Analysis of Twenty-Five Years of Heavy Rainfall Events in the Texas Hill Country

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1. Introduction

Forecasting heavy rain events and the area of greatest threat has been a long standing challenge in operational meteorology. Quantifying rainfall as a distribution provides forecasters with supplementary information on precipitation thresholds that can lead to significant flash flooding or major flooding.

Twenty-five years of daily (24-hour) rainfall data were examined for the Texas Hill Country using observations from 86 cooperative climate stations in the region; the period examined for this study was 1982-2006. Days with measurable precipitation were treated as a gamma distribution in order to determine the top 2%, 1%, and 0.5% to define events as unusual, rare, and extreme, respectively. This approach was applied to each station as well as to the aggregate data for all 86 stations, resulting in an analysis of 130,986 observations of 24-hour precipitation. From this sample, rainfall amounts were also calculated for each station that represent 25-, 50-, 100-, and 200-year return frequencies.

2. Previous work

Classifying flash flood storm types arose in the Maddox et al. (1979) study of the synoptic and meso-α aspects of more than 150 flash flooding events across the nation. Using storm data reports for the years 1933-1977, a flood climatology was compiled. This climatology supplied essential information to identify a vast sample of intense precipitation events. The flash floods were broken down into four sub-categories: synoptic, frontal, mesohigh, and western.

Later, Doswell et al. (1996) advanced forecasting flash floods using a basic ingredients approach. An event's odds in producing a flash flood are significantly affected by such factors as antecedent precipitation, the extent of the drainage basin, topography of the basin, and urban influences within the basin. Since rainfall is usually an ordinary occurrence, raising public awareness about heavy rainfall and flash flooding can be a challenge.

Another prior study, conducted by Grice and Maddox (1982), focused on heavy rain events in south Texas and the Texas Hill Country. An event was defined by rainfall equal to or greater than 5 inches within 24 hours for the area excluding the Hill country, and equal to or greater than 4 inches in 24 hours within the Hill Country.

Up to this point, studying large-scale patterns, key ingredients, and their durations have all provided a qualitative approach for studying heavy rainfall events. Quantitative understanding can arise through viewing rainfall as a distribution. Panofsky and Brier (1968) discussed multiple statistical distributions and how they are calculated. A gamma distribution is such a transformation and it is very useful in fitting and transforming various distributions that only yield positive values. We shall employ this approach as we build toward a more quantitative understanding of these events.

3. Methods

Within each county, there is at least one site where daily maximum and minimum temperature and precipitation amounts are recorded and sent to the local National Weather Service office. The local office in New Braunfels, Texas receives 86 of these reports. Precipitation is the primary interest for this study spanning from January 1, 1982 to December 31, 2006. All instances of missing data, values of zero precipitation, or trace amounts were removed from the dataset. Only measurable precipitation amounts are desired.

The new filtered data set was then imported into statistical analysis software to calculate the alpha and beta values for each observing site, as well as, one alpha and one beta value for the entire dataset. These values were then used in the gamma distribution equation in Excel® to

determine the top 0.5%, 1.0%, and 2% limits. The 2% values set the threshold for what we termed "unusual" events, 1% values represented "rare" events, and the 0.5% values set the threshold for "extreme" cases.

4. Results and Conclusions

For the aggregate gamma distribution, the parameters values of α=0.4678 and β=1.0082 were obtained. While individual stations varied greatly (shown in Table 1), the aggregate data yielded a 24-hour rainfall threshold of 67 mm (2.64 in) for an observation to be in the upper 2%, 82.6 mm (3.25 in) to be in the upper 1%, and 98.30 mm (3.87 in) to be in the upper 0.5% of the distribution.

Over the course of 25 years, 127 days were found on which at least five (5) stations in the region had a 24-hour rainfall total that would be in the top 2% (or higher). Of these, only four (4) were the direct result of a tropical cyclone. Most of the observing sites were near or above the 25-yr storm values. Return frequencies for 25-, 50-, 100-, and 200-years are given in Table 2 (PSC 2006). A few locations actually had rainfall totals greater than the 200-yr return frequencies. When this happens it is an especially rare event and impressive flooding and damage will most likely occur. The return frequencies provide supplemental aide for forecaster that is crucial in the issuing of flash flood warnings.

5. Future Research

Using the three thresholds that were defined in Section 3, cases that had five or more stations receiving heavy rainfall were considered an event. Cases were then sorted into the number of days of duration. Seventy-six cases were 1-day events and are the focus of our ongoing studies. With these cases a detailed analysis will be performed using archived NARR data to reconstruct a proximity sounding for the location of the greatest rainfall.

The reason for deriving a mean proximity sounding is to gain a sense of the near-storm environment and build a small checklist of parameters that the cases have in common. By combining a successful checklist with the storm typing described by Maddox et al. (1979), we expect that the new approach will then be implemented into a forecasting script that will locate the area where the greatest rainfall will occur. A forecasting tool such of this kind would advance operational meteorology by greatly increasing lead time on flash flooding forecasts for the emergency managers and the general public.

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Table 1: The α and β values for each observing station in the Austin/San Antonio county warning area.

	Alpha	beta
Amistad Dam	0.2614225	1.0382852
Andice	0.6449028	0.7432511
Austin-Bergstrom	0.3595487	1.1164348
Austin-Mueller/Mabry	0.3989107	0.9615519
Bankersmith	0.4774281	1.0923644
Blanco	0.4134955	0.9918664
Boerne	0.3998823	1.2180467
Bracketville	0.6324914	0.8530191
Bracketville2	0.3555031	1.2412971
Bulverde	0.5250332	1.1669291
Burnet	0.5861518	0.7739256
Camp Wood	0.4454732	1.016521
Canyon Dam	0.3981996	0.9607089
Carrizo Springs	0.3800568	0.9465922
Carta Valley	0.6010366	1.10289
Cedar Creek	0.601679	0.8411823
Charlotte	0.4239757	1.0081067
Cottonwood	0.8785352	0.7719252
Crystal City	0.4085534	0.7897406
Del Rio	0.2490632	1.1980343
Derby	0.5539298	0.9966717
Dilley	0.2763036	1.4042526
Dime Box	0.6360674	0.8805016
Eagle Pass	0.3255983	1.0829307
El Indio	0.528441	0.902073
Elgin	0.6670754	0.8375299
Falls City	0.8268895	0.8225273
Fedor	0.878378	0.9112327
Fischer's Store	0.6683739	0.9326911
Flatonia	0.4458862	0.9984894
Florence	0.8714998	0.8345514
Floresville	0.5195538	1.0287024
Fredericksburg	0.3734212	1.0225214
Georgetown Lake	0.4786407	0.8944238
Giddings	0.5730452	0.908346
Gold	0.600214	0.9303134
Gonzales	0.3880223	1.0972607
Granger Dam	0.4183716	0.9487864
Granger	0.5306622	0.9721094
Hallettsville	0.4039177	1.0914637
Harper	0.4994632	0.9199041
Hondo	0.4994632	0.9199041
Hye	0.5818993	0.9949265
Jarrell	0.6443733	0.7665276
Jeddo	0.4865832	1.0522236
Johnson City	0.4147756	1.0441761
Jourdanton	0.3483983	1.1091171
Karnes City	0.6175178	0.7787566
Kerrville	0.3543205	1.0051047
La Grange	0.6387278	0.9070755
La Pryor	0.3833542	1.117383
Langtry	0.4924936	0.6986199
Lexington	0.5241861	0.9730205
Llano	0.5745424	0.7104657
Luling	0.3982106	1.0934566
Lytle	0.3322025	1.0159358
Medina	0.3175974	1.36796
New Braunfels	0.370239	1.2675667
Nixon	0.4228016	1.0433347
Northington Ranch	0.4763213	1.0933745
Pandale	0.432849	0.8158874
Pearsall	0.6039508	0.8864863
Pleasanton	0.3887896	1.1094812
Poteet	0.4741076	1.0110009
Prade Ranch	0.5378163	1.0883369
Riomedina	0.6236685	1.1263997
Rocksprings	0.418884	1.0068602
Round Mountain	0.797704	0.8618233
Round Rock	0.6174818	0.9193972
Runge	0.4066217	1.0258372
Sabinal	0.4563644	0.8904785
San Antonio-KSAT	0.3215588	1.2027805
San Antonio-Stinson	0.3972188	1.0302648
San Marcos	0.3742575	1.1171351
Schulenburg	0.6942169	0.848205
Smithville	0.5874113	0.9705555
Speaks2	0.6059852	1.1002157
Spicewood	0.5522464	0.9054166
Spring Branch	0.5621936	1.0091286
Stockdale	0.3978367	0.9963893
Teague Ranch	0.5002231	0.9337707
Tow	0.7310043	0.7010701
Watson	0.5567901	0.7927996
Wimberly	0.483105	1.1384011
Yoakum	0.3684474	1.2020028
Yorktown	0.5367178	0.9580281

Table 2: The calculated storm-return frequencies for each observing station in the Austin/San Antonio county warning area. Units on last four columns ("25-yr" "50-yr", etc) are inches.

	average	Sigma	B	Psi	25-yr	50-yr	100-yr	200-yr
Amistad Dam	3.07	1.167	0.9103	2.56299	5.474907	6.11482	6.750181	7.383722
Andice	3.08	0.836	0.6521	2.71679	4.802795	5.261208	5.716359	6.170207
Austin-Bergstrom	2.59	1.374	1.0717	1.99305	5.421484	6.174903	6.922964	7.668881
Austin-Mueller/Mabry	3.56	1.168	0.911	3.05255	5.966968	6.607429	7.243335	7.877419
Bankersmith	3.95	1.231	0.9602	3.41518	6.486796	7.161802	7.832008	8.500293
Blanco	3.68	1.039	0.8104	3.2286	5.82113	6.390855	6.956528	7.52058
Boerne	4.6	1.345	1.0491	4.01565	7.371722	8.10924	8.841511	9.571685
Bracketville	2.88	0.976	0.7613	2.45597	4.891302	5.426482	5.957855	6.487706
Bracketville2	3.74	1.02	0.7956	3.29685	5.841975	6.401282	6.956611	7.510348
Bulverde	4.4	1.945	1.5171	3.55498	8.408178	9.4747	10.53364	11.58954
Burnet	3.03	0.897	0.6997	2.64029	4.878502	5.370363	5.858725	6.345689
Camp Wood	3.61	1.183	0.9227	3.09603	6.047879	6.696565	7.340638	7.982865
Canyon Dam	3.53	0.688	0.5366	3.23109	4.947803	5.325061	5.699636	6.073137
Carrizo Springs	2.82	1.337	1.0429	2.23913	5.575236	6.308367	7.036283	7.762114
Carta Valley	3.55	1.929	1.5046	2.71193	7.525206	8.582954	9.633179	10.68039
Cedar Creek	3.48	0.793	0.6185	3.13547	5.114183	5.549016	5.980757	6.411261
Charlotte	3.48	0.844	0.6583	3.11332	5.219281	5.68208	6.141588	6.599778
Cottonwood	3.58	0.925	0.7215	3.17812	5.486203	5.993418	6.497025	6.999189
Crystal City	2.51	0.583	0.4547	2.25671	3.711423	4.031105	4.348514	4.665013
Del Rio	3.08	2.093	1.6325	2.17068	7.393171	8.540846	9.680359	10.81661
Derby	3.44	1.505	1.1739	2.78614	6.541444	7.366696	8.186078	9.003112
Dilley	3.83	2.337	1.8229	2.81467	8.645996	9.927467	11.19982	12.46853
Dime Box	3.8	1.194	0.9313	3.28125	6.260547	6.915265	7.565327	8.213525
Eagle Pass	3.24	1.429	1.1146	2.61916	6.184826	6.968404	7.746409	8.522184
El Indio	3.06	0.948	0.7394	2.64813	5.0136	5.533427	6.049556	6.564206
Elgin	3.68	0.994	0.7753	3.24815	5.728395	6.273445	6.814619	7.354241
Falls City	3.47	0.785	0.6123	3.12895	5.087697	5.518144	5.945529	6.37169
Fedor	3.9	1.845	1.4391	3.09842	7.702102	8.71379	9.718281	10.71989
Fischer's Store	3.99	1.159	0.904	3.48646	6.378421	7.013947	7.644953	8.274151
Flatonia	3.73	1.233	0.9617	3.19431	6.270917	6.94702	7.618315	8.287686
Florence	3.73	1.037	0.8089	3.27946	5.867008	6.435637	7.000221	7.563188
Floresville	3.69	1.471	1.1474	3.05091	6.721378	7.527986	8.328857	9.127434
Fredericksburg	3.68	1.144	0.8923	3.18298	6.037509	6.66481	7.28765	7.908704
Georgetown Lake	3.39	0.613	0.4781	3.12368	4.653246	4.989378	5.32312	5.655905
Giddings	3.69	0.82	0.6396	3.33374	5.379823	5.829462	6.275903	6.721064
Gold	3.68	0.773	0.6029	3.34416	5.272967	5.696834	6.117686	6.537333
Gonzales	3.9	1.825	1.4235	3.10711	7.660887	8.661608	9.655211	10.64597
Granger Dam	3.41	1.325	1.0335	2.83434	6.140507	6.867058	7.588441	8.307757
Granger	3.87	1.074	0.8377	3.40339	6.083256	6.672173	7.256902	7.839955
Hallettsville	4.08	0.962	0.7504	3.66205	6.062451	6.589954	7.113705	7.635956
Harper	3.57	1.063	0.8291	3.10817	5.760588	6.343473	6.922213	7.499294
Hondo	2.84	0.86	0.6708	2.46636	4.612254	5.083826	5.552044	6.018921
Hye	3.84	1.23	0.9594	3.30561	6.374735	7.049193	7.718854	8.386597
Jarrell	3.17	0.711	0.5546	2.8611	4.6352	5.02507	5.412167	5.798155
Jeddo	4.05	1.376	1.0733	3.45218	6.885606	7.640122	8.389271	9.136274

Johnson City	3.9	1.348	1.0514	3.31435	6.677904	7.417067	8.150972	8.882774
Jourdanton	3.66	1.273	0.9929	3.10693	6.283347	6.981384	7.674456	8.365543
Karnes City	3.03	0.571	0.4454	2.78192	4.206694	4.519796	4.830671	5.140656
Kerrville	3.55	0.866	0.6755	3.17376	5.334618	5.809481	6.280966	6.7511
La Grange	3.86	1.677	1.3081	3.13141	7.315895	8.235461	9.148487	10.0589
La Pryor	3.56	1.361	1.0616	2.9687	6.364694	7.110985	7.851968	8.590828
Langtry	2.28	0.621	0.4844	2.0102	3.559732	3.900251	4.238348	4.575477
Lexington	3.85	1.465	1.1427	3.21352	6.869013	7.672332	8.469936	9.265255
llano	2.81	0.781	0.6092	2.47069	4.419454	4.847707	5.272915	5.696904
Luling	4.05	1.604	1.2511	3.35313	7.355459	8.234996	9.108278	9.979058
Lytle	3.49	0.682	0.532	3.1937	4.895438	5.269406	5.640714	6.010958
Medina	4.48	1.455	1.1349	3.84786	7.478406	8.276241	9.068401	9.858291
New Braunfels	3.9	2.854	2.2261	2.66005	9.781409	11.34637	12.9002	14.44958
Nixon	3.72	1.271	0.9914	3.1678	6.339226	7.036166	7.728149	8.41815
Northington Ranch	4.1	1.059	0.826	3.63991	6.282345	6.863037	7.439599	8.014509
Pandale	2.6	0.71	0.5538	2.29153	4.06314	4.452461	4.839013	5.224458
Pearsall	3.04	0.997	0.7777	2.60684	5.094578	5.641273	6.184079	6.725331
Pleasanton	3.37	0.624	0.4867	3.0989	4.655914	4.998078	5.337809	5.676566
Poteet	3.65	1.065	0.8307	3.1873	5.844709	6.428692	7.00852	7.586687
Prade Ranch	3.86	1.393	1.0865	3.2548	6.730639	7.494476	8.252881	9.009113
Riomedina	4.27	1.325	1.0335	3.69434	7.000507	7.727058	8.448441	9.167757
Rocksprings	3.15	1.084	0.8455	2.67905	5.383864	5.978264	6.568437	7.156919
Round Mountain	3.71	1.233	0.9617	3.17431	6.250917	6.92702	7.598315	8.267686
Round Rock	3.8	0.93	0.7254	3.39595	5.716507	6.226463	6.732792	7.237671
Runge	3.64	1.01	0.7878	3.2012	5.721368	6.275191	6.825075	7.373384
Sabinal	3.04	1.146	0.8939	2.54211	5.401631	6.030029	6.653957	7.276097
San Antonio-KSAT	4.04	1.945	1.5171	3.19498	8.048178	9.1147	10.17364	11.22954
San Antonio-Stinson	2.04	0.817	0.6373	1.68505	3.723641	4.171635	4.616442	5.059975
San Marcos	4.03	1.268	0.989	3.4791	6.643044	7.338339	8.028689	8.717061
Schulenburg	3.66	0.926	0.7223	3.25769	5.568264	6.076027	6.580178	7.082885
Smithville	3.84	1.302	1.0156	3.27433	6.52311	7.237048	7.945909	8.652739
Speaks2	4.82	2.729	2.1286	3.63436	10.44381	11.94023	13.42601	14.90753
Spicewood	3.65	1.199	0.9352	3.12908	6.120851	6.778311	7.431094	8.082008
Spring Branch	3.87	1.492	1.1638	3.22179	6.944654	7.762777	8.575082	9.385059
Stockdale	3.52	1.248	0.9734	2.97779	6.091828	6.776157	7.455618	8.133132
Teague Ranch	3.66	1.155	0.9009	3.1582	6.040178	6.673511	7.302339	7.929365
Tow	2.96	0.811	0.6326	2.60765	4.631276	5.07598	5.517521	5.957797
Watson	3.22	0.965	0.7527	2.80075	5.208633	5.737782	6.263166	6.787045
Wimberly	4.31	2.02	1.5756	3.43239	8.472735	9.580382	10.68015	11.77677
Yoakum	4.27	1.596	1.2449	3.5766	7.558973	8.434124	9.30305	10.16949
Yorktown	3.83	1.048	0.8174	3.37469	5.989676	6.564337	7.13491	7.703848