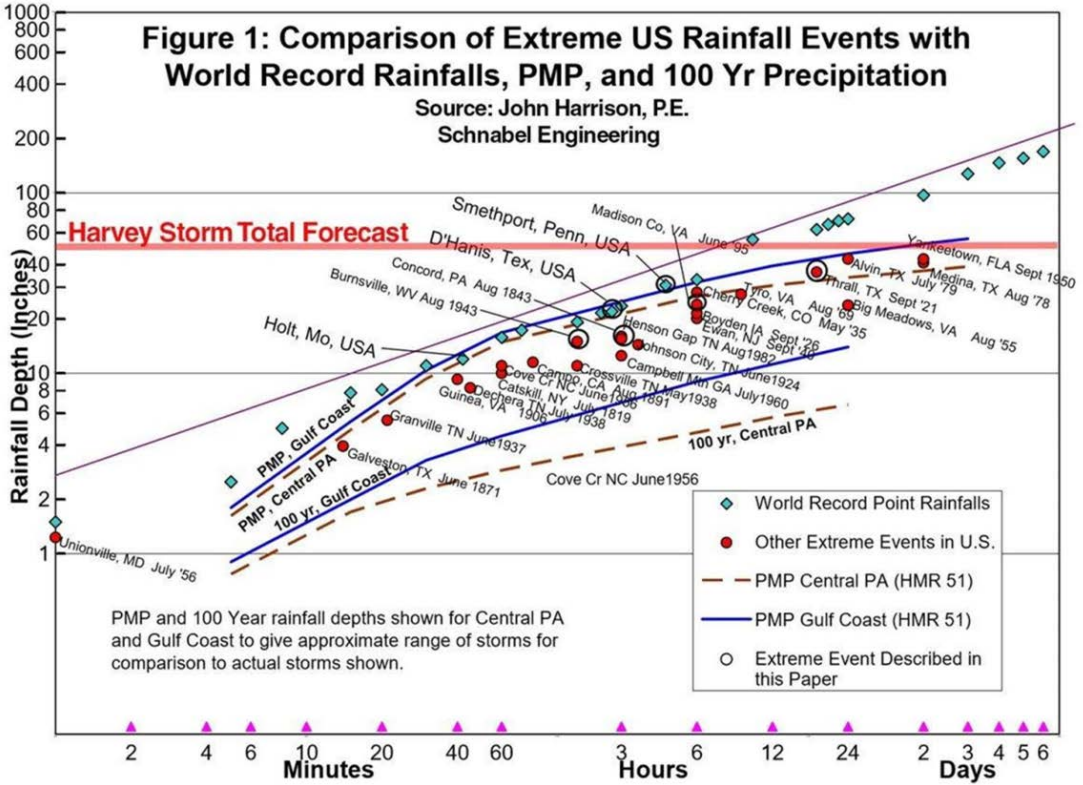


WATERSHED	5-DAY RAINFALL (IN.)
SPRING CREEK	26.9
SAN JACINTO RIVER	30.9
CYPRESS CREEK	31.2
CEDAR BAYOU	37.2
GREENS BAYOU	35.3
WHITE OAK BAYOU	32.9
ADDICKS DAM	34.0
BARKER DAM	34.3
BUFFALO BAYOU	34.3
BRAYS BAYOU	34.9
SIMS BAYOU	36.4
SAN JACINTO & GALVESTON BAY	37.5
CLEAR CREEK	37.5

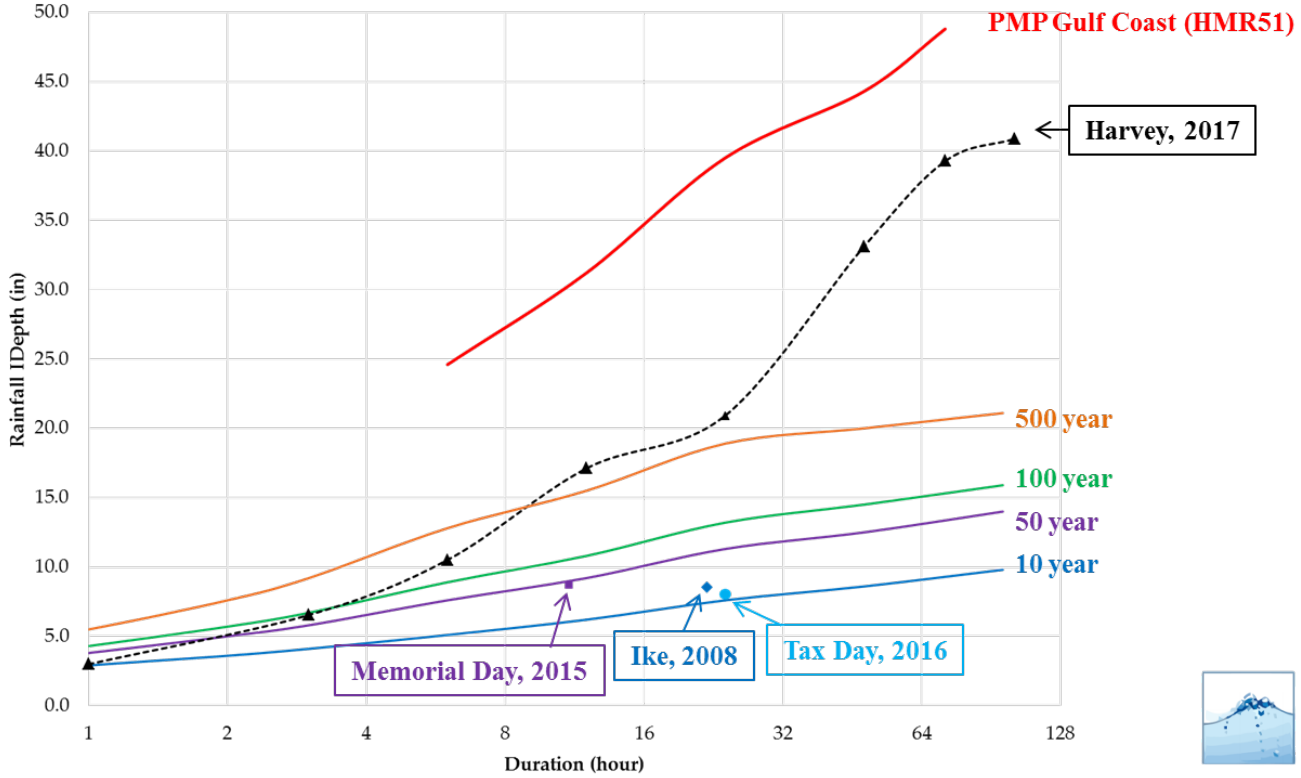
Rainfall totals from 8/25/- 8/30/2017 for Greater Houston Region watersheds (Data Source: NWS)

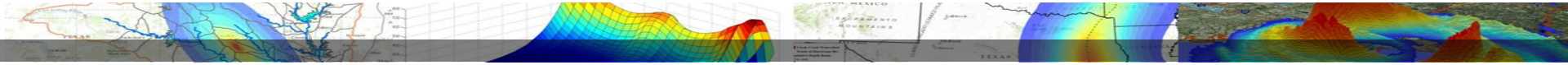
Comparison of Extreme U.S. Precipitation Events with World Record Rainfalls, PMP, and 100-Yr Precipitation

It is difficult to imagine the extreme precipitation events that have led to the PMP estimates contained in NOAA's various HMR publications. In an effort to provide perspective on the magnitude and intensity of these storms, a sampling of extreme events are shown in the figure.

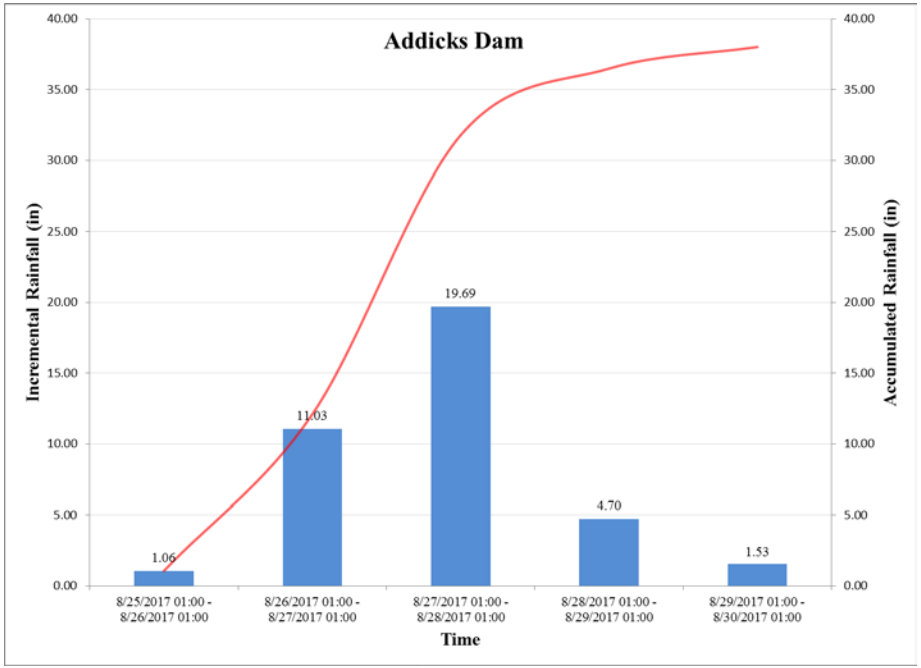


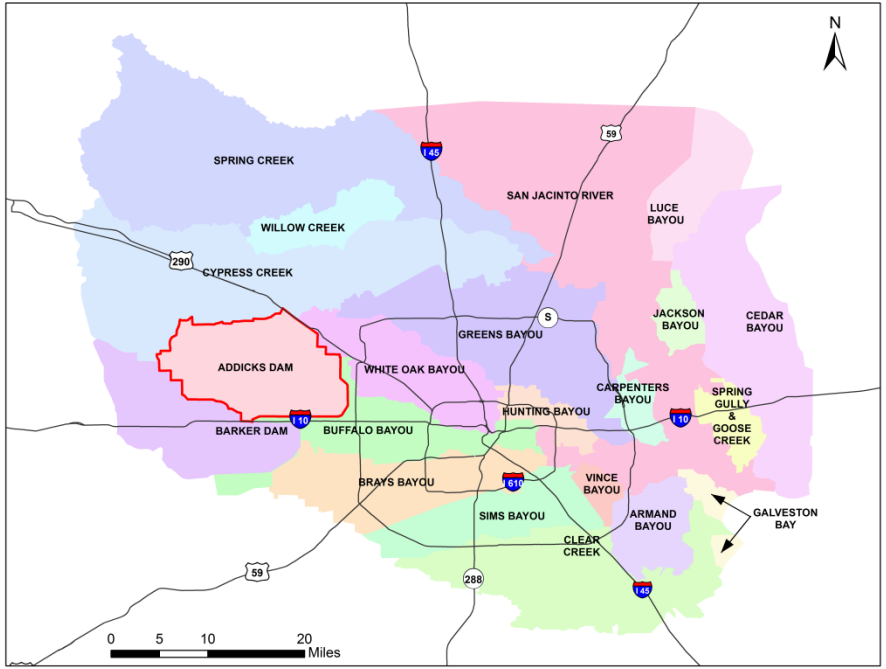
Comparison of Harvey with Recent Extreme Rainfall Events, PMP, and Frequency Design Precipitation





Maximum 24 hr Rainfall for Addicks Dam





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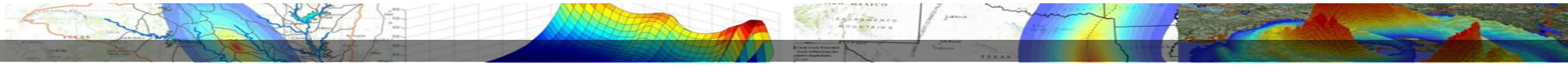
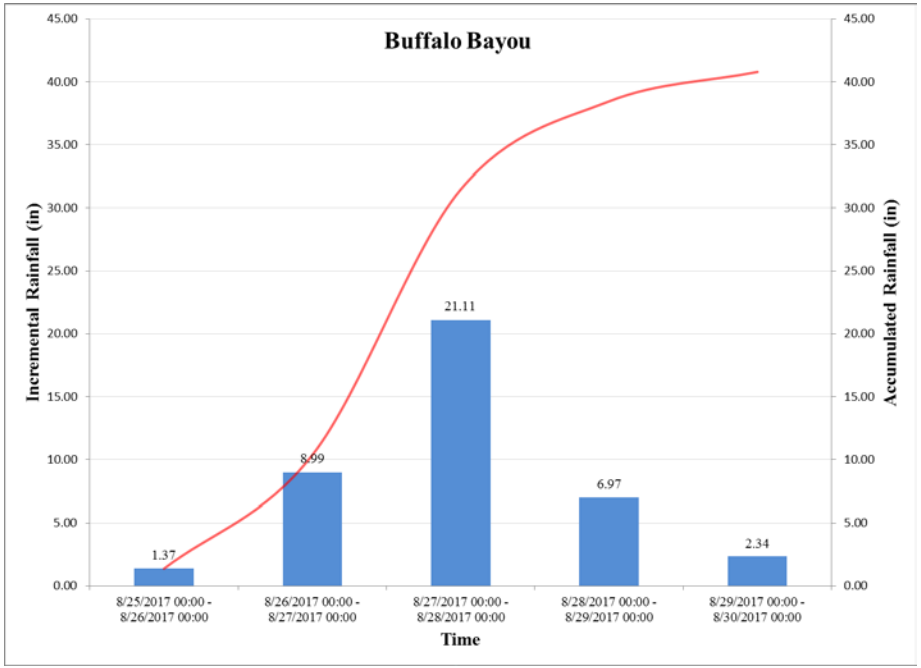
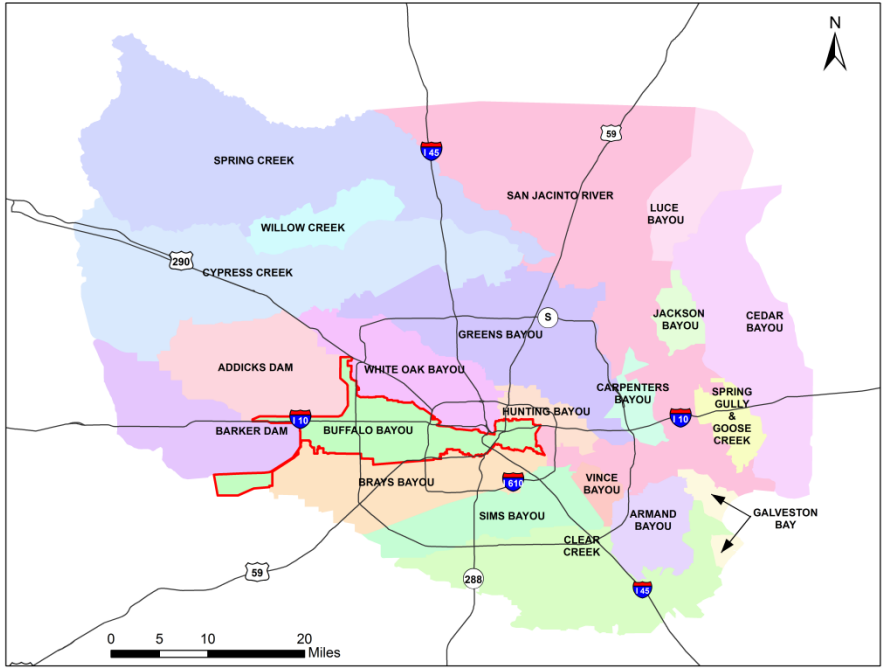


Maximum 24 hr Rainfall for Buffalo Bayou





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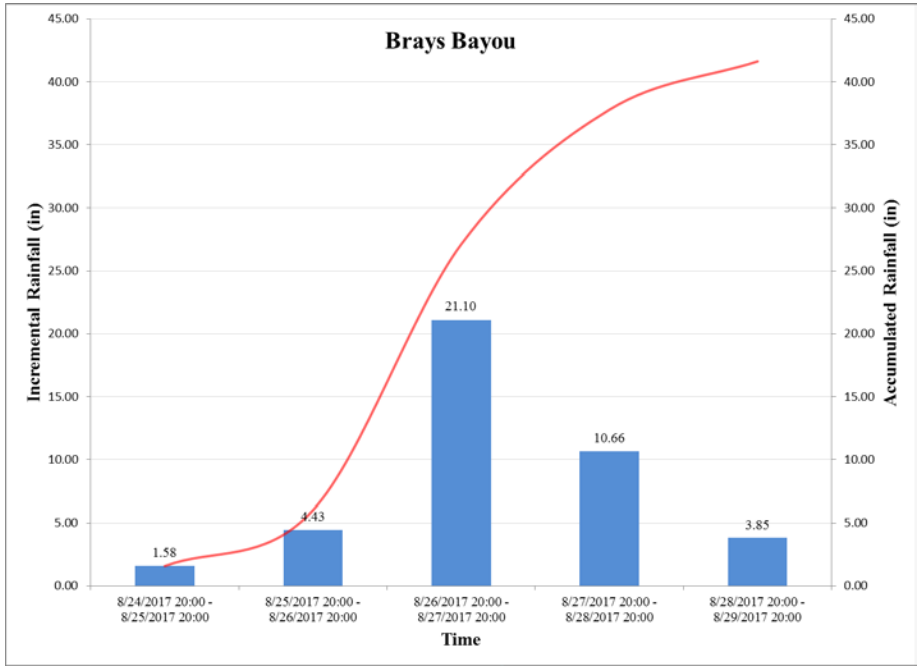
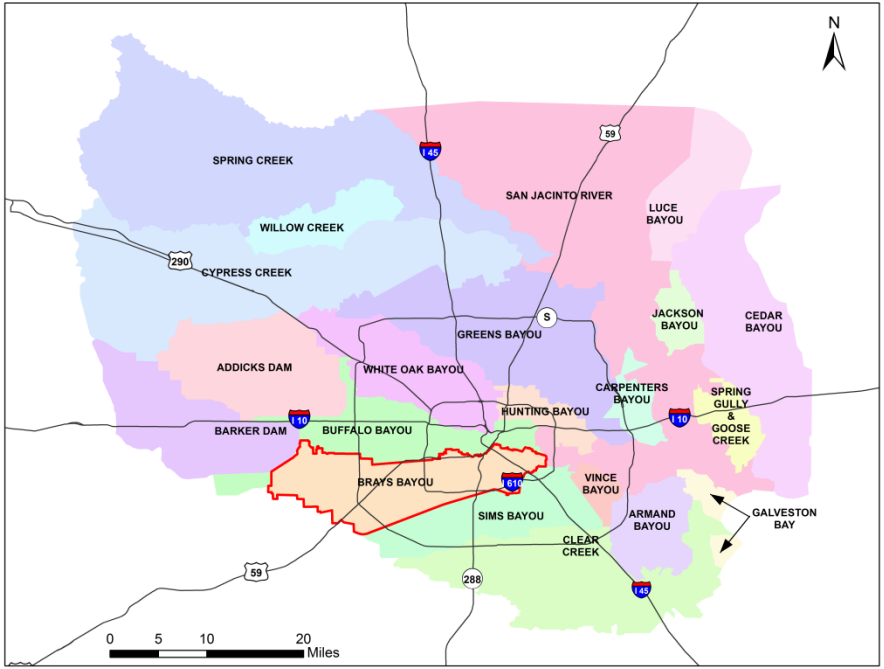
Maximum 24 hr Rainfall for Brays Bayou





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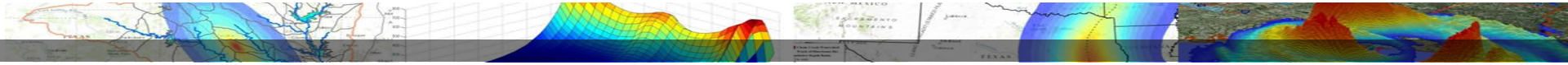
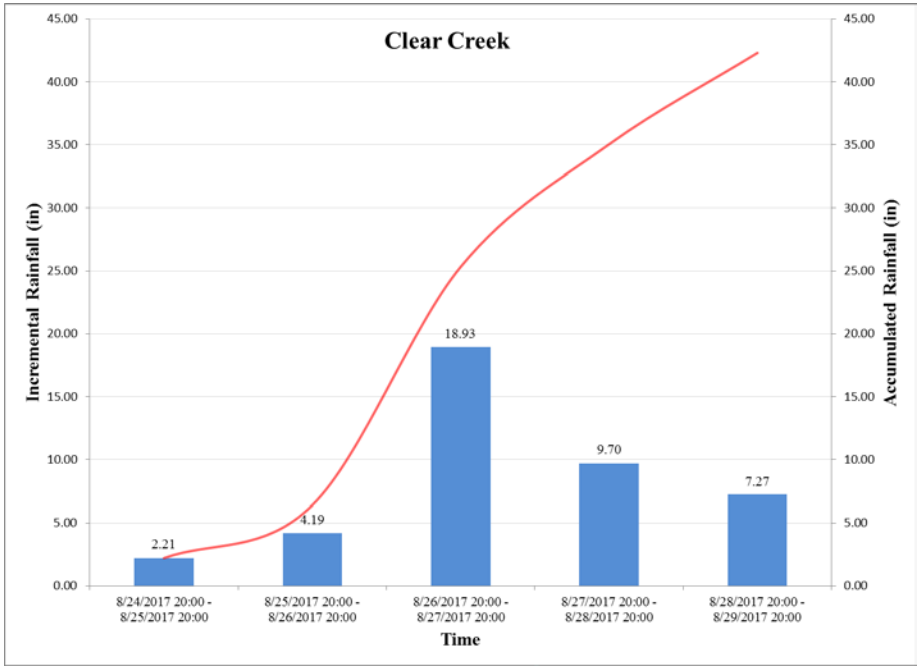
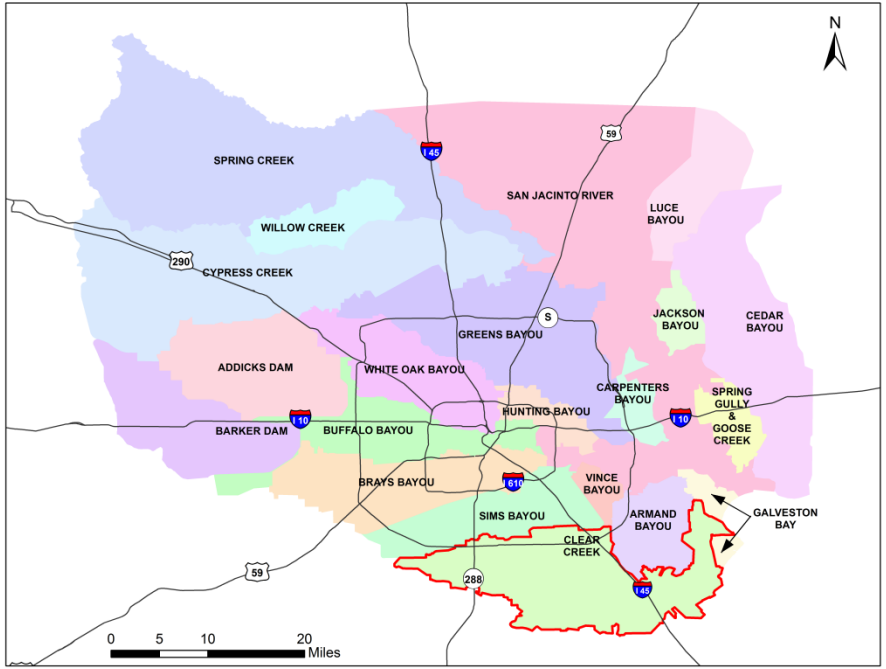


Maximum 24 hr Rainfall for Clear Creek





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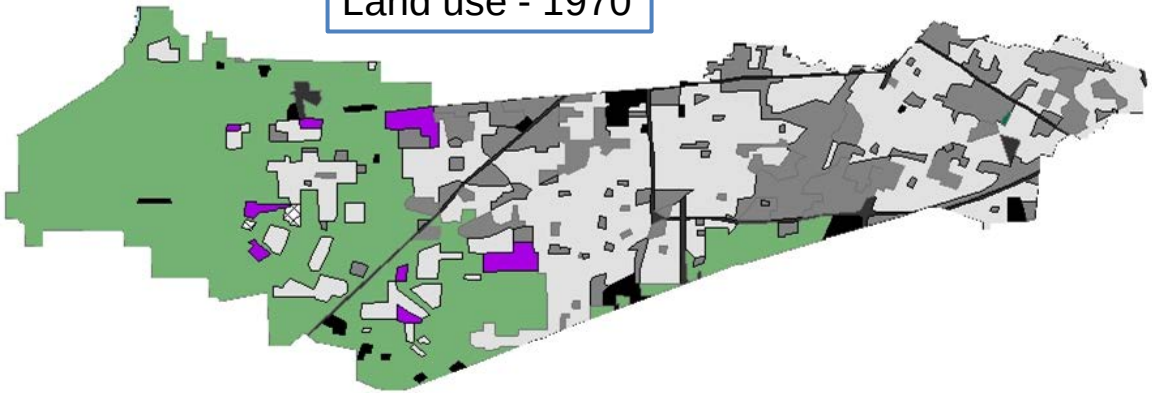
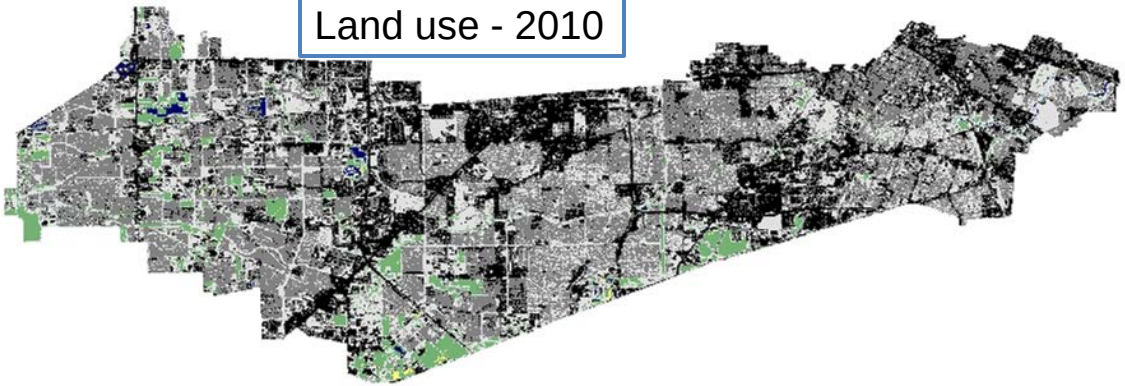
Nearly 500,000 people moved to Houston between 1990 and 2010. Many bayous prone to flooding

Land Use Changes in Brays Watershed

Land use - 1970



Land use - 2010



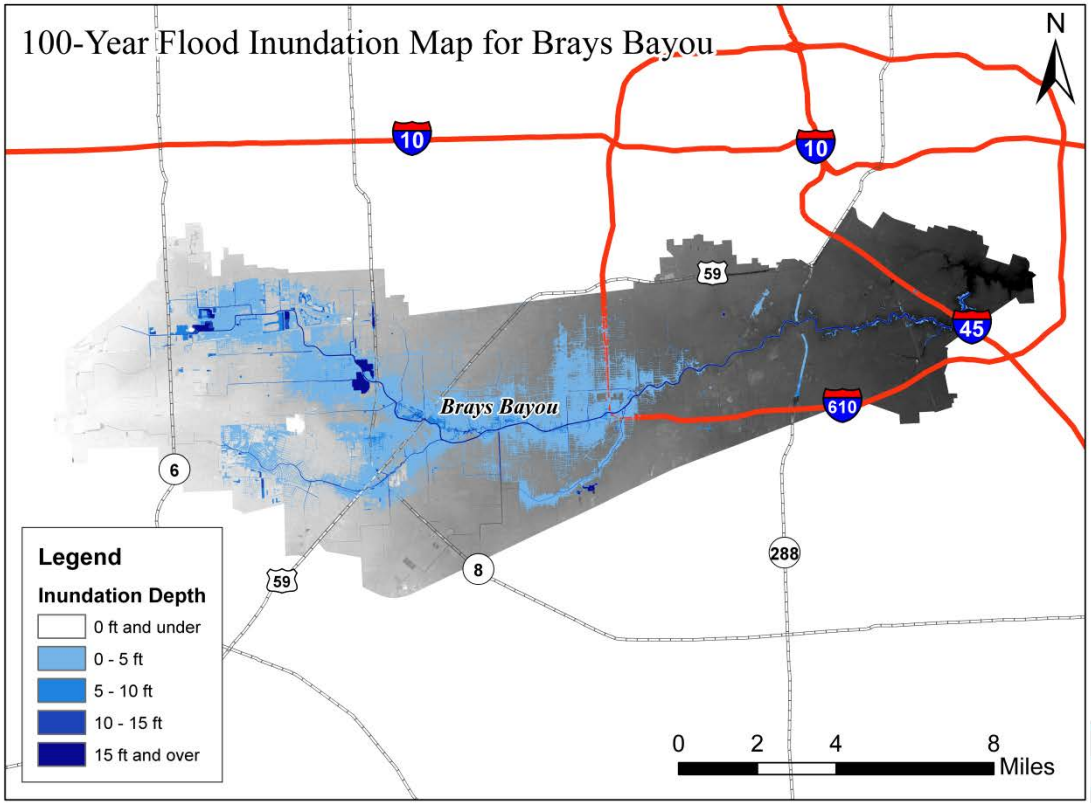
Low Intensity Development

Medium Intensity Development

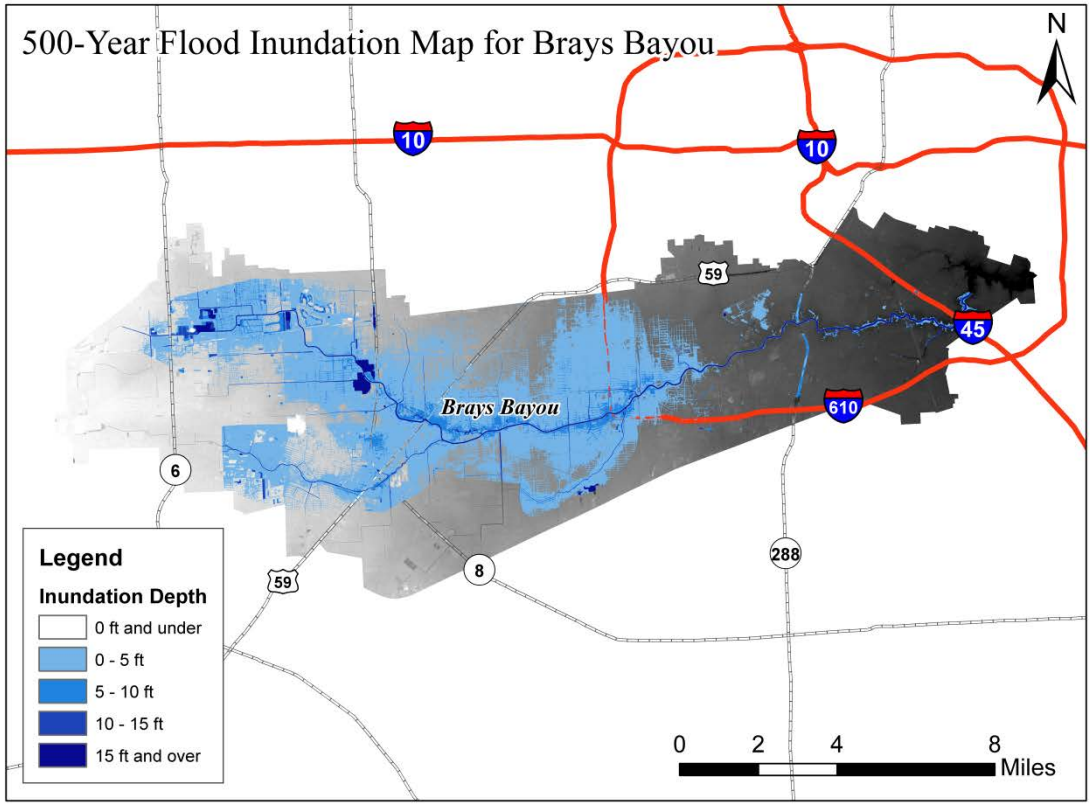
High Intensity Development

Green Space

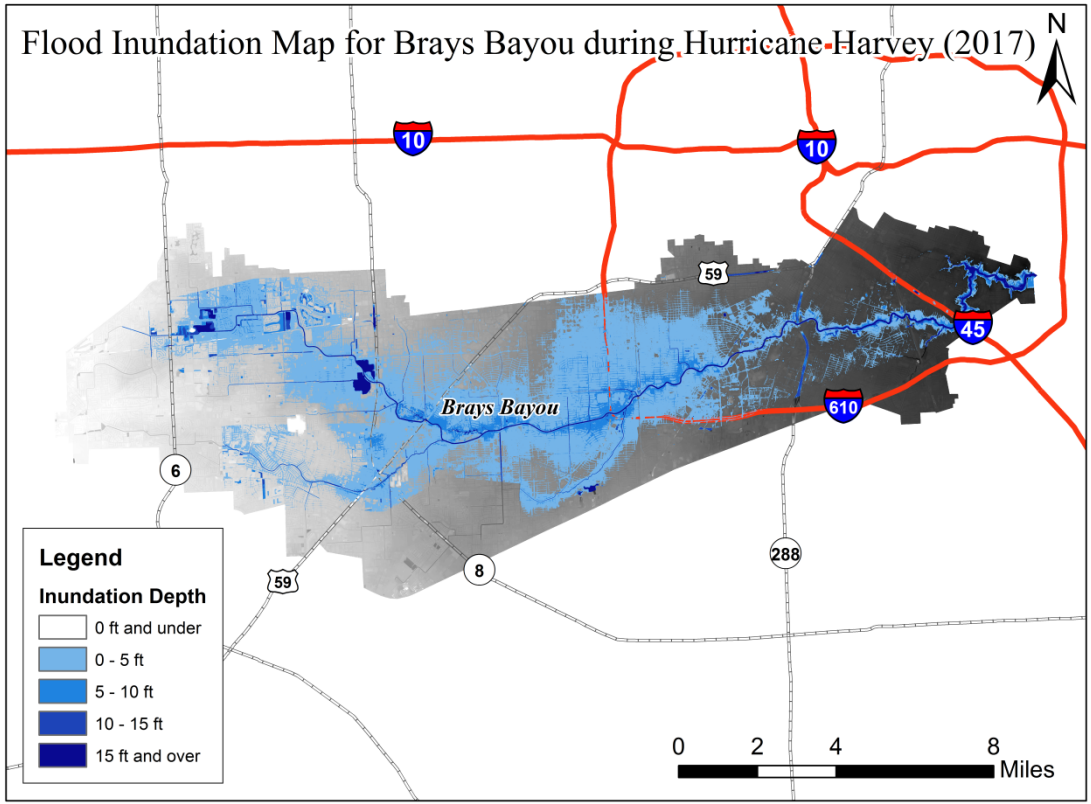
100-Yea


100-Year Flood Inundation Map for Brays Bayou
N
10
10
59
45
610
Brays Bayou
6
8
59
288
Legend
Inundation Depth
0 ft and under
0 - 5 ft
5 - 10 ft
10 - 15 ft
15 ft and over
0 2 4 8
Miles

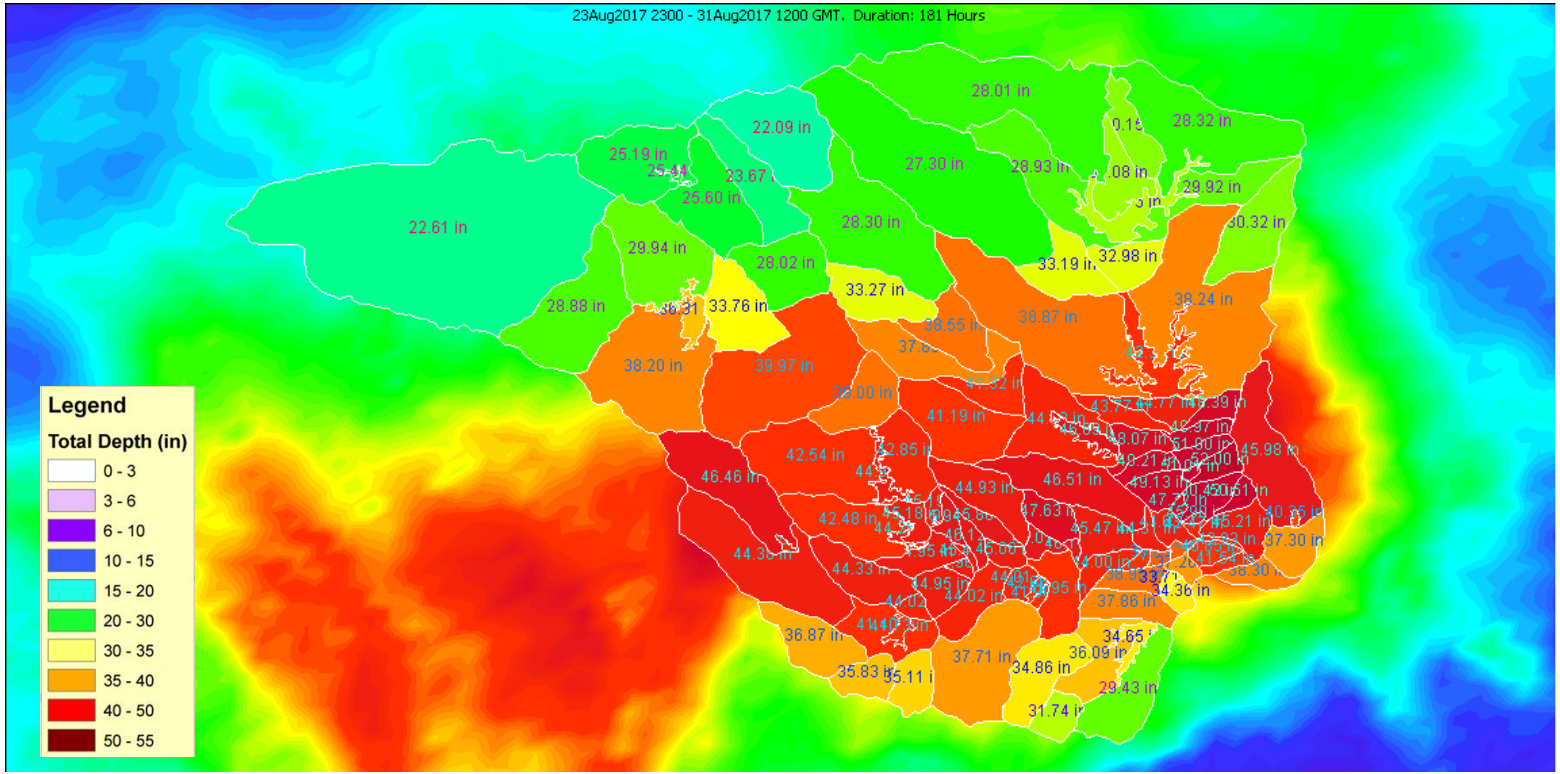
500-Year Flood Inundation Map for Brays Bayou



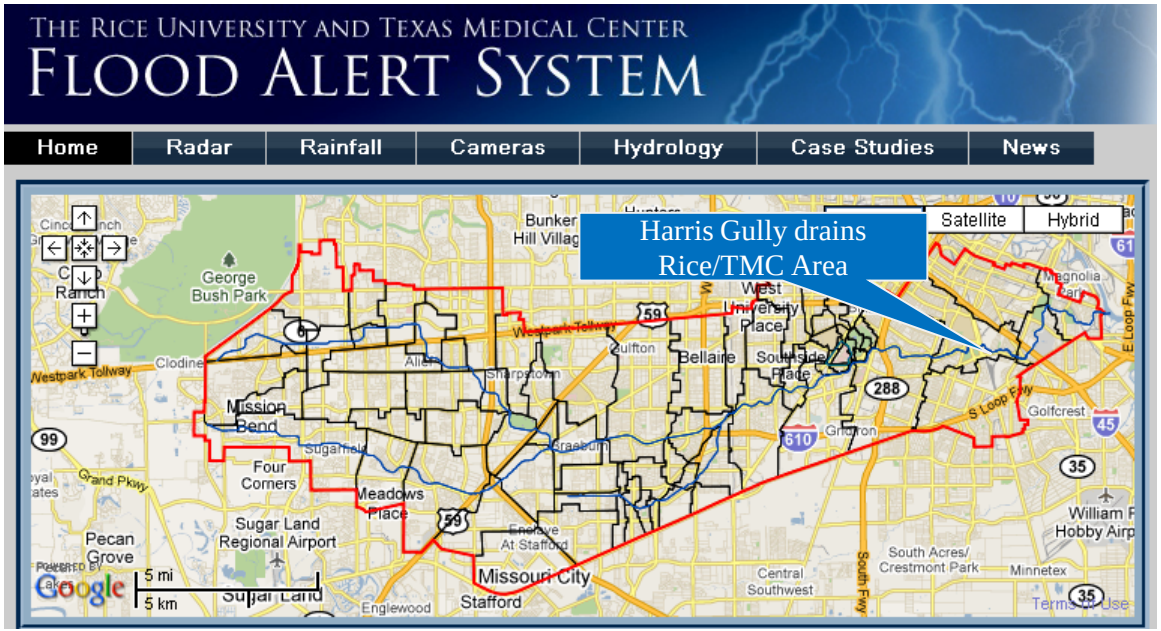
Flood Inundation Map for Brays Bayou during Hurricane Harvey, 2017

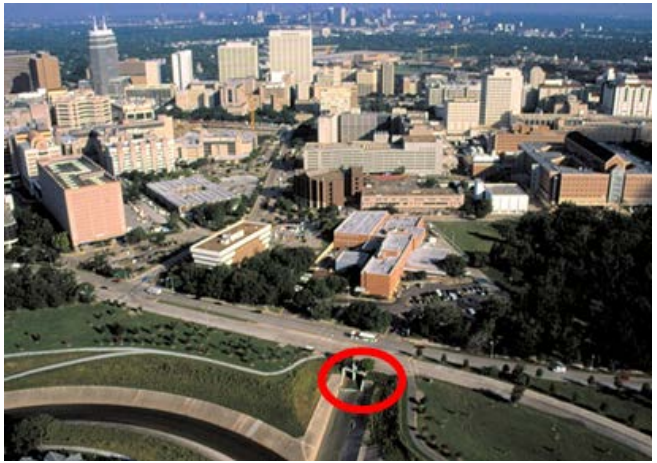


Hurricane Harvey Transposed Over DFW



Brays Bayou and Harris Gully

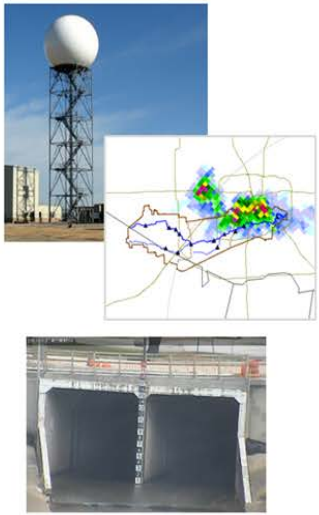




Harris Gully: 4.5 sq. mi.
Brays Bayou: 129 sq. mi.

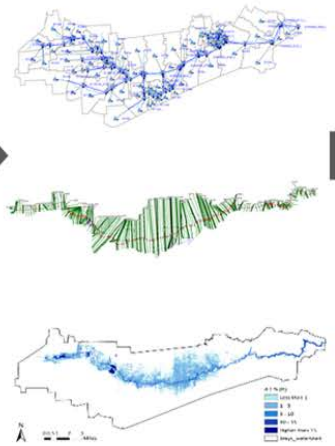
Rice / TMC Flood Alert System Flowchart

DATA ACQUISITION



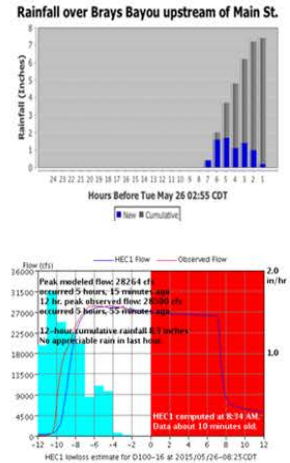
- Radar rainfall (NEXRAD)
- Flow and stage gage data
- Water levels at watch points via bayou cameras

HYDROLOGIC / HYDRAULIC ANALYSIS



- Hydrologic and hydraulic models (HEC-HMS and HEC-RAS)
- Floodplain mapping

REAL-TIME FLOOD WARNING INFO



- Real-time rainfall and flow hydrographs at watch points
- Floodplain map library (FPML)

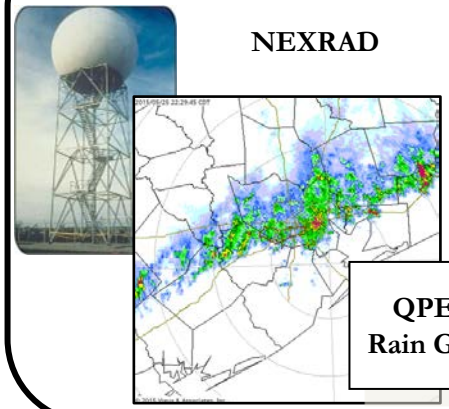
COMMUNICATION

- Establish warning thresholds
- Automatic communication via text, email, and/or FAS website

Rice/TMC Flood Alert System (FAS4)

Data Retrieval Module

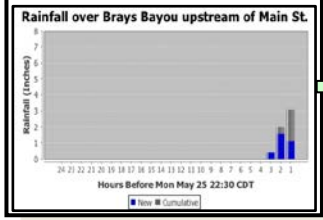
NEXRAD



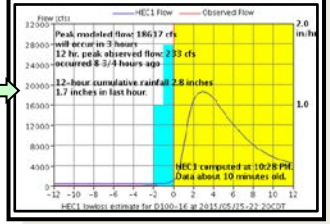
QPE & Rain Gages

Flood Prediction Module

Real-Time Rainfall

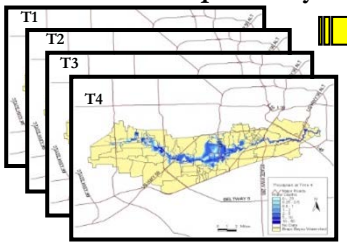


Real-Time Hydrographs



Visual Monitoring & Verification

Flood Plain Map Library

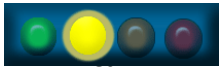


Real-Time Forecast Flood Map

Warnings & Communication Module

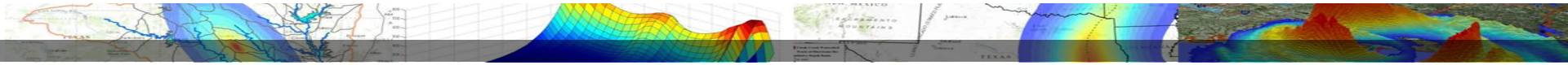
Rice/TMC
- Website
- Social Media
- E-mail
- Phone

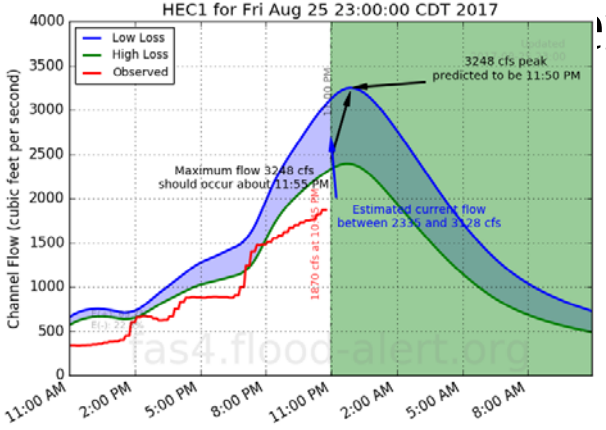
Alert Levels

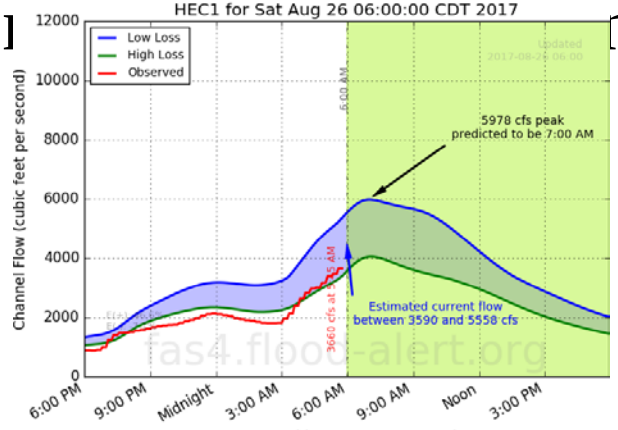


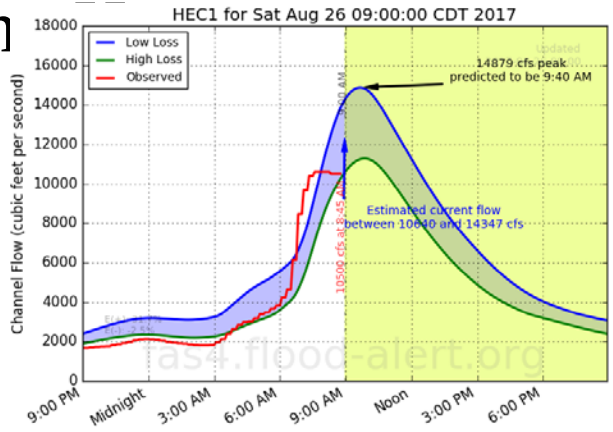
Flood Protection Action Levels

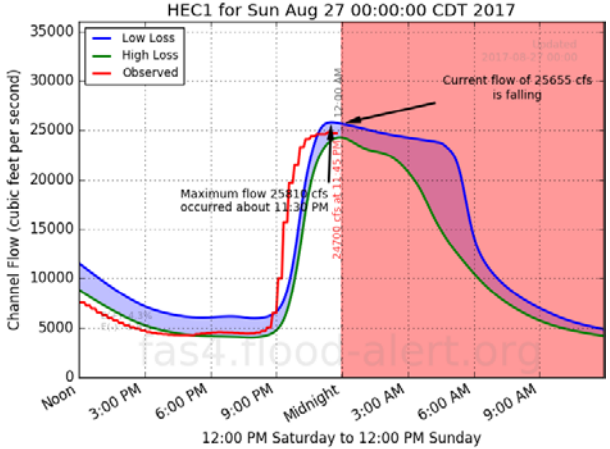
Flood Protection & Emergency Actions
- Evacuations
- Flood door closure
- Recall of Personnel
- Backup Power

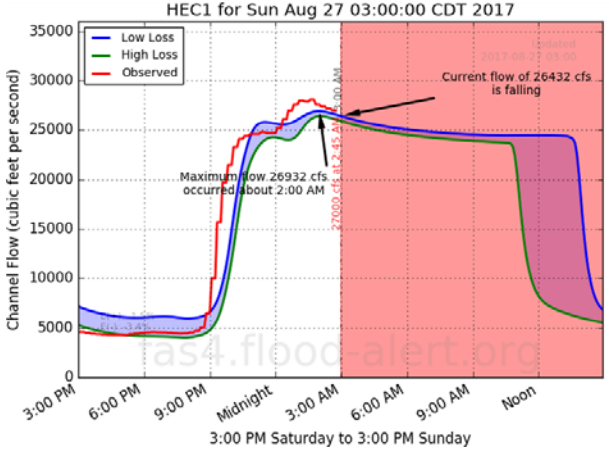


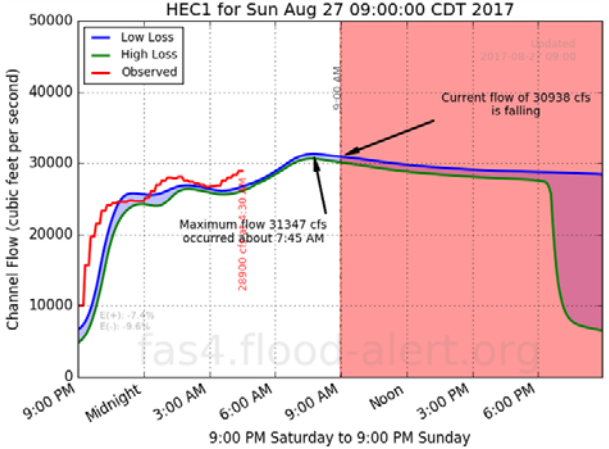

HEC1 for Fri Aug 25 23:00:00 CDT 2017
Low Loss
High Loss
Observed
3248 cfs peak
predicted to be 11:50 PM
Maximum flow 3248 cfs
should occur about 11:55 PM
Estimated current flow
between 2336 and 3128 cfs
Channel Flow (cubic feet per second)
11:00 AM Friday to 11:00 AM Saturday


HEC1 for Sat Aug 26 06:00:00 CDT 2017
Low Loss
High Loss
Observed
5978 cfs peak
predicted to be 7:00 AM
Estimated current flow
between 3590 and 5558 cfs
Channel Flow (cubic feet per second)
6:00 PM Friday to 6:00 PM Saturday


HEC1 for Sat Aug 26 09:00:00 CDT 2017
Low Loss
High Loss
Observed
14879 cfs peak
predicted to be 9:40 AM
Estimated current flow
between 10640 and 14347 cfs
Channel Flow (cubic feet per second)
9:00 PM Friday to 9:00 PM Saturday

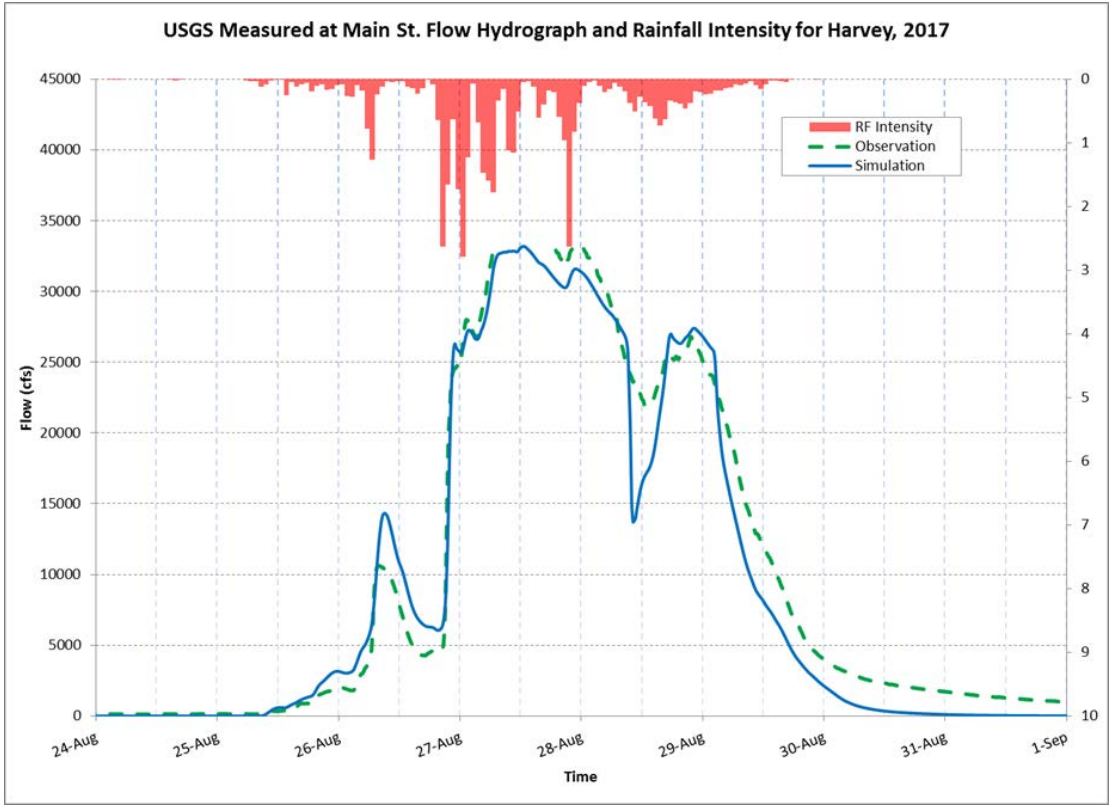

HEC1 for Sun Aug 27 00:00:00 CDT 2017
Low Loss
High Loss
Observed
Current flow of 25655 cfs
is falling
Maximum flow 25816 cfs
occurred about 11:30 PM
Channel Flow (cubic feet per second)
12:00 PM Saturday to 12:00 PM Sunday

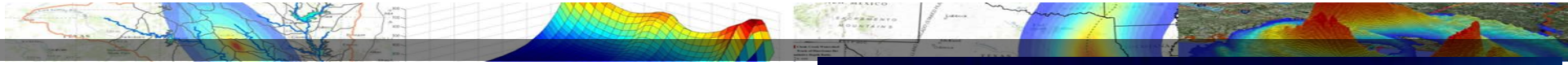

HEC1 for Sun Aug 27 03:00:00 CDT 2017
Low Loss
High Loss
Observed
Current flow of 26432 cfs
is falling
Maximum flow 26932 cfs
occurred about 2:00 AM
Channel Flow (cubic feet per second)
3:00 PM Saturday to 3:00 PM Sunday


HEC1 for Sun Aug 27 09:00:00 CDT 2017
Low Loss
High Loss
Observed
Current flow of 30938 cfs
is falling
Maximum flow 31347 cfs
occurred about 7:45 AM
Channel Flow (cubic feet per second)
9:00 PM Saturday to 9:00 PM Sunday

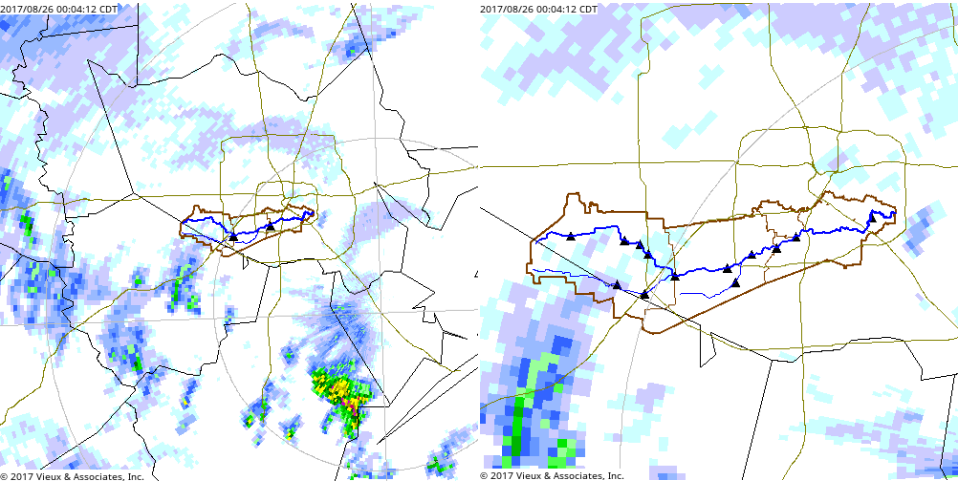
USGS Measured at Main St. Flow Hydrograph and Rainfall Intensity for Harvey, 2017

Time	FAS3 Predicted Flow (cfs)	USGS Measured Flow (cfs)
8/26/2017 21:00	7370	6500
8/27/2017 0:00	25706	24700
8/27/2017 6:00	29968	31800
8/27/2017 12:00	33082	N/A
8/27/2017 18:00	31226	N/A
8/27/2017 19:00	30794	32900
8/28/2017 0:00:00	31372	33000
8/28/2017 6:00:00	28379	28900
8/28/2017 18:00:00	26830	25300
8/29/2017 0:00:00	26831	25100

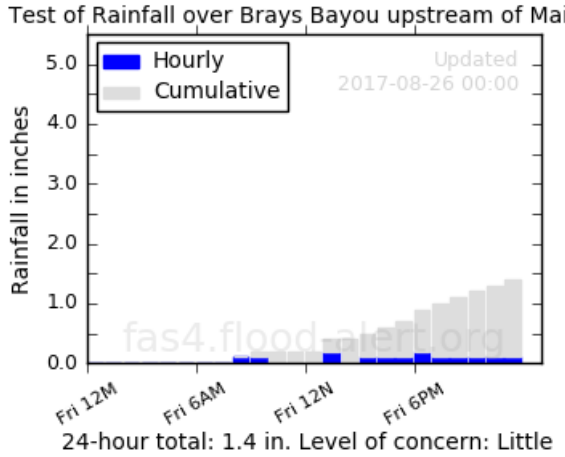


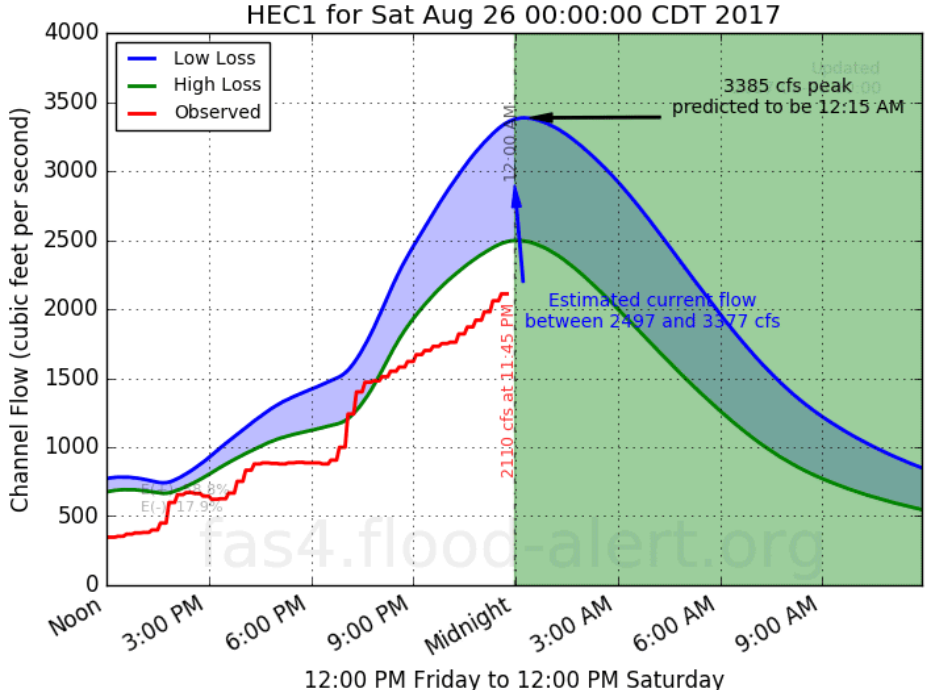


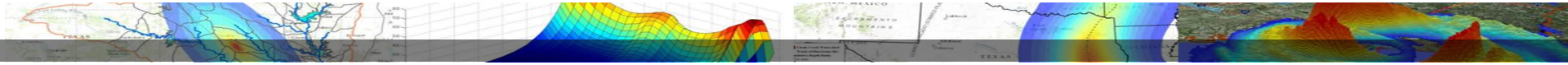
The Rice University and Texas Medical Center
Flood Alert System



Aug 26 00:00







Summary

- Rainfall from Hurricane Harvey is unprecedented (30-50’’ over 5 days) close to PMP level
- Southern Harris County received more than 40’’ of rainfall
- 70% of Harris County is under the water and the midstream of Brays Bayou experienced massive inundation
- Storms like Harvey will occur more often in the nation
- Our nation’s infrastructure design criteria need to be updated
- New technologies available for addressing urban flood issues
- Smart cities need sustainability and recilience

Acknowledgments

Graduate Students

- *Shang Gao (Ph.D.)*
- *Daniel Li (Ph.D.)*
- *Cassie Zhang (Ph.D.)*
- *Hannah Jiang (Ph.D.)*
- *Kevin Wienhold (M.S.)*
- *Trevor Stull (Undergrad)*

- Tarrant Regional Water District (TRWD)
- The University of Texas Arlington (UTA)
- SSPEED Center
- The City of Kennedale
- National Science Foundation (NSF)
- U.S. Army Corps of Engineers (USACE)
- National Oceanic and Atmospheric Administration (NOAA)