MEMORANDUM

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SUBJECT: **Atlas 14 Rainfall Depth Revisions and IDF Curves**

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PROJECT: PFL19308 – Pflugerville Staff Augmentation

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Introduction

In September 2018, the National Oceanic and Atmospheric Administration (NOAA) published *Atlas 14: Precipitation-Frequency Atlas of the United States, Volume 11 Version 2.0: Texas*. This study provides precipitation frequency estimates for the entire state of Texas, including a set of digital rasters that cover the state at a resolution of approximately 100 feet. These estimates were computed based on hundreds of daily and hourly rain gage records throughout the state covering a period of record ranging from the mid-1800s through 2018. Atlas 14 serves as the United States government's official source of precipitation frequency estimates and associated information for Texas, and replaces previous federal studies, including National Weather Service TP-40 (1961) and NOAA HYDRO-35 (1977).

Before publication of Atlas 14, Volume 11, most Texas communities have relied on either TP-40 (1961) or USGS SIR-2004: *Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas* (2004). The City of Pflugerville's Engineering Design Manual (EDM) currently refers to rainfall depths published in the City of Austin's Drainage Criteria Manual, which are based on a 2001 study by Dr. William Asquith of the USGS. The 2001 study is based on the same dataset used to publish USGS SIR-2004. Continued use of this data would not accurately reflect the latest rainfall statistics for the City of Pflugerville.

In order to take advantage of the latest available data, more accurately document the risk of extreme rainfall in Pflugerville, and provide a consistent basis for drainage analysis and design, Freese and Nichols (FNI) has developed Atlas 14 rainfall depths and intensity-duration-frequency (IDF) curve parameters for incorporation into the City of Pflugerville's EDM. This technical memorandum documents (1) the procedure used to spatially average the rainfall depths from NOAA geospatial data and (2) the procedure used to fit the IDF curve parameters to the rainfall intensities.

Rainfall Depths

NOAA has provided Atlas 14 precipitation frequency estimates for the state of Texas on their website (https://hdsc.nws.noaa.gov/hdsc/pfds/). This includes a series of rasters that document precipitation-frequency estimates in inches for a range of storm durations and average recurrence intervals. For this analysis, FNI used the partial-duration rasters covering storm durations between 5 minutes and 24 hours and for average recurrence intervals from 1 to 500 years.

FNI used ArcMap's Zonal Statistics tool to average the NWS partial-duration precipitation frequency rasters across the entirety of the City of Pflugerville's city limits. The tool provides a minimum, maximum, range, mean, and standard deviation of each precipitation-frequency estimate raster. The mean value for each precipitation-frequency estimate (e.g., the 100-year 24-hour storm) represents the mean 100-year 24-hour storm within Pflugerville's city limits. The range and standard deviation values show the level of variation within the city limits and indicates how closely the actual value at any given point is represented by the mean value.

The recommended rainfall depths are shown in Table 1 below. Table 2 provides the range and standard deviation of depths for select durations and recurrence intervals. The Table 2 results indicate that the mean values selected for the EDM generally match the underlying Atlas 14 values within less than 2%. This holds true across a range of durations and recurrence intervals.

Table 1. Recommended Atlas 14 Rainfall Depths

	Rainfall Depth (in.) by Average Recurrence Interval								
Duration	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
5 min	0.44	0.52	0.66	0.77	0.94	1.08	1.23	1.38	1.59
10 min	0.69	0.83	1.05	1.23	1.51	1.73	1.97	2.21	2.52
15 min	0.88	1.05	1.31	1.54	1.88	2.15	2.44	2.74	3.16
30 min	1.25	1.48	1.84	2.16	2.62	3.00	3.39	3.82	4.42
60 min	1.62	1.94	2.43	2.86	3.49	4.00	4.55	5.16	6.03
2 hr	1.93	2.38	3.04	3.65	4.55	5.32	6.16	7.12	8.52
3 hr	2.10	2.64	3.41	4.15	5.25	6.20	7.27	8.49	10.28
6 hr	2.41	3.09	4.05	4.98	6.40	7.63	9.04	10.66	13.07
12 hr	2.75	3.55	4.67	5.75	7.40	8.84	10.49	12.41	15.31
24 hr	3.14	4.03	5.31	6.53	8.38	9.98	11.82	13.97	17.22

Table 2. Variation in Atlas 14 Rainfall

		Average Recurrence Interval			
Duration	Value (in.)	2-yr	10-yr	25-yr	100-yr
5 min	Mean	**0.52**	**0.77**	**0.94**	**1.23**
	Range	0.52–0.53	0.77–0.78	0.93–0.95	1.20–1.25
	Std. dev.	0.001	0.002	0.004	0.010
3 hr	Mean	**2.64**	**4.15**	**5.25**	**7.27**
	Range	2.62–2.67	4.10–4.18	5.15–5.32	7.03–7.42
	Std. dev.	0.009	0.017	0.032	0.076
6 hr	Mean	**3.09**	**4.98**	**6.40**	**9.04**
	Range	3.07–3.13	4.92–5.02	6.28–6.48	8.77–9.22
	Std. dev.	0.012	0.022	0.039	0.087
24 hr	Mean	**4.03**	**6.53**	**8.38**	**11.82**
	Range	4.01–4.07	6.46–6.59	8.29–8.47	11.66–11.95
	Std. dev.	0.012	0.030	0.044	0.071

The City of Austin and many surrounding communities currently distribute 24-hour storms using the NRCS' regional Type III rainfall distribution as documented in NRCS TR-55 (1975). Due to the ready availability of local rainfall frequency information, the Type III distribution is now obsolete. The NRCS now recommends distributing Atlas 14 rainfall using nested frequency storms. This method is built into the freely available HEC-HMS software: users can simply enter the depths from Table 1 below into a HEC-HMS model to have a nested frequency storm created automatically. FNI recommends that the City of Pflugerville require this method for HEC-HMS or other time-varying models.

Intensity-Duration-Frequency Curves

The City's ECM currently references the City of Austin's Drainage Criteria Manual (DCM). This manual provides a depth-duration-frequency (DDF) table, an intensity-duration-frequency (IDF) table, and a set of parameters fitted to the IDF power-law equation $i = a/(b+t)^c$. The parameters *a*, *b*, and *c* are provided for each recurrence interval and used in conjunction with the time of concentration *t* (in minutes) to produce the rainfall intensity in inches per hour for use with the rational method. These parameters need to be updated to match the new Atlas 14 data described above.

The Atlas 14 data does not necessarily follow a smooth, idealized set of IDF curves. The objective of the IDF curve-fitting process is to produce a set of parameters that minimize the difference between the fitted curves and the mean values. Each set of parameters was fitted to the mean Atlas 14 depths in Table 1.

FNI used the evolutionary algorithm in Excel's Solver to fit the *a*, *b*, and *c* parameters to the Atlas 14 depths. The objective of the Solver procedure was to minimize the sum of squared differences between the original intensity value and the calculated value by adjusting the *a*, *b*, and *c* parameters. The use of IDF curves is only appropriate for use with rational method calculations for drainage areas under 100 acres; therefore, these curves are rarely needed for times of concentration exceeding 2 hours. FNI weighted the sums of squared differences more heavily for the lower durations to encourage a closer match to those values. The sums of squared differences were also weighted more heavily when the calculated value was below the original value. These adjustments encouraged the algorithm to produce curves that fit the original rainfall values as closely as possible without significantly underestimating rainfall for any duration between 5 minutes and 2 hours.

The first pass of the algorithm was run using broad minimum and maximum values for the *a*, *b*, and *c* parameters. This first pass explored a large decision space with many possibilities. The resulting set of parameters fit the curves well but exhibited some inconsistencies between recurrence intervals. For example, the *a* and *b* values are generally expected to increase with recurrence interval while the *c* value is generally expected to decrease. FNI ran a second pass of the algorithm for each recurrence interval using the neighboring storm event parameters as minimum and maximum values. This allowed the algorithm to explore a smaller decision space for each recurrence interval and find alternate solutions that preserved consistency between recurrence intervals.

The recommended IDF parameters are shown in Table 3 below. A plot of the IDF curves is shown in Figure 2. For durations between 5 minutes and 2 hours, the maximum error is +4.5% and the average error is +1.1%.

Table 3. IDF Curve Parameters – Fit to Atlas 14 Data

Average Recurrence Interval	*a*	*b*	*c*
1-yr	43.66	10.43	0.7744
2-yr	45.97	9.37	0.7472
5-yr	51.35	8.44	0.7217
10-yr	60.02	8.44	0.7184
25-yr	67.90	7.88	0.6998
50-yr	75.82	7.79	0.6906
100-yr	78.75	7.05	0.6691
200-yr	79.51	6.36	0.6418
500-yr	80.44	5.57	0.6087

Engineering Design Manual Changes and Conclusion

Section 4 (Drainage) of the current EDM refers to the City of Austin's DCM and states that Pflugerville's guidelines shall govern where conflicts occur. Austin's forthcoming DCM updates will provide new tables of rainfall depths and IDF curve parameters similar to those documented in this memo. Pflugerville's new rainfall depths and IDF parameters can be included in the City's EDM without requiring significant changes to other portions of the EDM.

Note that the design storm for any given infrastructure in the City need not change – for example, drainage facilities will still be designed to convey 100-year runoff (DG4.2.C), and no peak flow increases will be permitted for the 2, 25, and 100-year storms (DG4.0.E). The only significant change required for the EDM is to document the specific rainfall depths that should be used to calculate those runoff rates.

We recommend that the City of Pflugerville add a new Rainfall section to the EDM to incorporate Table 1 and Table 3 provided in this memo. Minor changes may be needed in other sections, for example, clarifying that Pflugerville's rainfall depths take precedence over Austin's (DG4.0.A), requiring that IDF curves only be used with the rational method for areas smaller than 100 acres and with times of concentration under 2 hours (DG4.1.D), and clarifying that rainfall should be distributed in HEC-HMS using nested frequency storms (DG4.8.B).