

A satellite image of Hurricane Harvey, showing a large, well-defined eye and a dense, swirling cloud structure over the Gulf of Mexico. The surrounding landmasses, including parts of North and Central America, are visible in shades of green and brown.

Hurricane Harvey, August 2017

Rainfall & Streamflow Frequency Analysis

OUTLINE

- ❑ Hurricane Harvey
- ❑ Purpose of Analysis
- ❑ Rainfall Analysis
- ❑ Streamflow Analysis
- ❑ Summary

HURRICANE HARVEY



- ❑ Landfall 8/25, 22:00
- ❑ 8/26, 1800 - Tropical Storm
- ❑ Lingered for 5 days
- ❑ Record rainfall
- ❑ Catastrophic flooding

PURPOSE OF STUDY

- ❑ FIMA Risk Management Directorate (RMD)
- ❑ AECOM Part of Compass PTS JV
- ❑ Quantify The Storm & Flood Magnitude
- ❑ 39 Designated Counties
- ❑ 44,700 Square Miles



RAINFALL ANALYSIS

- ☐ Frequency Estimates
- ☐ Historical Context & Reports by Other Entities
- ☐ Gage Analysis
- ☐ Gage Adjusted Radar Analysis

RAINFALL ANALYSIS – FREQUENCY ESTIMATES

- ❑ NOAA Atlas 14 TX
(not available at time of study)
- ❑ USGS, Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas (SIR 2004-5041)

Comparison of USGS & Atlas 14 (Jefferson County)

Duration	USGS SIR 2004-5041 ⁽¹⁾			NOAA Atlas 14 ⁽²⁾		
	100-y	250-y	500-y	100-y	200-y	500-y
1 hour	4.35	5.10	5.64	4.79	5.40	6.29
2 hours	6.60	7.75	8.90	6.26	7.13	8.41
3 hours	7.90	9.55	11.00	7.53	8.65	10.30
6 hours	10.70	13.30	15.50	10.20	11.80	14.20
12 hours	13.20	16.50	19.50	13.50	15.60	18.60
1 day	15.00	18.20	20.80	16.50	19.10	22.80
2 days	17.20	20.30	22.70	18.50	21.60	26.00
4 days	18.88	22.11	24.72	20.80	24.00	28.60

⁽¹⁾ USGS (2004)

y = year

⁽²⁾ NOAA (n.d.c)

RAINFALL ANALYSIS – HISTORICAL CONTEXT

Comparison of Rainfall Maxima for Tropical Storm Allison, Tax Day Storm, and Hurricane Harvey

Storm (date)	Maximum Rainfall (inches)	
	12-hour	Total
Tropical Storm Allison (June 5–9, 2001) ⁽¹⁾	28.0	38.8
Tax Day Storm (April 17–18, 2016) ⁽²⁾	16.7	17.4
Hurricane Harvey (2017) ⁽³⁾	20.8	51.1

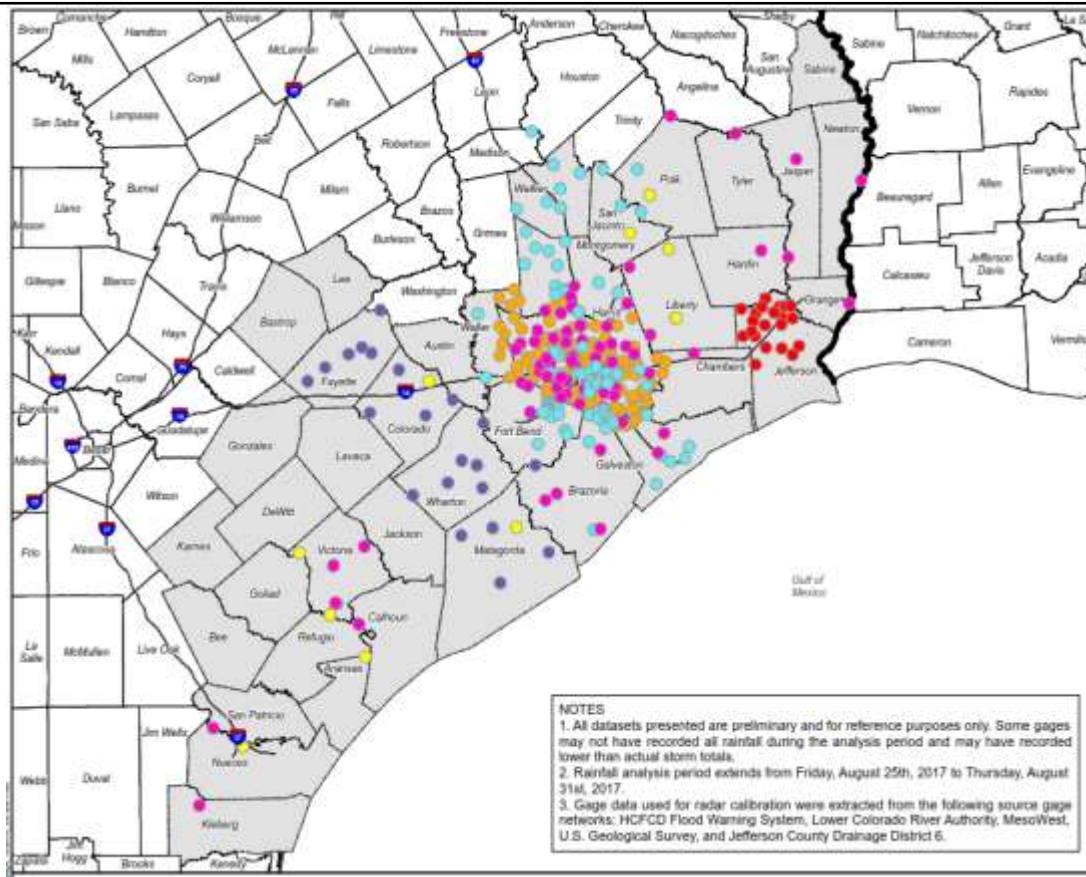
⁽¹⁾ Rainfall totals for the Greens Bayou watershed (Tropical Storm Allison Recovery Project, 2002)

⁽²⁾ Northwest Harris County (Linder, 2016)

⁽³⁾ Rainfall totals for the Clear Creek (12-hour) and Cedar Bayou (Total) watersheds. Total rainfall measured over 4 days.

❑ *1973 Tropical Storm Claudette – 43 Inches of RF in 24 HRS in Alvin, TX*

RAINFALL GAGE ANALYSIS

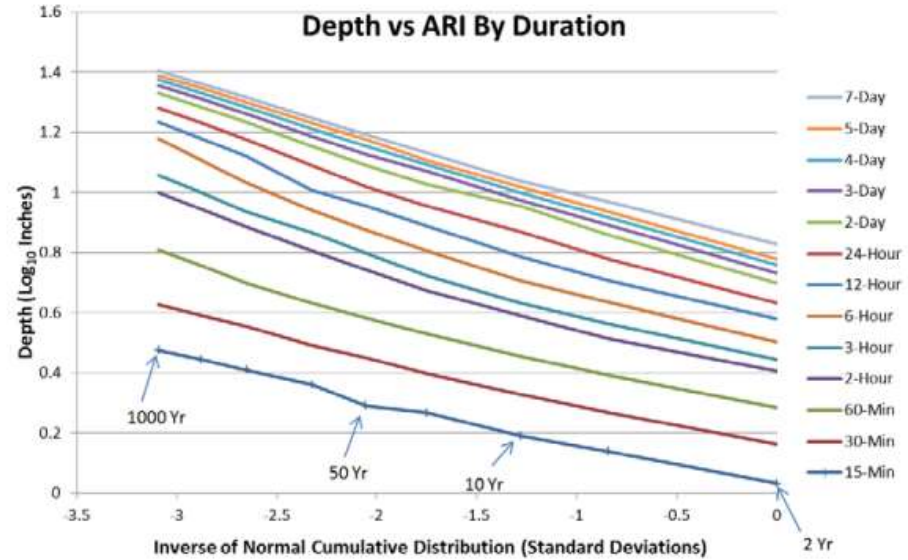
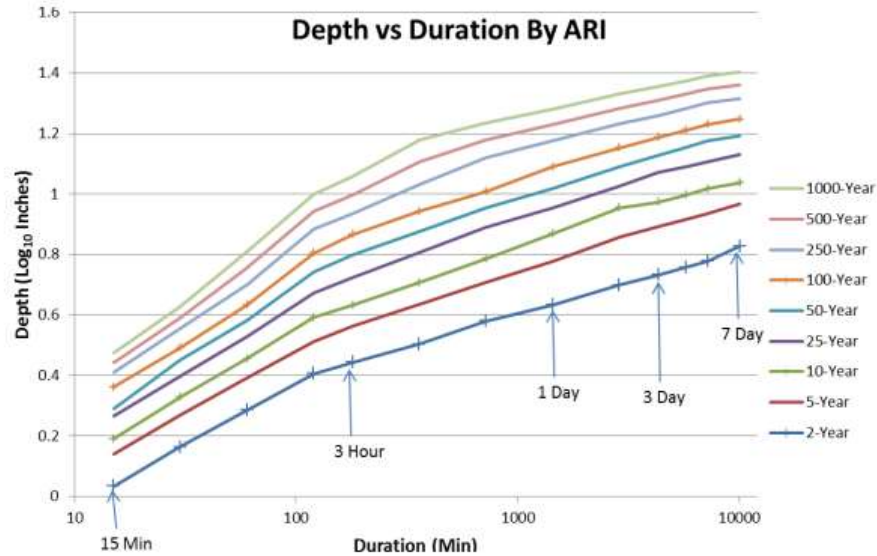


- ❑ Coverage – 39 Counties
- ❑ Data Source
 - ❑ NWS, USGS, HCFCF, LCRA, Jefferson County DD6, & Others
- ❑ Over 250 Gages

ESTIMATED AVERAGE RECURRENCE INTERVAL (ARI)

- ❑ Precipitation Depth Duration Frequency (DDF) Data
 - ❑ HCFCD DDF For Harris County
 - ❑ USGS
 - ❑ 96 Depth Maps for Texas (Georeferenced Each Map)
 - ❑ Durations 15 min to 7 days
 - ❑ ARIs from 2-year to 500-year
 - ❑ Depths for 1,000 year ARI estimated by extrapolated using inverse of the normal cumulative distribution of the 250 and 500 ARI and logarithm of total depth

ESTIMATED AVERAGE RECURRENCE INTERVAL (ARI)



RAINFALL GAGE ANALYSIS ESTIMATED ARI

Jefferson County DD6 Gage Data

Note: A storm value of "250 to 500" means "between the 250-year and 500-year storm", and 100-year storm is shorthand for a storm with 1 percent Annual Exceedance Probability.

Gage	3-Hour		6-Hour		12-Hour		24-Hour		2-Day		4-Day		Gage Data Not Used	Total Rainfall (in)
	RF	Storm	RF	Storm	RF	Storm	RF	Storm	RF	Storm	RF	Storm		
Jefferson County														
J1200	4.90		8.62		10.72		12.96		23.27		33.94		X	
J1400	5.82	10 to 25	8.03	25 to 50	10.18	25 to 50	17.04	100 to 250	22.90	500 to 1000	37.08	> 1000		37.80
J2100	5.06	10 to 25	7.28	10 to 25	11.11	50 to 100	19.88	250 to 500	25.83	> 1000	40.45	> 1000		41.50
J2300	6.89	50 to 100	10.75	100 to 250	14.44	100 to 250	27.05	> 1000	33.94	> 1000	47.24	> 1000		49.05
J2500	5.52	10 to 25	8.42	25 to 50	14.47	100 to 250	22.32	500 to 1000	28.27	> 1000	44.73	> 1000		46.50
J2700	6.87	50 to 100	10.51	50 to 100	13.50	100 to 250	23.19	500 to 1000	31.25	> 1000	45.01	> 1000		46.58
J2900	7.90	50 to 100	11.03	100 to 250	13.85	100 to 250	26.10	> 1000	32.99	> 1000	45.55	> 1000		46.37
J3020	6.69	25 to 50	10.35	50 to 100	12.17	50 to 100	20.13	250 to 500	29.05	> 1000	42.60	> 1000		43.31
J3600	4.43	5 to 10	6.07	5 to 10	10.77	50 to 100	17.57	100 to 250	22.51	250 to 500	37.38	> 1000		38.51
J4300	4.55	5 to 10	6.77	10 to 25	12.41	50 to 100	18.98	250 to 500	23.99	500 to 1000	40.12	> 1000		41.42
J5100	5.16	10 to 25	8.97	25 to 50	10.41	25 to 50	16.32	100 to 250	22.48	250 to 500	38.87	> 1000		39.81
J5200	6.46	25 to 50	11.11	100 to 250	13.82	100 to 250	20.48	250 to 500	29.43	> 1000	46.44	> 1000		47.44
J5400	6.72	25 to 50	10.22	50 to 100	13.49	100 to 250	21.51	500 to 1000	29.94	> 1000	44.33	> 1000		45.00
J5500	5.13	10 to 25	7.64	25 to 50	10.82	50 to 100	17.35	100 to 250	26.50	> 1000	40.96	> 1000		41.81
J5620	8.59	100 to 250	11.85	100 to 250	14.08	100 to 250	25.63	> 1000	32.67	> 1000	46.39	> 1000		47.28
J5700	6.77	25 to 50	8.61	25 to 50	10.42	25 to 50	17.92	100 to 250	27.56	> 1000	39.04	> 1000		39.77
J5800	6.00	25 to 50	9.56	50 to 100	11.04	50 to 100	18.03	100 to 250	24.57	500 to 1000	38.15	> 1000		39.25
J5820	6.82	50 to 100	8.56	25 to 50	13.50	100 to 250	21.78	500 to 1000	30.37	> 1000	38.82	> 1000		39.53
J6200	6.04	25 to 50	9.75	50 to 100	12.75	50 to 100	19.13	250 to 500	28.55	> 1000	44.35	> 1000		45.00
J6300	7.18	50 to 100	10.11	50 to 100	15.77	100 to 250	26.17	> 1000	32.64	> 1000	43.40	> 1000		44.09
J7200	7.17	50 to 100	11.38	100 to 250	13.95	100 to 250	21.53	500 to 1000	28.64	> 1000	43.60	> 1000		45.79

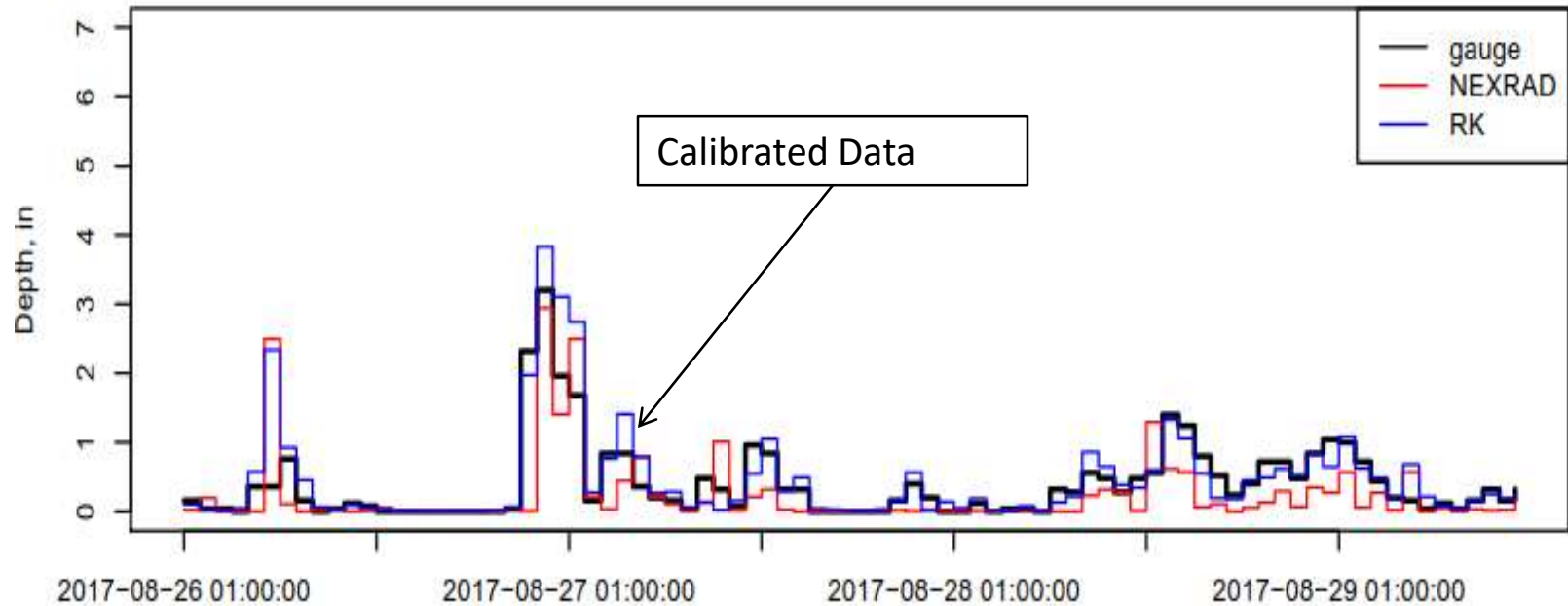
RAINFALL GAGE-ADJUSTED RADAR ANALYSIS

- ❑ Gridded Radar Estimates From NOAA
- ❑ Radar Estimates Preserve Spatial Characteristics of Storm
- ❑ Gage Measurements Considered Ground Truth
- ❑ Combine Both Sets of Data – Gage-Adjusted Radar Rainfall (GARR)

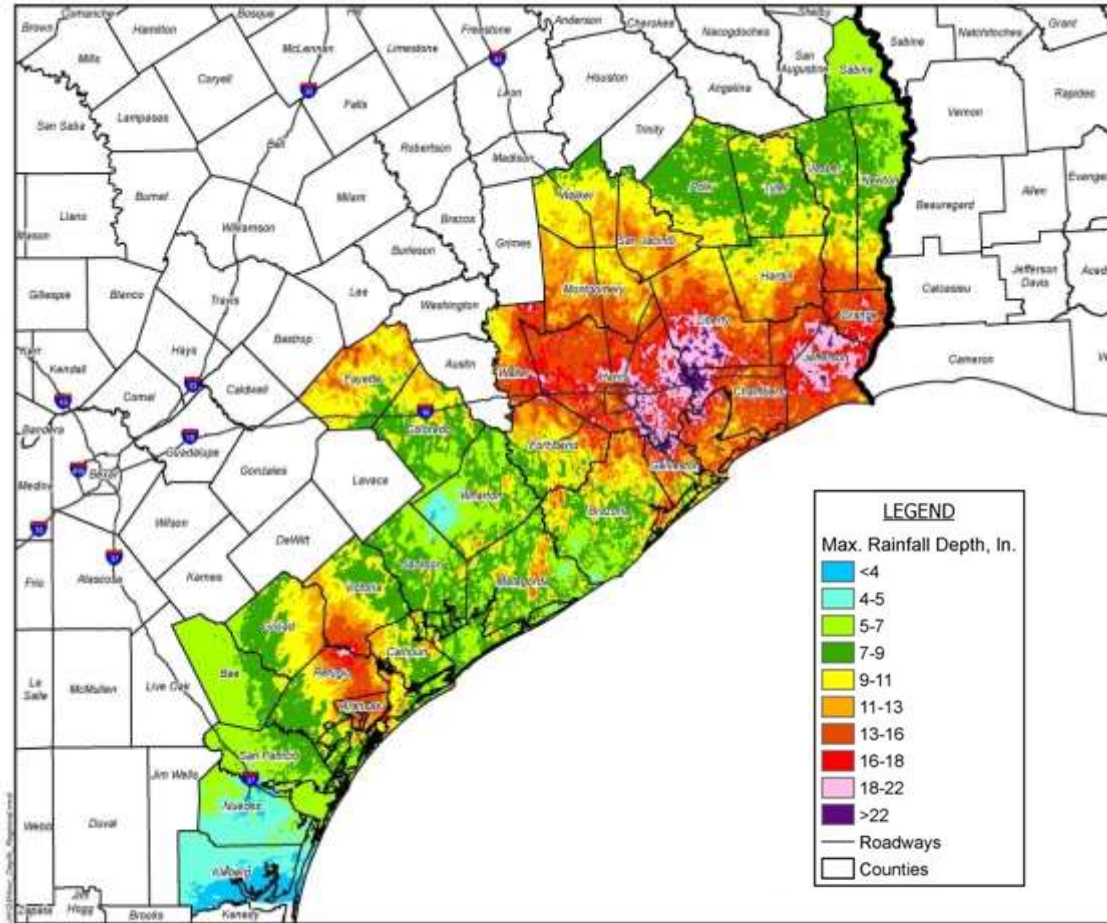
GARR - CALIBRATION OF RADAR DATA

- ☐ Regression-Kriging (RK) Spatial Interpolation
- ☐ Calibrated Using Gage Measurements
- ☐ RK – 2 Step Process
 - ☐ Global Correction Factor (0.89 for this study)
 - ☐ Regional Adjustment
- ☐ Calibrated Radar Estimates Adjusted To Best Conform With Gage Measurements
- ☐ A Root Mean Square Error Analysis – Assess Error Reduction Due to The Adjustment Process

GARR – GAGE, RADAR, CALIBRATED

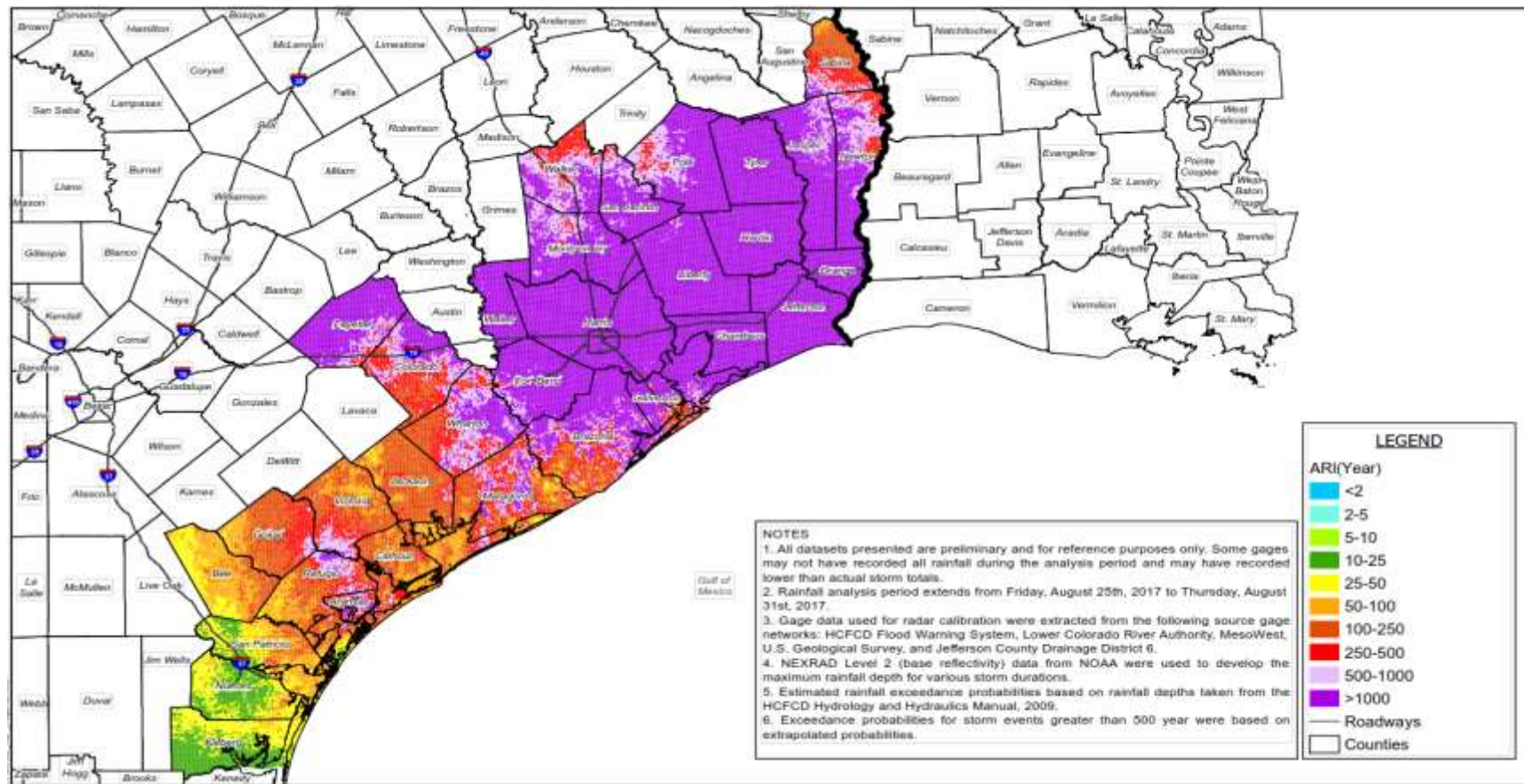


GARR RESULTS – MAXIMUM RAINFALL DEPTHS



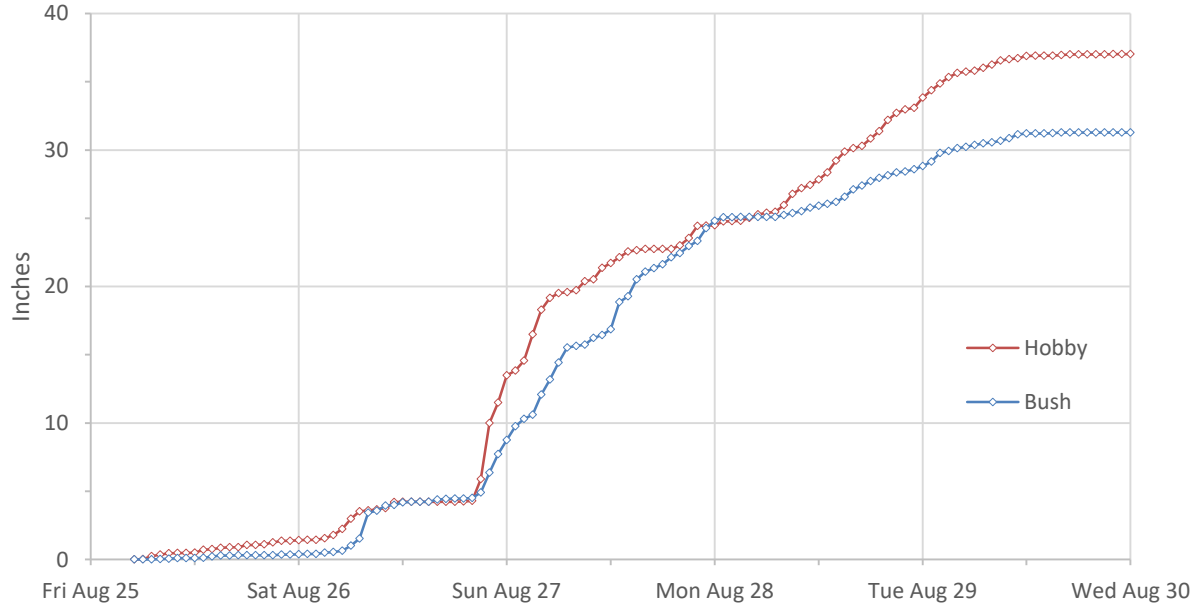
- ☐ Maximum Duration Rainfall Depths for
- ☐ 12-Hour
- ☐ **24-Hour**
- ☐ 48-Hour
- ☐ 96-Hour
- ☐ Spatial Distribution of Rainfall

GARR RESULTS – MAXIMUM 96-HR ARI



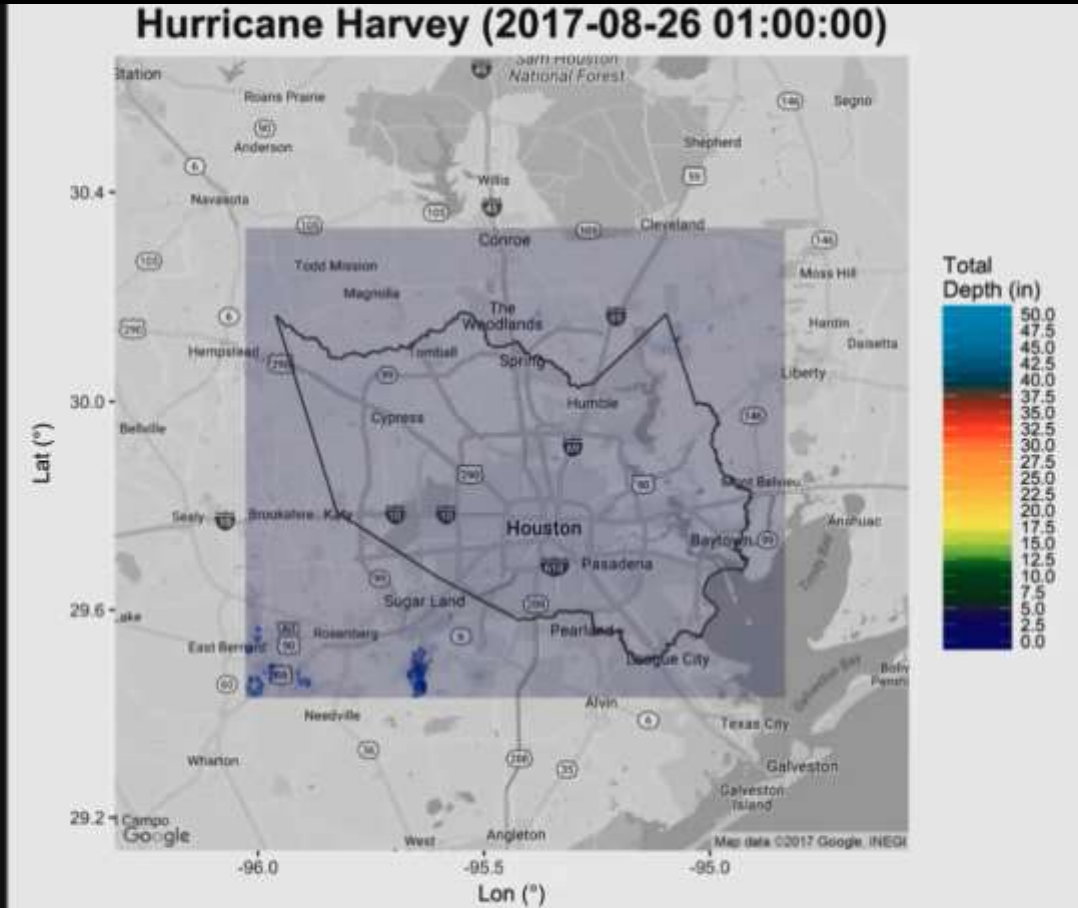
RAINFALL DURATION

Rainfall at Houston Airports



- ☐ Cumulative Hourly Rainfall
- ☐ 4 Days
- ☐ Minimal Dry Periods
- ☐ Initial Rain Saturated Soils

HARVEY RAIN EVENT (CUMMULATIVE RAINFALL DEPTH)



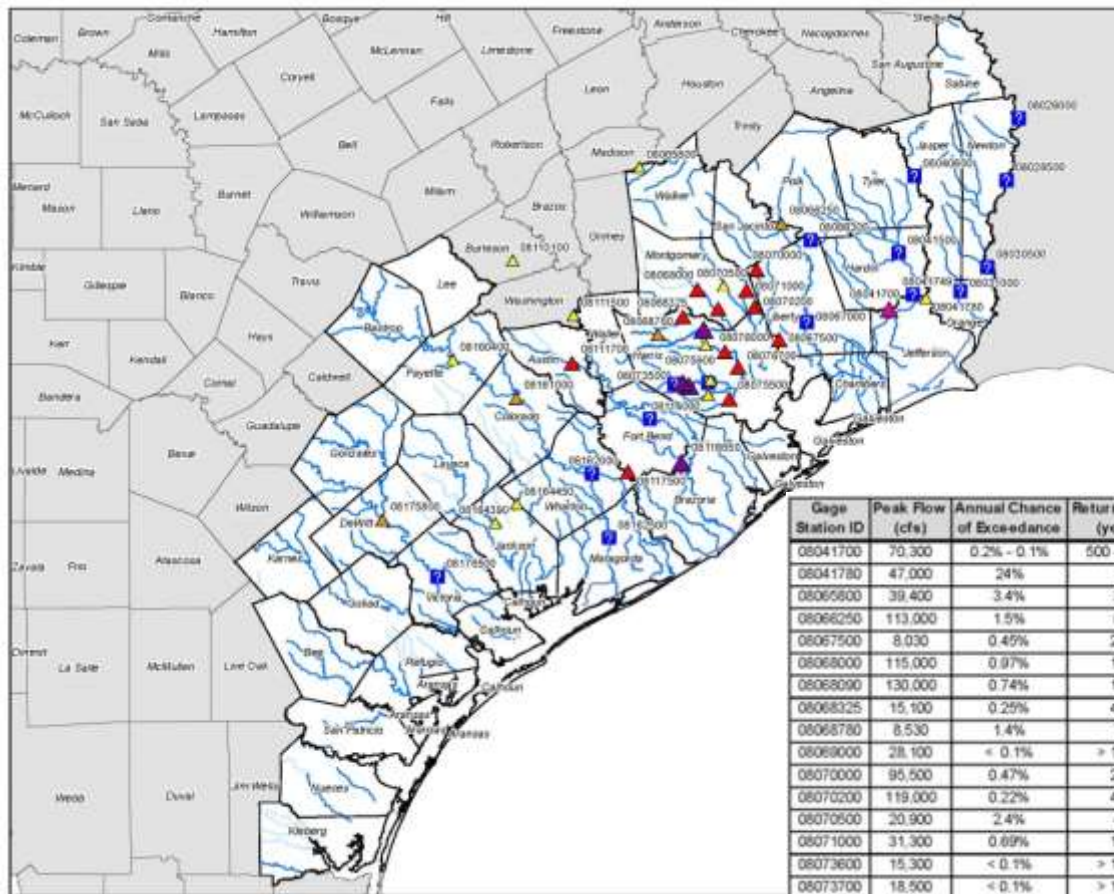
STREAMFLOW ANALYSIS

- ❑ Gulf Coast River Systems Impacted
 - ❑ Guadalupe, Colorado, Brazos, Trinity, Sabine, San Jacinto
- ❑ 46 Gages Analyzed
 - ❑ USGS
 - ❑ Average Record Period ~ 56 Years
- ❑ Updated Flood Frequency Analysis (FFA) For Records Through 2016 Water Year
- ❑ FFA Performed According to Bulletin 17B

STREAMFLOW ANALYSIS – ESTIMATED AEP

- ❑ FFA Records compared with observed peak discharges
- ❑ Preliminary Estimates
 - ❑ 17 Gages > 1% AEP
 - ❑ 5 Gages > 0.2% AEP
 - ❑ 4 Gages > 0.1% AEP

STREAMFLOW ANALYSIS – RESULTS



Gage Station ID	Peak Flow (cfs)	Annual Chance of Exceedance	Return Period (years)	Gage Station ID	Peak Flow (cfs)	Annual Chance of Exceedance	Return Period (years)
08041700	70,300	0.2% - 0.1%	500 - 1,000	08074500	22,900	3.2%	32
08041780	47,000	24%	4	08075000	33,000	4.3%	24
08065600	39,400	3.4%	29	08075500	31,500	0.27%	373
08066250	113,000	1.5%	66	08075900	12,000	5.1%	20
08067500	8,030	0.49%	220	08076000	25,700	0.85%	118
08068000	115,000	0.97%	103	08076700	56,500	0.54%	185
08068090	130,000	0.74%	135	08110100	24,100	2.3%	43
08068325	15,100	0.25%	406	08111500	101,000	10%	10
08068780	8,530	1.4%	74	08111700	87,900	0.26%	392
08069000	28,100	< 0.1%	> 1,000	08116650	133,000	< 0.1%	> 1,000
08070000	95,500	0.47%	211	08117500	38,500	0.49%	204
08070200	119,000	0.22%	462	08160400	118,000	2.5%	41
08070500	20,900	2.4%	41	08161000	164,000	1.9%	52
08071000	31,300	0.69%	145	08164390	19,600	7.1%	14
08073600	15,300	< 0.1%	> 1,000	08164450	20,500	6%	17
08073700	18,500	< 0.1%	> 1,000	08175800	178,000	1.6%	64

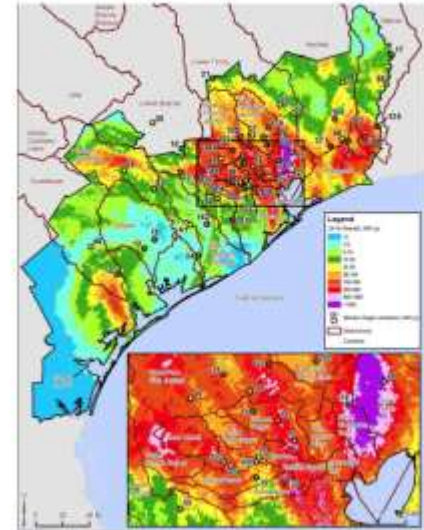
STREAMFLOW ANALYSIS – RESULTS

USGS Station Number	USGS Station Name	Drainage Area (mi. ²)	10 percent (cfs)	2 percent (cfs)	1 percent (cfs)	0.2 percent (cfs)	Peak Flow (cfs)	Peak Gage Height (feet above gage datum)	Peak Date	Estimated AEP (%)	Est. ARI (years)
08041700	Pine Island Bayou near Sour Lake	336	12,100	25,130	33,070	59,280	70,300	39.42	8/30/17	0.2% - 0.1%	500 - 1,000
08041780	Neches River Saltwater Barrier at Beaumont	9,789	69,170	123,600	155,300	256,300	231,000	7.94	9/1/17	0.28	356
08065800	Bedias Creek near Madisonville	321	25,150	46,560	57,520	87,370	39,400	25.87	8/28/17	3.4	29
08066250	Trinity River near Goodrich	16,844	87,860	110,400	117,200	128,400	113,000	48.39	8/29/17	1.5	66
08067500	Cedar Bayou near Crosby	64.9	4,430	6,296	7,104	9,022	8,350	58.96	8/28/17	0.35	290
08068000	W Fork San Jacinto River near Conroe	828	35,590	83,100	113,500	218,100	115,000	126.97	8/29/17	0.97	103
08068090	W Fork San Jacinto River above Lake Houston near Porter	962	46,440	94,490	119,100	184,600	130,000	94.83	8/29/17	0.74	135
08068325	Willow Creek near Tomball	41.0	4,141	7,867	9,924	16,030	15,100	133.70	8/28/17	0.25	406
08068780	Little Cypress Creek near Cypress	41.0	4,018	7,514	9,397	14,840	8,530	161.10	8/28/17	1.4	74
08069000	Cypress Creek near Westfield	285	11,570	15,840	17,350	20,240	28,100	97.10	8/28/17	<0.1%	> 1,000
08070000	E Fork San Jacinto River near Cleveland	325	21,310	51,010	69,890	133,700	95,500	27.17	8/28/17	0.47	211
08070200	E Fork San Jacinto River near New Caney	388	20,070	48,190	65,640	122,600	119,000	80.05	8/29/17	0.22	462
08070500	Caney Creek near Splendora	105	9,656	23,030	31,910	63,750	20,900	26.58	8/28/17	2.4	41
08071000	Peach Creek at Splendora	117	7,978	19,530	26,820	51,030	31,300	25.57	8/28/17	0.69	145
08073600	Buffalo Bayou at W Belt Drive Houston	290	5,557	7,409	8,191	10,020	18,900	71.18	8/31/17	<0.1%	> 1,000
08073700	Buffalo Bayou at Piney Point	299	6,142	8,206	9,053	10,980	18,500	63.89	8/28/17	<0.1%	> 1,000
08074500	Whiteoak Bayou at Houston	95.1	17,550	24,810	27,280	31,830	22,700	41.29	8/27/17	3.3	30
08075000	Brays Bayou at Houston	94.9	26,330	38,410	42,790	51,360	33,000	45.67	8/27/17	4.3	24
08075500	Sims Bayou at Houston	63.0	12,990	20,520	24,110	33,350	31,500	26.56	8/27/17	0.27	373
08075900	Greens Bayou near US Hwy 75 near Houston	36.6	9,524	15,990	19,180	27,640	12,000	85.86	8/27/17	5.1	20
08076000	Greens Bayou near Houston	68.7	11,390	19,970	24,560	37,820	25,700	62.62	8/28/17	0.85	118
08076700	Greens Bayou at Ley Rd Houston	182	23,950	40,650	49,560	75,360	58,500	39.51	8/27/17	0.54	185
08110100	Davidson Creek near Lyons	195	12,850	25,500	32,130	50,400	24,100	19.47	8/28/17	2.3	43

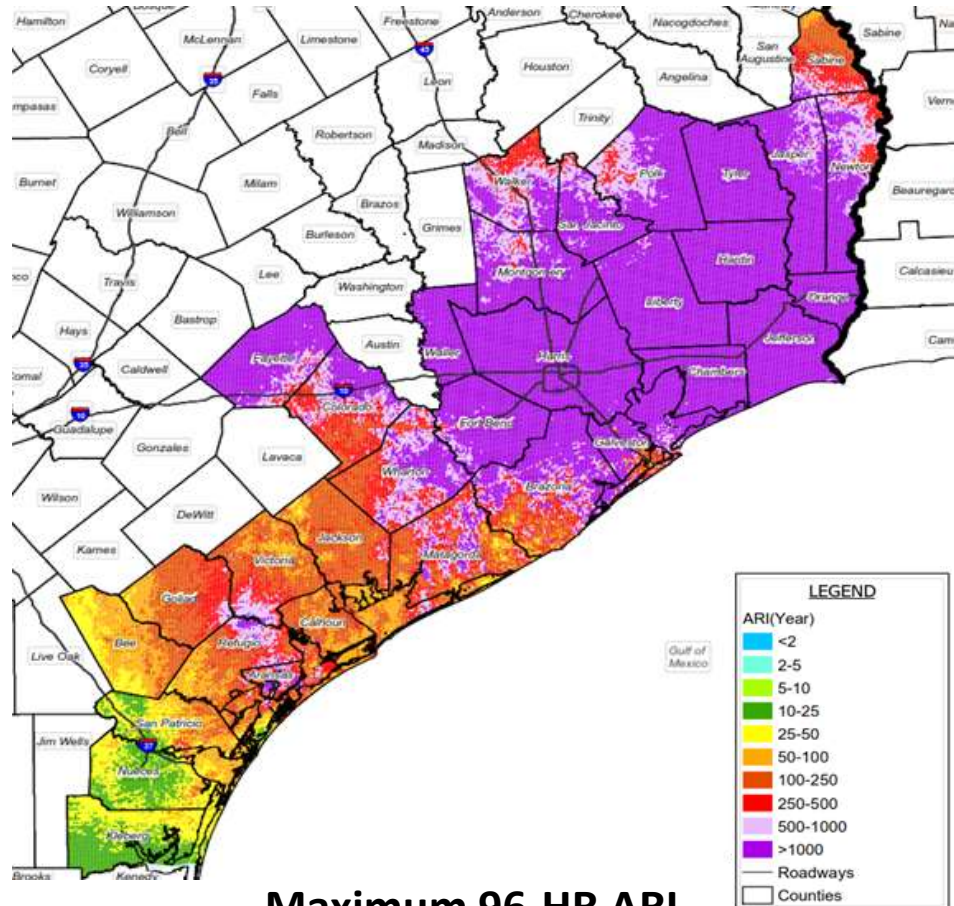
SUMMARY

- ❑ Hurricane Harvey/Tropical Storm Harvey
 - ❑ Locally High Rainfall Intensity (Max. 3HR RF 7.9 inches)
 - ❑ Large Spatial Distribution (ARIs 50 yr -1,000 yr)
 - ❑ Extended Duration (4 Days, minimal dry periods)

- ❑ Precipitation & Stream Flow Analysis
 - ❑ AECOM Team – Accelerated Schedule
 - ❑ Delivered Report To RMD in 6 Weeks



QUESTIONS



Maximum 96-HR ARI