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Application of Storm Statistics to TxDOT Construction and Stormwater Management Maintenance

by
David B. Thompson, Texas Tech University
Theodore Cleveland, University of Houston
Xing Fang, Lamar University

Research Report Number 5-4194-01-2
Project Number 5-4194-01
Implementation of Storm Event Statistical Data
for Project Planning Purposes

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16. Abstract:

The purpose of this report is to present a set of findings and examples for application of U.S.G.S Professional Paper 1725, “Statistical characteristics of storm interevent time, depth, and duration for Eastern New Mexico, Oklahoma, and Texas.” The examples are intended to provide guidance for end users of the Professional Paper for application of project results to design activities associated with construction as well as stormwater best management practices.

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Department of Civil and Environmental Engineering
Texas Tech University
P.O. Box 41023
Lubbock, Texas 79409–1023

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1. Introduction

1.1. Purpose and Objectives

The purpose of this report is to present results of Implementation Project 5–4194, *Implementation of Storm Event Statistical Data for Project Planning Purposes*.

Two broad tasks were part of Implementation Project 5–4194: **Task 1** involves use of storm statistics developed as part of Texas Department of Transportation (TxDOT) Project 0–4194 as applied to construction practice. Specifically, the purpose of Task 1 was to provide case-study application of methods developed as part of TxDOT Research Project 0–4194 to stormwater best management practices (BMPs) used in TxDOT construction activities and to estimate the impact of storms on construction activities [rain delays]. **Task 2** was to shepherd the draft report generated as part of TxDOT Project 0–4194 through the U.S. Geological Survey (USGS) review process for publication and dissemination to TxDOT designers and other end-users of technology produced by the research team. Task 2 resulted in publication of Asquith et al. (2006) as a U.S. Geological Survey Professional Paper, which is the most prestigious report series of the agency.

1.2. Background

As part of the scope of work for now-completed TxDOT Research Project 0–4194 *Regional Analysis of Rainfall Hyetographs*, a consortium comprising Texas Tech University (TTU), Lamar University (LU), University of Houston (UH), and USGS researchers pursued documentation of rainfall hyetographs and the probability distributions of storm depth for Texas for seven selected values of mean inter-event time (MIT; 6, 8, 12, 18, 24, 48, and 72 hours). The study area for the research project was expanded into Oklahoma and 21 counties of eastern New Mexico to enhance statistical interpretation of storm-depth statistics near the borders of Texas. The study area thus includes eastern New Mexico, Oklahoma, and Texas. National Weather Service (NWS) hourly rainfall data provided the underlying dataset. Because of the substantial parallel processing involved, the consortium, lead by William H. Asquith (USGS), completed statistical analysis of the distribution of storm duration and mean storm arrival rates.[1]

A substantial body of research precedes results presented in this report. A depth-duration-frequency analysis was published by Asquith (1998) and revisited a few years later for publication as an atlas (Asquith and Roussel, 2004). Precipitation areal-reduction factors were studied by Asquith (1999). A study of precipitation interoccurrence intervals was executed by Asquith and Roussel (2003). The distribution of storm depth, explicitly for Texas, was documented within Asquith et al. (2004) as a substantial completion of TxDOT Research Project 0–4194, *Regional Analysis of Rainfall Hyetographs*.

During the course of executing TxDOT Research Project 0–4194, additional storm statistics were developed beyond the scope of the original project. Although a faithful effort was made by the consortium to publish comprehensive documentation of these storm statistics for the entire study area, the consortium unfortunately was not able to complete the resulting document. The process that led to the publication of the 0–4194–4 report (Asquith et al., 2004) provides a critical blue print for the documentation of storm duration and arrival; thus the 0–4194–4 report is an important milestone. Furthermore, William H. Asquith (USGS), on invitation, conducted nearly a dozen technical lectures in fiscal year 2004 concerning storm statistics (TxDOT Implementation Project 5–1301) to a broad audience of state, regional, and local agencies (Texas Commission on Environmental Quality, North Central Texas Council of Governments, City of Austin, and others) and attendees from private engineering firms. From these lectures, it is evident that there exists much public demand, hence federal interest, for comprehensive documentation of storm statistics in Texas. Because there is considerable federal interest in storm statistics in the study area, USGS Cooperative Water Program funding is available to contribute to the proposed project.

A justification for TxDOT Implementation Project 5–4194 was to publish the additional storm statistics developed, but unpublished, during execution of 0–4194. This document is Asquith et al. (2006), published as a USGS Professional Paper, one of the most prestigious publications of USGS. (Asquith et al. (2006) will hereafter be referred to as PP1725.) It is important that end-users of PP1725 understand that the report is more than a typical report explaining research techniques and results, but in fact, it better thought of as a reference book. The storm statistics documented in the manuscript provide the basis for site-specific case-study design problems.

[1] As an example of the scale of the data processing, over 155 million values of hourly precipitation from more than 770 stations were used, and almost 900,000 storms for an 8-hour minimum interevent time were extracted.

2. Asquith et al. (2006)

The development of the storm statistics underlying PP1725 are documented by Asquith et al. (2006). The work leading up to PP1725 is substantial and highly technical. However, a series of examples (see Chapter Example Applications in PP1725) are presented in which development of a few of the possible applications of the work presented in PP1725 are explored. The list of examples presented in PP1725 is not exhaustive but illustrative. Therefore, clever exploration of PP1725 by end-users may reveal additional applications beyond the few examples presented.

Some terms from PP1725 are important. *Minimum interevent time of rainfall* (MIT) refers to the length of time without rainfall (period of zero rainfall) that defines a boundary between distinct storm events. In the context of a stormwater best management practice (BMP), if the structure is designed such that it drains completely during the MIT, then the system is termed *memoryless* because it will begin in the dry state before the next runoff event occurs.

The *mean storm interevent time* is the total length of record divided by the number of observed storm events less the mean storm duration. The mean storm interevent time is a statistic describing the average arrival rate of storm events. It is used as the basis for further computations.

3. Site-Specific Applications

A typical highway project in east Texas is the U.S. Highway 96 rehabilitation project in Jasper County, Texas. Work is under direction of the Beaumont District, TxDOT. The project began construction in 2006 and will continue for about one and one-half years.

The U.S. Highway 96 project was chosen in part because it is in east Texas where annual rainfall depths are the largest in the state. In addition, Beaumont District TxDOT personnel and contractor personnel are interested in Implementation Project 5–4194 results. Therefore, a series of possible problems associated with stormwater management and construction practices were suggested.

3.1. Construction Activities

Jose Torres (APAC Corporation; personal communication) suggested that a threshold precipitation depth of about 0.1 inches is sufficient to impact certain construction activities. One approach to examining the statistics of rainfall is to compute the expected number of events over the life of a construction project. An MIT of 24-hours is used for the following example computations.[1] As an initial estimate, storm statistics for Station 7936 in Jasper County are shown on table 3.1 (after appendix 4–1.5 of PP1725). The mean interevent time for Station 7936 in Jasper County is 306,666 hours/1,847 events or 6.91 days/event. Therefore, over the long term, a storm event is expected about once every 6.91 days. During a two-year period, approximately 106 events are expected (730.5 days/6.91 days). Although this statistic suggests the number of events expected over a two-year period, it does not exactly answer the original question because a depth of precipitation for the expected number of events is not specified.

The expected number of events is readily estimated if the occurrence of rainfall events

[1] An MIT of 24-hours seems reasonable because construction activities are generally undertaken on a daily basis. Choice of a different MIT will impact resulting computations. However, determination of appropriate MIT is an analyst decision and should take into consideration factors appropriate to the topic under consideration.

Table 3.1: Storm Statistics for a minimum interevent time of 24 hours at Sam Rayburn Dam in Jasper County (Station 7936).

Number of storm events	1,847
Hours of observations	306,666
Storm interevent time (hours)	6.40

is assumed to follow a Poisson process. The Poisson process is defined by

$$F_n(T) = e^{-T/\Lambda} \sum_{i=0}^{n} \frac{(T/\Lambda)^i}{i!}, \tag{3.1}$$

where $F_n(T)$ is the cumulative probability of n events in T days given a Poisson parameter of Λ days.

Example 1 of PP1725 presents use of the Poisson process for estimating the number of events for the 75th percentile for a site near Briggs, Texas. A similar approach can be taken for the U.S. Highway 96 project in Jasper County to estimate the median (50th percentile) number of events. The resulting computation should produce an estimate similar to that presented a few paragraphs above, but is illustrative of the power of application of equation 3.1.

Statistics for Station 7936 in Jasper County are presented in table 3.1 (after appendix 4-1.5 of PP1725). For this application, T is 730.5 days (two years), the number of storms is 1,847, and observations occurred over 306,666 hours. Therefore, $\Lambda = 306666/(1847 \times 24) = 6.91$ days.[2] If $F_n(T)$ is taken to be 0.50 (the median), then application of equation 3.1 will be return the expected value (median, or 50th percentile) of the Poisson distribution. Using these values, equation 3.1 becomes

$$0.50 = e^{-730.5/6.91} \sum_{i=0}^{n} \frac{(730.5/6.91)^i}{i!}. \tag{3.2}$$

Solution of equation 3.2 is not algebraic, but iterative. The solution is approachable with a handheld calculator or through application of a standard spreadsheet program, however a more substantive tool is available in use of R from the R-project (R Development Core Team, 2006). When equation 3.2 is solved for n, the result is between

[2]The mean interevent time from this computation is 6.91 days. However, the storm interevent time from table 3.1 is 6.40 days. The difference is attributable to the mean duration of the storm event, which is implied to be $6.91 - 6.40 = 0.51$ days, or about 12 hours.

105 and 106 events (figure 3.1). That is, an estimate for the 50th percentile number of events over a two-year period is about 105 events. This result is very similar to the result arrived at using a less sophisticated arithmetic analysis. It is also important to observe that $730.5/6.91 = 105.7$ events.[3]

The choice of the cumulative percentile rests with the analyst. The 50th percentile represents the median number of events at a particular location. If a greater risk is acceptable, then a lower percentile value could be used. In contrast, if the situation demands a risk-averse approach, then a larger value of the percentile could be selected. In the case of Jasper County, if the 99th percentile is chosen, then the result of application of equation 3.1 produces about 130 events during the two-year time frame. This is about an additional month of impact.

```
> library(distributions)
> poissoncdf(mu=(730.5/6.91),x=100)
[1] 0.3102184
> poissoncdf(mu=(730.5/6.91),x=125)
[1] 0.9702258
> poissoncdf(mu=(730.5/6.91),x=102)
[1] 0.3828083
> poissoncdf(mu=(730.5/6.91),x=103)
[1] 0.4207270
> poissoncdf(mu=(730.5/6.91),x=104)
[1] 0.4592714
> poissoncdf(mu=(730.5/6.91),x=105)
[1] 0.4980787
> poissoncdf(mu=(730.5/6.91),x=106)
[1] 0.5367823
```

Figure 3.1: Output from R used to compute results presented for the Poisson process.

The output from R for computation of the Poisson process is shown on figure 3.1. The Poisson parameter, Λ, is 6.91 days. Therefore, the expected value of the Poisson distribution is $T/\Lambda = 730.5/6.91 = 105.7$ events. From examination of figure 3.1, the computation returns the mean, or expected value of the distribution, when the median (50th percentile) is selected as the target event. This is what is supposed to result from the statistics, however the process serves to illuminate execution of the computations using a tool such as R. A different number of expected events would be computed if the

[3]This means application of equation 3.1 for the median (50th percentile) is work that is not required. That is, if the 50th percentile is desired, use the mean, $730.5/6.91 = 106$ events, is appropriate. However, the result of this example is implicit in Example 1 of PP1725, which uses the 75th percentile, and so is presented here.

percentile target was different from 0.5.

Unfortunately, the expected number of events from both preceding approaches does not address the number of events expected with a depth of 0.10 inches or more. Estimation of that value requires a different computation. The quantile function of the dimensionless kappa distribution (equation 6 in PP1725) can be used to relate the expected number of events to the threshold depth of precipitation,

$$x(F) = \xi + \frac{\alpha}{\kappa}\left[1 - \left(\frac{1-F^h}{h}\right)^{\kappa}\right], \tag{3.3}$$

where $x(F)$ is the value of the quantile function for a nonexceedance probability F; and ξ, α, κ, and h are parameters of the function. Given the distribution parameters for the kappa distribution (ξ, α, κ, and h), the threshold precipitation depth, and the nonexceedence frequency (F), an estimate of the number of events exceeding the threshold depth can be computed. When equation 3.3, which is dimensionless, is multiplied by the mean storm depth, then the distribution of storm depth results.

For Texas statewide, basic distribution parameters for the dimensionless kappa distribution are listed in table 3.2. For Jasper County, the basic statistics are listed in table 3.3.

Table 3.2: Dimensionless kappa distribution parameters for a minimum interevent time of 24 hours for Texas. (From table 7 of PP1725, p. 66.)

kappa ξ	-0.5790
kappa α	1.115
kappa κ	-0.1359
kappa h	1.747

Table 3.3: Storm statistics for a minimum interevent time of 24 hours in Jasper County. (Tables in parenthesis indicate the data table from PP1725 used.)

Storm interevent time, days (table 18)	6.30
Mean storm depth, inches (table 19)	0.899
Mean storm duration, hours (table 20)	14.3

In table 3.3, the storm interevent time is 6.30 days. The mean storm duration is 14.3 hours. Therefore, the mean interevent time is $6.30 + 14.3/24 = 6.89$ days. This is slightly different than the mean interevent time computed using values from table 3.1, but the values are very close.

Application of equation 3.3 using the statistics for Texas and Jasper County can be approached using a statistical tool (such as R) or a standard spreadsheet. Input and output to R is shown on figure 3.2.[4] Tabular output (stored in output file `file.24`) is shown on figure 3.3. A few results form figure 3.3 are listed on table 3.4. From table 3.4, over a two-year period, about 90 events will occur with a threshold rainfall depth of 0.10 inches or more. Therefore, if the threshold precipitation of 0.10 inches indeed results in a substantive delay in construction either by re-tasking of activities or simply slower progress on scheduled activities, then over a two-year period about three months of weather-related impact are to be expected.[5]

```
> library(lmomco)
>
> # Establish the length of the 'simulation'
> Ty <- 2  # two-year project time
>
> ############### SET VALUES FOR EACH MIT OF INTEREST #######################
> Ibar.24 <- 6.30   # interevent in days,  TABLE 18 in PP1725
> Pbar.24 <- 0.899  # mean storm depth,    TABLE 19 in PP1725
> Dbar.24 <- 14.3   # mean storm duration, TABLE 20 in PP1725
> # Parameters of parent dimensionless 24-hour MIT kappa distribution of depth
> deppar.24 <- vec2par(c(-0.5790, 1.115,-0.1359, 1.747),type='kap') # TABLE 7 in PP1725
> EVENT.CURVE <- function(time.period.years,
+                         minimum.interevent.time,
+                         mean.interevent.days,
+                         mean.depth.inches,
+                         mean.duration.hours,
+                         depth.parameters) {
+   mean.interevent.hours <- mean.interevent.days*24  # now in hours
+   depths          <- seq(0,10,by=.1)                # sequence of thresholds
+   dimless.depths  <- depths/mean.depth.inches       # dimensionless depth
+   number.events   <- (time.period.years*24*365)/(mean.interevent.hours + mean.duration.hours)
+   counts          <- (1-cdfkap(dimless.depths,depth.parameters))*number.events
+   return(data.frame(mit=minimum.interevent.time,threshold=depths,counts=counts))
+ }
> EVENTS.24 <- EVENT.CURVE(2,24,Ibar.24,Pbar.24,Dbar.24,deppar.24) # 24-hour MIT calculations
> file.24 <- "mit24.txt"
> write.table(EVENTS.24,file=file.24,col.names=TRUE,row.names=FALSE,quote=FALSE)
```

Figure 3.2: Output from R used to compute results for the kappa distribution applied to Jasper County.

3.2. Stormwater-Management Maintenance

An analogous problem occurs when attempting to compute the number of times a stormwater management practice will require maintenance. In the case of U.S. Highway 96 construction, a site visit is required each time a rainfall event occurs. That means

[4]The library `lmomco` is not part of the standard R libraries and requires external installation. The `lmomco` library is available from the Comprehensive R Archive Network (`http://cran.r-project.org/`), where instruction for downloading and installation are presented.

[5]In addition, about one-half month (15 days) of working during precipitation events (105 events with precipitation less 90 days of 0.10 inches or more of precipitation) is also anticipated.

```
mit threshold counts
24 0 105.861027190332
24 0.1 90.1170121963352
24 0.2 74.396249742786
24 0.3 64.2010743453874
24 0.4 56.3932094764981
24 0.5 50.0558190705848
24 0.6 44.7515696200966
24 0.7 40.2257839852815
24 0.8 36.3124742448844
24 0.9 32.8953302580300
24 1 29.8886542194696
24 1.1 27.2269478138070
24 1.2 24.8587436504045
24 1.3 22.7427164451502
24 1.4 20.8451077898182
24 1.5 19.1379514790556
```

Figure 3.3: Output from R (`file.24`) with the threshold precipitation depth and number of events expected over a two-year period for Jasper County.

that over a two-year period, the expected number of visits to stormwater management practices for the site exceeds 100.

Application of equation 3.3 using the statistics presented in table 3.3 was implemented using R. Results from that computation (figure 3.2) are shown on figure 3.3, depicted graphically on figure 3.4.[6], and a few values summarized in table 3.4.

From table 3.4, the count of occurrences for threshold depths of 0.2 inches and 0.3 inches is 74 and 64 occurrences, respectively. So, if inspections of the stormwater practices were required only when rainfall depth exceeded about 0.25 inches, then the number of visits required would be approximately 69 (halfway between 64 and 74). Furthermore, if site stormwater-management practices required visits only for rainfall events exceeding 0.5 inches, then about 50 visits would be required.

Therefore, the materials of PP1725 can be used to estimate the number of occurrences of rainfall threshold depths of arbitrary size. Depending on the application, information about the expected number of events can provide insight into planning (and cost-estimating) the number of inspections or maintenance events for an period of time

[6]The graphical output from figure 3.4 is shown in its rough form to demonstrate output from the tool. In actuality, that graphic would be post-processed to produce a figure more appropriate for a professional publication. But, for a working graphic, the output from R is sufficient.

Table 3.4: Selected values from output file `file.24`.

Threshold (inches)	Number of Events
0.00	105.9
0.10	90.1
0.20	74.4
0.30	64.2
0.50	50.0
1.00	29.9
1.50	19.1

representing the planning horizon for the project.

The material in PP1725 and a simple runoff model can be used to assess maintenance/inspection frequency for stormwater-management practices or BMPs for arbitrary planning horizons. For example, a runoff coefficient for undeveloped landscapes in Jasper County is probably between 0.3 and 0.5. If maintenance or inspection of BMPs or other stormwater facilities is required only when 0.5 inches or more runoff occurs, then the rainfall associated with a half-inch of runoff is between 1.0 (0.5/0.5) and 1.5 inches (0.5/0.3). From table 3.4, somewhere between 19 and 30 events of this magnitude would be expected over a two-year period.

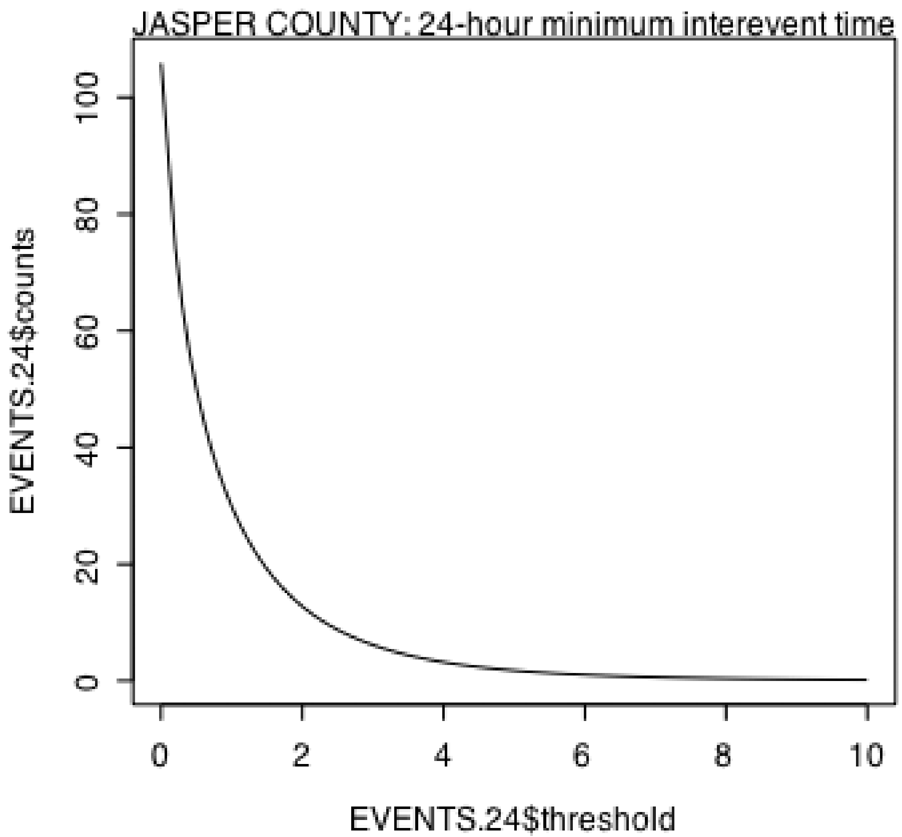

Figure 3.4: Output from R depicting expected number of events (counts) in relation to threshold precipitation depth over a two-year period for Jasper County.

4. Summary and Conclusions

PP1725 (Asquith et al., 2006) is the culmination of a large body of statistical computations applied to rainfall events in Texas, New Mexico, and Oklahoma. Much of this work stemmed from analyses associated with TxDOT Project 0–4194 in which precipitation distributions were analyzed to develop design storm distributions. Implementation Project 5–4194 was intended to extend and complete the work begun in 0–4194 and to allow analyses not part of the original project.

The results presented in PP1725 can be applied to a broad set of problems. A significant problem is the estimation of the number of events expected to occur during the construction period for a highway project. In this report it is demonstrated how such computations could be executed in the contexts of construction planning and stormwater management using materials presented in PP1725. Specifically, the number of events associated with a relatively low precipitation depth (threshold) was computed for an example project. In addition, the number of events expected for a larger precipitation depth (threshold) that might be associated with a stormwater-management practices or BMPs was computed.

If costs were associated with shifts or delays in construction activities, stormwater-management and BMP maintenance activities, then the expected costs associated with storm events could be estimated for the life of the construction project. Application of the tools presented in this report and PP1725 can provide insight into the costs associated with rainfall events and can provide means for estimating impacts of rainfall events on highway construction related activities.

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Texas Tech University | Lubbock, Texas 79409
P 806.742.3503 | F 806.742.4168