## RAINFALL INTENSITY IN DESIGN

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### **ABSTRACT**

An empirical, dimensionless-hyetograph that relates depth and duration, and thus whether a storm is front loaded, back loaded, or uniformly loaded, based on 92 gaging stations for storms known to have produced runoff is available for Texas. Statistical characteristics of storm interevent time, depth, and duration, based on analysis of hourly rainfall data for 533 rain gages are used to "dimensionalize" this hyetograph and produce a set of simulated storms.

These simulated storms are analyzed to generate a set of rainfall intensities, and these intensities are compared to global maximum observed rainfalls, intensities estimated using the National Weather Service TP-40, and HY-35 publications, and a current Texas Department of Transportation design equation.

The simulated storms agree well with the other methods for rare (i.e. 90-th percentile and above) occurrences and lie within the global maxima envelope. The simulated results are quite different for common (i.e. 50-th percentile) events.

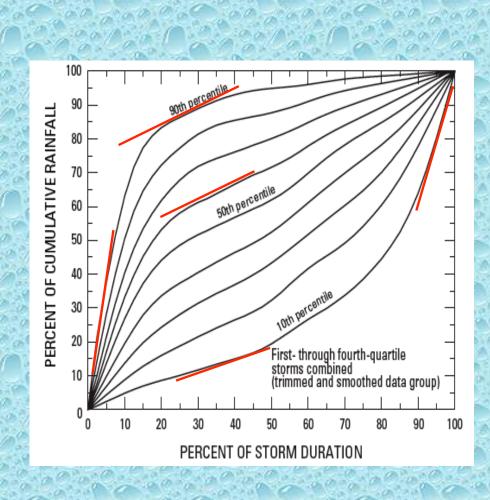
### INTRODUCTION

The work presented is the result of a question (see acknowledgements) "How hard can it rain?" Rainfall intensity has a variety of practical uses: : BMP design, detention design, rational runoff rates, and so forth.

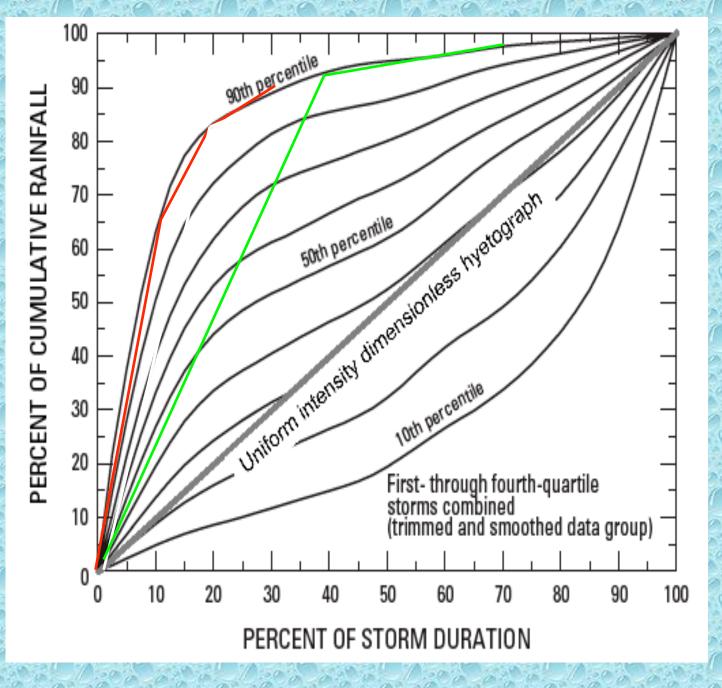
### **DATA SOURCES:**

The following sources constitute the database discussed in this poster: Asquith and others (2006), Asquith and others (2004), Williams-Sether and others (2004), Smith and others (2001), Barcelo and others (1997), Paulhus (1965), Jennings (1950)





DIMENSIONLESS HYETOGRAPH Slopes are dimensionless intensity



INTRESITY SIMULATION (DIMENSIONLESS) Use different portions of dimensionless hyetograph; simulate many different intensities, then sort and rank.

### **EMPIRICAL HYETOGRAPHS**

Sether-Williams and others (2004) analyzed 92 stations, 1507 storms, known to have produced runoff. Each storm duration was divided into 4-quartiles. The quartile with largest accumulation of rainfall defines "storm quartile."

The observed rainfall collected into 2.5-percentile "bins" and smoothed to force monotonic dimensionless hyetographs. Result is empirical-dimensionless-hyetograph.

Subsequent to that report, the authors noted that the slopes of these hyetographs are dimensionless "intensity". Used that concept to generate various collections of dimensionless intensity, but need a way to dimensionalize for comparison to actual data or for practical application.

### **INTENSITY SIMULATION**

Asquith and others (2006), analyzed 774 stations in New Mexico, Oklahoma, and Texas. Generated depth quantiles for each "storm." (Half-million in Texas). The computed L-moments for each station for duration and depth. Stuided various distributions, ultimately recommended a Kappa distribution as most appropriate distribution for depth and duration.

event times is

They provided "tools" to parameterize the empiricaldimensionless-hyetographs.

Page 42 explains how to use Kappa quantile function and L-moments to recover storm depth (vertical axis of dimensionless hyetograph)

Page 43 explains how to use Kappa quantile function and L-moments to recover duration (horizontal axis of the empirical hyetograph).

However, at the time they did not provide the "code" to access the tools (except by reference).

of a design. The maps in

(table 18). Linear interpo

minimum interevent time in Texas is

Distribution of Storm Depth

distribution is the mean depth multiplied by the dimensionles

 $P(F) = 0.750 \times x(F),$ 

PROBLEM: A BMP is to be built with a 36-hour draw-

equation 13. The runoff from the 95th-percentile storm is about (fig. 3A), is desired. The 2.34 inches from equation 12. To further illustrate the application of this report, from equation 13 the quantiles for each of the selected percentiles or minimum interevent tir nonexceedance probabilities (0.01, 0.02, 0.10, 0.25, 0.50, 0.75, report. However, 24-hor 0.90, 0.98, and 0.99) are listed in column three of table 22. As times bracket 40 hours. seen in the table, the empirical storm depth percentiles and County, the mean storm storm depth percentiles from the kappa distribution are similar minimum interevent tim for each percentile as expected.

storm interevent time for Example 5: Statistical Simulation of Rainfall Intensity the result is about 11.8 \*PROBLEM: An analyst wants to construct synthetic temporal distributions of average rainfall intensity for station | Example 7: Computat 4311 Houston Alief, Tex., to investigate the influence of rainfall Percentage

rates on the spill volume of a numerical model of a particular for nonexceedance probability F is given as equation 13 in example 4. The L-moments of storm duration for the station are listed in appendix 4-3.5. The mean, L-scale, L-skew, and L-kurtosis are 13.434 hours, 8.1389 hours, 0.46763, and 0.20844, respectively. Fitting a kappa distribution to these L-moments using the Hosking (1996) algorithm (data not shown in this report) results in the following equation for the storm duration D in terms of nonexceedance probability, F  $D(F) = -23.466 + \left(\frac{28.137}{0.003807}\right)$ 

where x(F) is the dimensionless multiplier (a frequency factor) for nonexceedance probability F. The storm depth are independent random variables, which is supported by the scattered relation in figure 9. Under this assumption, storm and 1, substituting this value for F, and solving equation 13 for where P(F) is the storm depth for nonexceedance probability P. A similar process for storm duration is done with the generbest illustrated by example. A random number of 0.78687 is generated for storm depth and results in a depth of 1.33 inches using equation 13. Another random number of 0.040703 is generated for storm duration and results in a duration of 1.01 hours F satisfying the equality is 0.859. Thus, under the ordiusing equation 14. The average rainfall intensity for this storm nance, about 86 percent of all storms will be captured by the thus is 1.33 divided by 1.01 or 1.32 inches per hour.

Example & Regional Estimation of the Empirical Regional Approach by County Example 6: Regional Estimation of Storm Occurrence down time in Randall County, Tex. (fig. 3A). The empirical dis PROBLEM: The storm interevent time for storms defined tribution, specifically the 50th, 75th, 90th, 98th, and 99th perby a 40-hour minimum interevent time in Randall County, Tex. centiles of storm depth, are needed as part of the design process.

time; hence an analysis of storms with a 24-hour minimum where F is the cumulative or nonexceedance probability for interevent time is required. Engineering firm B is questioning the x interevent time, and MIT is the minimum interevent whether a 2-inch design runoff would accommodate the 90thpercentile storm as reflected by the ordinance or instead would time in days. The parameter  $\Lambda$  is the mean interevent time in days. The inclusion of the minimum interevent time adjusts the accommodate approximately the 95th-percentile storm. Thus, exponential distribution because interevent times less than the firm B believes that the ordinance might contribute to overminimum interevent time are not possible. Equation 10 can be design of BMPs. The scientific credibility of the ordinance solved in terms of x. The resulting equation is the quantile hence is in question; the results of this report can be used to function of interevent time and is evaluate the ordinance. Assume, for the purpose of illustration

Papa, 2000, p. 74). The cumulative distribution of storm inter-

 $F(x) = 1 - e^{\frac{2\pi i}{A - MIT}}$  for  $x \ge MIT$  and n = 1, 2, ... (10) ordinance states that the BMP is to have a 24-hour drawdown

the BMP is to be ignored. Engineering firm A is to design a

BMP for a given watershed in which the ordinance applies. The

that near the planned BMP is long-term station 4311 Houston.

 $R = \phi(P - S_D)$ ,

where R is runoff in inches,  $\phi$  is the runoff coefficient, P i

rainfall in inches, and  $S_D$  is depression storage or an initial

abstraction in inches. It is widely accepted that a typical initial

abstraction for the watershed is 0.25 inch and the runoff coeffi-

cient is about 0.8. Upon variable substitution, the rainfall pro-

The L-moments of storm depth for a 24-hour minimum

interevent time for this station are 0.88849 inch, 0.52954 inch

L-kurtosis, respectively (appendix 4–2.5). A four-parameter

kappa distribution (see section "Quantile Functions of Storm Depth and Duration" in this report) can be fit by use of these

L-moments using an algorithm such as in Hosking (1996) (data

where P is storm depth and F is nonexceedance probability.

Substituting 2.75 inches for the left side of the equation and

solving the equation for F yields 0.932 or 93.2 percent. In

other words, a rainfall depth of 2.75 inches is about the 93rd-

percentile storm depth. Therefore, a statistical estimate of the

storm percentage associated with 2 inches of runoff for the

watershed is 3 percentage points larger than 90 percent. The

90th percentile for the distribution (F = 0.90) is 2.24 inches.

Thus, the ordinance reflects a depth of 2.75 inches;

whereas, the statistical estimate of the 90th-percentile storm

is 2.24 inches using the Hosking (1996) algorithm. Therefore,

the claim of engineering firm B that a storm associated with 2

inches of runoff would accommodate approximately the

not shown in this report). The fitted kappa distribution com-

0.45778, and 0.23879 for the mean, L-scale, L-skew, and

ducing 2 inches of runoff is 2.75 inches.

sponding to these L-moments is

SOLUTION: The first step toward the solution is to com-

 $x(F) = MIT - (\Lambda - MIT) \ln(1 - F)$  for  $x \ge MIT$ . (11) Alief, Tex. (station considered in example 3). When random numbers between 0 and 1 are substituted for pute the depth of rainfall that produces 2 inches of runoff on the F in equation 11 with A equal to 7.60 days and MIT equal to watershed. A simple runoff model (Adams and Papa, 2000, p. 1 day (24 hours), a random sequence of interevent times is generated. Five simulations based on a random sequence of five interevent times are listed in table 21 (at end of report). The

mean of the simulations is 7.19 days—the mean approaches 7.60 as the number of simulations becomes larger. It is illustrative to compare the 7.60 days mean interevent time to the results of Asquith and Roussel (2003, fig. 4). Asquith and Roussel (2003, fig. 4) shows that the interoccurrence of daily rainfall (not hourly) of 0.05 inch or more is, on average about 8 days for the Amarillo area. The two interevent times are of the same order as expected, but the values should not be equal.

### Example 3: Estimation of the Empirical Distribution of

PROBLEM: The 98th-percentile storm from the empirical distribution of storm depth for a site very close to station 4311 Houston Alief, Tex. (fig. 3C) (62 years of record), is required by an environmental consulting firm working on a project proposal in a watershed where BMPs are to have a 24-hour drawdown time. Hence, the statistics of storms with a 24-hour minimum interevent time are appropriate.

SOLUTION: The 98th percentile and other selected percentiles of storm depth are listed in appendix 4-4.5 and in column two of table 22 (at end of report). The 98th-percentile storm has a depth of 4.55 inches. (Column three of table 22 is a component of example 4.) The median storm depth is 0.44 inch and the interquartile range is 1.03 inches (1.18 minus 0.15) for station 4311.

## Example 4: Estimation of the Continuous Distribution of

\*PROBLEM: As part of a city ordinance, a BMP for a 90 percent of all storms when 2 inches or less of runoff is cappercentile storm is 3.18 inches by substituting F = 0.95 into

curve using the kappa distribution (eq. 6; table 7) for a 24-hour

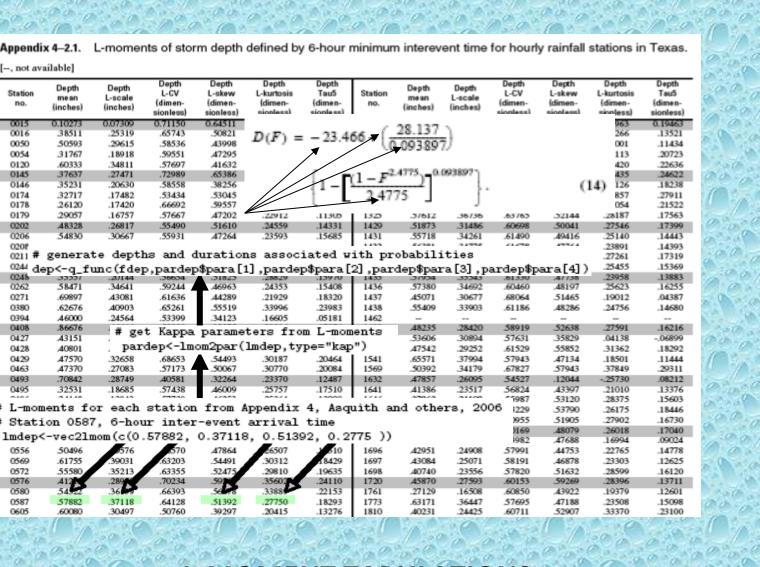
In cooperation with the Texas Department of Transportation Statistical Characteristics of Storm Interevent Time, Depth, and Duration for Eastern New Mexico, Oklahoma, and Texas

U.S. Department of the Interior

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### L-MOMENT TABULATIONS

Used to dimensionalize the empirical hyetograph

### INTENSITY SIMULATION (CONT.)

An example (with the necessary code) is presented here.

Selected 4 stations in Harris County, Texas. Global maxima have been observed in the region (not these particular stations).

Necessary code to compute using R is provided below.

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

lmdep < -vec2lmom(c(0.57882, 0.37118, 0.51392, 0.2775))

# get Kappa parameters from L-moments

pardep<-lmom2par(lmdep,type="kap")

# generate 2500 random probabilities fdep<-runif(2500,0,1); fdur<-runif(2500,0,1)

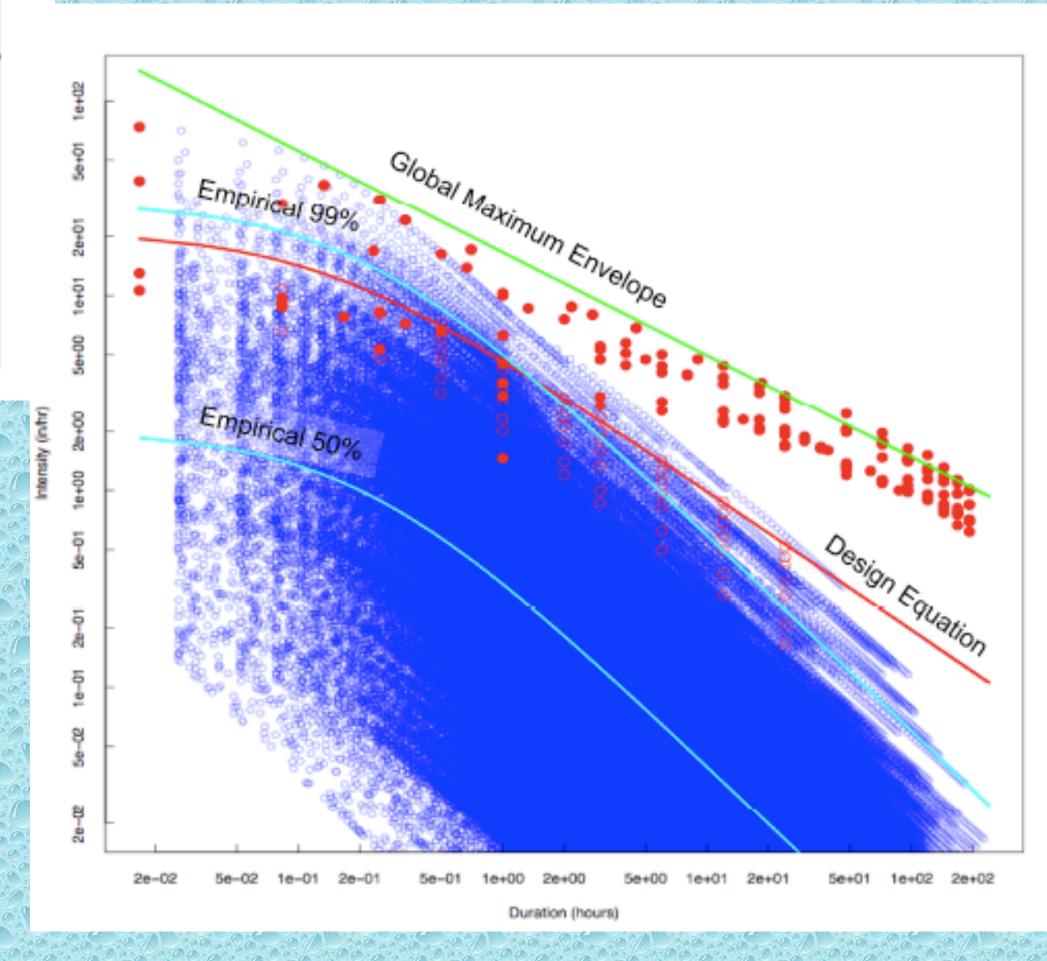
# generate depths and durations associated with probabilities dep<-q\_func(fdep,pardep\$para[1],pardep\$para[2],pardep\$para[3],pardep\$para[4]) dur <- q\_func(fdur,pardur\$para[1],pardur\$para[2],pardur\$para[3],pardur\$para[4])

### # R Code to simulate Harris County Intensities (6-hour) # Load the L-moment package from CRAN and attach as a library library(lmomco) # Quantile Functions for Depth and Duration. # Asquith and others, 2006, Eqns 13, and 14. $q_func<-function(f,p1,p2,p3,p4){(p1+(p2/p3)*(1-((1-f^p4)/p4)^p3))}$ # L-moments for each station from Appendix 4, Asquith and others, 2006 # Station 0587, 6-hour inter-event arrival time lmdur<-vec21mom(c(6.3865, 3.1849, 0.43733, 0.2504 ))</pre> pardur<-lmom2par(lmdur,type="kap")

O 100 200 OLDMETERS

# calculate intensities avg\_intensity<-dep/dur **R CODE** 

R commands needed to use tabular data in PP 1725



### **INTENSITY-DURATION DIAGRAM**

Comparison of simulated intensities (blue markers) and global maxima,. Red open markers areond "Design Equation" are TP-40, HY-35 values.

### **RESULTS**

0146

4311

HARRIS COUNTY RAINGAGE STATIONS

Four (4) stations used in example calculations. Tabular values of

L-moments (and equations) are shown in figure below.

Computed empirical percentiles by count fraction above and below line an ad-hoc model line (labeled as 99% and 50% on the figure. "Design" Equation is from TxDOT manual, derived from TP-40, HY-35 reports.

These results are consistent with prior work; are within the global envelope. There are considerable differences at higher duration - Texas storms are less intense (than global maxima) if long. As a practical matter, if used to estimate intensities, rare (99th-percentile) estimates about the

Median estimates (50th-percentile) quite different.

Biggest assumption is independent depth and duration, along with the extrapolation to short time intervals.

### **FUTURE WORK**

There is evidence that these variables are highly coupled, especially for longer durations. Conditional dependence should be examined. The common (low percentile) events seem especially important for water quality issues.

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