A 50,000-Year Storm…Really?

Communicating Risk "Part 2"

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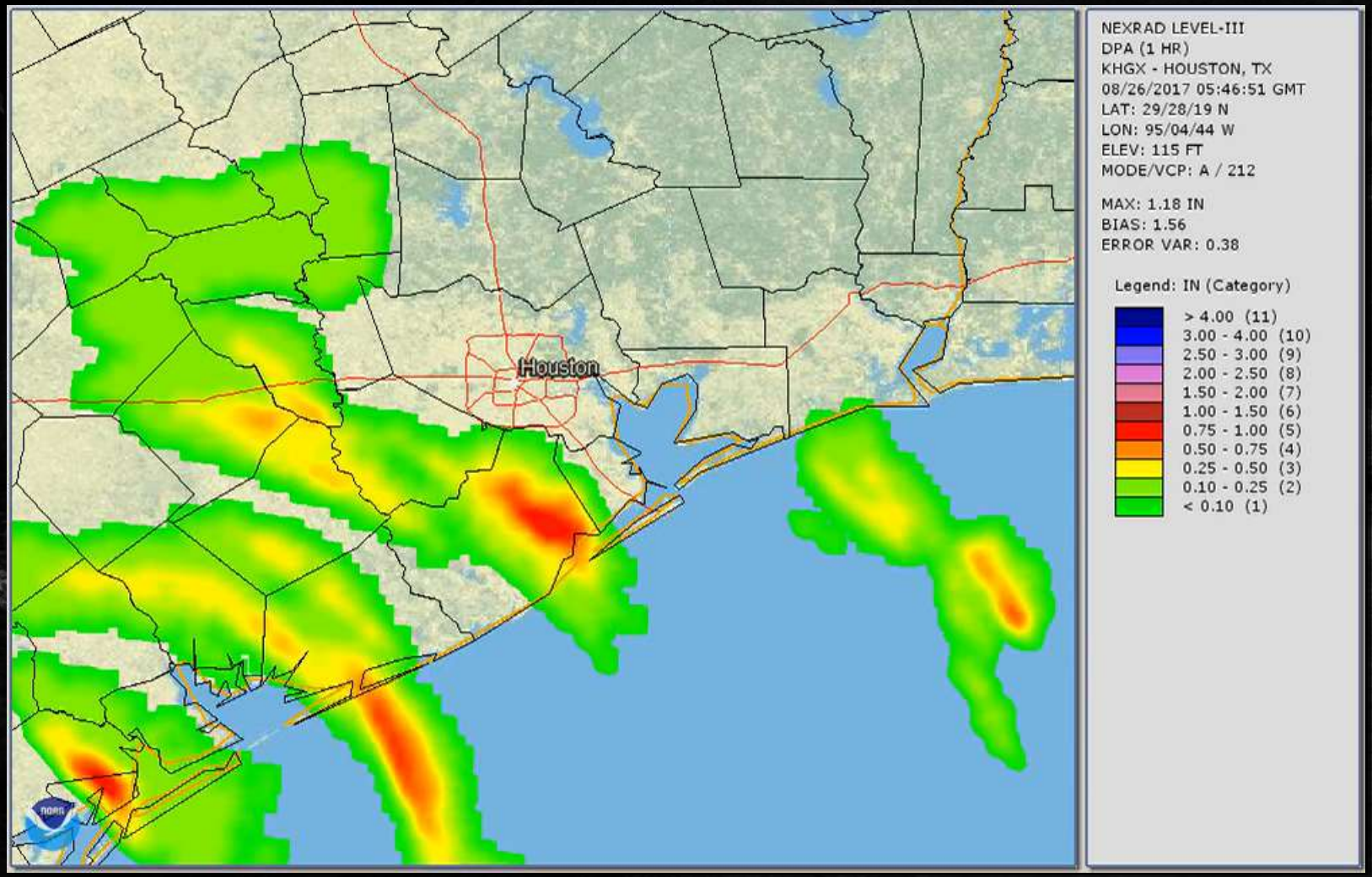
Harvey's R.I.



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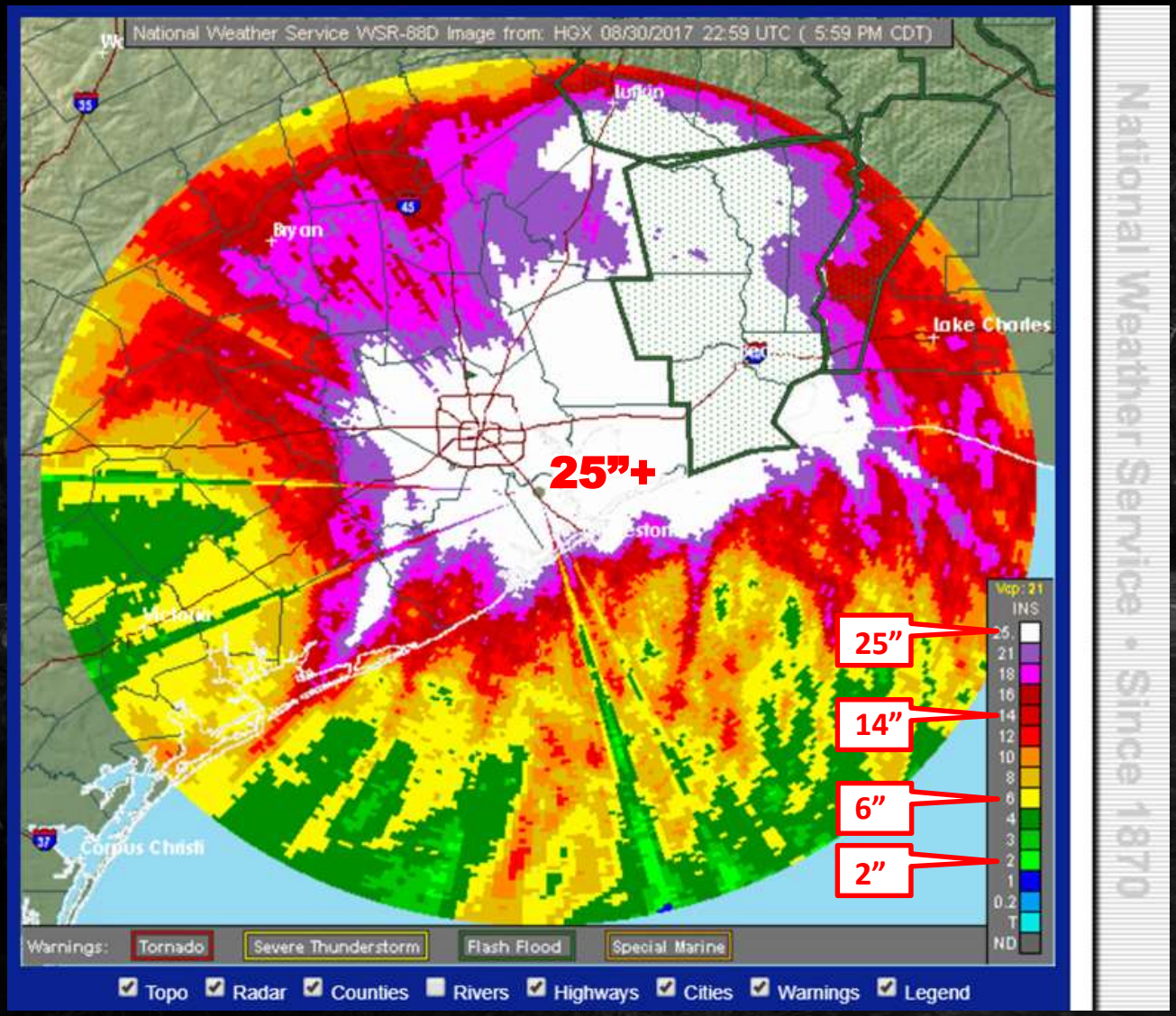
Rainfall (KHGX Radar Estimates)



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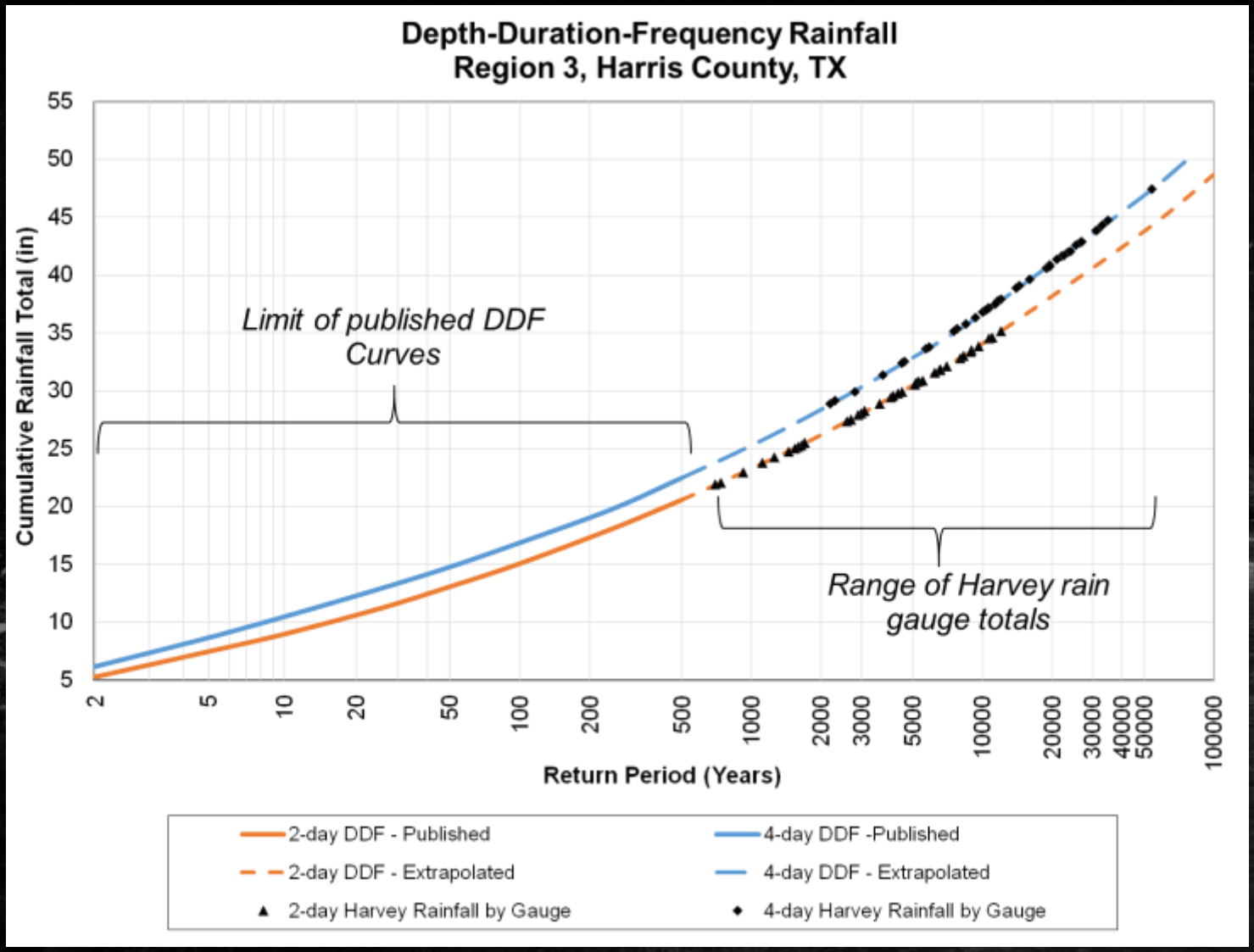
Rainfall (HCFCD Gage Recordings)

Rainfall (HCFCD Gage Recordings)

- 4-day rainfall totals at all rainfall gages across Harris County recorded greater than a 500-year (0.2%) event
- 24-hour rainfall totals generally exceeded a 100-year (1.0%) event
- Shorter duration rainfall measurements of significance were much less widespread with one location receiving 18.9 inches in six hours and another receiving 6.8 inches in one hour

Storm	1-Hour Max	6-Hour Max	24-Hour Max	4-Day Max
October 1994	3.7	7.2	20.9	28.9
Allison (2001)	5.7	**21.2**	**28.4**	38.5
Memorial Day 2015	4.8	10.1	11.0	11.1
Tax Day 2016	4.7	13.9	17.4	19.1
Harvey (2017)	**6.8**	18.9	25.6	**47.4**

Rainfall (HCFCD Gage Recordings)



Rainfall (HCFCD Gage Recordings)

A METHOD TO ESTIMATE RETURN PERIOD OF EXTREME EVENTS APPLIED TO HURRICANE HARVEY RAINFALL

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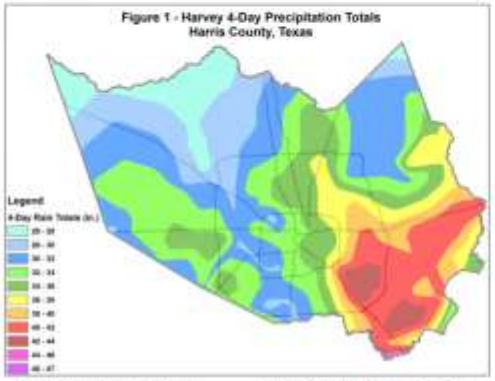
Depth-Duration-Frequency (DDF) rainfall curves provide a means to understand the return period, or annual exceedance probability†, of observed rainfall totals. Whether determined for a local region or interpolated from NOAA Rainfall Atlases (Atlas 14 or TP-40), DDF curves propose probabilistic rainfall totals for different durations and return period frequencies, in some cases up to the 500-year return period, a common benchmark for extreme events. When a more severe event occurs, however, how do you quantify the return period for rainfall that exceeds the published DDF levels?

Figure 1 - Harvey 4-Day Precipitation Totals
Harris County, Texas



Hurricane Harvey produced an unprecedented amount of rain across the Houston Metropolitan Area, far exceeding previous historical records and causing proportional flood damages. The entire Harris County averaged over 33 inches of rainfall in four days (Figure 1). Every County rain gauge (with one exception) exceeded the published 500-year rainfall totals for the two- and four-day durations. With such astronomical numbers plotting off the charts, it begs the question: what was the return period of Harvey?

A commonly accepted method to estimate return period is to analyze the probability distribution of a sample, in this case the available period of rainfall record. The current DDF curves for Harris County were developed using about 84 years of rainfall data ending in 1994. Thus there is already a great deal of uncertainty inherent to the short period of analysis of the published curves. However, in order to extrapolate a return period to the observed Harvey rainfall, the probability distribution of the rainfall record was estimated with an L-Moment Diagram. The L-Moment method was chosen due to its acceptance as an unbiased predictor of the underlying probability distribution for small sample sizes (Vogel and Fennessey, 1993).

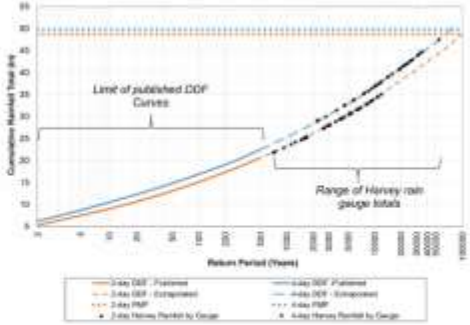
The L-Moment ratio estimators were back-calculated using a best fit approach to reproduce the published DDF data. Since these parameters estimate an overall probability distribution, they provided a means to extend the DDF curves up to a 100,000-year level (Figure 2). Using this method, the 100,000-year storms in southeast Harris County (Region 3) are approximately 49 and 52 inches for durations of two and four days, respectively. When plotted on the L-Moment-derived distribution, individual two-day Harris County rain gauge totals in Region 3 align with return periods between 600 and 12,000 years, while the four-day totals fall in the 2,000 to 55,000-year range (Figure 2).

Although return periods for extreme events can always be mathematically approximated as described above, it should be noted that the further out curves are extrapolated, the more uncertain the return period. This method assumes that the underlying DDF relationships based on past hydrology represent the probability of a current event. Any uncertainty associated with the underlying curves is magnified in the extrapolation.

Another important caveat is that with this method the precipitation depth increases infinitely, so theoretically a non-zero probability exists for an event that is physically impossible. For comparison, the Probable Maximum Precipitation (PMP) recently published by the Texas Commission on Environmental Quality (TCEQ) for a 10 square-mile area and four-day duration is approximately 50 inches (Kappel et al., 2016), which equates to a return period of about 75,000 years. Therefore, although the four-day DDF curve was extrapolated out to 52 inches at the 100,000-year return period, the depth as plotted in Figure 2 should asymptotically approach the PMP (50 inches) when the return period is 75,000 years or greater. Although there is also uncertainty in the PMP determination, if we assume, by definition, that the PMP cannot be exceeded, it provides a practical upper limit bound to the DDF approximations.

This L-Moment-based extrapolation method offers a quick means to better understand the rarity of Harvey rainfall using existing data, but it should be used with caution. This method appears to prove that a rainfall like Harvey is extremely rare, something that is expected to occur about once every 50,000 years, on average.

Figure 2 - Depth-Duration-Frequency Rainfall
Region 3, Harris County, TX



However, given the return interval of this event, and the fact that it happened within the relatively short period of record, this assigned probability may be suspect. Harvey now serves as a new benchmark of meteorological possibilities, and as the database of observed information continues to grow, new and updated methods can be pursued for determining probabilistic rainfall and better understanding return periods.

Footnotes:

† It is more common today to avoid the term "return period" and use an annual exceedance probability instead. For instance, a 1% storm to denote the 100-year storm, an event that occurs in average once every 100 years. The authors opted to use return period given the extremely small probabilities associated with Tropical Storm Harvey rainfall totals.

References:

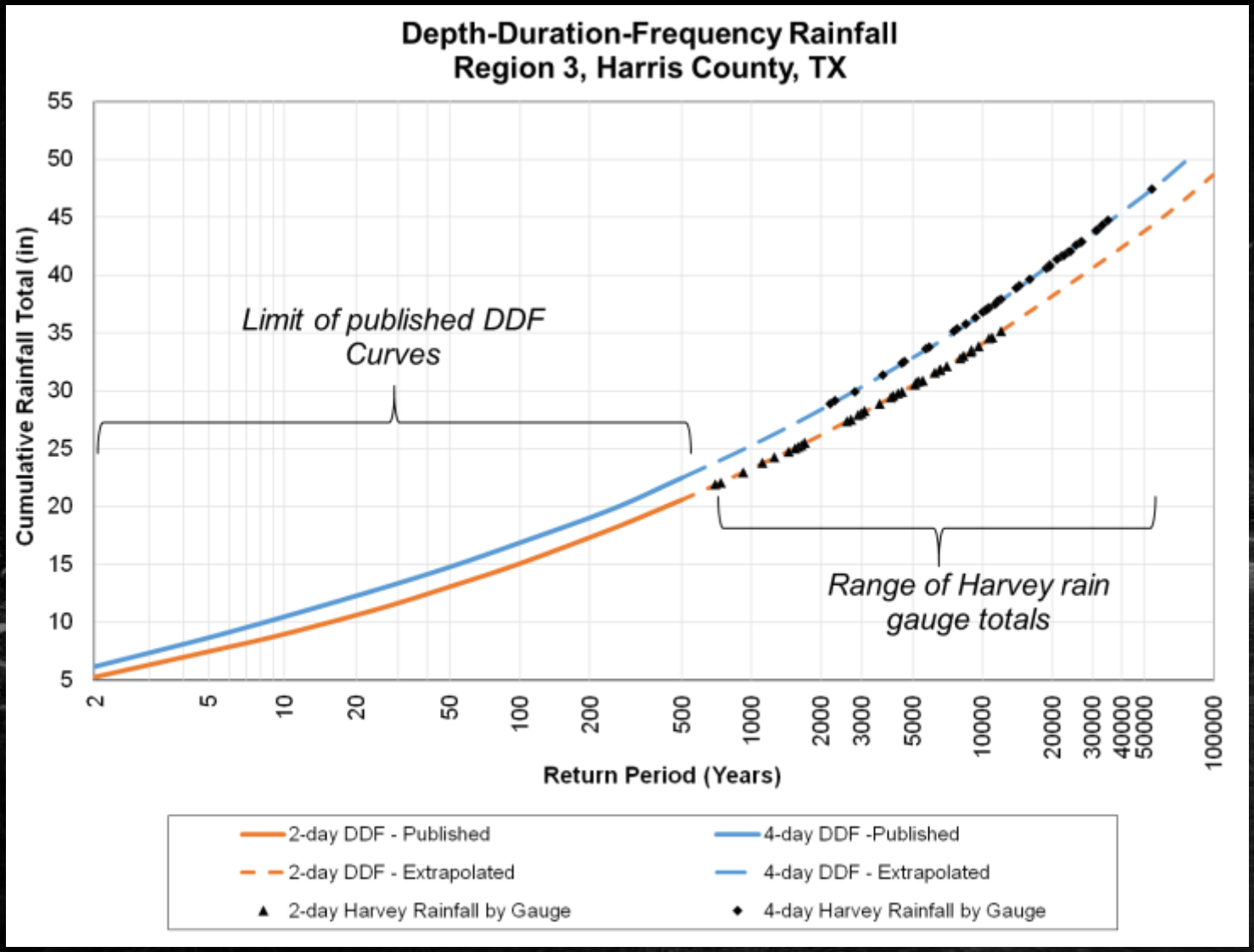
Bonnin, G. M., Todd, D., Lin, B., Parzybok, T., Yekta, M., & Riley, D. (2004). NOAA Atlas 14. Precip. Freq. Atlas United States, 1.

Hershfield, D. M. (1961). Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. US Department Commerce Technical Paper, 40, 1-61.

Kappel, B, Muhlestein, G., Hultstrand, D., McGlone, D., Steinhilber, K., Lawrence, B., Rodel, J. (2016). Probable Maximum Precipitation Study for Texas. Texas Commission on Environmental Quality PMP Study.

Vogel, R. M., & Fennessey, N. M. (1993). L moment diagrams should replace product moment diagrams. Water Resources Research, 29(6), 1745-1752.

Rainfall (HCFCD Gage Recordings)



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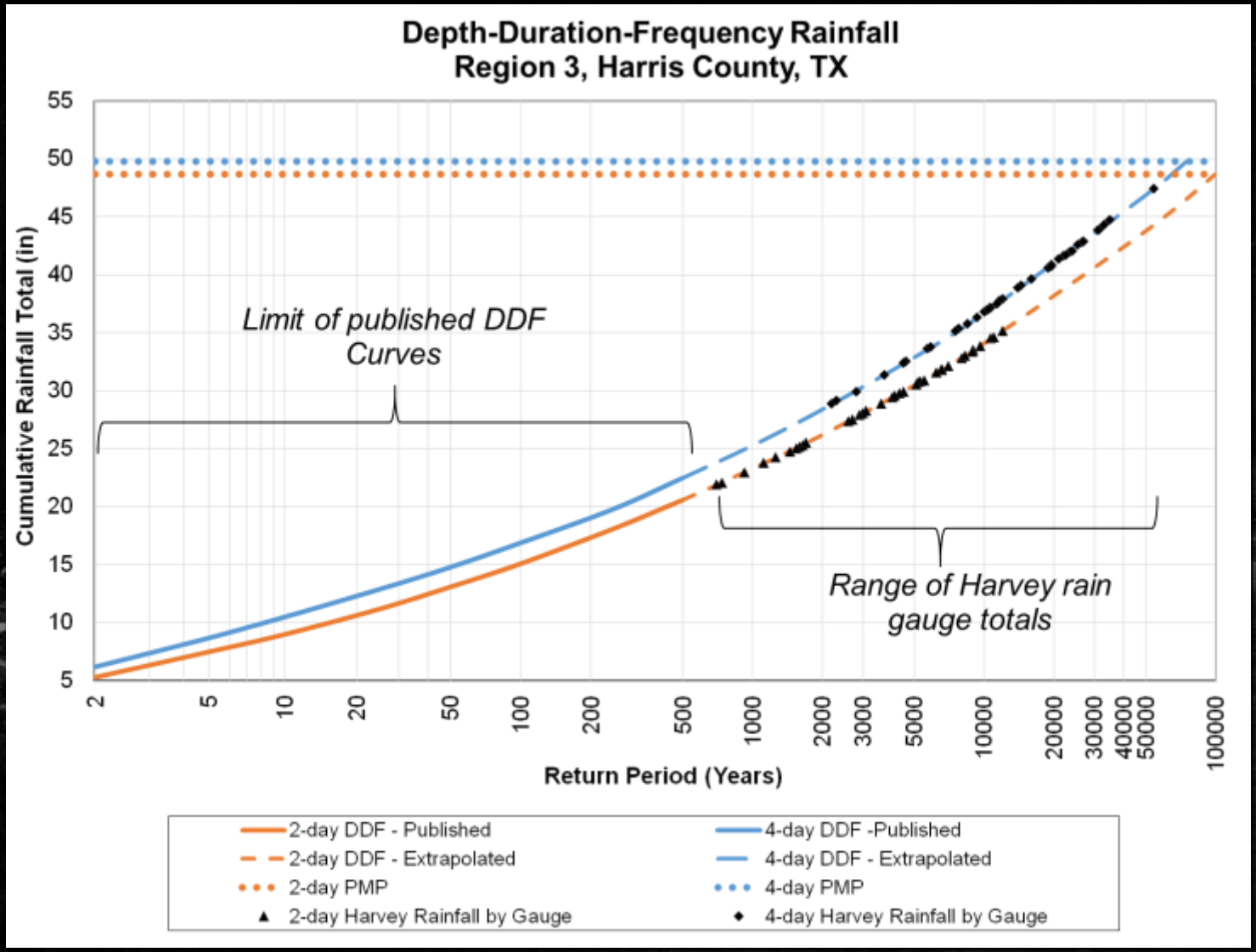
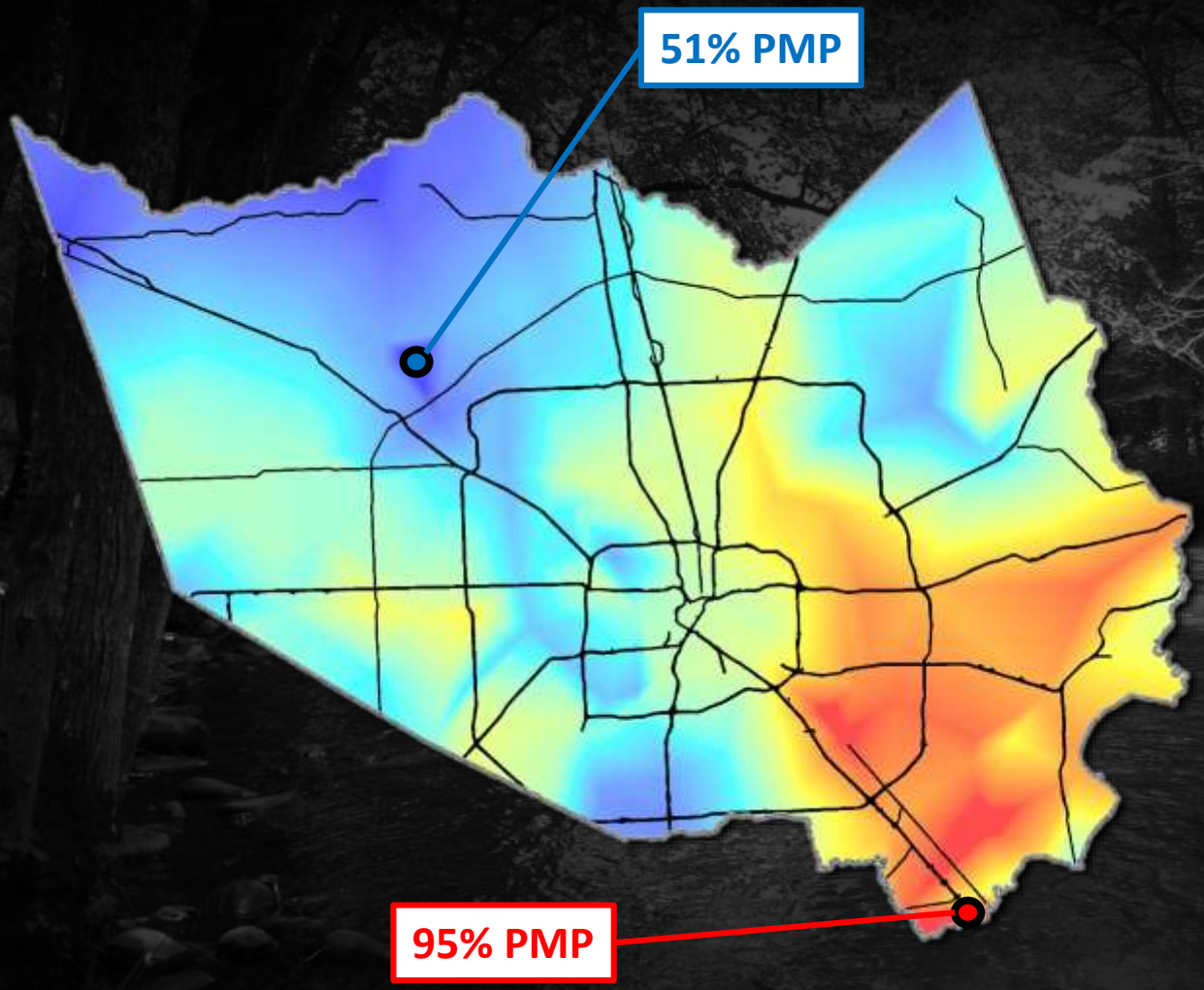


Rainfall (%PMP)



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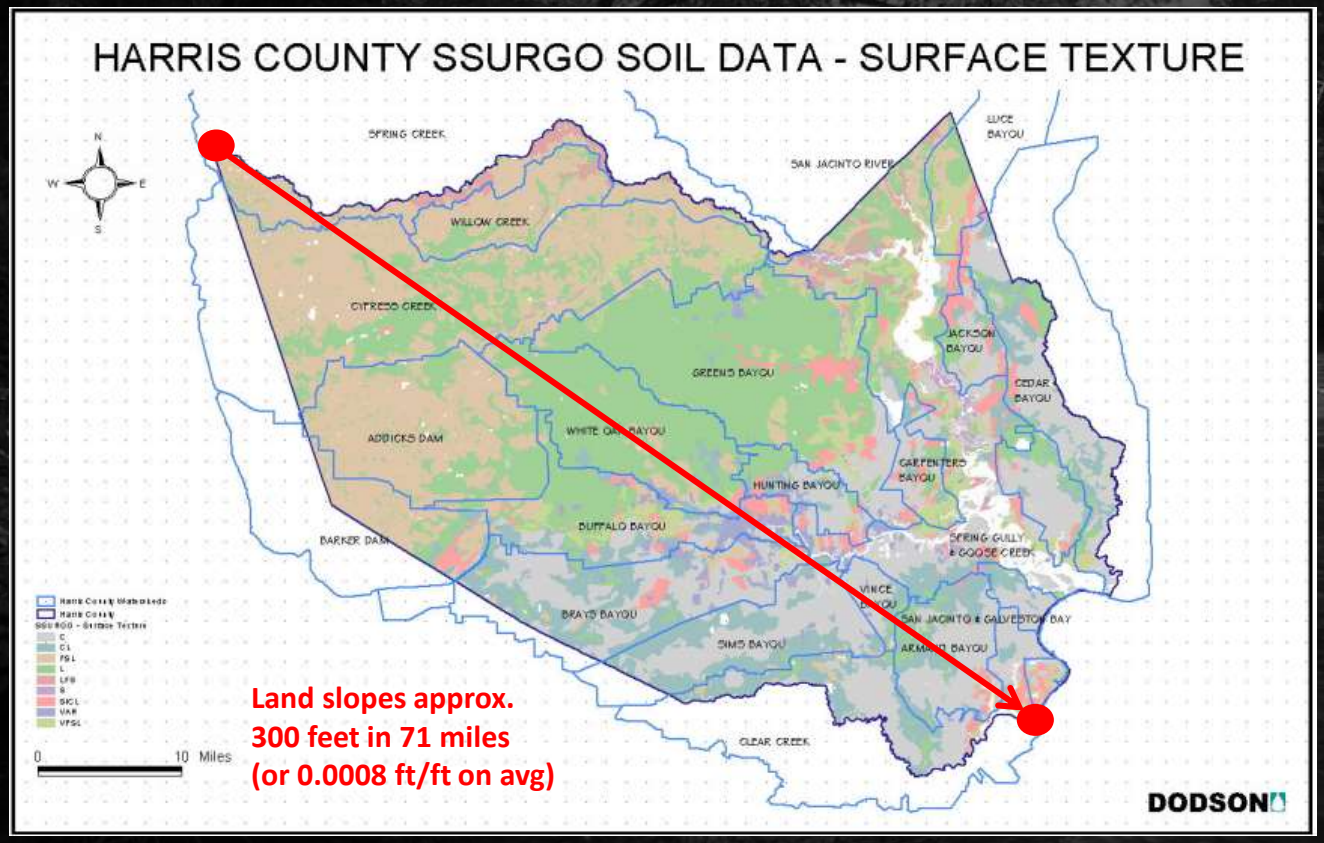
Major Contributors to Flooding

- Soils and Slopes
  - Predominately clay soils and flat slopes of the coastal plain



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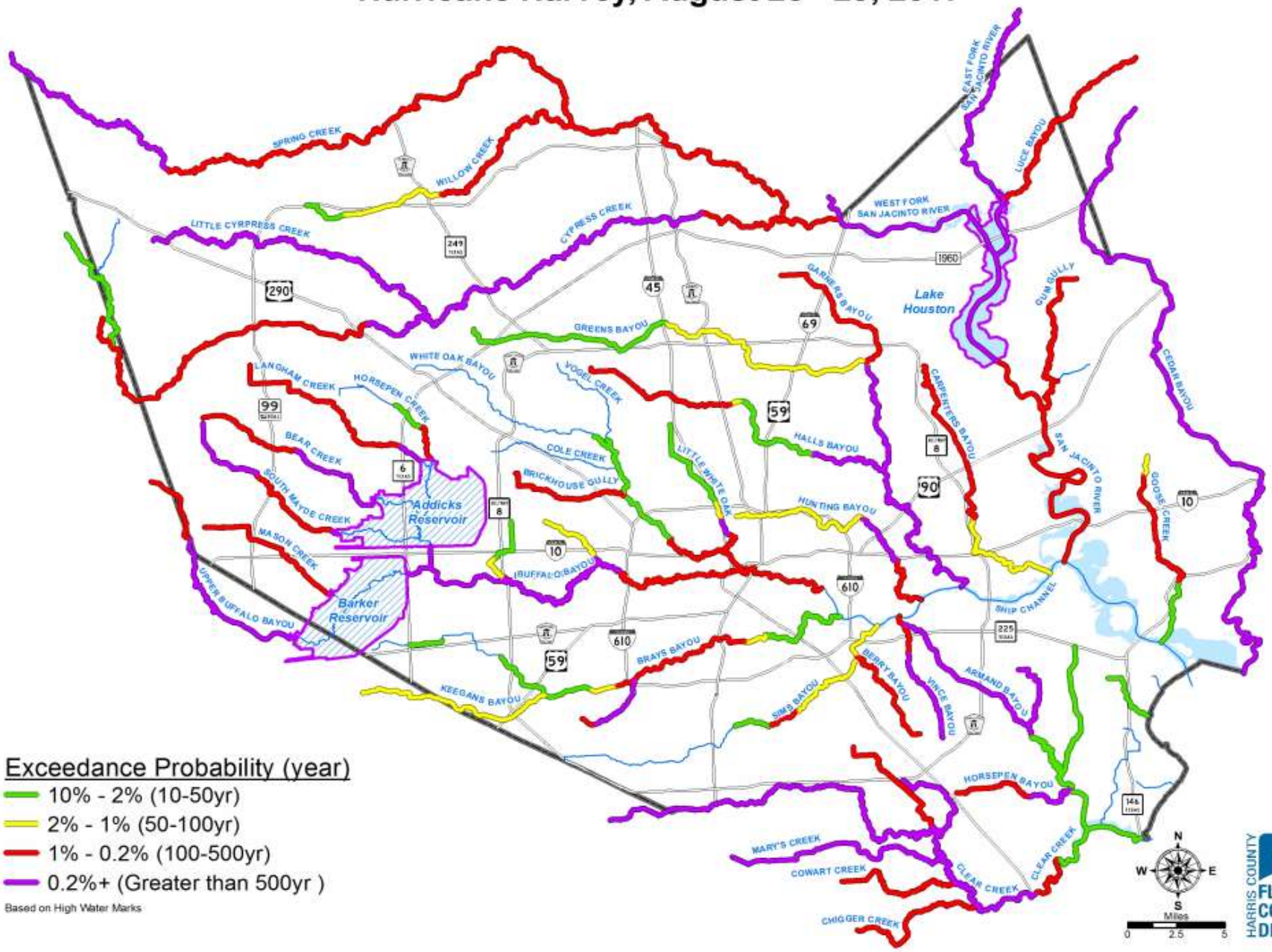
Peak Channel Water Surface Elevation Frequencies

Hurricane Harvey, August 25 - 29, 2017



Exceedance Probability (year)

- 10% - 2% (10-50yr)
- 2% - 1% (50-100yr)
- 1% - 0.2% (100-500yr)
- 0.2%+ (Greater than 500yr)

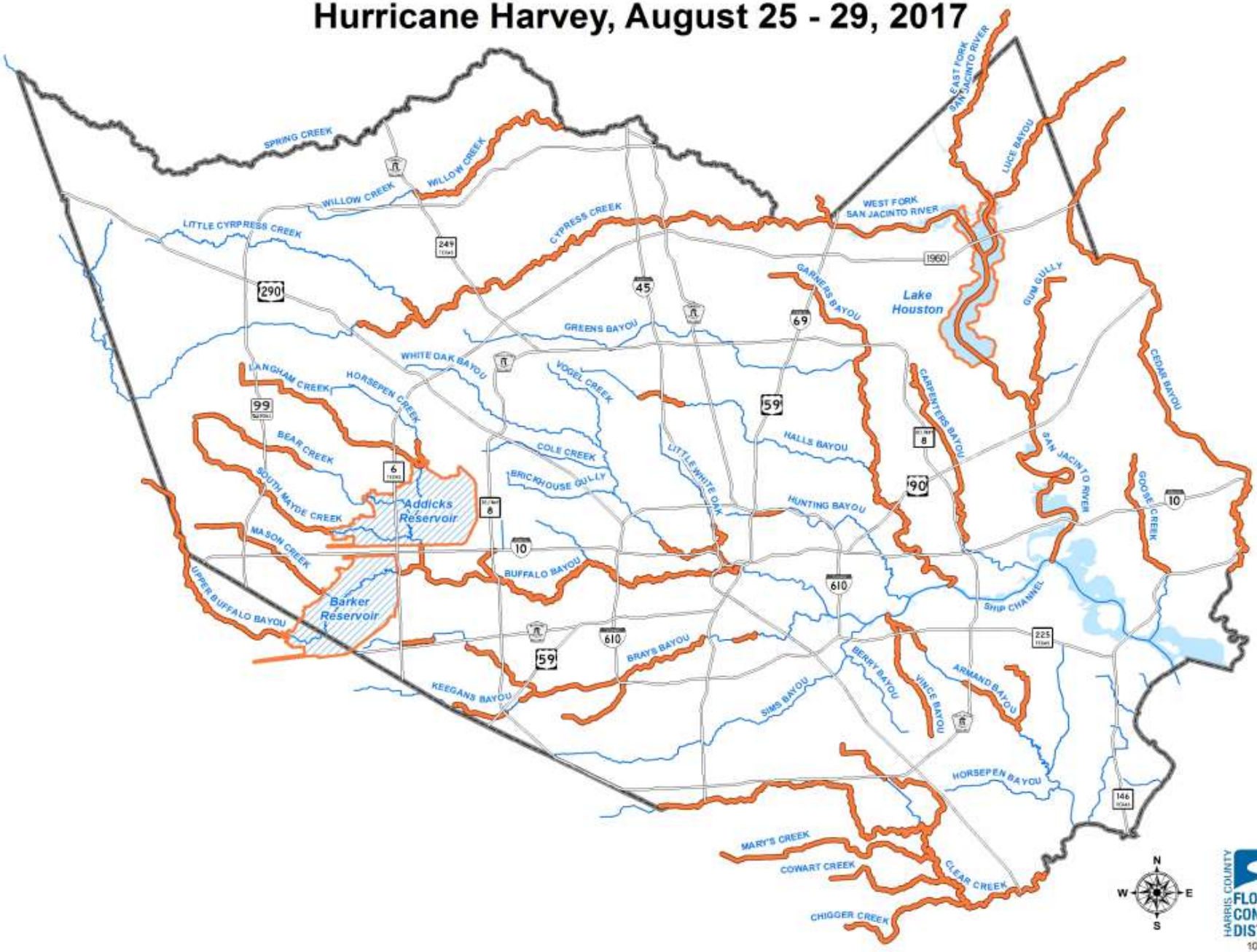
Based on High Water Marks

HARRIS COUNTY FLOOD CONTROL DISTRICT

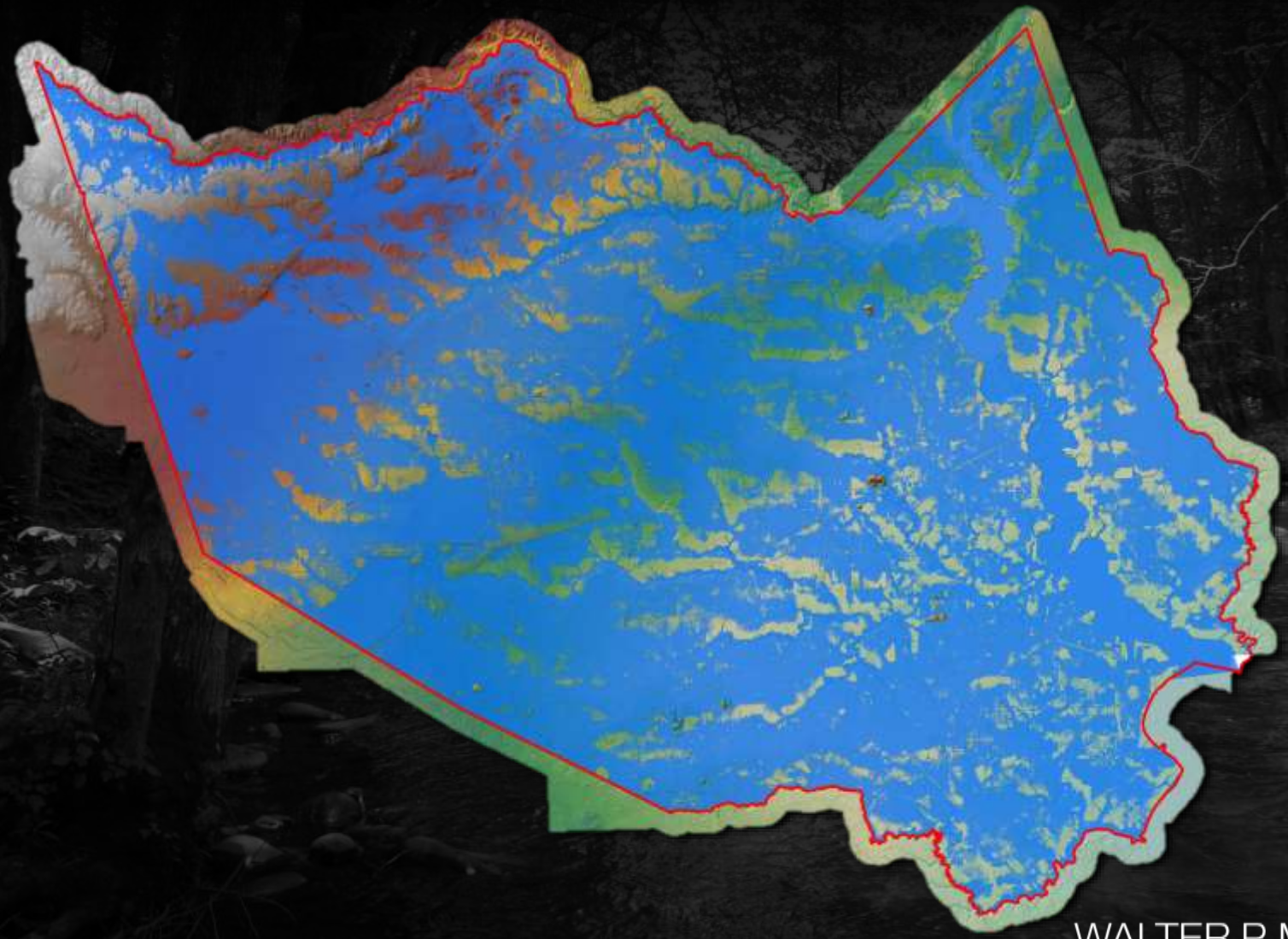
10/9/2017

Record Flood Levels

Hurricane Harvey, August 25 - 29, 2017



Estimate of Runoff Inundation



Harvey Key Facts

154,170 Structures Damaged

34”
Average rainfall in Harris County

83%
of homes do not have flood insurance

$81.5B
Estimated loss

9,400
Commercial flights cancelled


Success Stories – Stories Untold

Texas Medical Center

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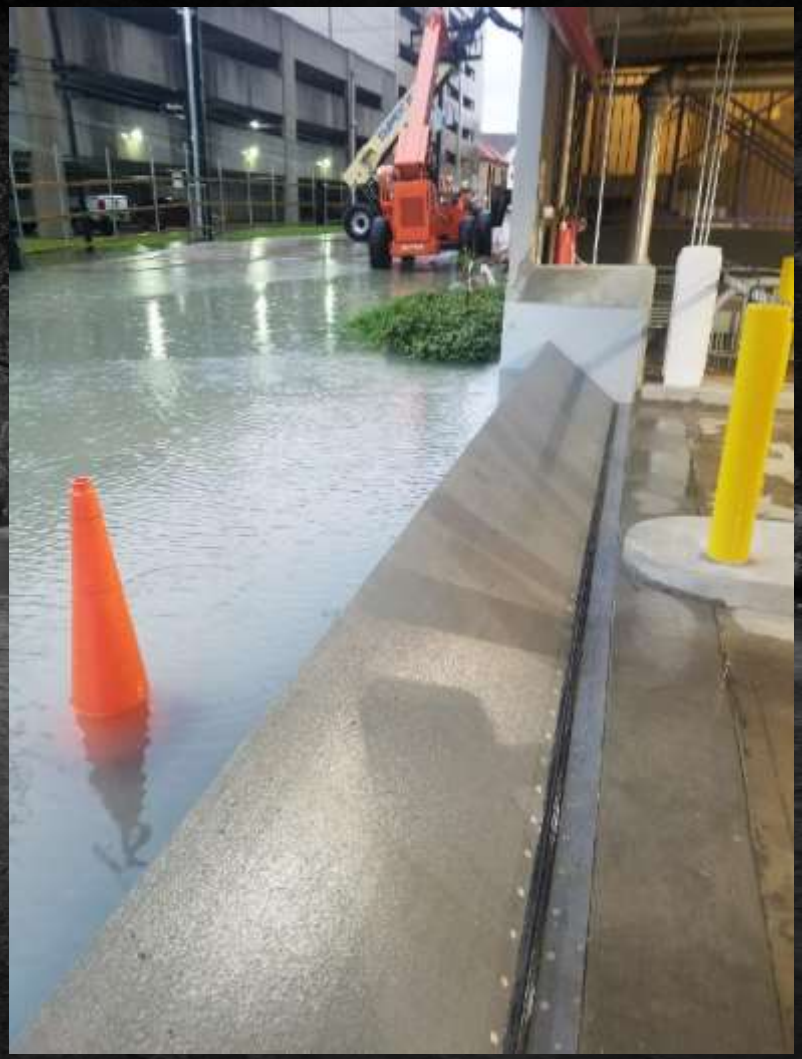
Texas Medical Center



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Sims Bayou Federal Project

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Sims Bayou Federal Project

Road Name	Harvey	Record	Record Storm
State Highway 3	20.7	20.7	Harvey (August 2017)
Interstate 45	22.1	26.1	Alica (August 1983)
Broadway	22.3	26.8	Alica (August 1983)
Telephone Road	26.3	28.5	Alica (August 1983)
Mykawa	30.9	35.6	October 1994
Martin Luther King	33.6	41.1	October 1994
Cullen	36.0	37.8	October 1994
Airport Boulevard	36.1	39.9	October 1994
State Highway 288	38.3	43.5	Allison (June 2001)
Almeda	43.1	49.4	Allison (June 2001)
Buffalo Speedway	44.6	50.8	June 1973
White Heather	45.8	52.5	Allison (June 2001)
Hiram Clarke	46.8	51.3	Allison (June 2001)
South Post Oak	49.8	53.5	Allison (June 2001)

Structural Flooding

- In Harris County unincorporated areas
  - Approx. 75,000 structures have been built since the latest floodplain regulations were adopted in 2009
  - 467 of these flooded
  - 99% of these did **NOT** flood
- Across Harris County (including the City of Houston)
  - Tragically, 154,170 Structures Damaged
  - This accounts for 9% to 12% all structures in the County
  - This means that roughly 90% all structures in the County did **NOT** flood…from an average of 34 inches of rain in four days

Conclusions

Conclusions

- Extreme events are difficult to characterize in terms of recurrence interval due to the lack of data

- How do events like Harvey affect they way we communicate what we mean by “100-year event?”

General Conclusions

- Issues of Understanding
  - "What if the WORST happens and we have a 100-year flood?"
  - How many of us engineers and floodplain managers would agree that the 100-year is the worst flood they can imagine?
  - Where does such thinking come from among the public?
  - Do we really think we can "control" flooding?

General Conclusions

- Issues in Communication
  - Big floods happen, but small floods can be deadly
  - Magnitudes of rainfall do not necessarily produce similar magnitudes of flooding
  - What does the public hear when we mention a 100-year (or a 1% AEP) flood?
  - Should we begin to relate flood events to historical events or level of risk (non-flood, near flood, minor, moderate, major, and record flooding)? Does that pose a communication problem?

General Conclusions

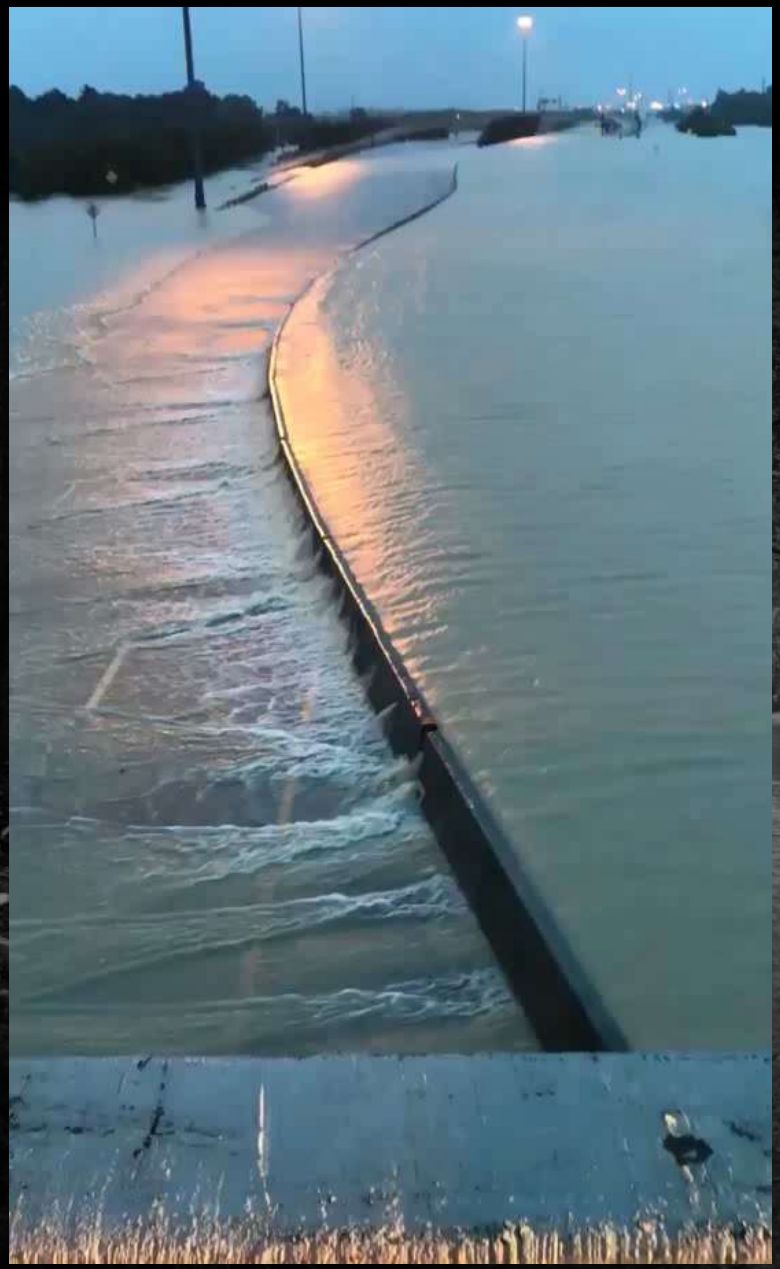
- Goal of Better Communication
  - To change behavior
    - Public (safety, insurance, rebuilding)
    - Developers (new development)
    - Engineers (promote community awareness to the public and to clients)
    - Public Agencies (policy and projects)

The Heartbreak

MOORE

A Photo Worth Remembering…

From Jeff Lindner's Twitter Page (https://twitter.com/JeffLindner1); original source unknown



Questions ???

West Fork San Jacinto River at U.S. 59 (Interstate 69)