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What shape is your rain?
A case study of precipitation distributions

Isaac Schrock | 2023 IAFSM | Tinley Park, IL

Outline

A. **What is rainfall-runoff modeling?**
B. Introduce case study watershed, context, and the challenge:
   1. Why do different hydrologic studies produce different peak flow estimates?
   2. Which distribution should be used?
C. Precipitation distribution drives peak flow (#1)
D. Introduce common precipitation distributions
E. Example: use calibration to select distribution
F. Comparison peak flow rates for the case study watershed (#2)
G. Final thoughts on precipitation distributions

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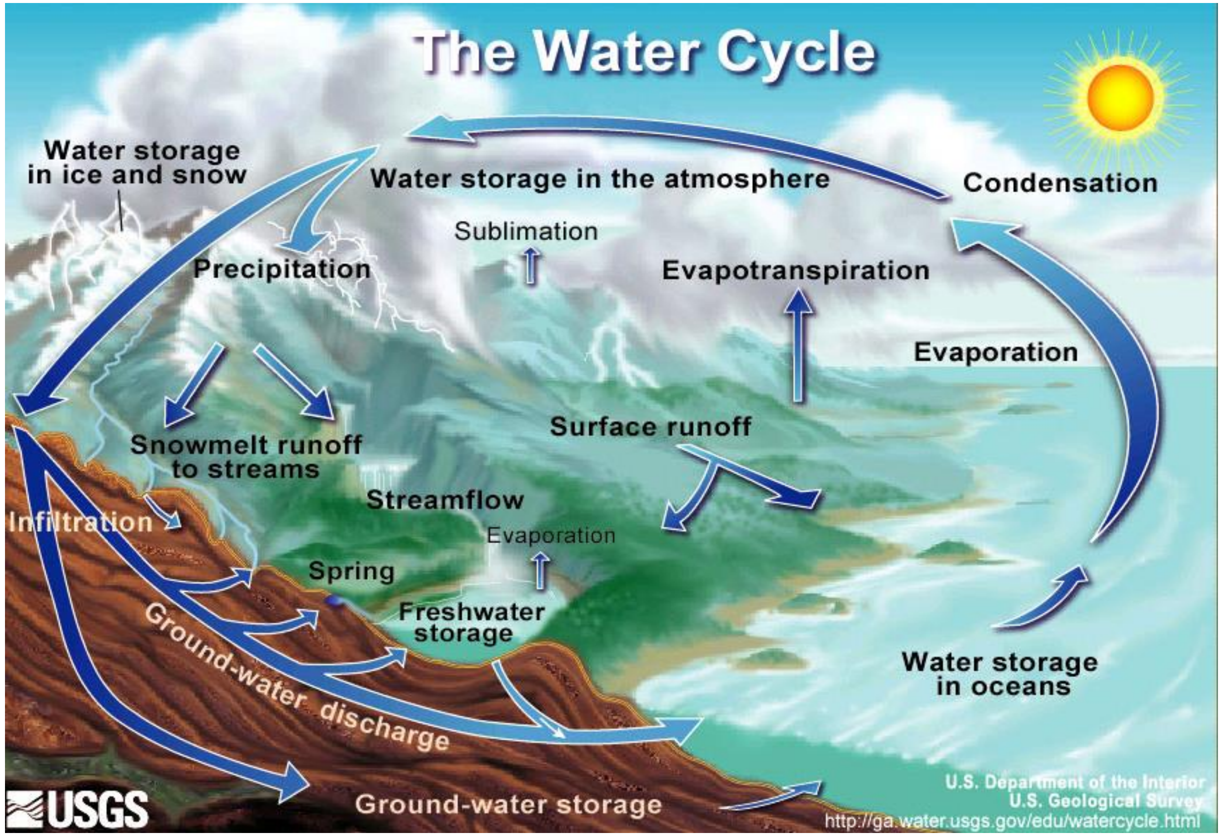
Rainfall-runoff models simulate land surface processes at a watershed scale to produce a runoff hydrograph

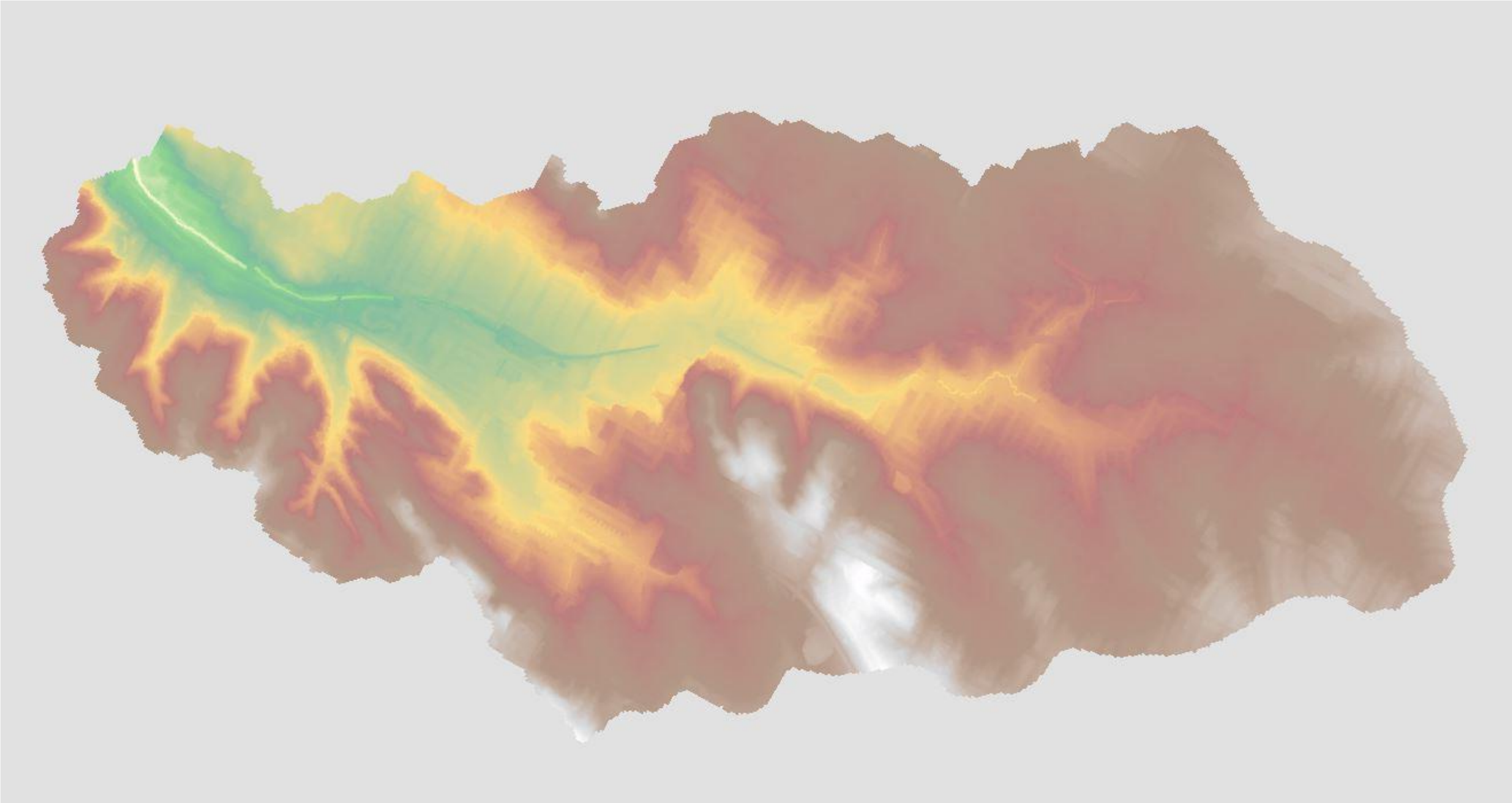
Hydrologic Model Characteristics

- Structure
  - **Empirical** (SCS Curve Number, regression equations, machine learning)
  - Conceptual
  - Physical
- Spatial Structure
  - **Lumped** (HMS, proprietary software)
  - Distributed
- Temporal Representation
  - **Event-based**
  - Continuous simulation
- Parameter Specification
  - **Deterministic**
  - Stochastic



Case Study Watershed

- 2.8 mi^2 drainage area
- Fully urbanized (commercial and single-family residential)
- Creek has a Zone AE floodplain and floodway
- No consistent flow monitoring data
- History of flooding



The Context

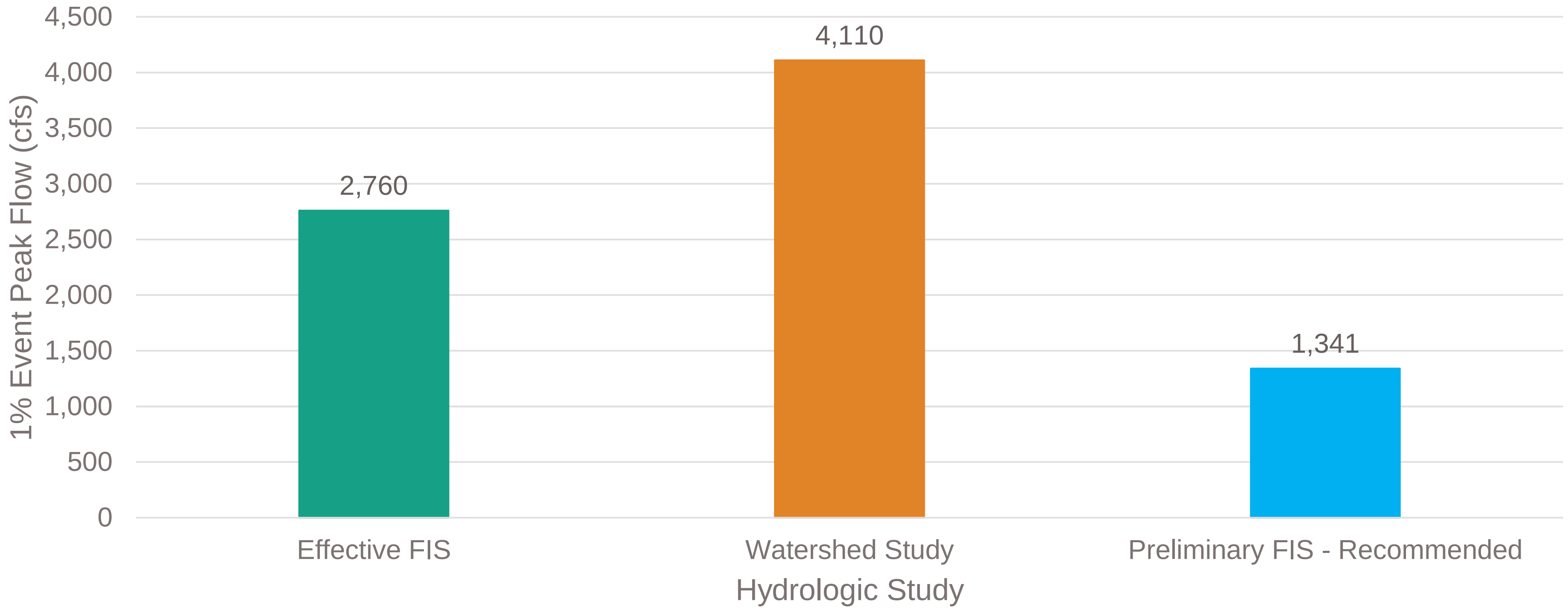
Over a 2-year period: Reconcile and manage simultaneous Hydrologic and Hydraulic studies and applications in the watershed

- FEMA re-study of hydrology and re-map of the floodplain
  - Effective FIS vs Preliminary FIS
- Watershed study
- Construction of CIP projects

Hydrologic and Hydraulic studies shaped each project
Different consultants working on each study

The Challenge – Different Peak Flow Estimates

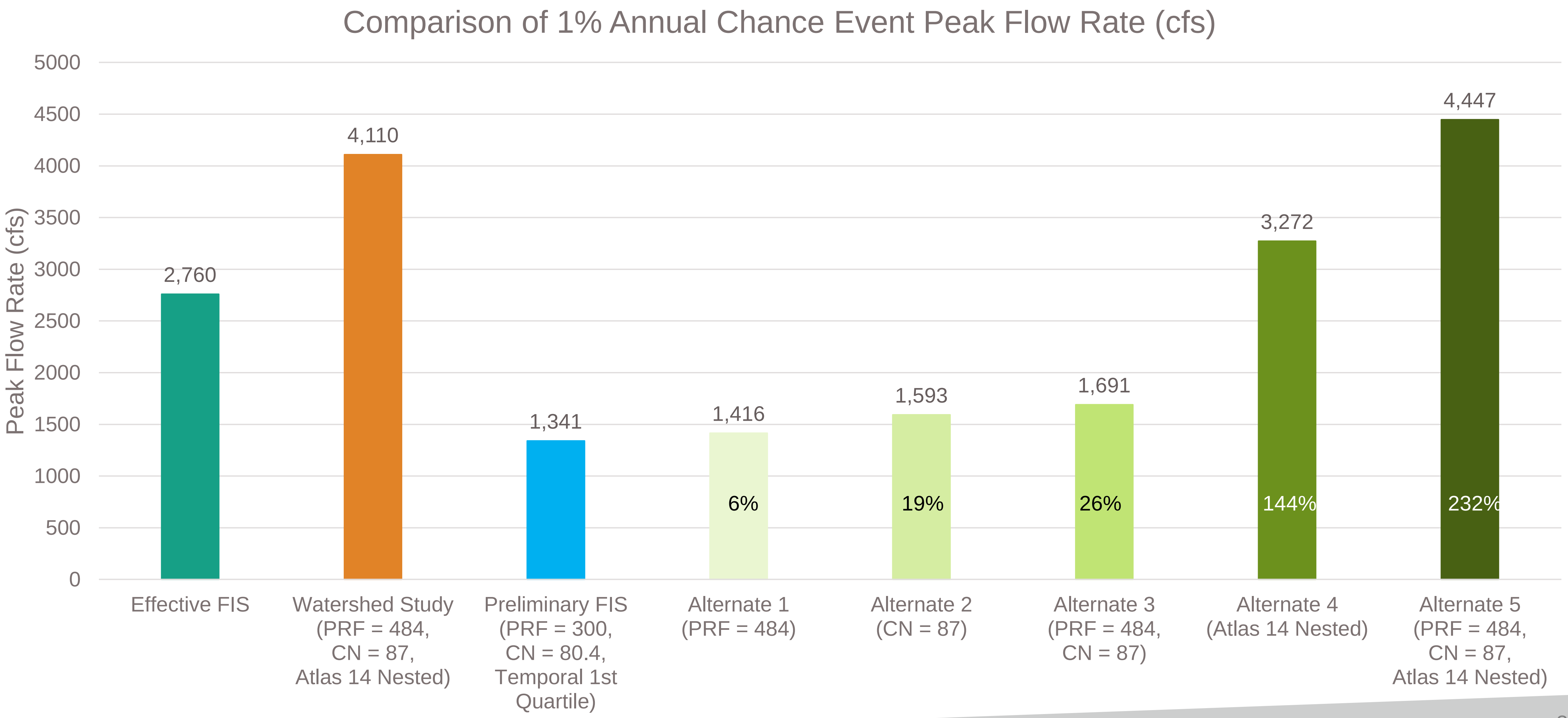
Hydrologic Study	Hydrology Approach (Software)	1% Event Peak Flow (cfs)1
Effective FIS	Rainfall-Runoff (HEC-1)	2,760
Watershed Study	Rainfall-Runoff (proprietary)	4,110
Preliminary FIS – Recommended	Rainfall-Runoff (HEC-HMS)	1,341
1 – Measured at outfall of watershed, with consistent tailwater assumptions		

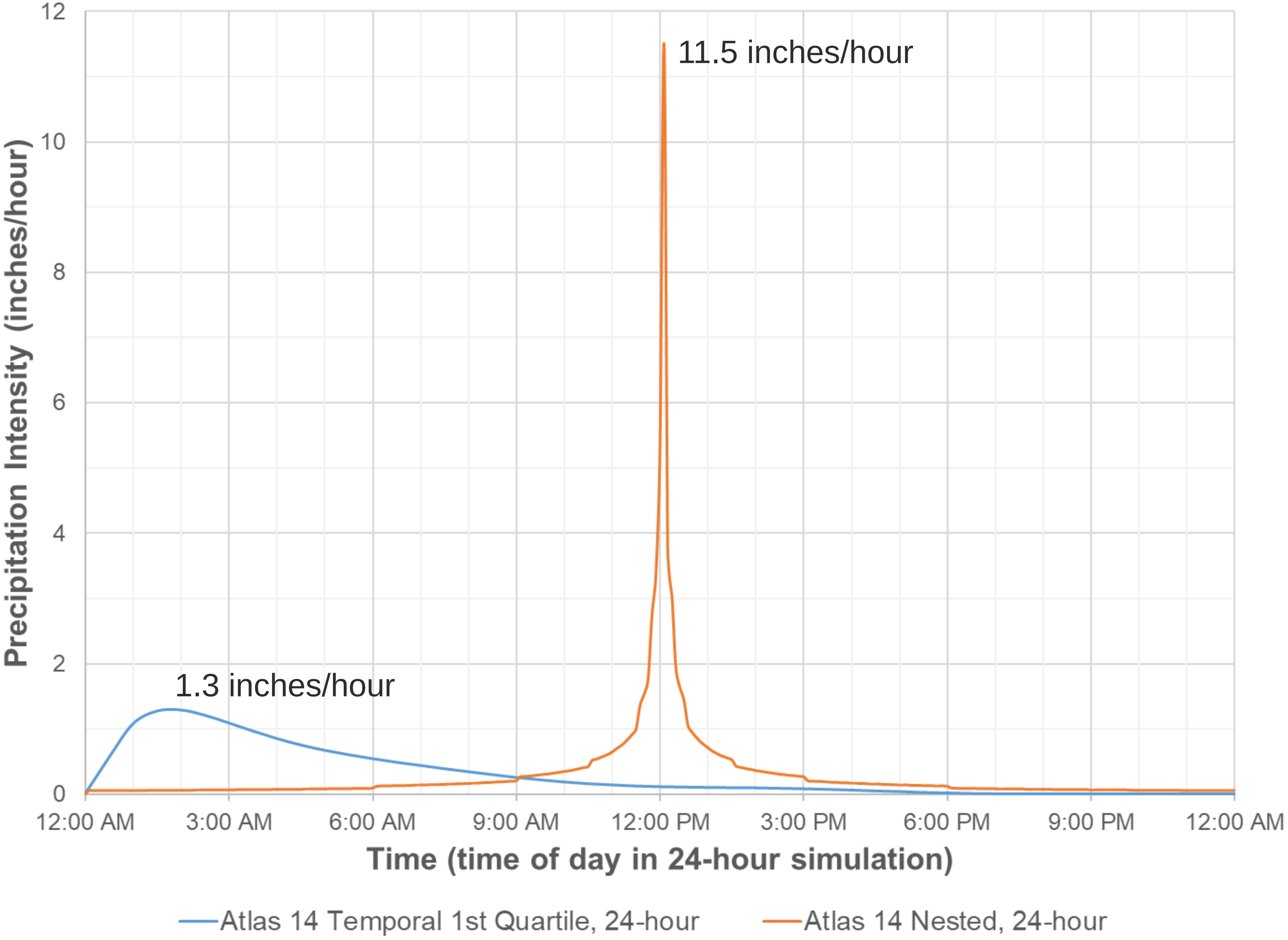


Why the difference in 1% Event flows?

Hydrology Methods

- All studies used NRCS TR-55
  - Loss Method – Curve Number? 80, 87
  - Transform Method – Peak Rate Factor? 484? 300? Lag Time?
  - Precipitation Distribution? Atlas 14 Temporal 1st quartile, 24-hour? Atlas 14 Nested, 24-hour?


Comparison of 1% Annual Chance Event Peak Flow Rate (cfs)
Peak Flow Rate (cfs)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2,760
4,110
1,341
1,416
1,593
1,691
3,272
4,447
6%
19%
26%
144%
232%
Effective FIS
Watershed Study (PRF = 484, CN = 87, Atlas 14 Nested)
Preliminary FIS (PRF = 300, CN = 80.4, Temporal 1st Quartile)
Alternate 1 (PRF = 484)
Alternate 2 (CN = 87)
Alternate 3 (PRF = 484, CN = 87)
Alternate 4 (Atlas 14 Nested)
Alternate 5 (PRF = 484, CN = 87, Atlas 14 Nested)


11.5 inches/hour
1.3 inches/hour
Precipitation Intensity (inches/hour)
0
2
4
6
8
10
12
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
12:00 AM
Time (time of day in 24-hour simulation)
Atlas 14 Temporal 1st Quartile, 24-hour
Atlas 14 Nested, 24-hour

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   1. Why do different hydrologic studies produce different peak flow estimates?
   2. Which distribution should be used?
C. Precipitation distribution drives peak flow (#1)
D. **Introduce common precipitation distributions**
E. Example: use calibration to select distribution
F. Comparison peak flow rates for the case study watershed (#2)
G. Final thoughts on precipitation distributions

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Common Precipitation Distributions

- Angel and Markus (Bulletin 75) aka “Huff Distributions”
  - Critical duration analysis.
- NOAA Atlas 14
  - Temporal (1st, 2nd, 3rd, 4th quartiles)
    - 6-, 12-, 24-, 96-hour durations
  - Nested (aka frequency storm)
    - Variable duration, often 24-hours
  - Ohio Valley and Neighboring States (Regions A, B, C and D)
    - 24-hour duration

Historical Precipitation Distributions

- SCS/NRCS Type I, II, III, IV Distributions
  - Based on rainfall frequency maps from TP40 (Weather Bureau 1961)
  - Development process outlined in TP-149 (SCS 1973)
  - Retire the Type II distribution

National Engineering Handbook, Part 640, Chapter 4 "Little documentation is available that describes the development of the Type II and other legacy rainfall distributions. **Study of what is available leads to the conclusion that their use be discontinued in areas covered by NOAA Atlas 14 data**."

NRCS publication (Merkel, et al) notes that SCS Type distributions are being replaced with Atlas 14 data and distributions.

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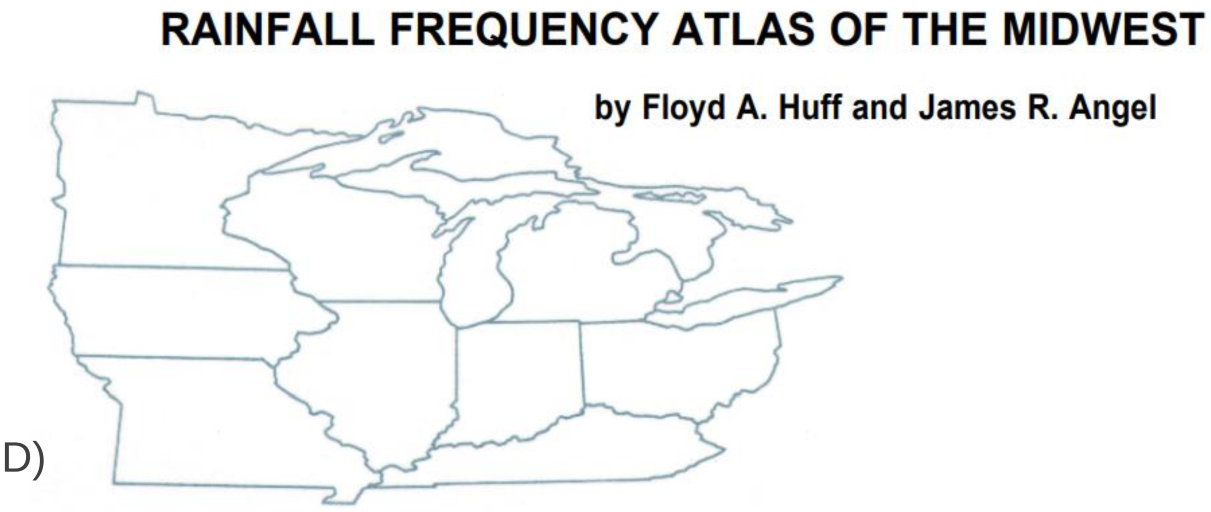

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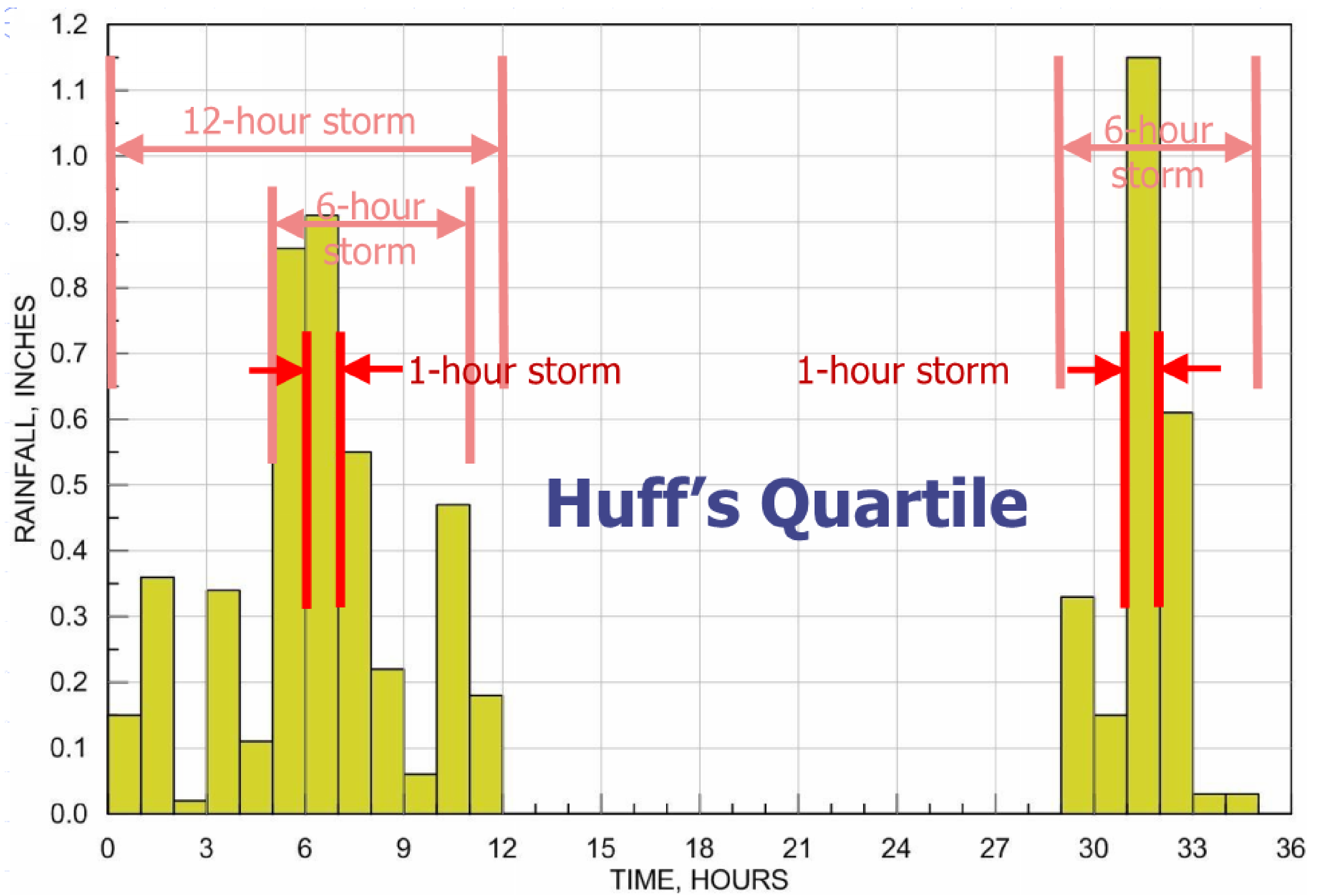

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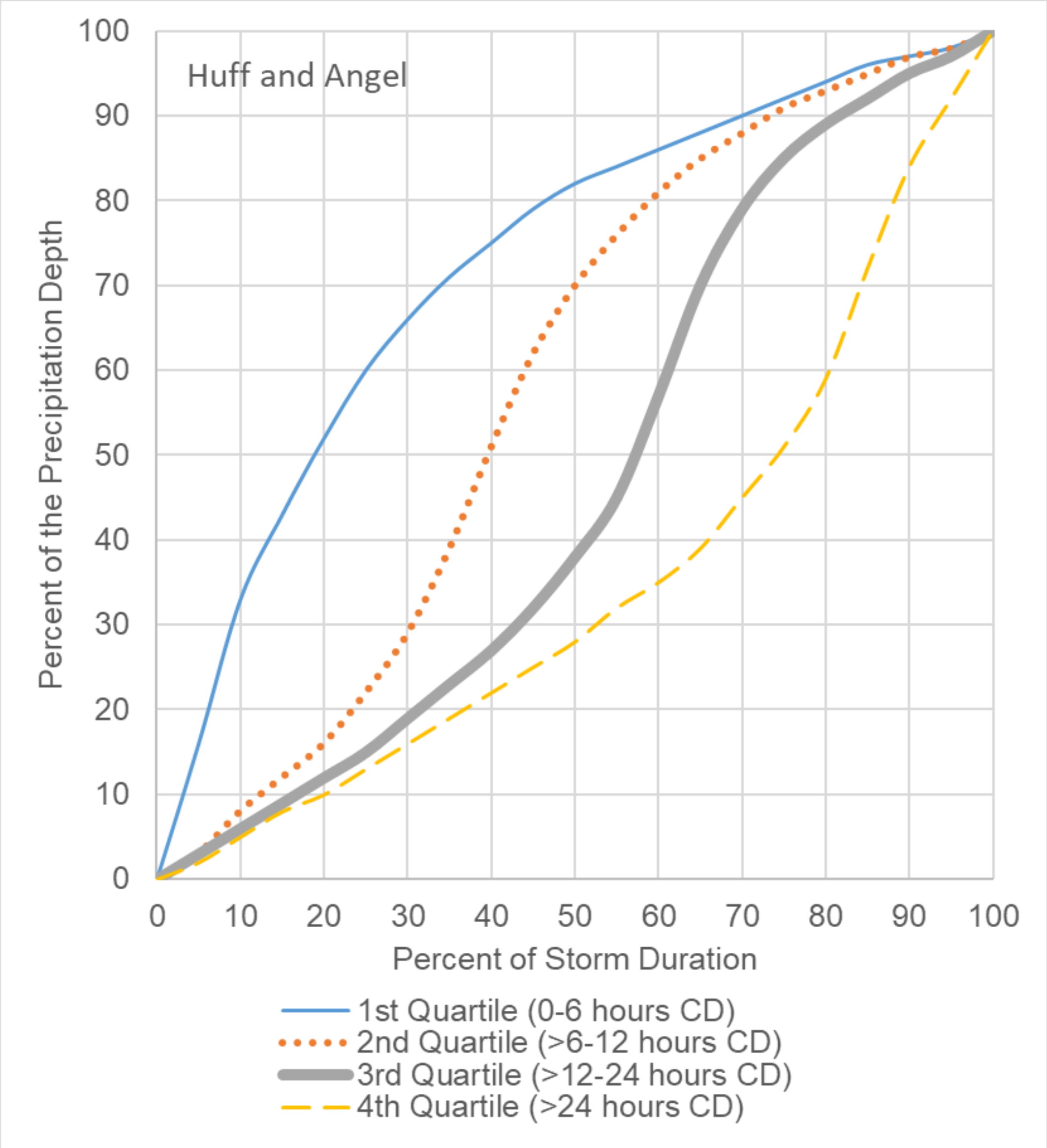

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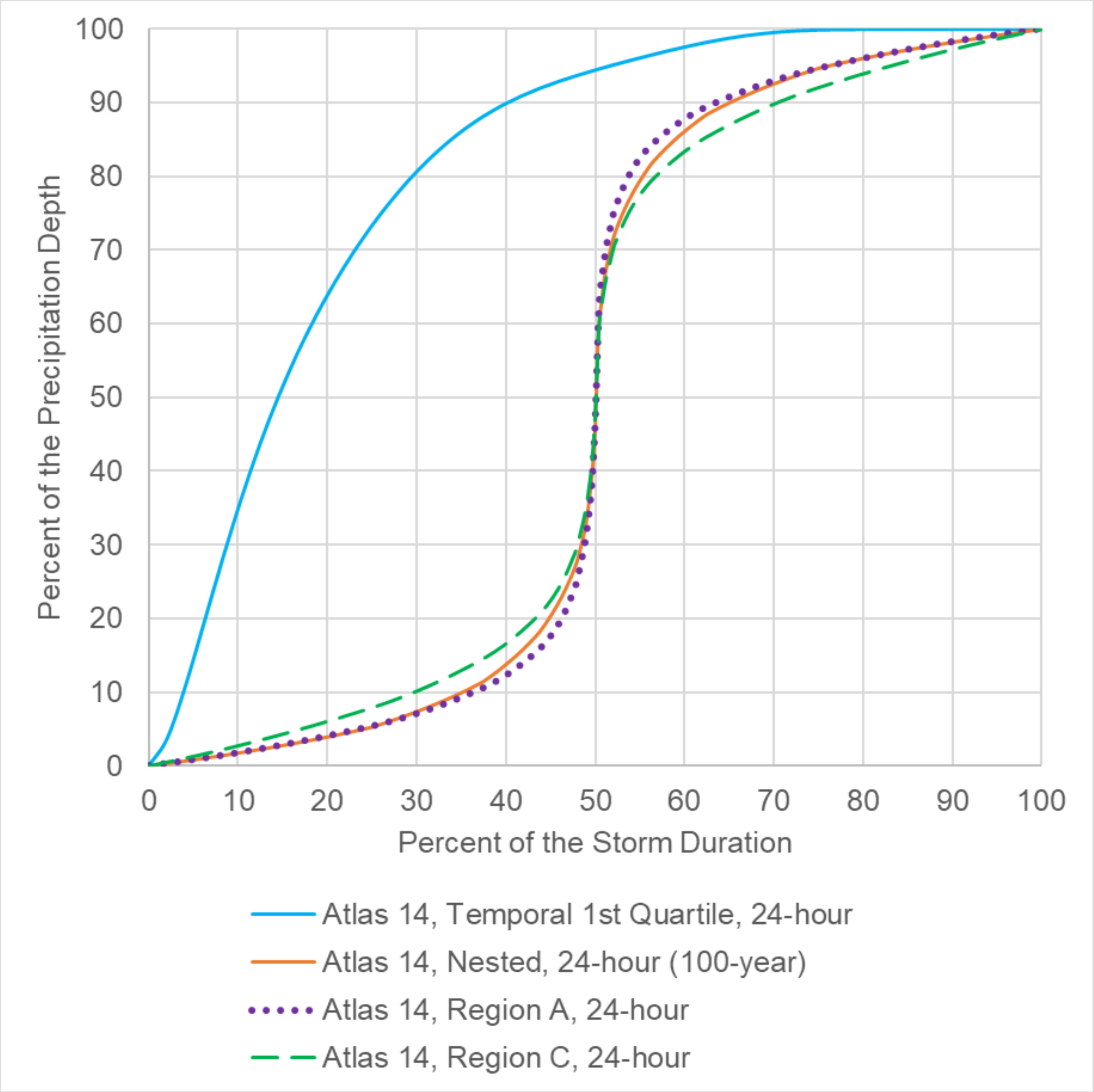

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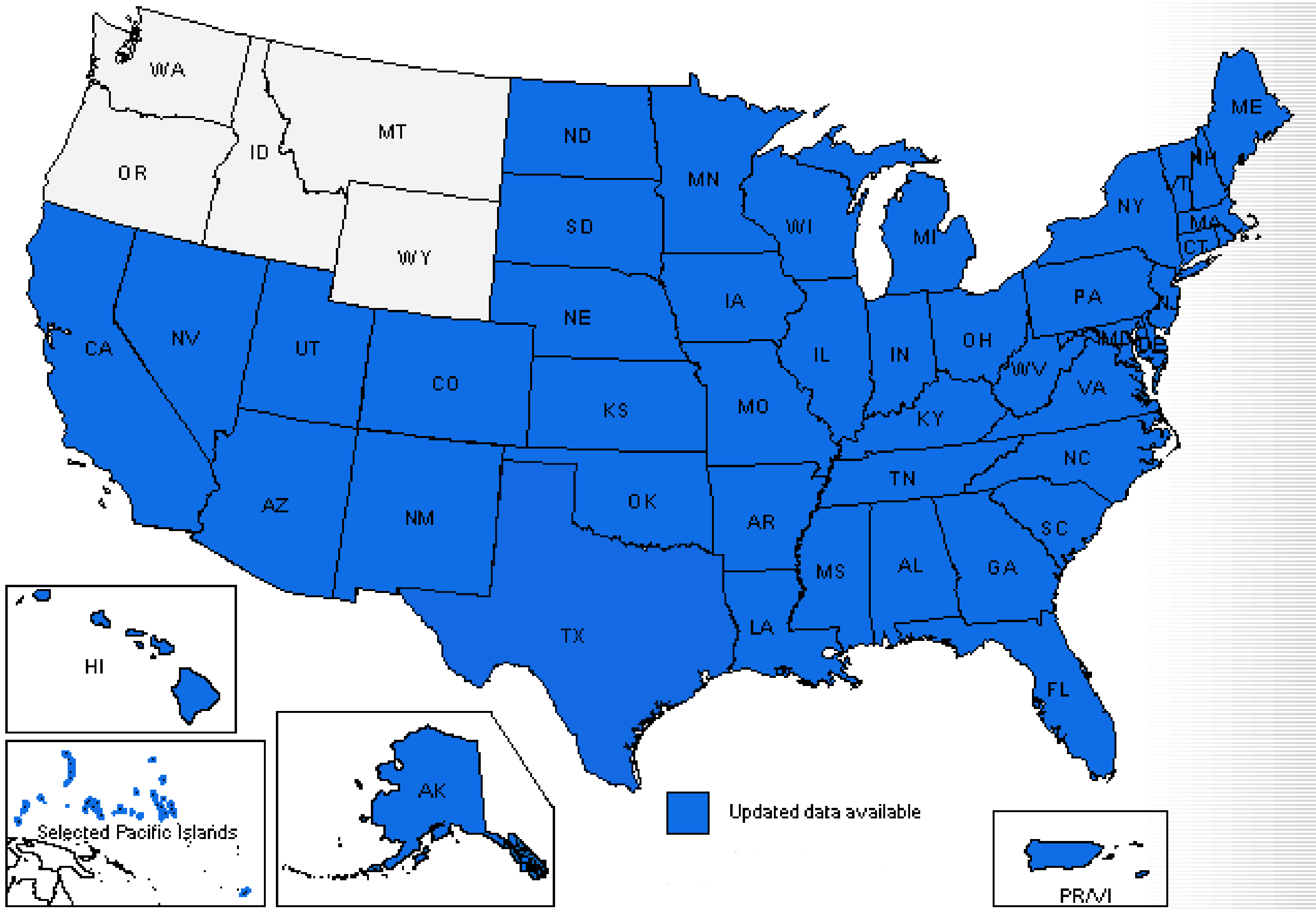

Atlas 14 data coverage (Precipitation Frequency Data Server)

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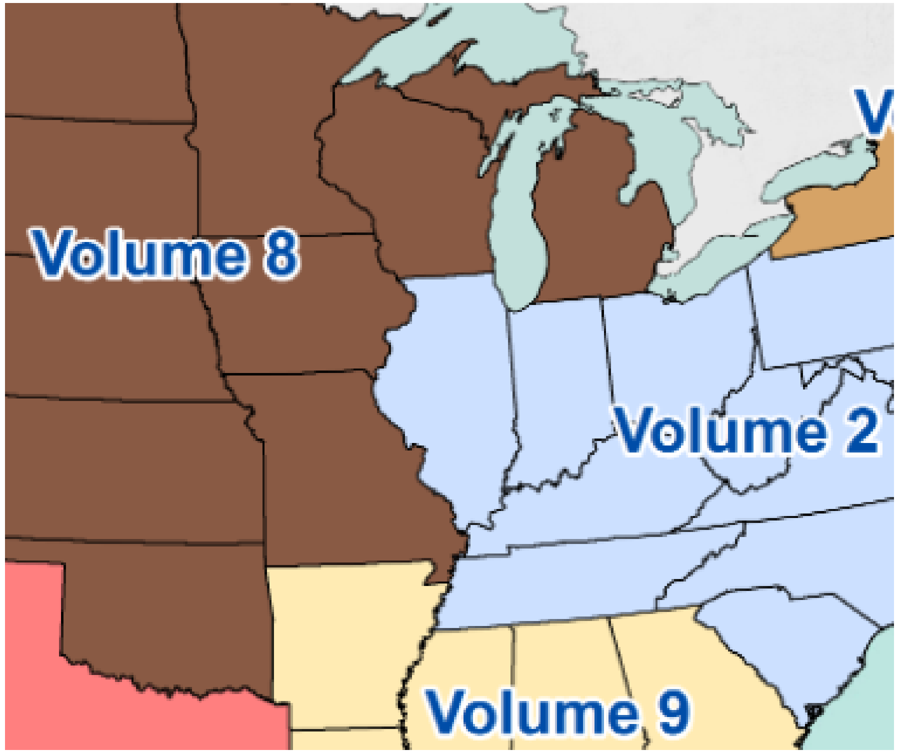

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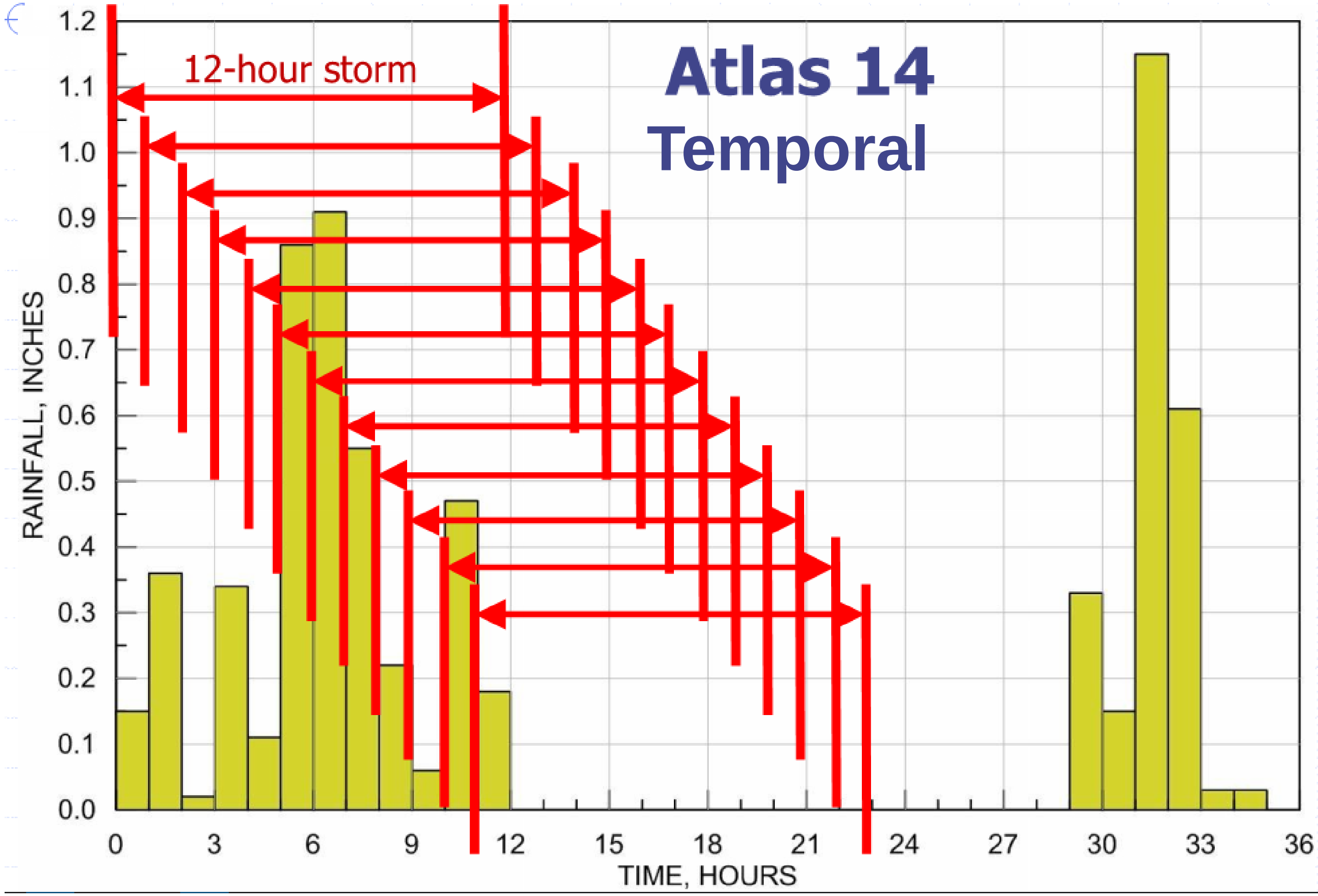

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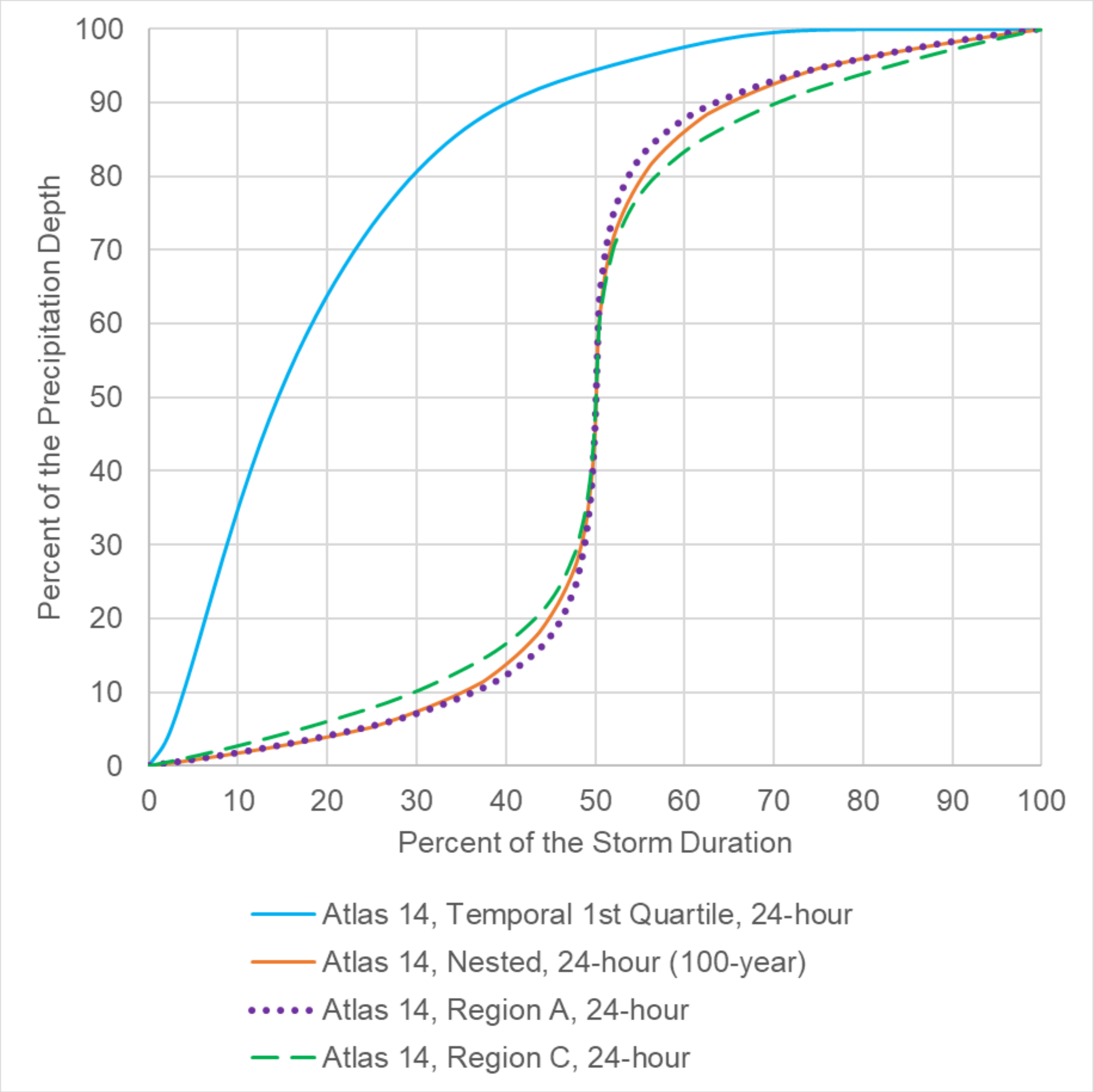

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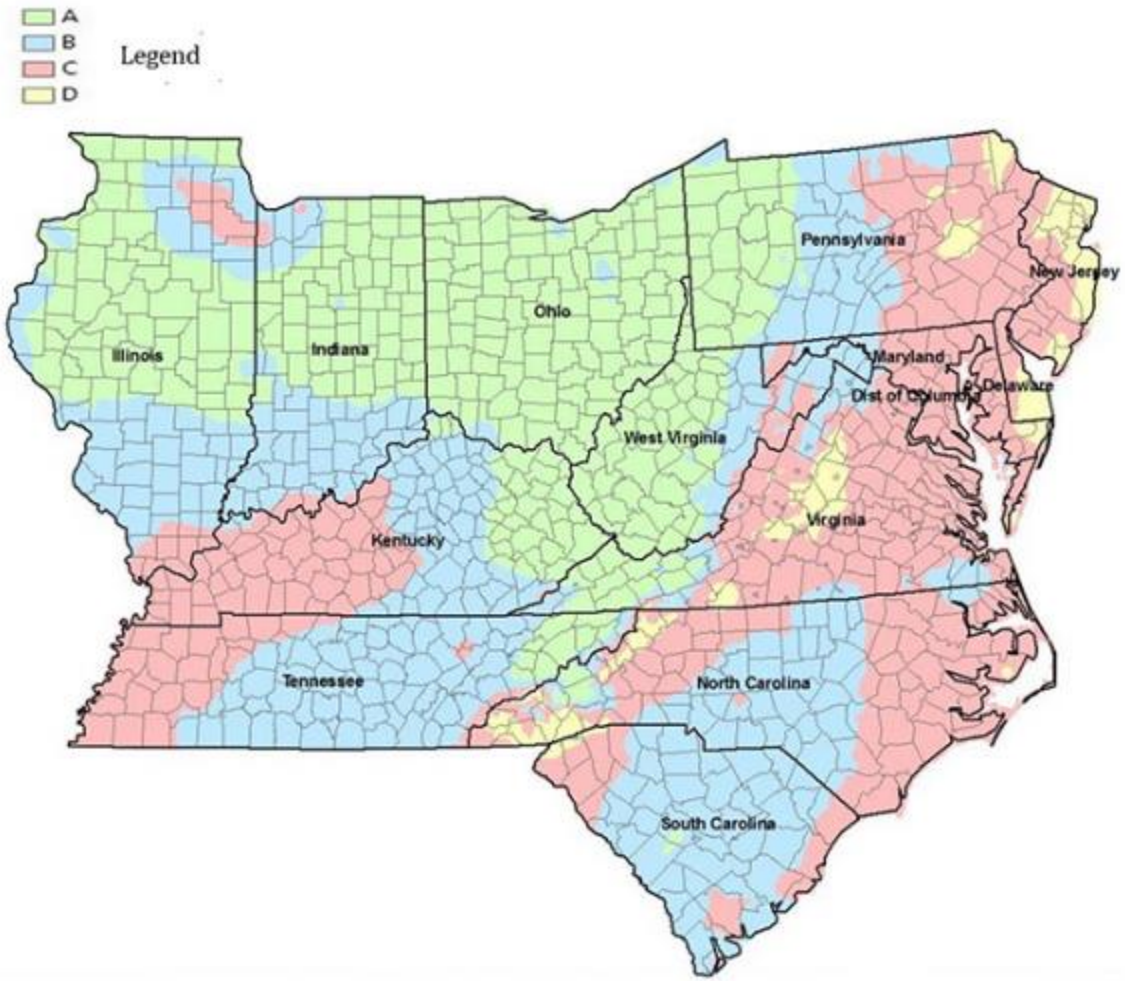
  - **Ohio Valley and Neighboring States (Regions A, B, C and D)**
    - **24-hour duration**

Figure 4-71: NOAA Atlas 14 Volume 2 Region, Rainfall Distribution Regions



Key takeaways

- Angel and Markus (Bulletin 75) aka “Huff”
  - Critical duration analysis is required. Storm definition lends accuracy to precipitation distributions.
- NOAA Atlas 14
  - Temporal (1st, 2nd, 3rd, 4th quartiles)
    - Method lacks guidance, clarity, and storm definition methods do not give the user confidence in applying the method
  - Nested (aka frequency storm)
    - Variable duration, often 24-hours
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Nested and Regions A, B, C, & D are similar distributions and produce similar results

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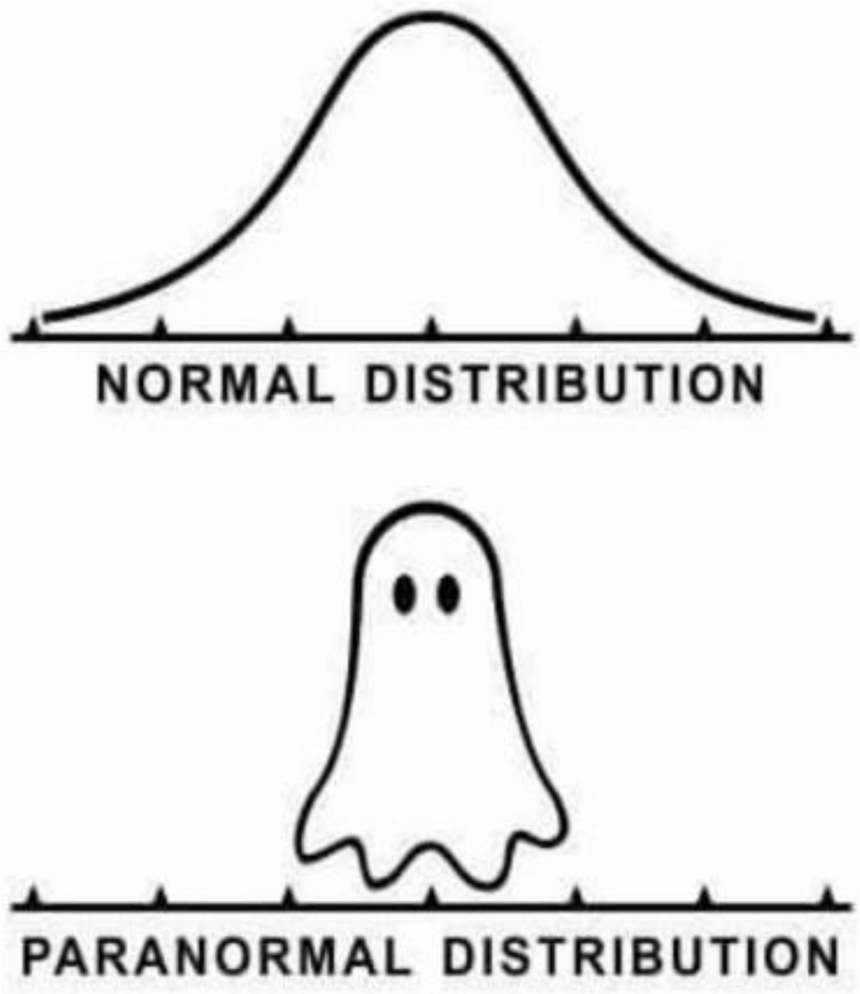
- Which distribution is the right one to use for floodplain mapping and infrastructure planning/design?



Distribution selection by precipitation gage data

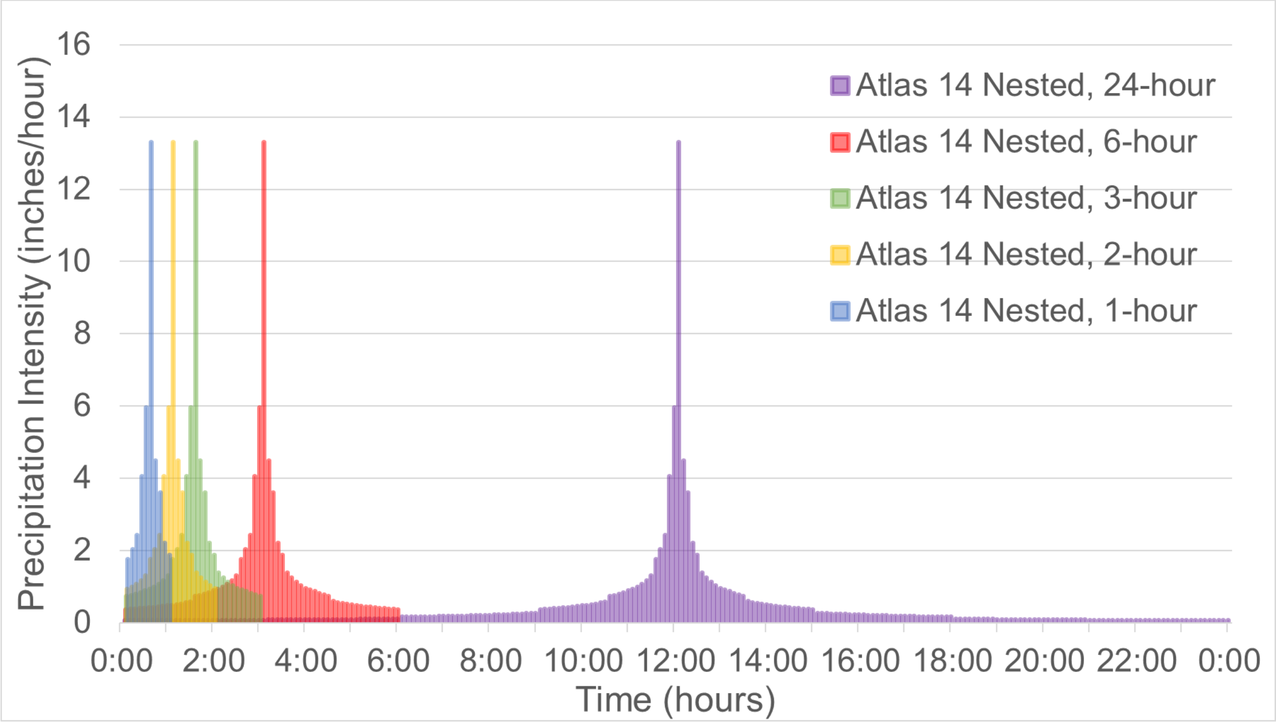
A low probability, high intensity, 1-hour event was present in the local precipitation records (depth/intensity 0.2% annual chance event recurrence interval)

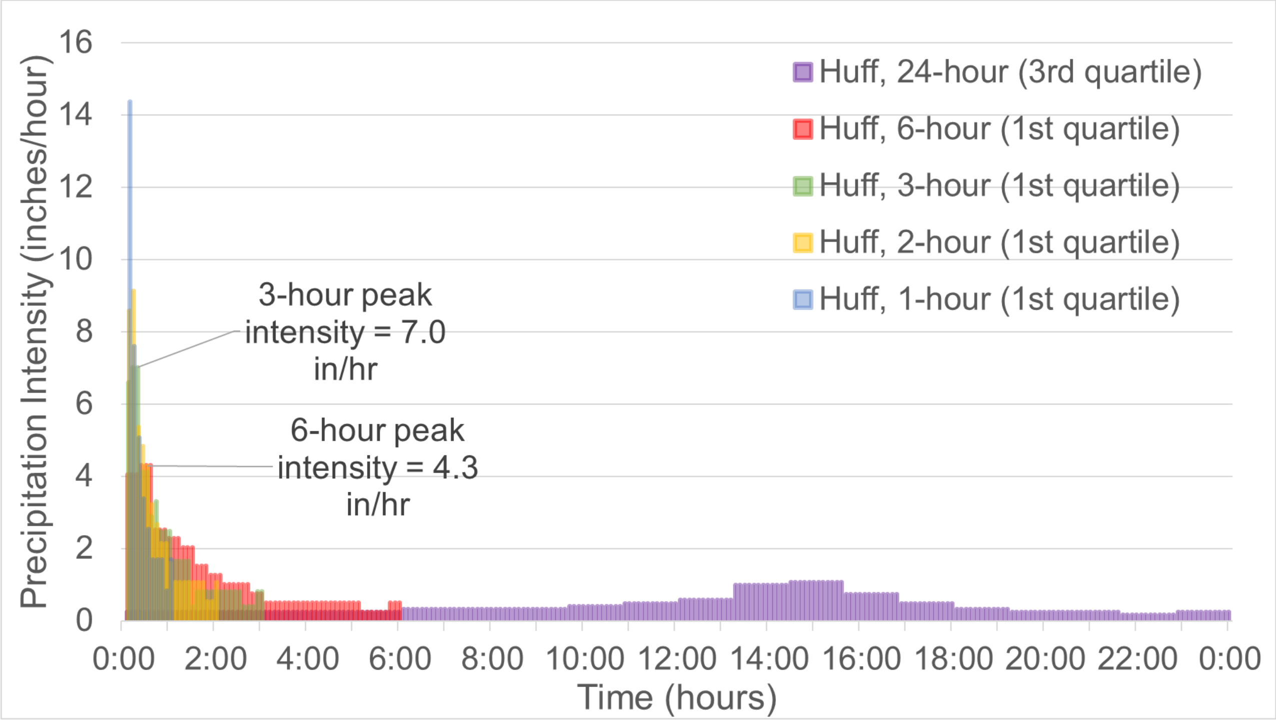
- Observed ~1-hour hyetograph	HEC-HMS model	**Estimate of observed discharge (cfs)**
- NOAA Atlas 14, 0.2%, 1-hour precip. depth - Atlas 14 Nested	HEC-HMS model	**Discharge (cfs)**
- NOAA Atlas 14, 0.2%, 1-hour precip. depth - Huff Critical Duration	HEC-HMS model	**Discharge (cfs)**

Comparison of Observed and Simulated storm events with 500-year (0.2% Annual Chance Event)											
	Observed Storm	Simulated Storms									
Precipitation Depth	Observed	Atlas 14, Volume 8 Precipitation Frequency Server									
Precipitation Distribution	Observed	Atlas 14 Nested Distribution					Illinois State Water Survey, Bulletin 75 Section 5, Huff Distribution				
Probability of storm occurrence	~500-year or 0.2% annual chance event	500-year or 0.2% annual chance event									
Storm Duration (hours)	**~1-hour**	**1-hour**	2-hour	3-hour	6-hour	24-hour	1-hour (1st quartile)	2-hour (1st quartile)	**3-hour (1st quartile)**	6-hour (1st quartile)	24-hour (3rd quartile)
Storm Depth (inches)	4.2 (1-hour), 4.9 (Total)	**4.2**	5.4	6.2	7.6	9.9	4.2	5.4	**6.2**	7.6	9.9
Maximum Precipitation Intensity - 5 minute increment (inch/hour)	*~7.8*	*14.6*	*14.6*	*14.6*	*14.6*	*14.6*	*13.9*	*9*	*7*	*4.3*	*1.1*
Maximum Precipitation Intensity - 1 hour increment (inch/hour)	*~4.2*	*4.2*	*4.2*	*4.2*	*4.2*	*4.2*	*4.2*	*4.4*	*4.3*	*3.5*	*1.1*
Peak flow rate (cfs)1	**4387**	**4081**	4891	5246	5708	6070	3730	4016	**4127**	3582	1812

1 - Same HEC-HMS model parameters used for all simulations (Loss, Transform), except distribution.

Huff Critical Duration method…basin response + storm duration = 1 peak flow





Atlas 14 Nested method…longer storm duration = higher peak flow

Key takeaways

- Key takeaways
  - Both the Atlas 14 Nested 1-hour and Huff critical duration produced reasonable estimates of peak flow for the observed 1-hour (0.2% depth/intensity) event.
  - Storm duration matters for the Atlas 14 Nested distribution. The 2-hour, 3-hour, 6-hour, 24-hour severely over-estimated peak flows
  - Use the Atlas 14 Region A, B, C and MSE1-6 distributions with caution. They requires a 24-hour storm duration, generating substantial peak flows.

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The Challenge – Different Peak Flow Estimates

Hydrologic Study	Hydrology Approach (Software)	1% Event Peak Flow (cfs)[1]
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Watershed Study	Rainfall-Runoff (proprietary)	4,110
Preliminary FIS – Recommended	Rainfall-Runoff (HEC-HMS)	1,341
HRG Study[2] (Huff Critical Duration)	Rainfall-Runoff (HEC-HMS)	2,227
HRG Study[2] (Atlas 14 Nested, 3-hour)	Rainfall-Runoff (HEC-HMS)	2,972
Revised Preliminary FIS (Atlas 14 Nested, 3-hour)	Rainfall-Runoff (HEC-HMS)	3,028
1 – Measured at outfall of watershed, with consistent tailwater assumptions 2 – Study was based on same HEC-HMS model and parameters as Preliminary FIS model		

HR Green recommended either the Huff critical duration, or the Atlas 14 Nested precipitation distribution with a duration that reflects the critical duration of the basin be used.

Ultimately, the Atlas 14 Nested, 3-hour distribution was the consensus choice.

Final recommendations

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- Consider basin size and response time when selecting Atlas-based precipitation distributions (temporal/Nested/Region A-B-C can produce unreasonable results in smaller/larger watersheds).
- Consider use of a Huff distribution, or at least a Huff critical duration study to select storm duration for Atlas-based distribution.
- Use gage or precipitation data from the watershed to inform selection of precipitation distribution.
- Do not arbitrarily select an Atlas-based precipitation distribution for your next Hydrology and Hydraulics study.
- Look for Atlas 15 data to be delivered sometime between 2023-2026

References

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Questions

Please contact Isaac Schrock, ischrock@hrgreen.com with any additional questions or comments.

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