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MEMORANDUM

Date: December 13, 2016

To: Ken MacKenzie, UDFCD
Holly Piza, UDFCD

From: Derek N. Rapp, PSE

Re: Summary of the NOAA Atlas 14 Impact on Rainfall Depths used by UDFCD

Introduction

This memorandum serves to provide summary documentation of the impact to Urban Drainage and Flood Control District (UDFCD) criteria as a result of changing from NOAA Atlas 2 rainfall depth-duration-frequency data to NOAA Atlas 14 data. Initially, when NOAA Atlas 14 was published, UDFCD determined that changing rainfall depths was not warranted as documented in a paper titled *Position on the NOAA Atlas 14 Precipitation-Frequency Atlas, Volume 8,* dated September 11, 2013. However, after continued use of NOAA Atlas 2 for several more years it was determined in 2016 that transitioning to NOAA Atlas 14 was warranted for several reasons.

Peak Stormwater Engineering, LLC (PSE) was retained by the Urban Drainage and Flood Control District (UDFCD) to: generate new rainfall depths within the District boundary based on NOAA Atlas 14, summarize the potential changes to the Urban Storm Drainage Criteria Manual (USDCM) Rainfall chapter, and implement the necessary changes within the applicable UD-workbooks. This memorandum focuses on documenting the comparison between NOAA Atlas 2 and NOAA Atlas 14 rainfall depths and the changes required to the Rainfall chapter.

Comparison of NOAA Atlas 2 and NOAA Atlas 14 Rainfall Depths

UD-Workbooks utilizing NOAA Atlas 2 rainfall included 1- and 6-hour depths for 22 locations within the District boundary. As part of transitioning to the NOAA Atlas 14 rainfall depths, additional locations were selected to account for all jurisdictions participating in the UDFCD and to fill in gaps in coverage, resulting in a total of 45 new locations.

When comparing the average rainfall depth of the original 22 locations, the Atlas 14 rainfall depth decreased anywhere from 0% to 20% below the Atlas 2 rainfall depths. Tables 1 and 2 provide a summary of the average differences for the 1-hour and 6-hour durations, respectively. The 100-year recurrence interval had the smallest percent decrease (9% for the 1-hour and no change for the 6-hour). The 5-year recurrence interval had the largest percent decrease (21% for the 1-hour and 14% for the 6-hour). It should be noted that all of the NOAA Atlas 2 rainfall depths in Tables 1 and 2 fell within the 90% confidence intervals of the NOAA Atlas 14 rainfall depths.

Table 1. Comparison of 1-hour Rainfall Depths

Average of 22 locations	1-hour Rainfall Depth (inches)					
	2-year	5-year	10-year	25-year	50-year	100-year
Atlas 2	0.97	1.39	1.63	1.99	2.29	2.60
Atlas 14	0.82	1.10	1.34	1.72	2.03	2.37
Difference	-0.16	-0.29	-0.28	-0.27	-0.26	-0.23
% Difference	-16%	-21%	-17%	-14%	-11%	-9%

Table 2. Comparison of 6-hour Rainfall Depths

Average of 22 locations	6-hour Rainfall Depth (inches)					
	2-year	5-year	10-year	25-year	50-year	100-year
Atlas 2	1.48	1.95	2.31	2.82	3.15	3.52
Atlas 14	1.28	1.68	2.04	2.58	3.03	3.52
Difference	-0.19	-0.27	-0.28	-0.24	-0.11	0.00
% Difference	-13%	-14%	-12%	-9%	-3%	0%

The default location selected to represent the average of all areas within the UDFCD boundary was Capitol Hill (200 E. Colfax Ave., Denver, CO). The NOAA Atlas 14 rainfall depths at this location were within +/- 3% of the average for all locations (this includes all durations and recurrence intervals).

Equations for 2-hr and 3-hr Rainfall Depths

The Rainfall Chapter of the USDCM provides Equations 5-1 and 5-2 to calculate the 2-hour and 3-hour rainfall depths from the known 1-hour and 6-hour rainfall depths. These equations (included below) were developed and published as part of NOAA Atlas 2 since it only included the 1-hour and 6-hour rainfall depths. NOAA Atlas 14 now provides numerical values for the 2-hour and 3-hour durations along with several other durations so the equations were not updated as part of the NOAA Atlas 14 update.

$$P_2 = P_1 + 0.342(P_6 - P_1) \qquad \text{Equation 5-1}$$

$$P_3 = P_1 + 0.597(P_6 - P_1) \qquad \text{Equation 5-2}$$

Currently, CUHP is the only UDFCD software product being maintained that utilizes the equations for 2-hour and 3-hour rainfall depths. These calculated depths are required to develop the 3-hour and 6-hour design storm distributions within CUHP. Consideration was given to eliminating the 2-hour and 3-hour equations and modifying CUHP to require the user to input all four rainfall depths manually. The modifications would have included adjusting the *DistArea* raingage sheet inputs and code along with more significant modifications to the *MultipleRuns* sheet to allow the user to input all four rainfall depths for each recurrence interval. However, it was prudent to first check the validity of the existing equations against the NOAA Atlas 14 rainfall depths to determine if the CUHP code changes were justified. Tables 3 and 4 provide a summary of the comparisons between the NOAA Atlas 14 rainfall depths and the rainfall depths calculated using Equations 5-1 and 5-2 from the Rainfall chapter.

Table 3. Comparison of 2-hour Rainfall Depths with Equation 5-1

Average of 45 locations	2-hour Rainfall Depth (inches)						
	2-year	5-year	10-year	25-year	50-year	100-year	500-year
Atlas 14	0.97	1.30	1.59	2.03	2.40	2.80	3.84
Equation 5-1	0.97	1.29	1.57	2.01	2.37	2.75	3.76
Difference	0.00	-0.01	-0.02	-0.02	-0.03	-0.05	-0.08
% Difference	0%	-0.7%	-1.3%	-1.0%	-1.3%	-1.8%	-2.1%

Table 4. Comparison of 3-hour Rainfall Depths with Equation 5-2

Average of 45 locations	3-hour Rainfall Depth (inches)						
	2-year	5-year	10-year	25-year	50-year	100-year	500-year
Atlas 14	1.07	1.41	1.72	2.20	2.60	3.03	4.16
Equation 5-2	1.09	1.44	1.75	2.22	2.62	3.05	4.16
Difference	0.02	0.03	0.03	0.02	0.02	0.02	0.00
% Difference	1.9%	2.1%	1.7%	0.9%	0.8%	0.7%	0%

As evident by the negligible difference between the actual NOAA Atlas 14 rainfall depths and the equation calculated depths, it was determined that the existing equations still adequately represent the rainfall depths. Therefore, no changes are recommended to CUHP and it is recommended that the Rainfall Chapter be updated to acknowledge that the existing equations adequately represent the 2-hour and 3-hour rainfall depths.

Design Storm Distributions

The transition between NOAA Atlas 2 and NOAA Atlas 14 has no impact on the Design Storm Temporal Distributions outlined in the USDCM. The recommendation is to leave the calculation methods for the 2-hour, 3-hour, and 6-hour storm distributions as they are. In effect, this leaves Equations 5-1 and 5-2 embedded in the storm distributions.

Depth Reduction Factor Adjustments

NOAA Atlas 14 did not develop new Depth Reduction Factor (DRF) Adjustment curves when the rainfall depths were updated. Therefore, the recommendation is to leave the current UDFCD methodology for DRF adjustments as it currently stands (based on a combination of NOAA Atlas 2 and the 2010 Carlton Engineering study for Colorado Springs).

Intensity-Duration Curves for Rational Method

The USDCM includes Equation 5-3 for calculating intensity, I (inches per hour) based on the 1-hour point rainfall depth, P_1 (inches) and storm duration T_d (minutes).

$$I = \frac{28.5P_1}{(10+T_d)^{0.786}} \qquad \text{Equation 5-3}$$

The constants in this equation (C_1 = 28.5, C_2 = 10, C_3= 0.786) were originally developed based on a best fit to the NOAA Atlas 2 rainfall depths at varying storm durations. Therefore, as part of the transition to NOAA Atlas 14 it was necessary to determine if the equation was still valid for the updated rainfall depths and durations. This was accomplished using the default location of Denver-Capitol Hill and evaluating the NOAA Atlas 14 rainfall depths for durations from 5 minutes up to 7 days and recurrence intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years. The results from Equation 5-3 were then compared to the actual NOAA Atlas 14 values to evaluate the difference. A new set of coefficients was also developed using Excel Solver to minimize the sum of squared errors (C_1 = 23.1, C_2 = 5.6, C_3= 0.755). Tables 5 and 6 provide summary comparisons for the 10-year and 100-year recurrence intervals, respectively.

Table 5. Intensity-Duration Equation Comparison for 10-year Recurrence Interval

Duration (min)	10-year Intensity (in/hr)				
	Atlas 14 (90% CI)	Current Equation	Difference Current Eqn.	Revised Equation	Difference Revised Eqn.
5	5.16 (4.06 – 6.55)	4.51	-0.65	5.18	0.02
10	3.78 (2.97 – 4.80)	3.60	-0.18	3.86	0.08
15	3.08 (2.41 – 3.90)	3.02	-0.06	3.13	0.05
30	2.16 (1.70 – 2.74)	2.09	-0.07	2.07	-0.09
60	1.33 (1.04 – 1.69)	1.34	0.01	1.31	-0.02
120	0.79 (0.63 – 0.99)	0.83	0.04	0.80	0.01
180	0.57 (0.45 – 0.71)	0.61	0.05	0.60	0.03

Table 6. Intensity-Duration Equation Comparison for 100-year Recurrence Interval

Duration (min)	100-year Intensity (in/hr)				
	Atlas 14 (90% Confidence)	Current Equation	Difference Current Eqn.	Revised Equation	Difference Revised Eqn.
5	9.05 (6.48 – 12.24)	7.84	-1.21	8.99	-0.06
10	6.60 (4.75 – 8.94)	6.25	-0.35	6.71	0.11
15	5.40 (3.86 – 7.28)	5.24	-0.16	5.44	0.04
30	3.74 (2.68 – 5.06)	3.62	-0.12	3.60	-0.14
60	2.31 (1.66 – 3.13)	2.33	0.02	2.27	-0.04
120	1.38 (1.00 – 1.84)	1.44	0.06	1.39	0.01
180	0.99 (0.72 – 1.31)	1.07	0.08	1.03	0.04

As you can see in Tables 5 and 6, the current intensity equation fits the data very well from 15 minutes through 7 days. However, at the 10 minute and 5 minute durations the current equation underestimates the NOAA Atlas 14 intensity more significantly. The large intensity difference at the 5-minute duration is primarily due to the difference in depth being multiplied by 12 (60 minutes / 5 minutes) to get intensity in inches per hour. For example, the 10-year, 5-minute intensity difference of 0.65 in/hr is based on a rainfall depth difference of only 0.05 inches.

The revised set of equation coefficients determined using Excel Solver resulted in a better fit to NOAA Atlas 14 intensity values for short and long durations. Interestingly, the current equation had a better fit at the 30- and 60-minute durations which are commonly used durations in typical Rational Method calculations.

The recommendation is that the current intensity equation should not be changed for the following reasons:

1. The wide 90% confidence intervals around the NOAA Atlas 14 rainfall depths and corresponding intensities encompass the current equation results.
2. The shorter duration depths and intensities from NOAA Atlas 14 are most likely based on exponential equations fit to measured rainfall data for longer durations (e.g. 15-min or 60-min measurements). As a result, the exponential equation tends to increase asymptotically to infinity as the duration approaches zero which is unrealistic with respect to the PMP. The current intensity equation limits the results for short durations.
3. The current equations fit better for the 30-minute and 60-minute durations for all recurrence intervals and even for the 15-minute duration for smaller recurrence intervals (<10 year). This is partially because the revised equation coefficients determined using Excel Solver to minimize the sum of squared errors was weighted more heavily toward the short duration 500-year differences due to their magnitude.