A 50,000-Year Storm...Really?

Communicating Risk “Part 2”

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WALTER P MOORE AND ASSOCIATES, INC.
Rainfall (KHGX Radar Estimates)
Rainfall (HCFCD Gage Recordings)

Questionable Amount Due to Gage Error
### 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

<table>
<thead>
<tr>
<th>Storm</th>
<th>1-Hour Max</th>
<th>6-Hour Max</th>
<th>24-Hour Max</th>
<th>4-Day Max</th>
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<td>October 1994</td>
<td>3.7</td>
<td>7.2</td>
<td>20.9</td>
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<td>Allison (2001)</td>
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<td><strong>21.2</strong></td>
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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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Rainfall (HCFCD Gage Recordings)

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?

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 chart, 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 (Kappe 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 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.

Footnotes:
1 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:
Rainfall (HCFCD Gage Recordings)

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

Limit of published DDF Curves

Range of Harvey rain gauge totals

Return Period (Years)
Cumulative Rainfall Total (in)

- 2-day DDF - Published
- 2-day DDF - Extrapolated
- 4-day DDF - Published
- 4-day DDF - Extrapolated

2-day Harvey Rainfall by Gauge
4-day Harvey Rainfall by Gauge
Rainfall (HCFCD Gage Recordings)

![Graph showing Depth-Duration-Frequency Rainfall](image)

- **Limit of published DDF Curves**
- **Range of Harvey rain gauge totals**

Legend:
- Orange: 2-day DDF - Published
- Orange dashed: 2-day DDF - Extrapolated
- Red: 2-day PMP
- Black triangle: 2-day Harvey Rainfall by Gauge
- Blue: 4-day DDF - Published
- Blue dashed: 4-day DDF - Extrapolated
- Blue dotted: 4-day PMP
- Black diamond: 4-day Harvey Rainfall by Gauge
Major Contributors to Flooding

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

Land slopes approx. 300 feet in 71 miles (or 0.0008 ft/ft on avg)
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
Estimate of Runoff Inundation
Harvey Key Facts

- 34” Average rainfall in Harris County
- 83% of homes do not have flood insurance
- 154,170 Structures Damaged
- $81.5B Estimated loss
- 9,400 Commercial flights cancelled
Success Stories – Stories Untold
Texas Medical Center
Texas Medical Center
Sims Bayou Federal Project
<table>
<thead>
<tr>
<th>Road Name</th>
<th>Harvey</th>
<th>Record</th>
<th>Record Storm</th>
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<tbody>
<tr>
<td>State Highway 3</td>
<td>20.7</td>
<td>20.7</td>
<td>Harvey (August 2017)</td>
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<tr>
<td>Interstate 45</td>
<td>22.1</td>
<td>26.1</td>
<td>Alica (August 1983)</td>
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<tr>
<td>Broadway</td>
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<td>Alica (August 1983)</td>
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<td>Almeda</td>
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<td>South Post Oak</td>
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<td>53.5</td>
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</table>
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 the way we communicate what we mean by “100-year event?”
• **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
A Photo Worth Remembering...

From Jeff Lindner’s Twitter Page (https://twitter.com/JeffLindner); original source unknown
Questions ???

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