# Use of Rainfall Distribution and Rainfall Statistics for Highway Projects

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# Outline of the Presentation

- *Introduction*
- *1. Design rainfall distribution*
- *2. Runoff coefficient C for different return periods*
- *3. NRCS dimensionless unit hydrographs*
- *4. Characteristics of rainfall parameters*
- *Summary*

# Acknowledgement

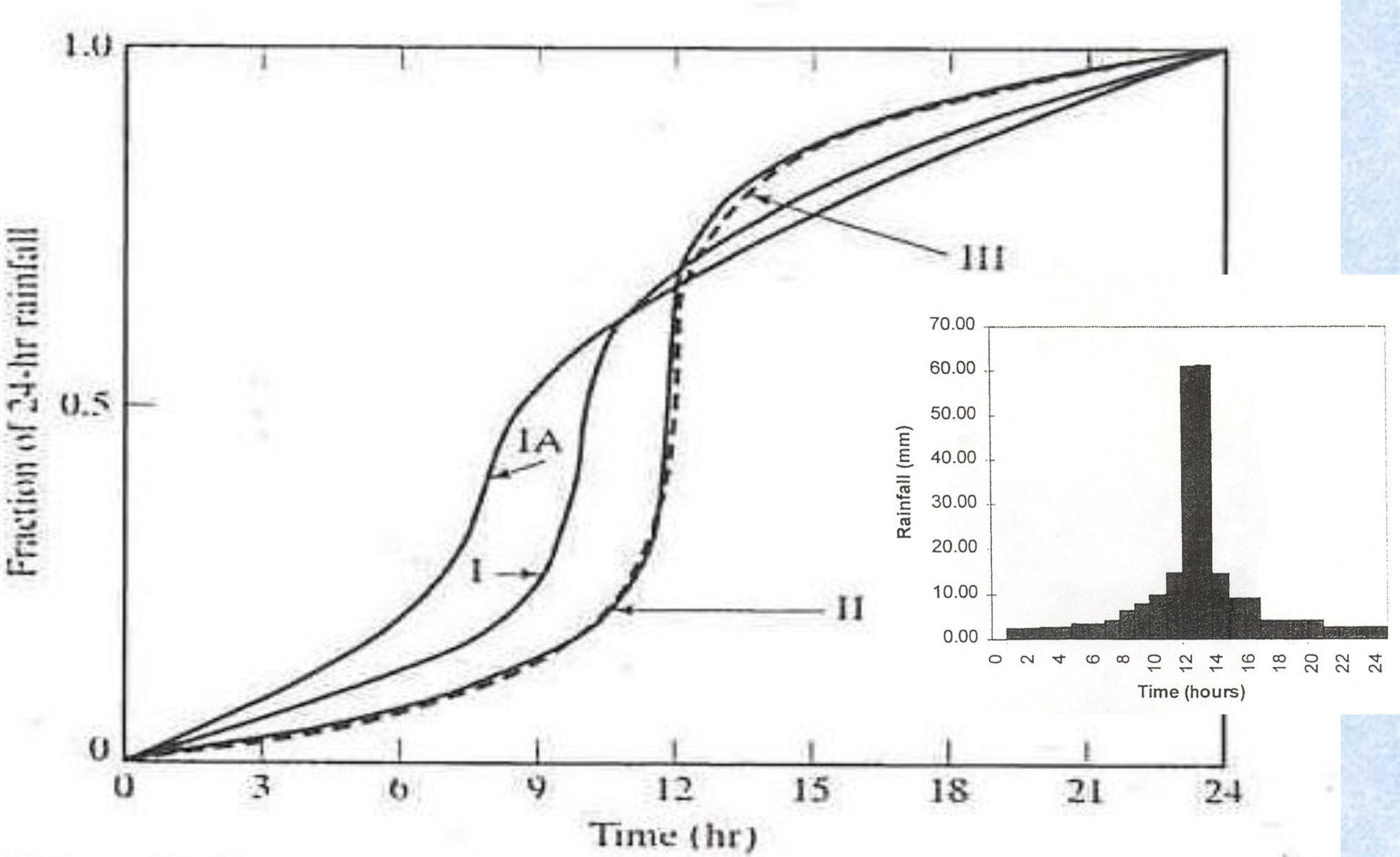
- Dr. David B. Thompson, formerly at Texas Tech University, currently as Director of Engineering, R.O. Anderson Engineering, Inc., Minden, Nevada.
- Dr. William H. Asquith, Research Hydrologist, USGS Texas Water Science Center.
- Dr. Theodore G. Cleveland, Associate Professor, Department of Civil and Environmental Engineering, Texas Tech University, Lubbock, Texas (formerly at University of Houston).
- Projects funded by TxDOT

# 1. Design Rainfall Distribution

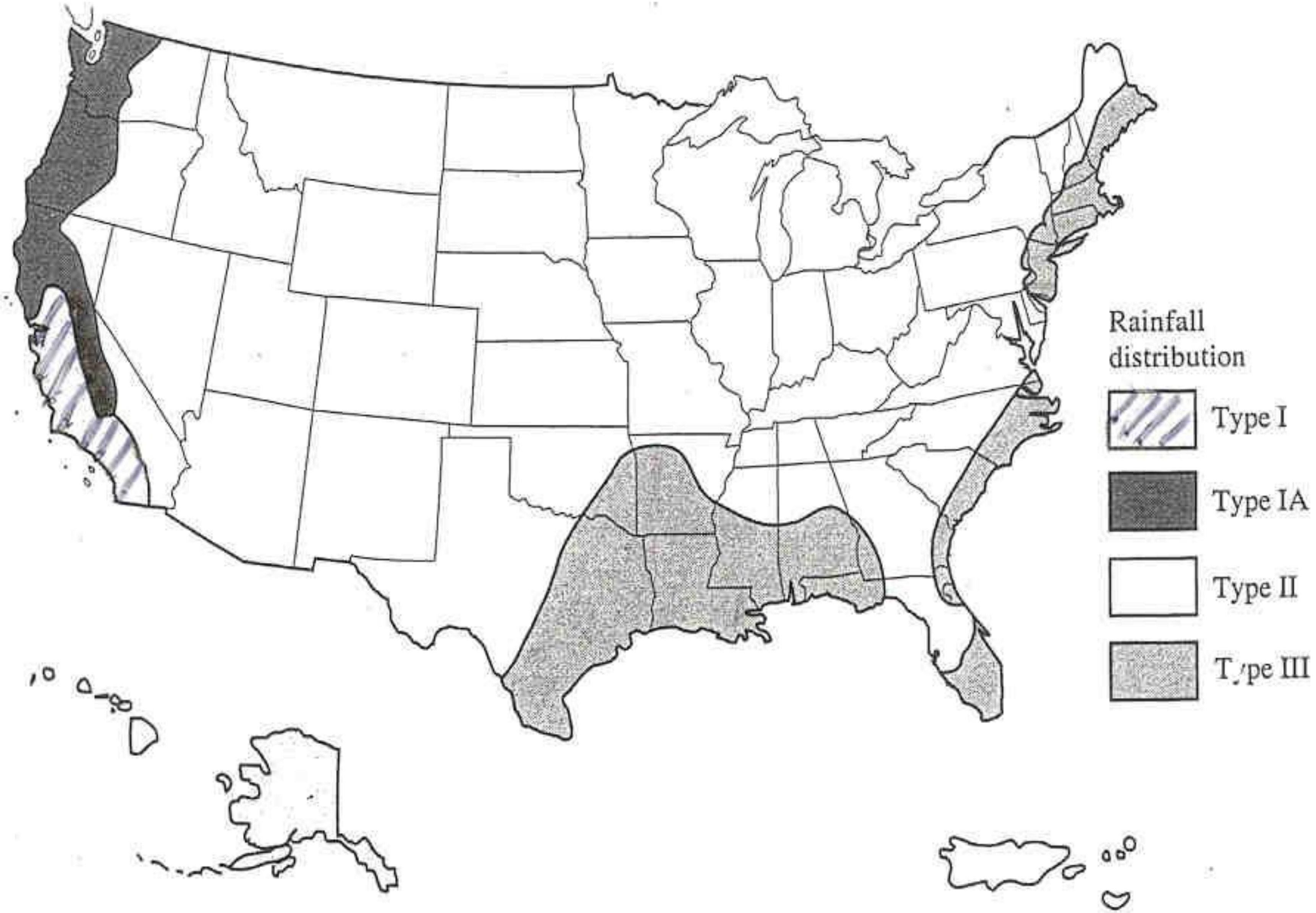
- Design discharges for highway drainage facilities are typically estimated by three methods: (1) rational method ($Q_p = CiA$), (2) unit hydrograph method – rainfall-runoff modeling, and (3) regression equations

- Design rainfall depth and distribution are necessary for us to model runoff discharge hydrograph used for routing through drainage system.

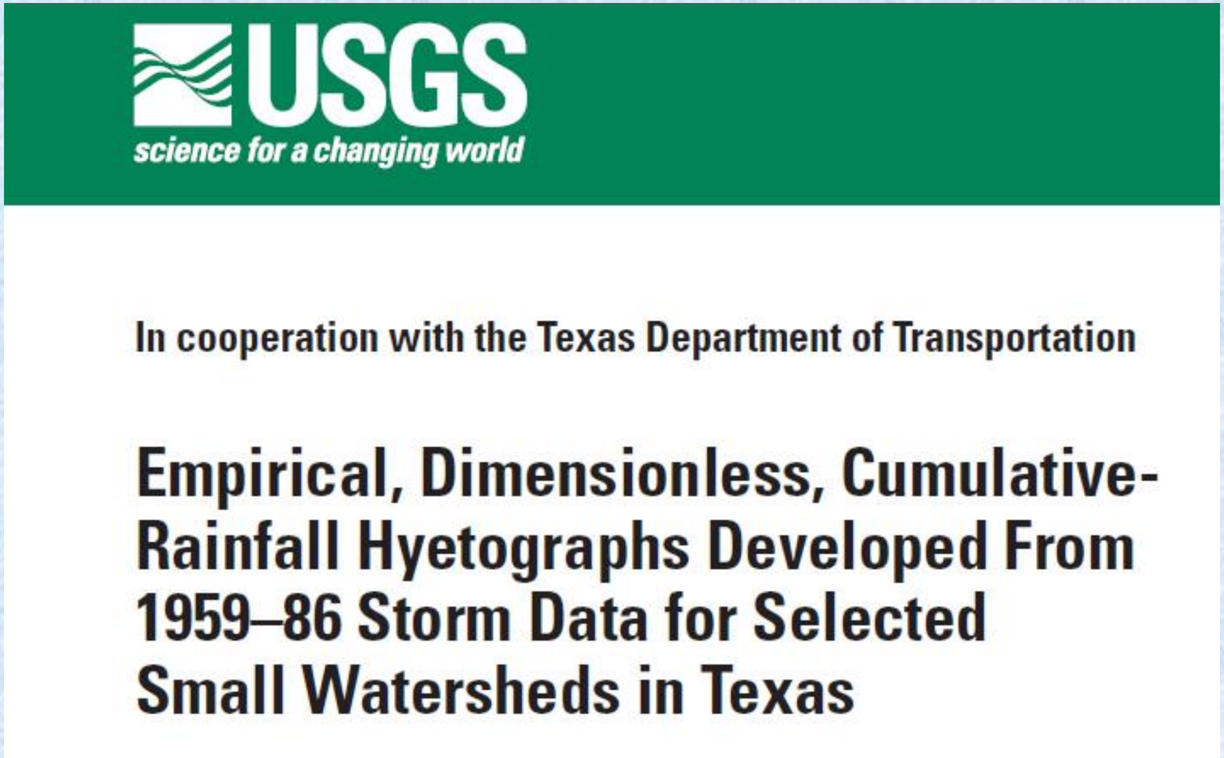
# NRCS 24 Design Rainfall Distributions



# Zones for NRCS 24-hr rainfall distributions (Type I, IA, II)



- Use 1,660 runoff-producing storms from 1959 to 1986 in Texas
- Normalized storms by duration and total rainfall depth, grouped storms by durations and quartiles where peak rainfall intensity occurred.
- *For a 12-hour or less storm duration, approximately 49 percent of the storms are first quartile.*



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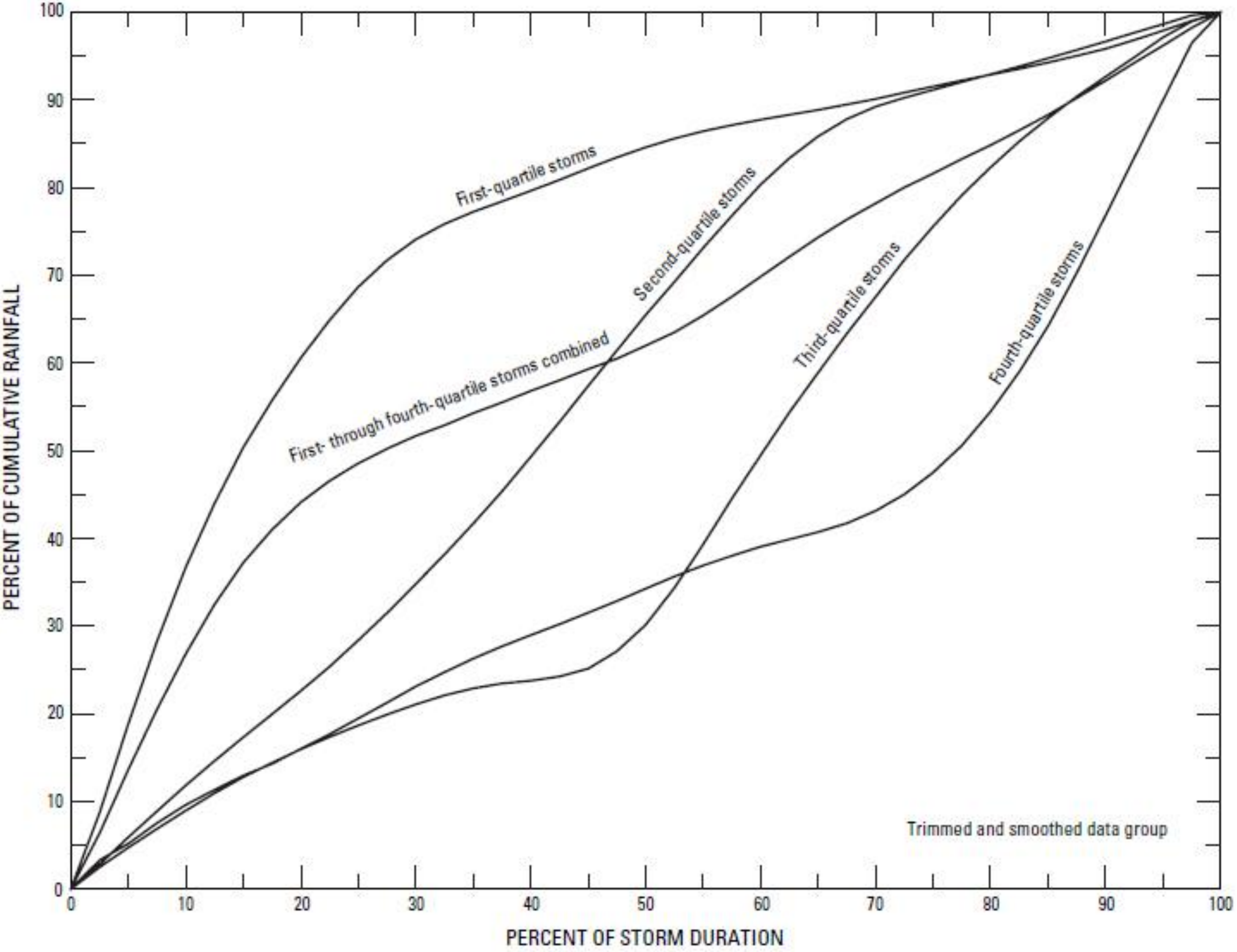
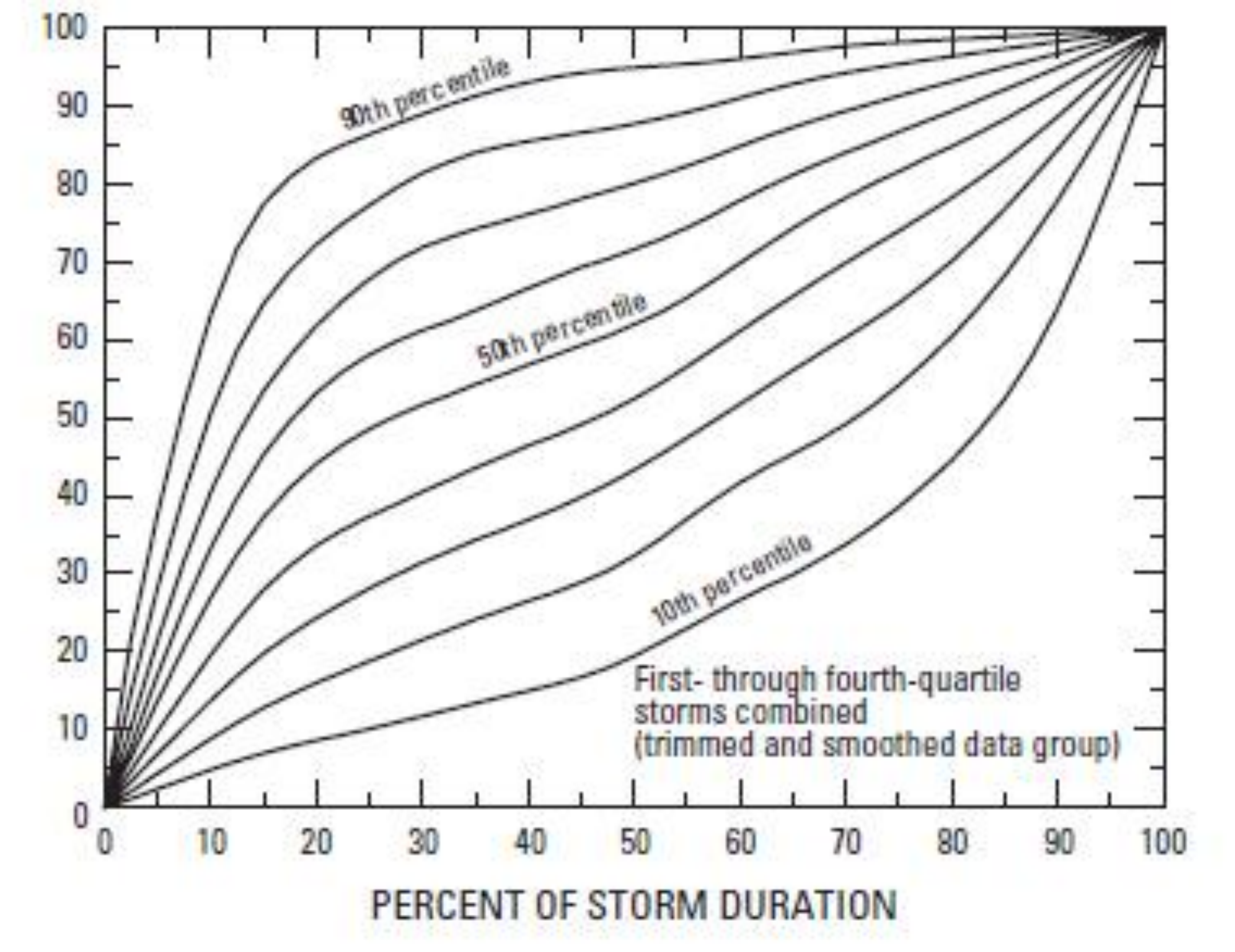
**Empirical, Dimensionless, Cumulative-Rainfall Hyetographs Developed From 1959–86 Storm Data for Selected Small Watersheds in Texas**

Scientific Investigation Report 2004-5075

By Tara Williams-Sether, William H. Asquith, David B. Thompson, Theodore G. Cleveland, and Xing Fang


PERCENT OF CUMULATIVE RAINFALL
PERCENT OF STORM DURATION
0
10
20
30
40
50
60
70
80
90
100
First-quartile storms
Second-quartile storms
Third-quartile storms
Fourth-quartile storms
First- through fourth-quartile storms combined
Trimmed and smoothed data group

# Dimensionless Rainfall Distribution for Different Percentiles



# 2. Peak Discharge for Small Drainage Areas

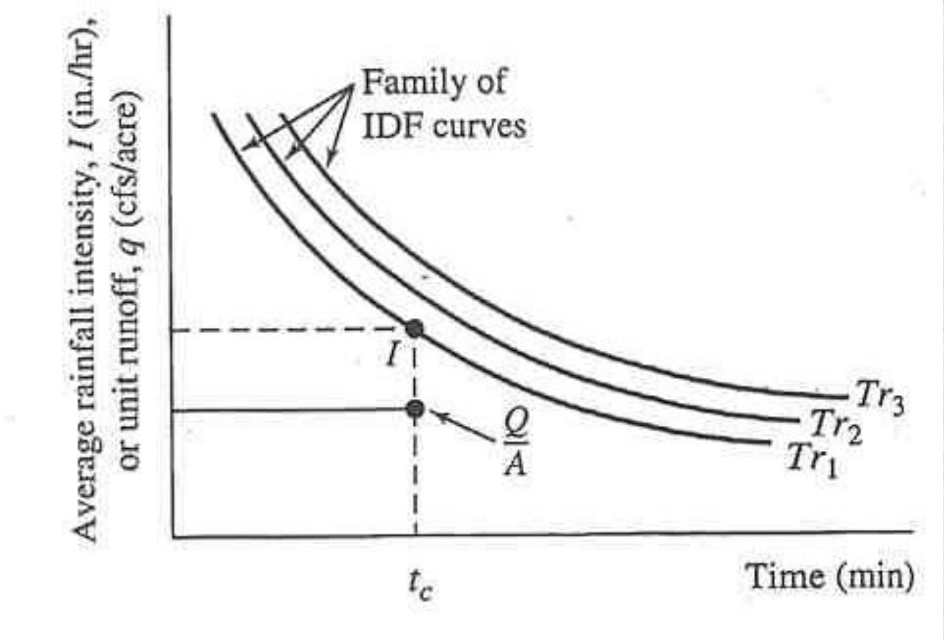
**Rational Method:** $Q_p = C\,i\,A$ ***(Emil Kuichling, 1889)***

**$Q_p$ = Peak runoff rate (cfs)**

**$C$ = runoff coefficient (dimensionless)**

**$i$ = average rainfall intensity (in/hr) for a storm with a duration equal to a critical period of time – $t_c$ (time of concentration)**

**A = drainage area (acres)**



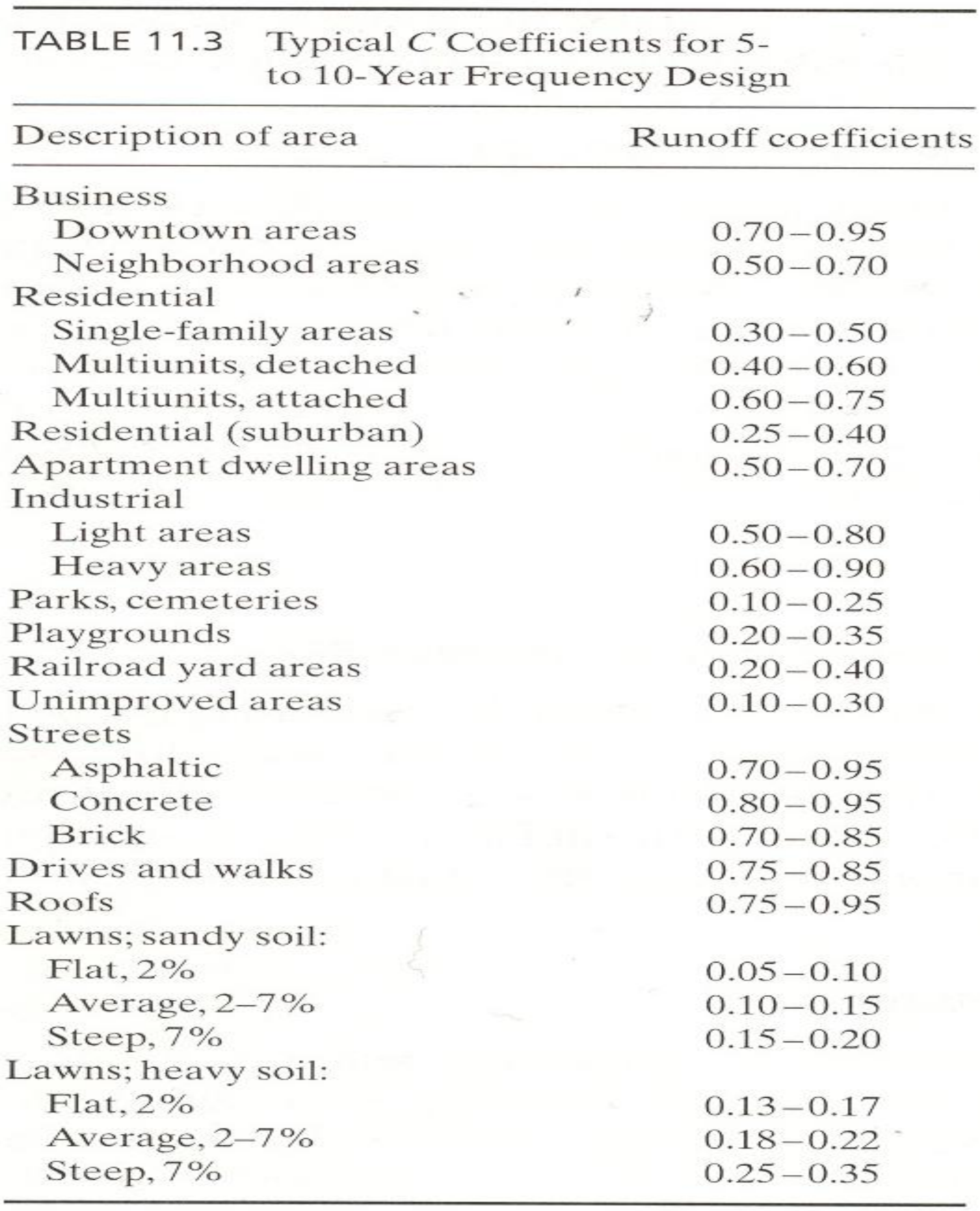


TABLE 11.3 Typical *C* Coefficients for 5- to 10-Year Frequency Design

| Description of area | Runoff coefficients |
|---|---|
| Business | |
| Downtown areas | 0.70–0.95 |
| Neighborhood areas | 0.50–0.70 |
| Residential | |
| Single-family areas | 0.30–0.50 |
| Multiunits, detached | 0.40–0.60 |
| Multiunits, attached | 0.60–0.75 |
| Residential (suburban) | 0.25–0.40 |
| Apartment dwelling areas | 0.50–0.70 |
| Industrial | |
| Light areas | 0.50–0.80 |
| Heavy areas | 0.60–0.90 |
| Parks, cemeteries | 0.10–0.25 |
| Playgrounds | 0.20–0.35 |
| Railroad yard areas | 0.20–0.40 |
| Unimproved areas | 0.10–0.30 |
| Streets | |
| Asphaltic | 0.70–0.95 |
| Concrete | 0.80–0.95 |
| Brick | 0.70–0.85 |
| Drives and walks | 0.75–0.85 |
| Roofs | 0.75–0.95 |
| Lawns; sandy soil: | |
| Flat, 2% | 0.05–0.10 |
| Average, 2–7% | 0.10–0.15 |
| Steep, 7% | 0.15–0.20 |
| Lawns; heavy soil: | |
| Flat, 2% | 0.13–0.17 |
| Average, 2–7% | 0.18–0.22 |
| Steep, 7% | 0.25–0.35 |

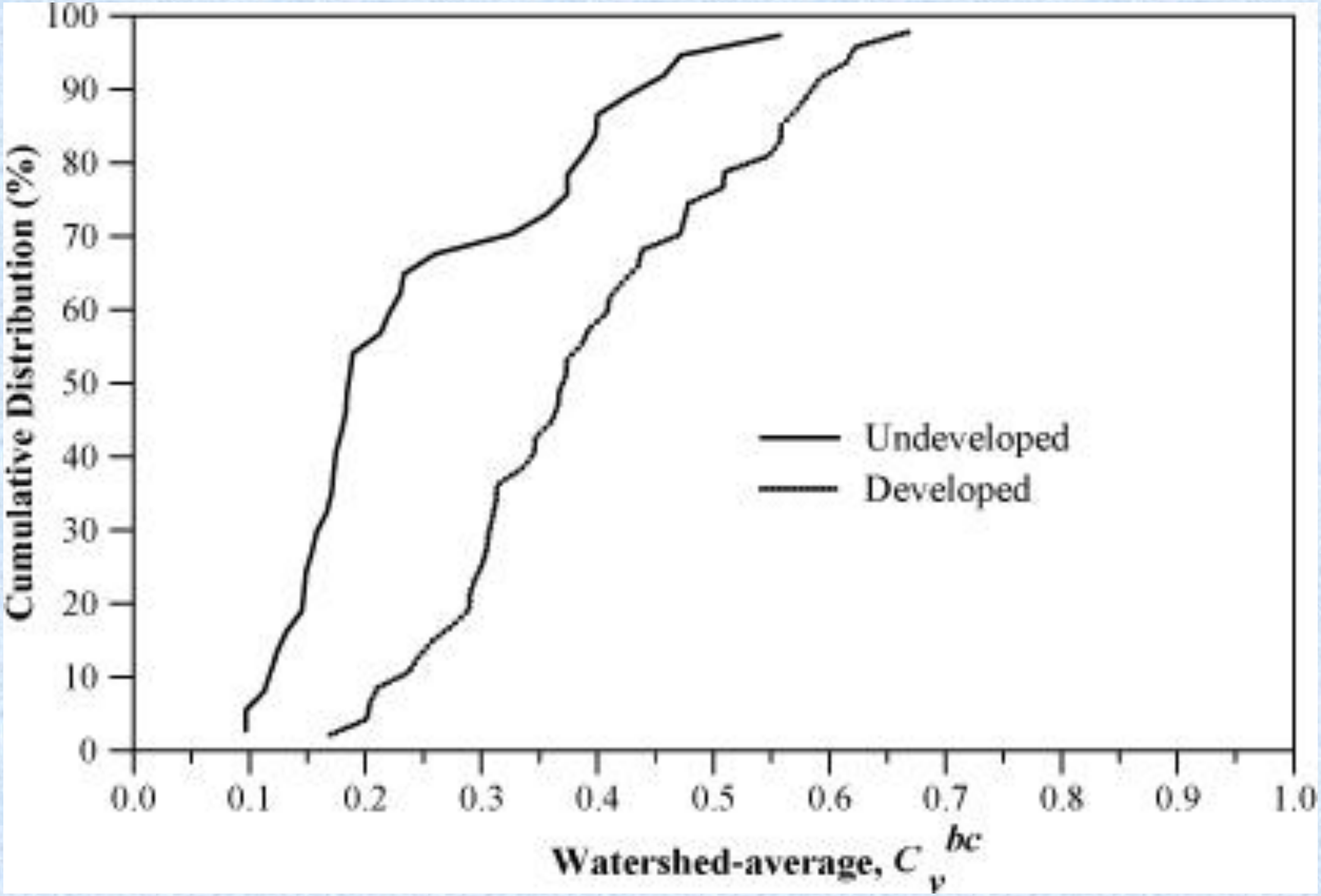
**Local agency may set *C* for different land use types based on Table 11.3 or other references**

- The source of these published *C* values can be traced back to the 1960 sanitary and storm sewer design manual produced by a joint committee of the American Society of Civil Engineers (ASCE) and the Water Pollution Control Federation (WPCF).

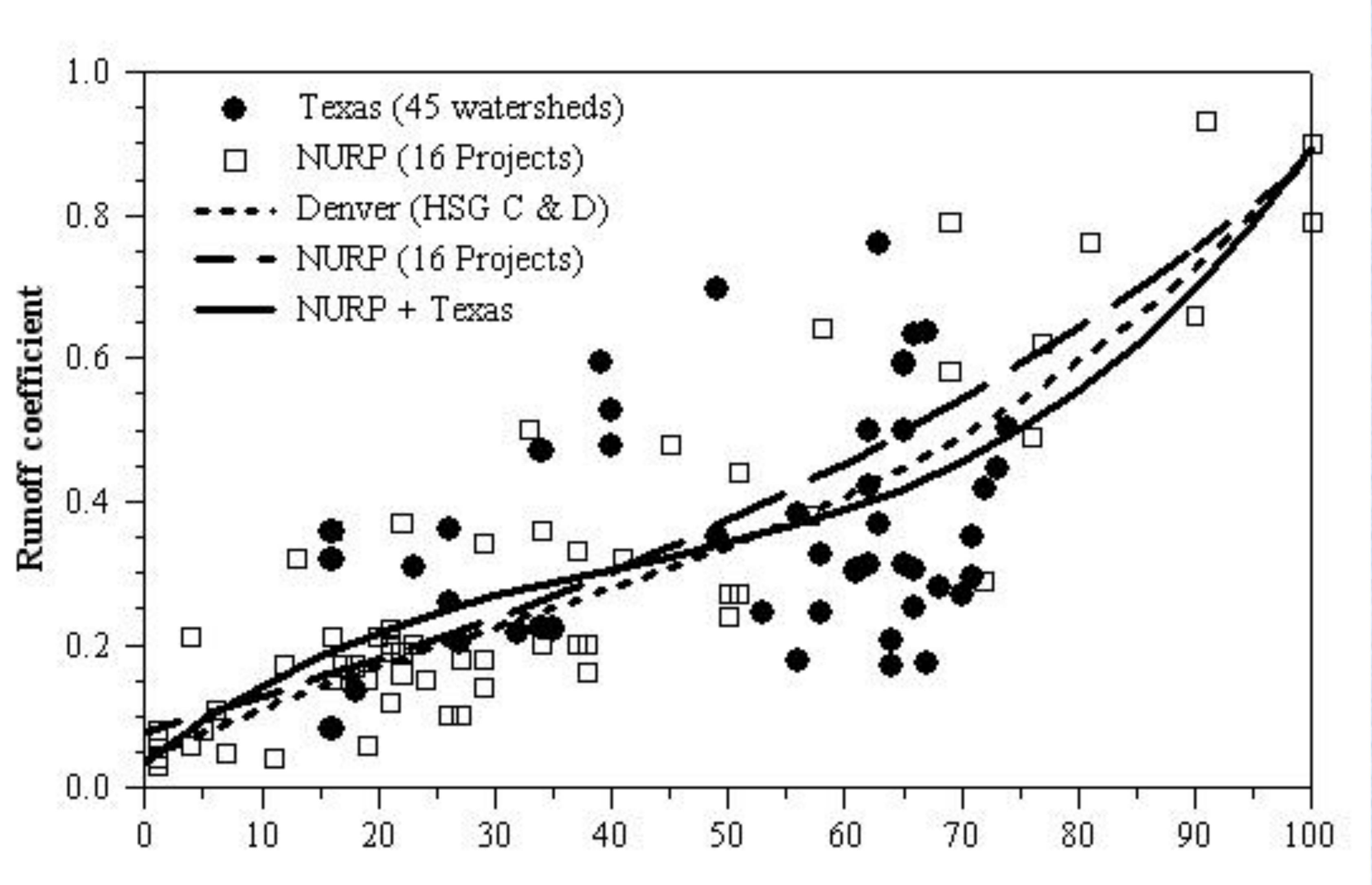
- Those values of runoff coefficients were obtained from a survey, “71 returns of an extensive questionnaire submitted to 380 public and private organization throughout the United States”. They are based on the decades of professional practice experience of the applications of the rational formula in runoff determination for storm-sewer design (ASCE and WPCF 1960).

- ASCE and WPCF (1960) manual did not provide justification for the *C* values selected using any observed rainfall and runoff data but Mr. Kuichling did in his original study (Kuichling 1889).

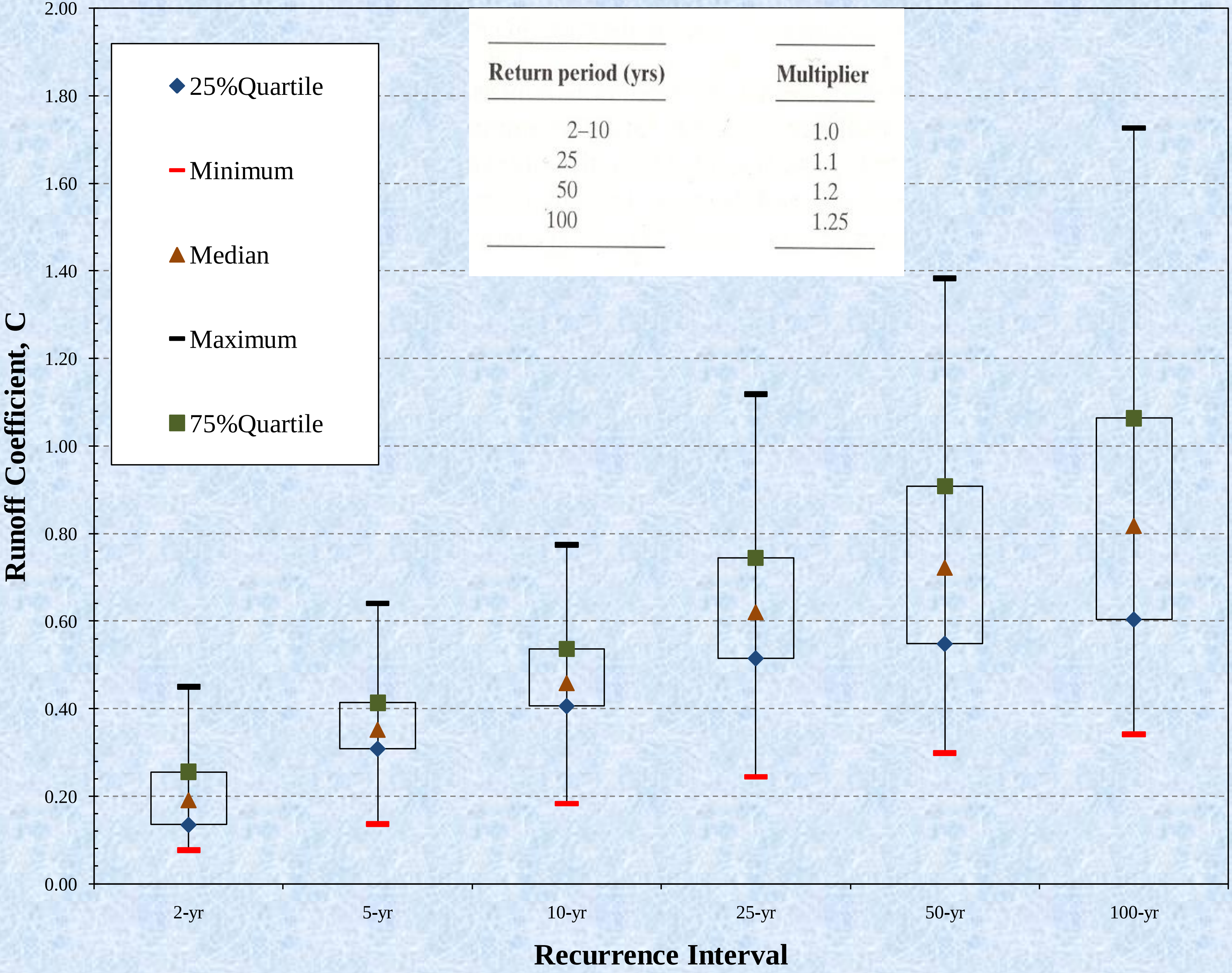
# Runoff Coefficients for 90 Texas Watersheds Developed from Rainfall-runoff Data



# Relation with Percent Impervious Area

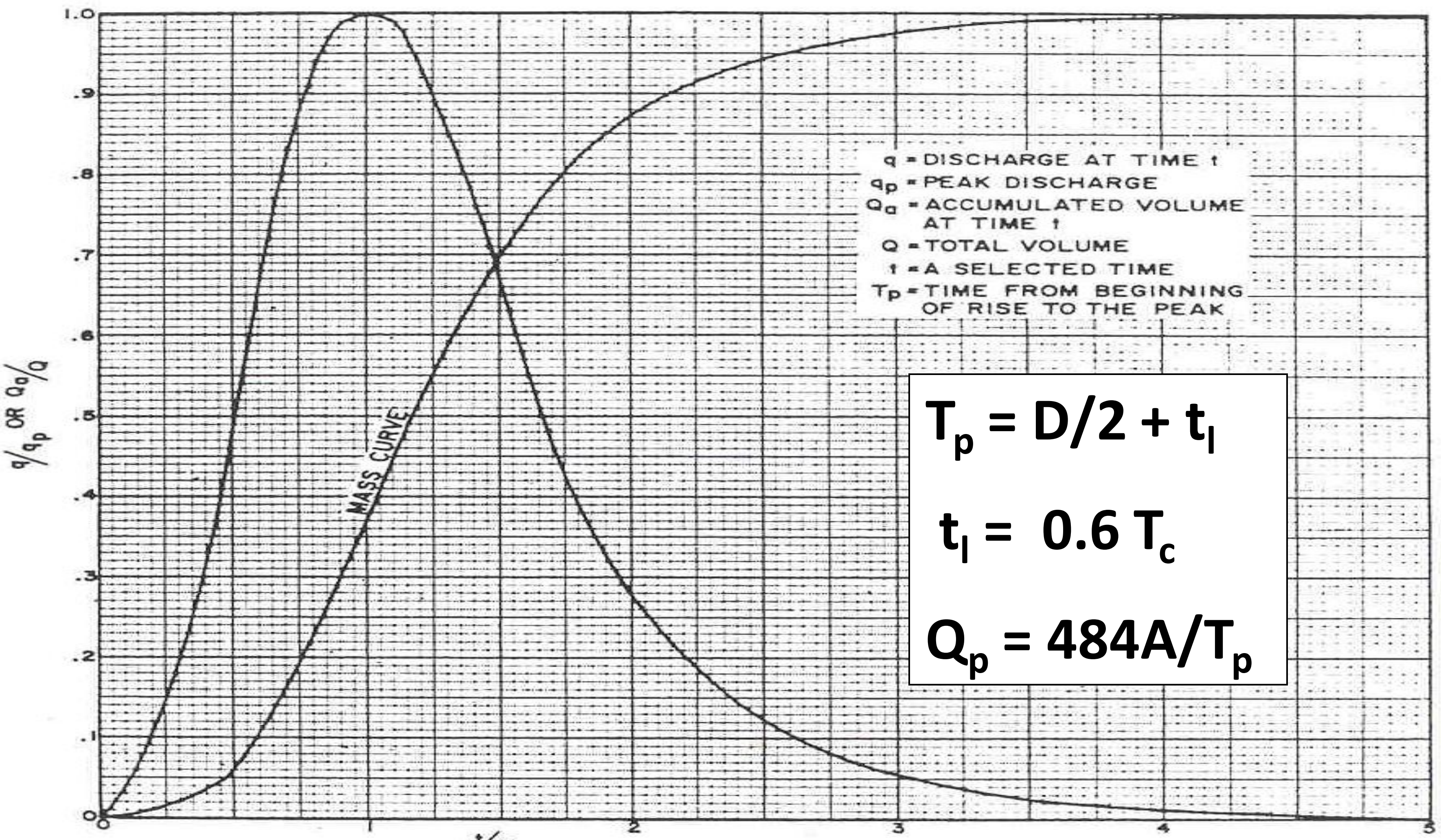


**Percent Impervious Area**



| Return period (yrs) | Multiplier |
|---|---|
| 2–10 | 1.0 |
| 25 | 1.1 |
| 50 | 1.2 |
| 100 | 1.25 |

# 3. Dimensionless NRCS Unit Hydrograph



q = DISCHARGE AT TIME t
$q_p$ = PEAK DISCHARGE
$Q_a$ = ACCUMULATED VOLUME AT TIME t
Q = TOTAL VOLUME
t = A SELECTED TIME
$T_p$ = TIME FROM BEGINNING OF RISE TO THE PEAK

$T_p$ = D/2 + $t_l$

$t_l$ = 0.6 $T_c$

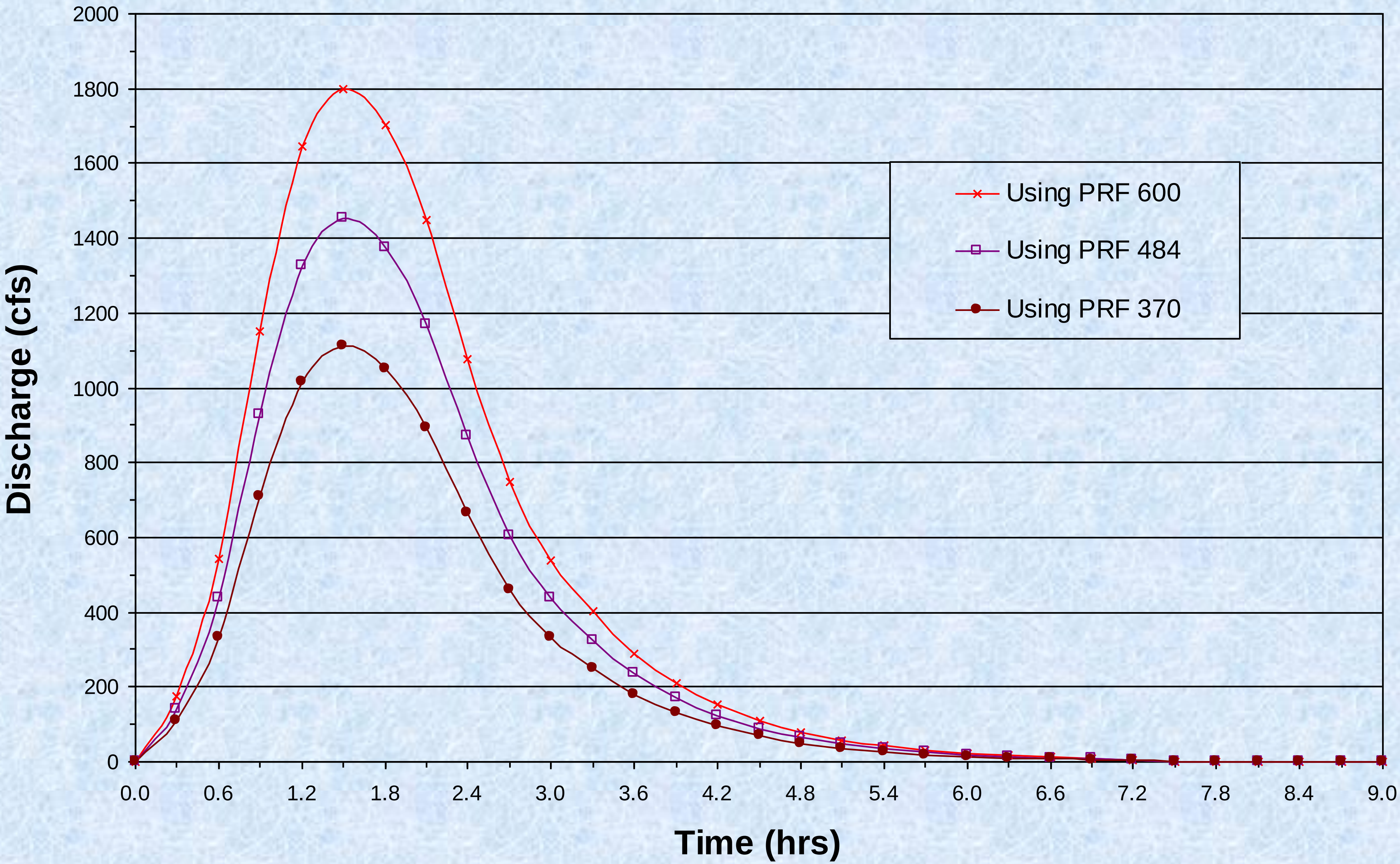
$Q_p$ = 484A/$T_p$

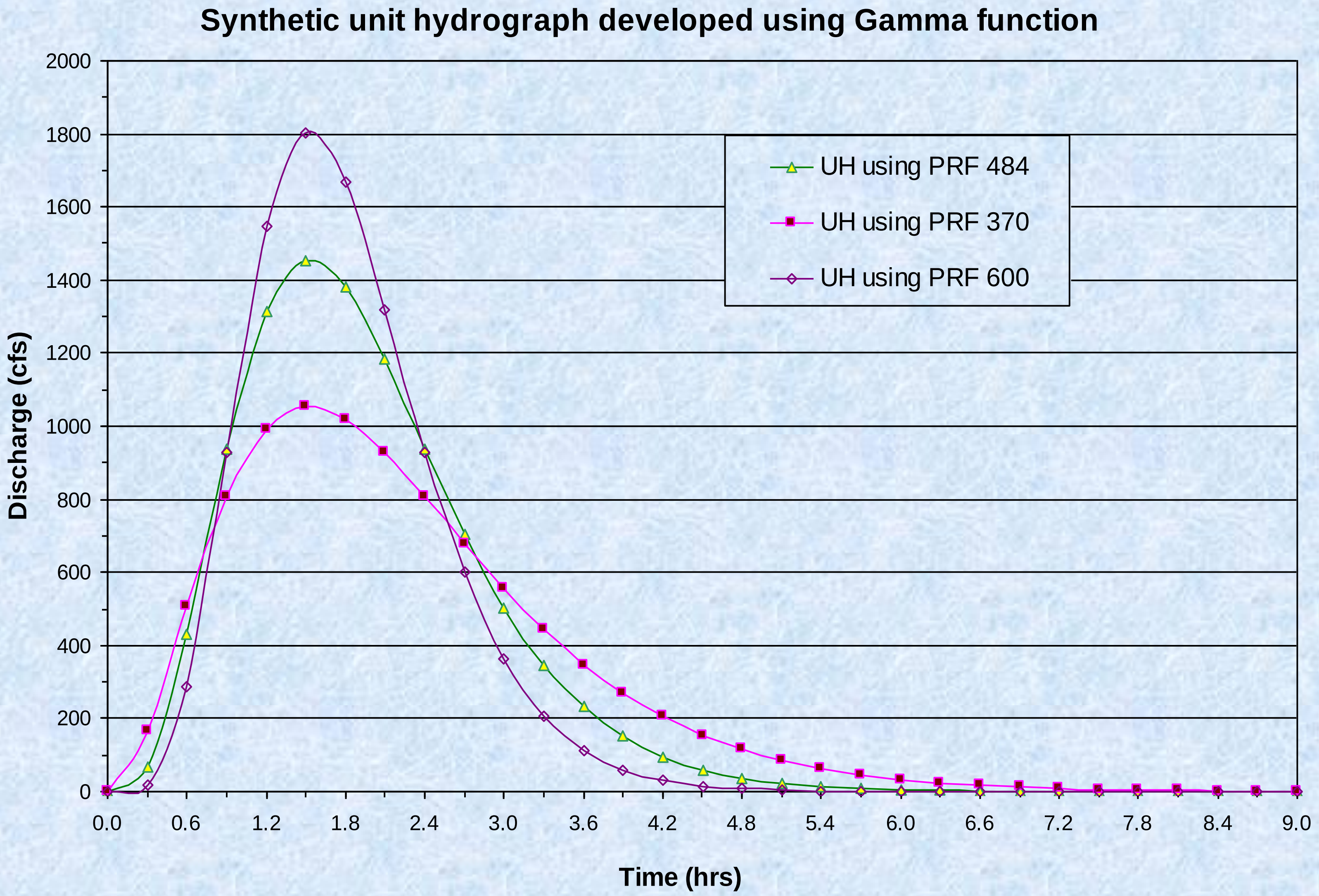
Dimensionless unit hydrograph and mass curve

# Peak Rate Factor

- $Q_p$ = PRF*A/$t_p$
- Standard PRF is 484
- Statement on page 291 " .. The resulting coefficient in Eq. 9.32 ranges from 600 for steep mountainous conditions to 300 for flat swampy conditions." - Be careful for application.
- When you use different PRF, peak discharge will be different.
- Do you need change the dimensionless unit hydrograph when you use different PRF?

# Synthetic unit hydrographs developed by NRCS procedures with PRF of 370, 484 and 600 with same time of concentration.

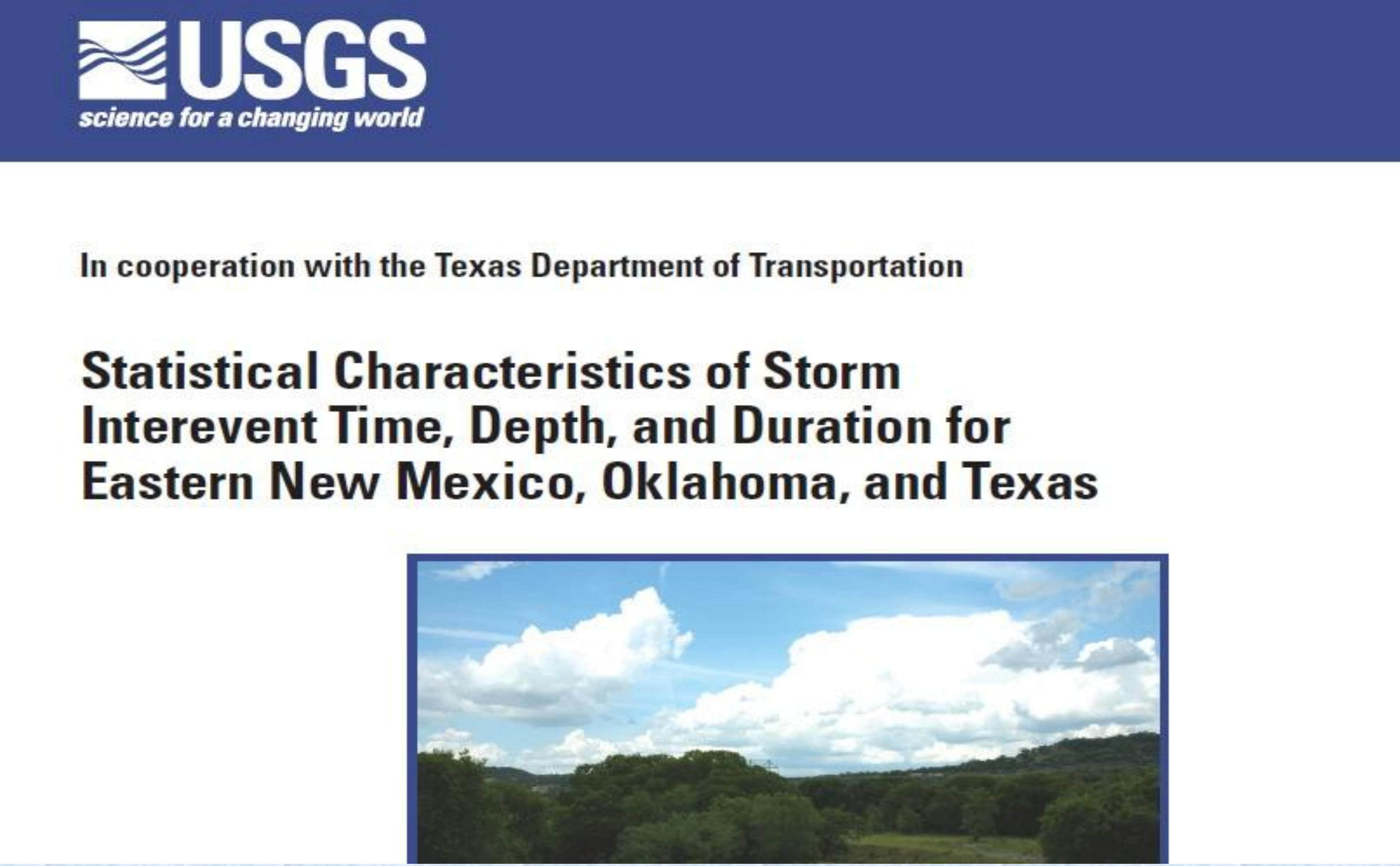




$$Q(t)/Q_p = (t/T_p)^{\alpha}\, e^{(1-t/T_p)\alpha}$$

# Texas Gamma Unit Hydrographs

- The regression equations for $T_p$ were developed for watersheds for drainage area less than 10 mile$^2$ and greater than 10 mile$^2$, respectively.
- $T_p = 2.65A^{0.134}L^{-0.089}S^{-0.317}$ for A < 10 mile$^2$
- $T_p = 34.82A^{0.431}L^{-0.491}S^{-0.970}$ for A >10 mile$^2$
- $Q_p = 46.99A^{0.910}L^{-0.219}S^{0.707}$ for all areas
- Shape factor $\alpha$ can be computed from $T_p$ and $Q_p$.
- Fang, X., Prakash, K., Cleveland, T. G., Thompson, D. B., and Pradhan, P. (2005). "Revisit of NRCS unit hydrograph procedures."



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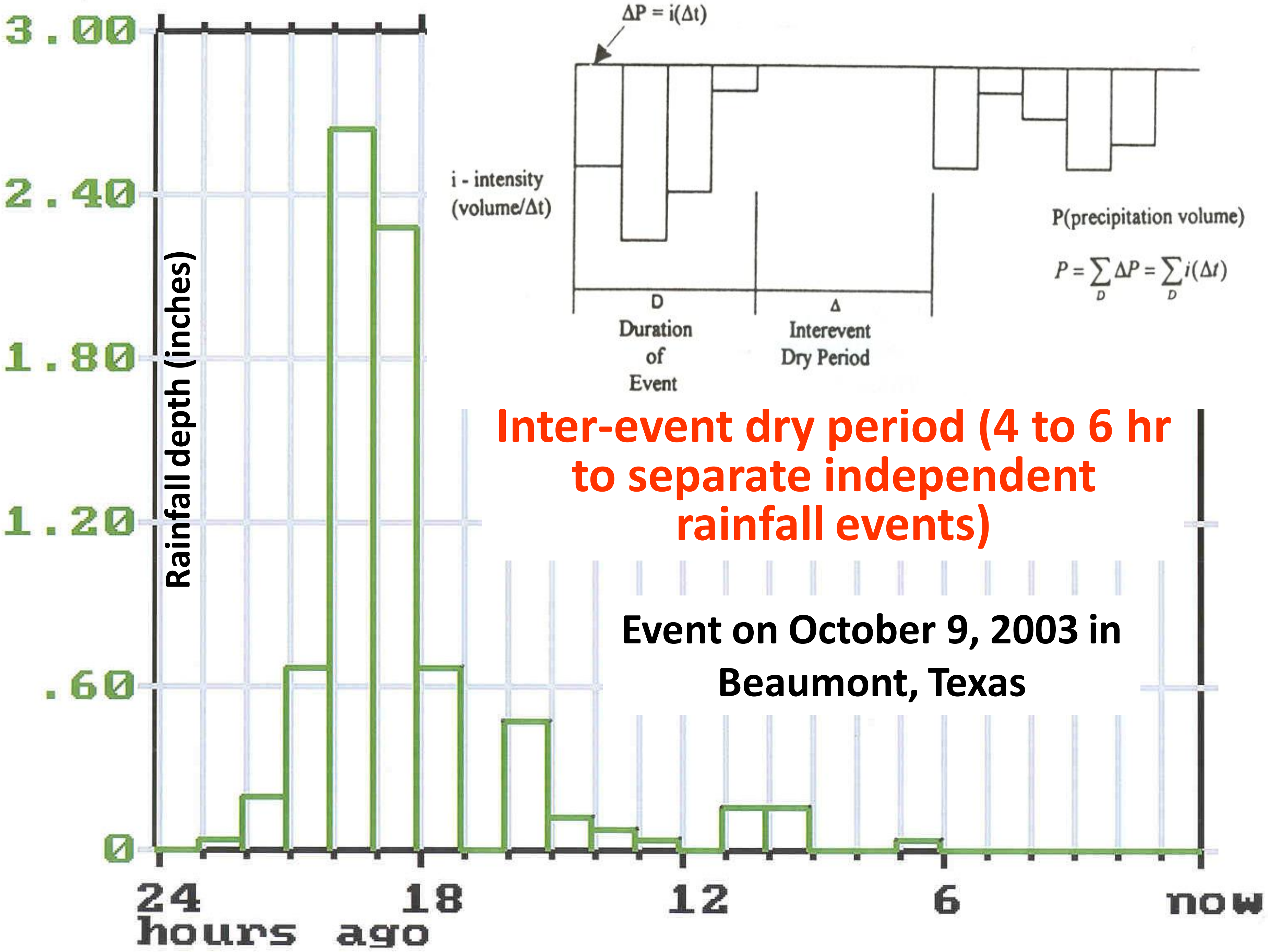
# Statistical Characteristics of Storm Interevent Time, Depth, and Duration for Eastern New Mexico, Oklahoma, and Texas

*Professional paper 1725*

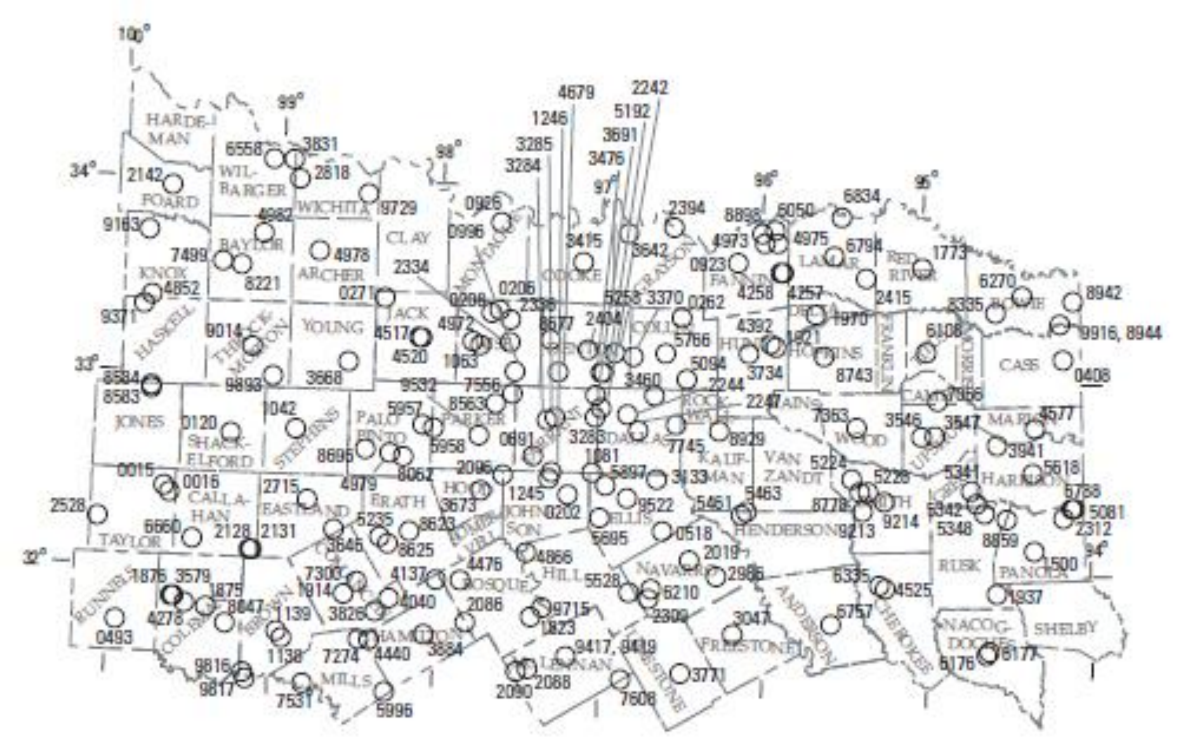
By William H. Asquith, Meghan C. Roussel, Theodore G. Cleveland,
Xing Fang, and David B. Thompson

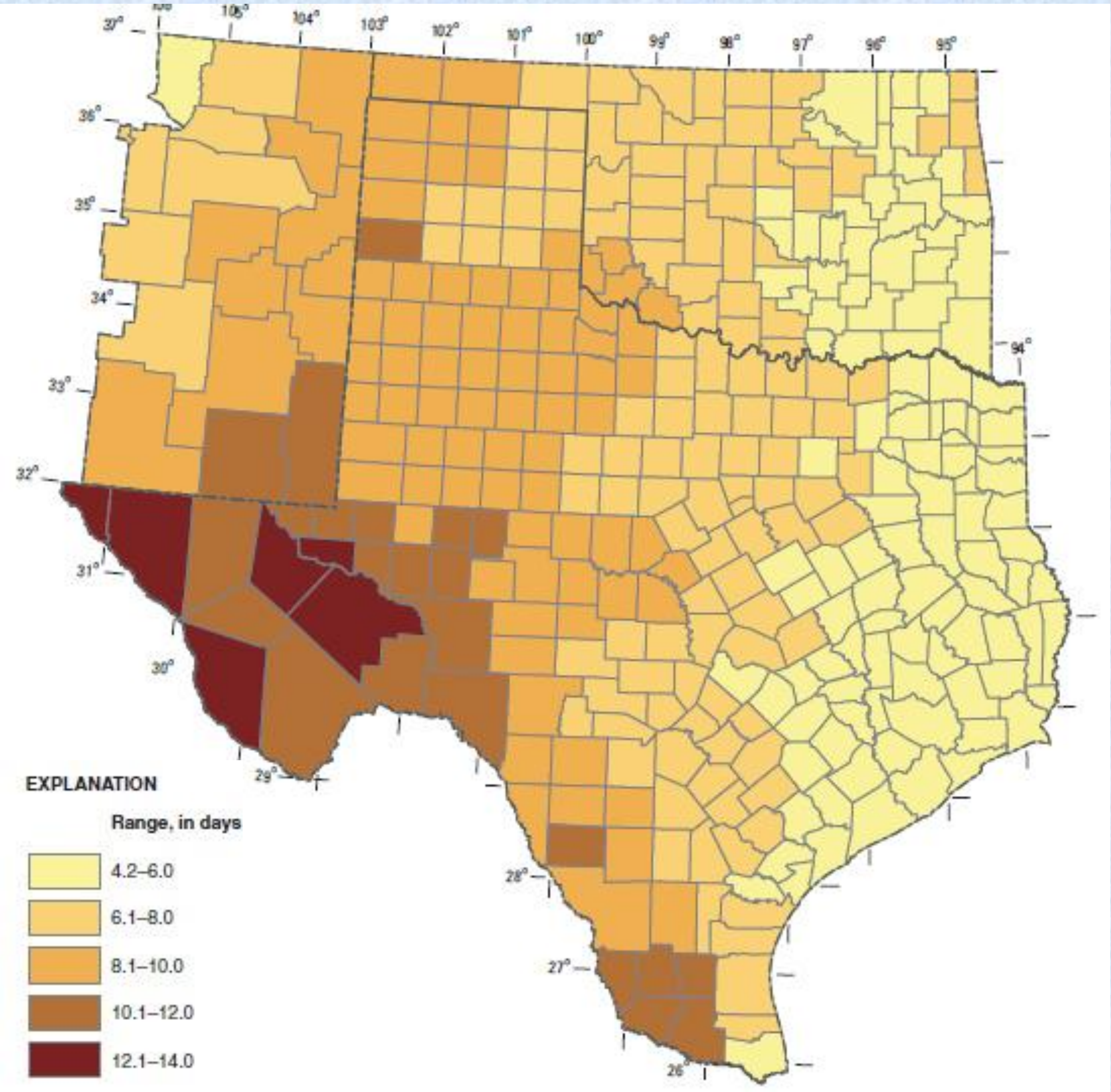


Inter-event dry period (4 to 6 hr to separate independent rainfall events)

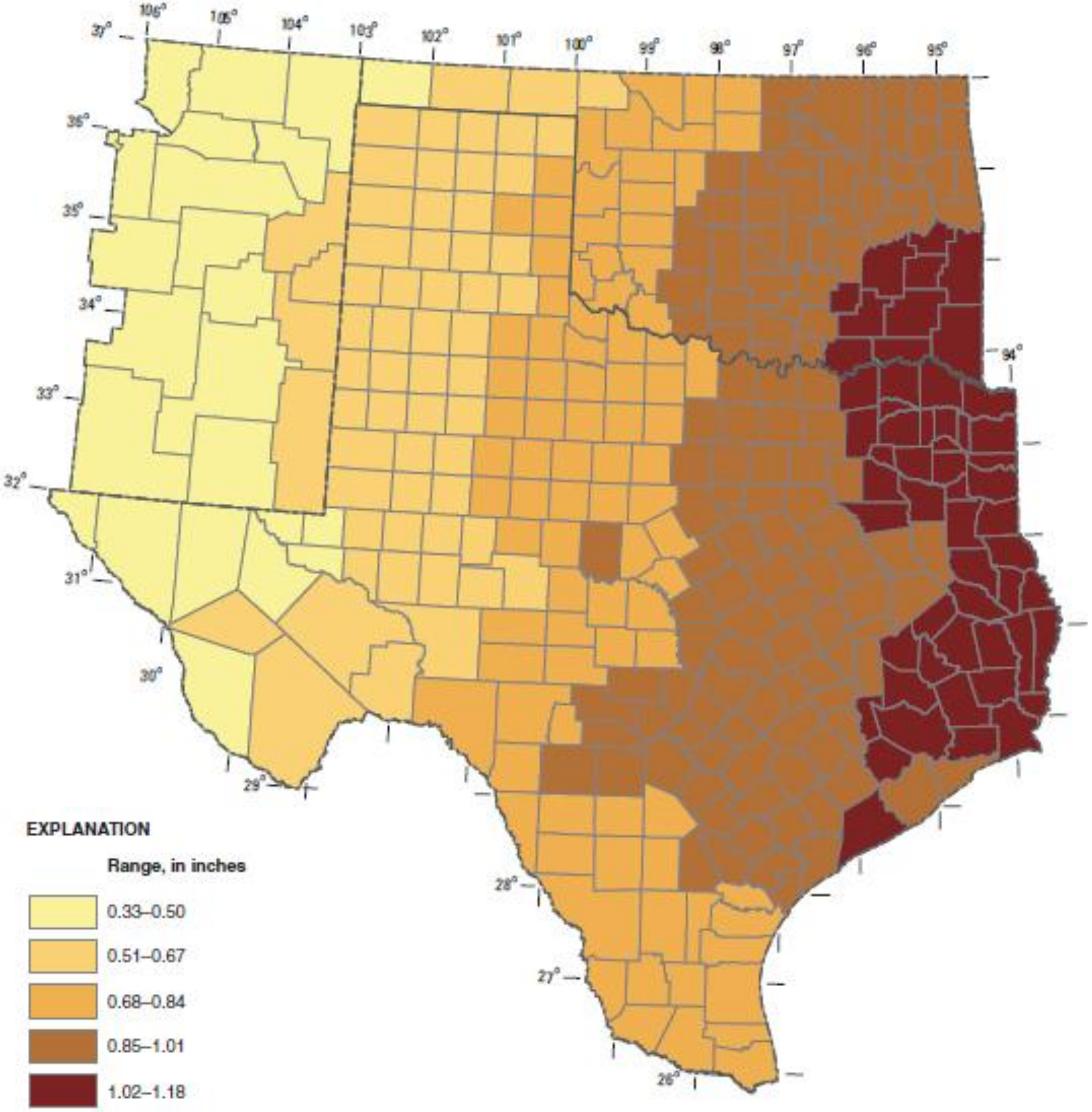
Event on October 9, 2003 in Beaumont, Texas

- The database contains more than 155 million hourly values from 774 stations in the study area.
- Developed seven sets of maps for storm inter-event times, distribution of storm depths and storm durations.
- Tables of rainfall distribution parameters for each station and county.





# Mean storm inter-event time defined by 6-hour minimum interevent time in eastern New Mexico, Oklahoma, and Texas



# Mean storm depth defined by 48-hour minimum interevent time in eastern New Mexico, Oklahoma, and Texas

# Applications

- **Construction Activities**: A threshold precipitation depth of about 0.1 inches is sufficient to impact certain construction activities.
- Rainfall statistics helps construction planers to estimate the expected number of events over the life of a construction projects.
- The occurrence of rainfall events is assumed to follow a Poisson process.

$$F_n(T) = e^{-T/\Lambda} \sum_{i=0}^{n} \frac{(T/\Lambda)^i}{i!}$$

Cumulative probability of n events in T days with $\Lambda$ Poisson parameter

# Implementation Project

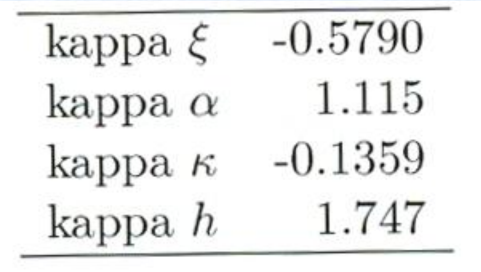
- U.S. Highway 96 rehabilitation project in Jasper County, Texas. It supposes to last for 2 years.
- We had data for 1,847 events with 306,666 hours of observations at a station near the construction site. Therefore, over the long term, a storm event is expected above once every 6.91 days (= 306666/1847/24).
- How many storm events we would expect during the construction period (2 years)? - use the median number of events:

$$F_n(T) = 0.5 = e^{-T/\Lambda}\sum_{i=0}^{n}\frac{(T/\Lambda)^i}{i!} = e^{-730.5/6.91}\sum_{i=0}^{n}\frac{(730.5/6.91)^i}{i!}$$

Solution: n = 106 events.

# Expected number of events to the threshold depth of precipitation?

- *The minimum interevent time of 24 hours is used.*
- *x(F) is the value of the quintile function for a non-exceedance probability F with four Kappa distribution parameters (given below of Jasper station).*
- *at the station, the mean storm depth is 0.899 inches*
- *Threshold depth = 0.1" = x(F) * 0.899", x(F) = 0.1112*
- *F = 0.1487, then number of events exceeded the threshold = (1-F)*106 = 90 events*



| | |
|---|---|
| kappa $\xi$ | -0.5790 |
| kappa $\alpha$ | 1.115 |
| kappa $\kappa$ | -0.1359 |
| kappa $h$ | 1.747 |

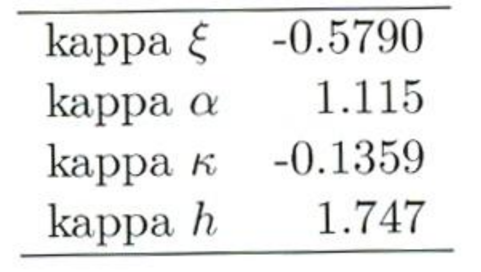
$$x(F) = \xi + \frac{\alpha}{\kappa}\left[1 - \left(\frac{1 - F^{h}}{h}\right)^{\kappa}\right]$$

# Expected number of events for depth of precipitation > 0.75”

- *The minimum interevent time of 24 hours is used.*
- *at the station, the mean storm depth is 0.899 inches*

- *Threshold depth = 0.75” = x(F) * 0.899”, x(F) = 0.8343*

- *F = 0.6391, then number of events exceeded the threshold = (1-F)*106 = 38 events*



| | |
|---|---|
| kappa $\xi$ | -0.5790 |
| kappa $\alpha$ | 1.115 |
| kappa $\kappa$ | -0.1359 |
| kappa $h$ | 1.747 |

$$x(F) = \xi + \frac{\alpha}{\kappa}\left[1 - \left(\frac{1 - F^{h}}{h}\right)^{\kappa}\right]$$

# Summary

- Rainfall distribution in a region may be different from NRCS 24-hour rainfall distribution.
- Rational runoff coefficients C were derived from rainfall and runoff data and for different return periods.
- Rainfall statistical information is useful for highway construction schedule planning and BMP inspection.

*Thanks for Your Attention*