Dewberry

2016 UDFCD Heavy Rainfall Guidance Tool – Performance and Validation

FINAL REPORT

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OVERVIEW

In early 2015, Dewberry constructed a Heavy Rainfall Guidance Tool (hereafter, Tool) for the Urban Drainage and Flood Control District (hereafter, UDFCD or District) to address four crucial questions regarding the summertime daily heavy rainfall threat across the UDFCD area: (i) timing, (ii) location, (iii) intensity and (iv) confidence. The Tool is based on an ensemble of high-resolution weather models that are able to directly simulate thunderstorm rainfall. The original 2015 operational version of the Tool was based on raw model data. In 2016, a Technical Memo documenting the 2015 Tool performance noted, among other things, a noticeable "overconfidence" bias where heavy rainfall was being predicted with higher probability than was being observed. Thus, a significant processing step was added for the 2016 operational season to reduce this bias. This Report provides an analysis of the Tool's performance during 2016 and comments on the potential for future refinement.

Tool description

The Tool accesses hourly Quantitative Precipitation Forecast (QPF) data from up to 23 high resolution weather models from the National Severe Storms Laboratory (NSSL), the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). All models have horizontal resolution of 4 km (2.4 miles) or less allowing for a more realistic representation of thunderstorm-based rainfall compared to conventional, lower-resolution weather models. QPF data from the model "ensemble" is re-gridded to a common ~3.9 km grid across an area centered on the UDFCD. From there, maximum hourly QPF (QPFMAX) and Probability of Exceedance (POE; for example, chance of exceeding 1 inch per hour) are constructed for each of six forecast Zones (See Figure 1). Although UDFCD's area is about 1,600 sq. miles, the Tool covers an area of about 7,300 sq. miles to ensure that rainfall is captured within contributing watershed boundaries that extend outside of the official UDFCD boundary but may be of interest to the District.

Tool output is displayed on a web-based user interface, and is publically available at: http://qpf.udfcd.org. Snapshots of the "Daily Summary" and 'Zone Forecasts" sections of the Tool's web interface are shown in Figure 1 from August 30th, when heavy rainfall was observed across the UDFCD area.

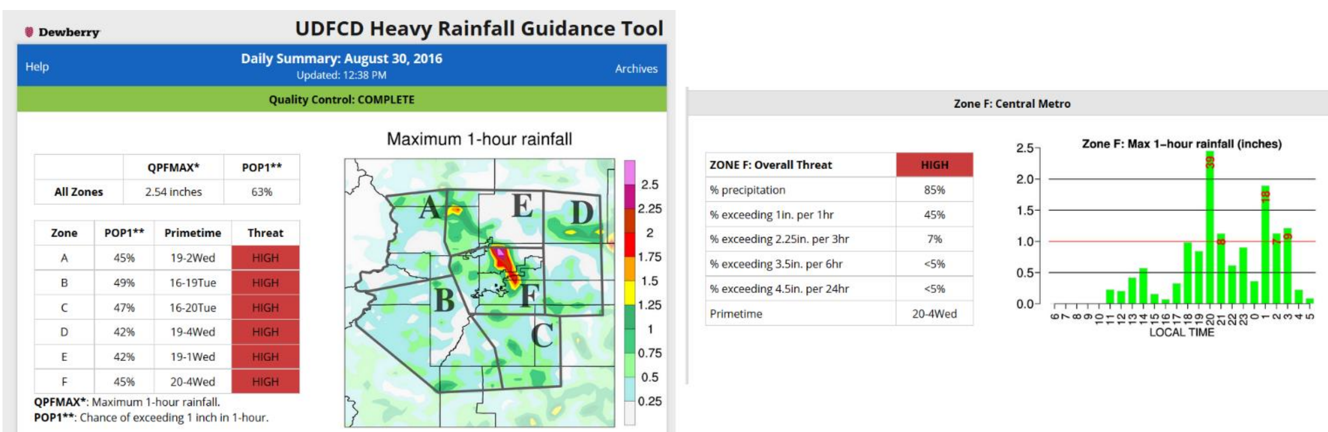

Figure 1: Snapshot of the "Daily Summary" and "Zone-Specific Forecasts" of the Tool's website for the morning update of August 30, 2016. Heavy rainfall was observed across the District during the late afternoon and evening hours.

Archives and daily validation of the Tool's output is available by clicking on the "Archives" link at the top right of the website. This Final Report represents an official validation of the Tool's performance during the 2016 operational season spanning May 1 to September 30. In this report, we first discuss the methodology for the validation effort and present Tool validation statistics, as well as an example of a particular event. Finally, we provide conclusions and recommendations of how two years' worth of Tool experience can be used to improve performance in subsequent seasons.

METHODOLOGY

Validating the performance of rainfall forecasts is notoriously difficult due to the large spectrum of possible metrics. This is especially relevant when data from multiple weather models is involved, as is the case with the Tool. For the purposes of this report, we must recall that the Tool was designed to detect the *maximum* rainfall amount on any given day. While it is possible and potentially useful to investigate other aspects of rainfall statistics (for example, distribution across the domain, relation to climatology, etc), the primary focus of this report will be on analyzing maximum rainfall amounts. Furthermore, since we are interested in relatively short-term rainfall capable of producing flash flooding, as in 2015, **the focus of the validation will be on the 1-hour time period**. We perform a validation for each of the six Forecast Zones as well as across the entire forecast area.

Rainfall Observations

We used UDFCD's 198 active ALERT gauges across the District as one of the primary inputs to the validation. Raw tipping bucket data was processed into total hourly accumulation. To supplement the ALERT data, we use gridded 4-km gauge-adjusted radar estimates provided by the National Oceanic and Atmospheric Administration's Stage IV product. The benefit of Stage IV is that it has full coverage in space and is especially useful due to UDFCD's proximity to the Denver NEXRAD Doppler radar. However, Stage IV's limitations are that:

(i) because it is first derived from radar reflectivity (and then gage corrected) it does not always accurately reflect the true rainfall, and

(ii) because the Stage IV product is on a 4-km grid, this may act to smooth out rainfall amounts, especially for spatially explicit storms. We noted in 2015 that Stage IV hourly rainfall is *lower* than corresponding ALERT data 67% of the time. However, during the 2016 operational season, Stage IV was actually *higher* than its ALERT counterpart. This could signify that more robust methods were used for the Stage IV product, or perhaps that rainfall more frequently missed ALERT gages during 2016.

For our validation, ***we use the maximum hourly rainfall from either ALERT or Stage IV***. This represents the best readily available estimate of maximum rainfall, which is what the Tool is designed to forecast. Hourly maximum rainfall for each day is presented in Appendix A, along with two other supporting observations: maximum 24-hour CoCoRaHS precipitation accumulation across the Zones and whether or not hail above 1 inch was observed. The former is used to correct for instances where ALERT rainfall was suspiciously much higher than Stage IV (e.g. snowmelt, hail, etc); 13 such instances are flagged, though each occurred in situations with very light to no rainfall. The latter is used to quality control Stage IV data that can overestimate rainfall due to hail scattering of the radar beam; no obvious overestimation was noted during this season. Appendix B provides Zone-specific maximum rainfall amounts, and morning threat level.

Table 1 describes the characteristics of the six forecast zones. Five of the six zones were roughly 1,000 square miles, while Zone B (Southern Foothills) was about 2,000 square miles due to its extension to the Continental Divide. Note that the total zone area decreased by about 300 sq. mi. since 2015 due to truncation of zones A and B at the Continental Divide.
Table 1 also shows that each Zone had a widely varying number of (active) ALERT gauges within it, ranging from zero in Zone D (Plains) to 92 in Zone F (Central Metro). The right two columns of Table 1 show rainfall statistics for the 2016 season. The number of hours of rainfall exceeding 0.5 inch ranged from 24 hours in Zone A to 61 in Zone C; in 2015, the range was from 29 to 87 hours. There were 189 total hours where at least one Zone measured 0.5 inches in 1 hour; in 2015, this was observed for 224 hours. Regarding the more important threshold of 1 inch over 1 hour, there were 39 such hours this season compared to 72 hours last season. Last season, Zone C alone observed 25 separate hours when at least 1 inch fell; this year, Zone F held the highest value, but with only 12 hours. Thus, **2016 experienced considerably fewer heavy rainfall days and hours compared to 2015**. Finally, note that in the two right columns of Table 1, the sum of the values across each Zone do not equal

the total: this occurs because there are often instances when multiple zones record rainfall accumulations exceeding these thresholds *simultaneously*.

Table 1: Summary of forecast Zones.

Forecast Zone	Area (sq. mi.)	# of ALERT gauges	# of hours >= 0.5 in/hr	# of hours >= 1.0 in/hr
(A) Northern Foothills	1,031	48	24 hours	2 hours
(B) Southern Foothills	1,961	25	43	5
(C) Palmer Divide	933	20	61	11
(D) Plains	1,283	0	55	8
(E) Northern Metro	1,051	13	37	6
(F) Central Metro	1,043	92	45	12
All Zones	**7,302**	**198**	**189**	**39**

Threat Classification System

Although the Tool outputs forecasted rainfall amounts, its broader purpose is to act as a decision support tool. Accordingly, we developed a classification table that translated the Tool's "raw" output into one of four Threat Levels: Low, Moderate, High and Very High. The Threat Level is based on two considerations: rainfall intensity and probability of exceedance. The following four rainfall duration thresholds are used to identify a possible threat: **1 inch per 1 hour**, **2.25 inches per 3 hours**, **3.5 inches per 6 hours** and **4.5 inches per 24 hours**. Using multiple durations captures the wide array of rainfall events, ranging from very intense, short-duration events (e.g. 1 hour) to low-to-moderate intensity, but long-duration events (e.g. 6+ hours). In addition to the threshold itself, we use the probabilistic capabilities of the Tool to quantify the confidence of a threshold being exceeded. Intuitively, a higher probability of exceedance warrants a higher threat level. The classifications are determined using the protocol in Table 2. For reference, Appendix D provides a breakdown of QPF-max for each ensemble member.

Table 2: Threat classification system

Threat	Description (POE = Probability of Exceedance)
LOW	Case 1: A threshold is exceeded with POE >= 9% OR Case 2: A threshold is exceeded with POE >= 8% and the district-wide POE >= 40%
MODERATE	A threshold is exceeded with POE >= 21%
HIGH	A threshold is exceeded with POE >= 40%
VERY HIGH	A threshold is exceeded with POE >= 60%

The threat classification table was originally developed in 2015 using the professional opinion of Dewberry's meteorologists and floodplain managers. Table 2 incorporates 2016's updates to reflect the gained experience from 2015's operations. Generally speaking, all probability of exceedance thresholds were *lowered* in 2016 because 2015's forecasts were overly confident (see 2016 Technical Memo). Table 3 shows the number of threats identified for each Zone, categorized by threat level (note that there were no "Very High" threats this season). Of the 153 days in the operational season, there were 35 days with at least a "Low" threat, 19 days with a "Moderate" threat and 7 days with a "High" threat in at least one of the Zones. This represents a significant drop from the 2015's 77 days where at least a "Low" flood threat was present. This is partially attributed to a less active weather pattern, but also partially due to changes in the protocol of issuing a threat based on the 2016 Technical Memo's improvements (as discussed in more detail later).

Table 3: 2016 Threat Level Summary, by Zone

Zone	None	Low	Mod	High	Very High
(A) Northern Foothills	123	18	9	3	---
(B) Southern Foothills	121	17	12	3	---
(C) Palmer Divide	120	17	12	3	1
(D) Plains	123	14	10	5	1
(E) Northern Metro	125	15	9	4	---
(F) Central Metro	121	19	10	3	---

VALIDATION

Seasonal Statistics

a. Worst-case scenario analysis

Figure 3 shows the hourly evolution of maximum 1-hour observed rainfall (QPE-max; thin black line) and maximum 1-hour forecasted rainfall (QPF-max; green bars) across all Forecast Zones. The x-axis tick marks are plotted at 6PM every day, which roughly coincides with the most active time of day for rainfall across the area. The climatological cycle of rainfall activity is easily seen, especially in the time series for June and July: this is attributed to the daily solar heating of the ground by the sun causing instability that can generate thunderstorms. Figure 3 shows that although many days saw precipitation fall somewhere across the Forecast Zones, the occurrence of rainfall exceeding 1 inch in 1 hour was relatively infrequent. However, unlike 2015 when most of the heavy rainfall days occurred surprisingly early in the season, 2016 was closer to climatological averages with most of the heavy rainfall occurring in June – August. Table 4 shows the # of days exceeding 0.75 and 1 inch in 1 hour as a function of month, as well as the climatological probability of observing heavy rainfall. July experienced the highest number of days exceeding 0.75 inch in 1 hour with 11, while June and August both experienced 6 days with 1 inch in 1 hour rainfall accumulations being exceeded. The highest hourly rain accumulation occurred on August 30th when 2.08 inches was observed.

Table 4: Monthly statistics of heavy rainfall occurrence during the 2016 season.

	# of days with hourly rainfall exceeding		Climatological daily probability of exceeding	
Month	**0.75 inch**	**1.0 inch**	**0.75 inch / hr**	**1.0 inch / hr**
May	9	4	5%	3%
June	8	6	7	4
July	11	5	20	14
August	9	6	13	7
September	2	2	4	4

One important characteristic of the Tool is to estimate the highest *realistic* rainfall intensity given the atmospheric conditions. From a theoretical standpoint, on any given day the maximum potential rainfall intensity will always be greater than or equal to the actual observed rainfall intensity since many factors have to conspire in perfect coincidence for such rainfall to occur. Note that this is more ambitious than simply using climatology. Stated differently, using historical ALERT data, one could simply state every morning that today's hourly QPF-max is 2.68 inches, which roughly corresponds to a 1 in 100 year event for the Denver metro area. This would "verify" for a vast majority of, if not all days, but would also cause an overwhelming amount of false alarms. Instead, the Tool uses the atmospheric conditions as simulated by the weather model ensemble to provide a constraint on the daily QPF-max.

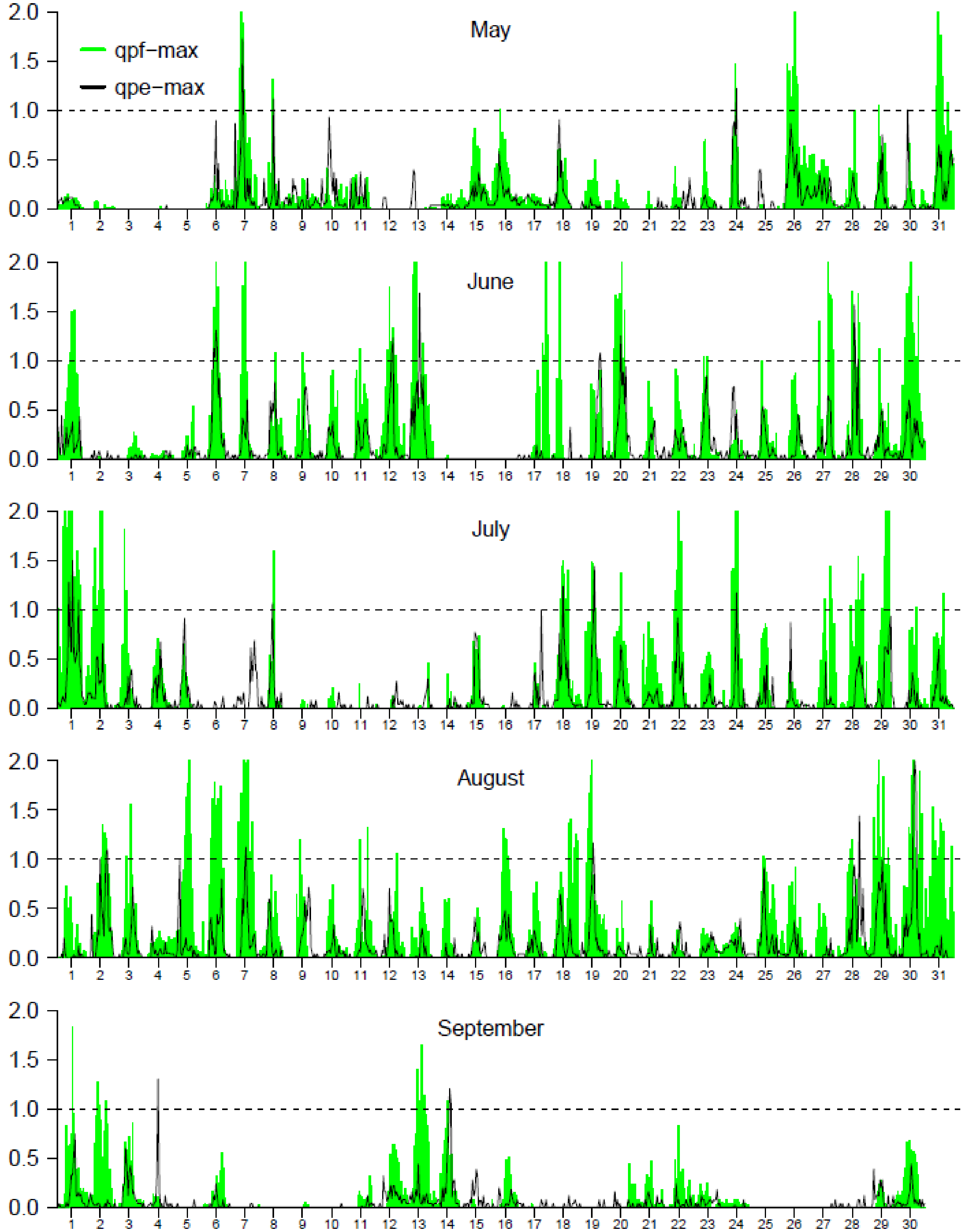

Figure 3: Maximum hourly observed rainfall (black line) versus forecasted rainfall (green bars). The 1 inch in 1 hour threshold line is included for reference. Unit is inches of accumulation over a period of 1 hour, measured on the hour. The x-axis tick marks correspond to 6PM, Mountain Time, of the indicated date.

The number of days when QPF-max exceeded various thresholds is shown in Table 5. For reference, Table 5 also shows the number of days when observed rainfall exceeded these thresholds. An interesting pattern is found where for low exceedance thresholds, QPF-max only slightly overestimates the observed number of days but this disparity grows with higher thresholds. For example, for the 1 inch in 1 hour threshold, the Tool forecasts such an event to occur about 3 times more frequently than it does. This suggests that heavier rainfall is more difficult to predict because many factors are required to act together. However, this is a useful metric to track and it is expected that further improvement of the Tool's methodology should aim to lower this ratio.

Table 5: Comparison of QPF-max with observed exceedance frequency.

	# of days when hourly rainfall accumulation exceeded:			
	0.25 inch	**0.50 inch**	**0.75 inch**	**1.00 inch**
QPF-max	126	108	89	72
QPE-max	100	62	39	23
QPF-max / QPE-max	1.3	1.7	2.3	3.1

Table 6: Comparison of hourly observed and forecasted maximum rainfall across each Zone.

a) For hourly rainfall >= 0.25 inches

Zone	Absolute timing	+/- 2 hours	# of hours >= 0.2"
A	50%	73%	132
B	60%	77%	216
C	50%	76%	184
D	61%	80%	153
E	40%	67%	114
F	32%	65%	166
All Zones	64%	83%	530

b) For hourly rainfall >= 0.5 inches

Zone	Absolute timing	+/- 2 hours	# of hours >= 0.5"
A	33%	67%	24
B	47%	67%	43
C	33%	66%	61
D	55%	78%	55
E	27%	59%	37
F	20%	56%	45
All Zones	57%	81%	189

c) For hourly rainfall >= 1.0 inches

Zone	Absolute timing	+/- 2 hours	# of hours >= 1.0"
A	0%	0%	2
B	60%	60%	5
C	36%	55%	11
D	38%	75%	8
E	17%	50%	6
F	8%	33%	12
All Zones	44%	69%	39

Figure 3, as well as Table 5, suggest that hourly QPF-max was higher than QPE-max for a vast majority of the season, which was true for both moderate and heavy rainfall intensity. This is quantified further in Table 6, which shows the percentage of hours during which QPF-max was higher than QPE-max. Across all Forecast Zones, QPF-max was higher 64%, 57% and 44% of the time for the 0.25, 0.50 and 1.00 inch thresholds, respectively (leftmost column). However, this "absolute timing" analysis does not allow for any uncertainty in the timing of the rainfall forecast. If this constraint is slightly relaxed using a +/- 2 hour window, then the percentage of time QPF-max is higher increases to 83%, 81% and 69% of the time respectively. These numbers are slightly lower than the 97%, 85% and 76% from 2015. This is likely in part due to the bias-correcting of several high-biased weather models contributing to the ensemble. However, **the frequencies shown in Table 6 demonstrate the Tool's utility in estimating the *realistic* worst-case scenario**.

Table 7 shows the seven days for which QPF-max underestimated the observed rainfall. Similar to 2015, on five of those seven days, heavy rainfall was very localized and limited to only 1 Forecast Zone. Furthermore, on six of the seven days, QPF-max exceeded 0.5 inch, indicating that the Tool underestimated, but did not miss rainfall altogether. An analysis of the atmospheric conditions during these days is ongoing to determine if they can be used to correct future forecasts.

Table 7: Comparison of days when rainfall was underestimated

Date	Max hourly observed	Hourly QPF-max	# of Zones with > 1 in per hour
May 8	1.12	0.54	1
May 30	1.01	0.66	1
June 19	1.08	0.89	1
June 28	1.56	0.87	2
August 28	1.44	1.19	1
September 4	1.31	0.13	1
September 14	1.21	1.08	2

b. Contingency Table

The Contingency Table is a useful metric for evaluating the effectiveness of the Tool's forecasts; Table 8 shows a sample table.

Table 8: Schematic of contingency table

		Heavy Rainfall Forecasted	
		NO	YES
Heavy Rainfall Observed	NO	HIT	FALSE ALARM
	YES	MISS	HIT

By adding up all of the total Hits and dividing by the number of total days (153), we find the "Accuracy" rate. Meanwhile, we are also interested in the quantifying the occurrence of Misses and False Alarms; these statistics are essential for guiding future refinement of the Tool. We run these calculations for each zone separately. For completeness and a reference point, we also calculate a contingency table across all zones to answer the broader question: "if a threat was forecast anywhere in the domain, did it verify anywhere in the domain?" Such a domain-wide contingency table is likely to yield higher Accuracy numbers than each Zone since there is more leniency in the spatial dimension. However, it is still a useful metric given the imperfect nature of heavy rainfall prediction.

Table 9 panels (a) through (g) present contingency tables for each Zone, including one for the entire Tool domain.

Table 9: Contingency tables of the Tool's performance, by location

		Heavy Rainfall Forecasted		
	a)Zone A	**NO**	**YES**	Accuracy: 81%
Heavy Rainfall	**NO**	**123 (80%)**	**29 (19%)**	False Alarm: 19%
Observed	**YES**	**0**	**1 (1%)**	Misses: 0%
	b)Zone B			Accuracy: 81%
Heavy Rainfall	**NO**	**123 (78%)**	**28 (18%)**	False Alarm: 18%
Observed	**YES**	**1 (1%)**	**4 (3%)**	Misses: 1%
	c)Zone C			Accuracy: 80%
Heavy Rainfall	**NO**	**117 (76.4%)**	**28 (18%)**	False Alarm: 18%
Observed	**YES**	**3 (2%)**	**5 (3.3%)**	Misses: 2%
	d)Zone D			Accuracy: 81%
Heavy Rainfall	**NO**	**119 (78%)**	**26 (17%)**	False Alarm: 17%
Observed	**YES**	**4 (3%)**	**4 (3%)**	Misses: 3%
	e)Zone E			Accuracy: 80%
Heavy Rainfall	**NO**	**120 (78%)**	**26 (17%)**	False Alarm: 17%
Observed	**YES**	**5 (3%)**	**2 (1%)**	Misses: 3%
	f)Zone F			Accuracy: 82%
Heavy Rainfall	**NO**	**120 (78%)**	**26 (17%)**	False Alarm: 17%
Observed	**YES**	**1 (1%)**	**6 (4%)**	Misses: 1%
	g)All zones			Accuracy: 80%
Heavy Rainfall	**NO**	**108 (71%)**	**20 (13%)**	False Alarm: 13%
Observed	**YES**	**10 (7%)**	**15 (10%)**	Miss: 7%

Table 9 shows the Tool's performance was about equal across all zones with accuracies near 80%. This is markedly higher than 2015's accuracy of 69%, shown in Table 10. The main reason for this increased accuracy is a much lower False Alarm rate, going from 29% in 2015 to 13% presently. However, the lower False Alarm rate was also accompanied by an increase in the Miss rate, from 2% in 2015 to 7% in 2016. A low Miss rate is important for the Tool's utility. Thus, it is recommended that the Probability of Exceedance thresholds be lowered for the 2017 season, which will lower the Miss rate (but raise the False Alarm rate). The exact amount of tweaking should be done using a case by case analysis of misses and false alarms.

Table 10: Contingency table from 2015.

		Heavy Rain Forecasted		
	All zones	**NO**	**YES**	Accuracy: 69%
Heavy Rainfall	**NO**	**73 (48%)**	**44 (29%)**	False Alarm: 29%
Observed	**YES**	**3 (2%)**	**33 (21%)**	Miss: 2%

Table 11 presents a comparison of how the 2015 forecast methodology would perform over the 2016 season. In other words, this is the contingency table that results if no post-processing is done on the weather model ensemble. While the overall accuracy drops significantly from 80% to 62%, the Miss rate also drops from 7% to less than 1%. Associated with this is an increase in the False Alarm rate from 13% to 37%. Thus, the main impact of the 2016 upgrades were to significantly lower the False Alarm rate at the expense of raising the Miss rate. Going forward, it is recommended that the processing algorithms be tweaked so that a balance is achieved between a lower Miss rate without excessively raising the False Alarm rate.

Table 11: Contingency table for 2016 using the 2015 methodology

		Heavy Rain Forecasted		
	All zones	**NO**	**YES**	Accuracy: 62%
Heavy Rainfall	**NO**	**73 (48%)**	**55 (37%)**	False Alarm: 37%
Observed	**YES**	**1 (0.6%)**	**24 (14%)**	Miss: 1%

Table 12 presents the Accuracy (or "Hit" rate) as a function of threat level. A robust forecasting system should have a higher hit rate as the threat level increases. This is confirmed in Table 12, which shows that a Low threat is verified 25% of the time, a Moderate threat is verified 50% of the time, while High and Very High threats are verified 100% of the time. A notable caveat is that there were only 4 High and Very High threat days. However, Table 12 clearly shows that as the threat level increases, the chances of an event occurring increase also confirming the classification methodology of Table 2 has merit.

Table 12: Hit and False alarm rate as a function of threat level across all Forecast Zones (compare with Table 9, panel g).

Threat Level	Hit	False Alarm
Low	25%	75%
Moderate	50%	50%
High*	100%	0%
Very High*	100%	0%

**indicates limited sample of events*

Table 13 presents the Equitable Threat Score (ETS), which can span from -1/3 to 1; negative values indicate no skill compared to climatology while 1 indicates a perfect score. The ETS is a binary (i.e. non-probabilistic) method that assesses forecast performance by considering Hits, Misses and False Alarms. Because the ETS is binary whereas the Tool's output is probabilistic, Table 13 shows six ETS values using different Probability of Exceedance (POE) thresholds for whether or not a Heavy Rain event was forecasted. For reference, two ETS values are calculated: one using the raw model output, and one using the post-processed methodology introduced in 2016. The first finding is that regardless of the POE threshold, all ETS values are positive, indicating value compared to climatology. The second finding is that while the raw model output performs slightly better for more marginal events where the POE is between 10 and 40%, the post-processed method performs sharply better for higher confidence events. This confirms that the 2016 post-processing method is improving the forecast performance, compared to the original method based on raw model data.

Table 13: Equitable Threat Score using raw model output and the 2016 processing method.

	Equitable Threat Score using POE threshold of:					
	10%	**20%**	**40%**	**50%**	**60%**	**70%**
Raw	0.14	0.22	0.21	0.13	0.06	0.06
Processed	0.10	0.15	0.19	0.23	0.23	0.26

Case Study: August 30th, 2016

While the approach of aggregate statistics, as presented up to this point, is a comprehensive way to measure the Tool's performance it has the limitation of funneling the outcome of many events into one statistic. Moreover, the threshold-based approach (e.g. exceeding 1 inch in 1 hour) treats two potentially disparate events equally. For example, a 1-hour QPF-max of 1.05 inches would be treated the same as 2.00 inches even though impacts likely scale exponentially. To achieve the goal of the Tool being an effective decision support tool, it must perform well in forecasting impactful events. Here, we investigate one such event, August 30th, 2016, that produced heavy rainfall across many parts of the District.

The morning upper-level weather map is shown in Figure 4. A rather innocuous pattern is seen, with a weak upper-level ridge situated north of Colorado, while a weak trough axis is noted across the Four Corners region. Despite the relatively weak upper-level forcing, high moisture content was seen at the surface with dew point temperatures exceeding 60F along the Colorado/Kansas border (not shown). Some of this moisture was forecasted to move westward towards the District, potentially igniting storms capable of very heavy rainfall.

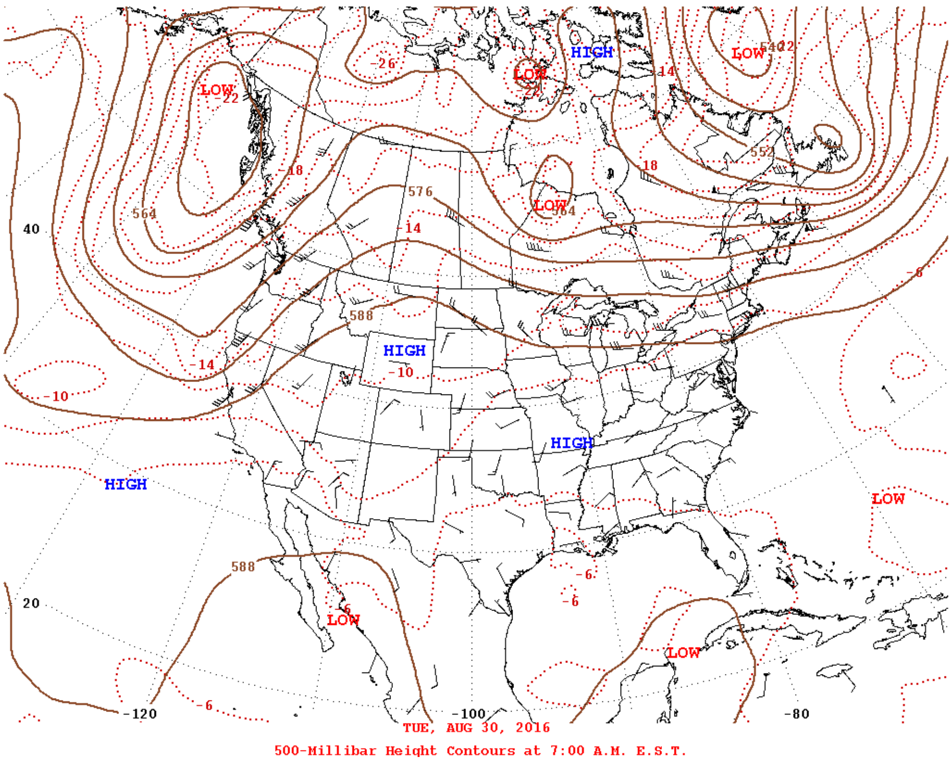

Figure 4: Morning upper-level weather chart on August 30th, 2016. Source: Weather Prediction Center.

Despite the seemingly marginal conditions, the Tool (Figure 5) showed an alarming forecast of a High threat across the District with both the morning and afternoon updates. A QPF-MAX of 2.54 inches in 1 hour was shown with a nearly 50% of exceeding 1 inch in 1 hour across all Zones, with the highest oddest being over Zones C, E and F. These are some of the highest probabilities seen all season (see Appendix C). Also of interest was the prolonged Primetime window (Figure 6), as late as 4AM in Zone D and F due to the uncertainty in how fast and for how long the moist easterly fetch would be maintained. In the morning, the Tool's forecast was at odds with the National Weather Service forecast and to a lesser extent the F2P2 Heavy Precipitation Outlook. For example, the HPO that morning called for up to 0.90 inches of rainfall in 45 minutes, along with a Moderate message potential.

As the day progressed, there was little change to the forecast of weather features and even as late as 5PM it was not clear that the Tool's High threat would verify. However, around 5PM, thunderstorms first began in the Plains east of I-25, quickly sending moist outflow boundaries south and west and igniting more storms. Several hours of very heavy rainfall were observed across two main areas (Figure 7): the northern part of Denver Metro and in the foothills above 6,000 feet west of highway 93 between Golden and Boulder. In particular, the District's ALERT gage at the Betasso treatment plant reported 2.99 inches of rainfall in a 60 minute period between 8:45 and 9:45PM. Though, it is interesting that the maximum 60 minute rainfall, as measured by the conventional top-of-the-hour method, only recorded 2.08 inches. It is recommended that a conversion factor be implemented in the future to estimate unconstrained QPF (i.e. that which is *not* measured at a constant frequency) based on the constrained QPF that is output by atmospheric models (e.g. Bonnin et al. 2006).

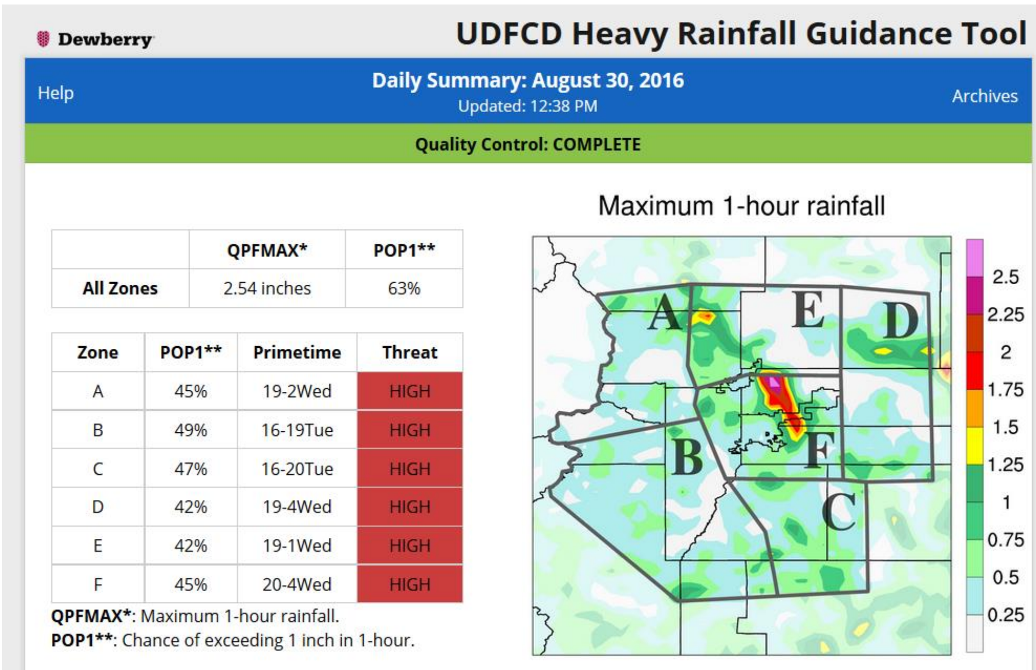

Figure 5: Daily Summary from the Tool as of the afternoon update of August 30th, 2016.

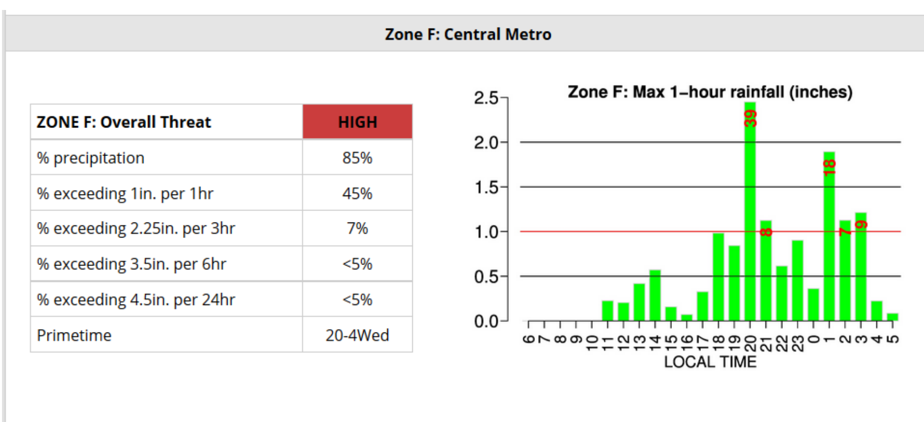

Figure 6: Zone-specific summary of heavy rainfall forecasts for Zone F (Central Metro).

The August 30th event is a particularly stark example of the Tool's utility. However, the use of that example is not meant to suggest the Tool can always pinpoint the location, timing and intensity with such skill. Instead, this example is used to suggest that the Tool's forecast is objective and bias-corrected to the District's rainfall climatology, giving it a different physical basis compared to conventional more human-centric forecasts such as the NWS and F2P2. The latter tend to be experience-driven and are certainly useful, but are limited in marginal situations due to the myriad of factors that play a role in creating a heavy rainfall event. However, because these marginal events arise rather frequently, it is of essence to improve their predictability. Our conclusion, as now supported by two years of operational experience, continues to be that forecasts of heavy rainfall will continue to improve in the future due to more realistic weather modeling and associated post-processing efforts. Despite this fact, the human quality-control aspect will be critical to put a stamp of approval on any given forecast. Collectively, this describes the essence of the Tool.

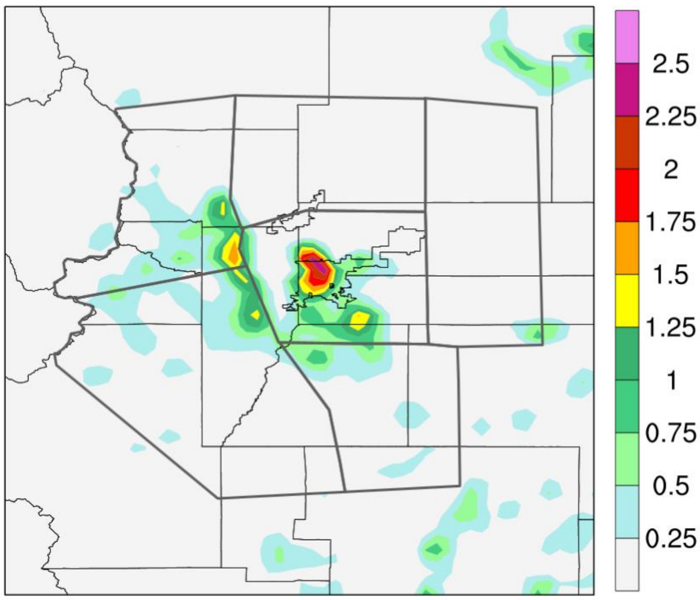

Figure 7: QPE, in inches, from NOAA Stage IV precipitation estimates for the 24-hour period ending 6AM on August 31st, 2016.

CONCLUSIONS

The UDFCD Heavy Rainfall Guidance Tool concluded its second season of operations on September 30th, 2016. The Tool incorporates a large number of state of the art high-resolution weather models to objectively estimate the chances of seeing heavy rainfall across the District. The Tool's methodology underwent a significant overhaul during the start of the 2016 season to incorporate bias-correcting methods.

Heavy rainfall occurred significantly less frequently in 2016 compared to 2015. For example, in 2016, there were 39 hours during which 1 inch of rainfall was observed; this compares to 72 hours in 2015. Similarly, there were 25 days that recorded rainfall exceeding 1 inch in 1 hour (Table 1); this is down from 35 days in 2015. Moreover, the seasonality of the rainfall was also notably different in 2016: it was closer to expected climatology. Whereas in 2015, May and June saw particularly frequent heavy rain; in 2016, June through August was the more active period. In all, 2016 provided for a good opportunity to observe Tool performance in a different set of conditions compared to 2015.

Performance in 2016 continued to be encouraging across a variety of metrics. First, the Tool provided a good estimate of the *realistic* worst-case scenario of the daily heavy rainfall threat. This was manifested by its forecasted maximum rainfall rates being at or above those that were observed on a vast majority of days and hours with heavy rainfall (see Table 6). For example, allowing for a +/- 2 hour window, maximum QPF was higher than observed QPE 81% of the time for all events exceeding 0.5 inch in 1 hour. There were 7 days where QPF was *lower* than QPE, though 5 of these 7 days had very isolated heavy rainfall that continues to present a forecasting challenge.

Contingency tables monitoring Hits, False Alarms and Misses showed that the Hit rate was near 80% in 2016, up sharply from 2015's 69% (Tables 9 – 11). The most notable reason for this is the processing algorithms implemented in 2016 (Dewberry, 2016) resulted in a steep drop in the False Alarm rate from 29% in 2015 to 13% in 2016 due to a better grasp on 2015's "overconfidence" problem. However, it is essential to note that the higher Hit rate and lower False Alarm rate was also accompanied by an increase in the Miss rate from 2% in 2015 to 7% in 2016. It is not uncommon for performance to behave in such a manner, but it is recommended that algorithms be tweaked to lower the Miss rate (even at the expense of a slightly higher False Alarm rate).

In conclusion, the findings of this Final Report suggest the Heavy Rainfall Guidance Tool continues to show utility in increasing lead time and accuracy of heavy rainfall forecasts for the District. Moreover, one of the Tool's main benefits is the ability to consistently update its methodology to include the latest data, the fruitful results of which can be seen in 2016 improved performance compared to 2015.

RECOMMENDATIONS

Several recommendations were identified during the preparation of this report. They are listed in order of suggested priority:

- Update 2016 processing equations to incorporate the 2016 validation statistics. Use the methods outlined by the 2016 Technical Memo (i.e. ensemble statistics, as well as incorporation of meteorological variables) as a foundation. Of additional particular interest is the ability to add a seasonally-dependent processing step as was suggested in the 2016 Technical Memo. Given that heavy rainfall occurrence followed the expected climatology during 2016, this should be attainable.
- In order to minimize the Miss rate lower Probability of Exceedance thresholds that signals a "threat". However, this must be done while keeping in mind that the false alarm rate will tend to increase. Thus, investigate where the optimal balance lies.
- Investigate potential to implement a conversion factor in QPF to better convey the true rainfall rates for instances where rainfall occurs between the conventional top of the hour measurement methods.

REFERENCES

Bonnin, G.M. et al., 2006: Precipitation-Frequency Atlas of the United States, Volume 2. National Oceanic and Atmospheric Administration, United States Department of Commerce, Silver Spring, MD.

Dewberry, 2015: UDFCD Heavy Rainfall Guidance Tool – Performance and Validation, 2015 Final Report. Submitted to the Urban Drainage and Flood Control District on November 2, 2015.

Dewberry, 2016: UDFCD Heavy Rainfall Guidance Tool – Upgrades for 2016 Operational Season. Submitted to the Urban Drainage and Flood Control District on May 27, 2016, revised on July 26, 2016.

APPENDIX A – DAILY OBSERVATIONS (ALL ZONES)

The table below shows daily summaries of the following values across all six Forecast Zones (starting from left to right): (1) the date (spans the 24-hour period starting on 8AM of the indicated date), (2) maximum 1-hour rainfall observed at ALERT gages, (3) the # of Forecast Zones where over 0.25 inches per hour of rainfall was observed, (4 & 5) the same two parameters as columns 2 and 3 except using the NOAA Stage IV gridded precipitation estimate, (6) the maximum *24-hour* rainfall from the CoCoRaHS observation network, (7) whether hail greater than or equal to 1 inch was reported within the Forecast Zones and finally (8) whether a correction was applied to estimate the maximum daily 1-hour rainfall accumulation. A correction was required 13 times during instances where ALERT gages recorded rainfall that was significantly higher than either the gridded estimates or CoCoRaHS. In Column 2, raw ALERT readings are shown in parenthesis, while corrected values are shown outside of the parenthesis. Column 9 shows the overall maximum 1-hour rainfall accumulation, which is taken to be the higher of the Stage IV gridded data and the ALERT gages. Yellow shading signifies values between 0.75 and 1.0 inch in 1 hour, while the pink shading signifies values exceeding 1 inch in 1 hour.

1	2	3	4	5	6	7	8	9
Date	**ALERT**	**# Zones > 0.25**	**QPE**	**# Zones > 0.25**	**Coco**	**Hail > 1 in.**	**Correction**	**QPE-MAX**
5/1	0.12	0	0.09	0	0.31			0.12
5/2	0.01 (0.52)	3	0	0	0.01		Y	0.01
5/3	0 (0.59)	1	0	0	0		Y	0.00
5/4	0 (0.08)	0	0	0	0		Y	0.00
5/5	0	0	0	0	0			0.00
5/6	0.08	0	0.9	4	0.17			0.90
5/7	0.87	5	1.73	6	0.88	Y		1.73
5/8	1.12	3	NA	NA	0.65			1.12
5/9	0.31	1	0.12	0	0.41			0.31
5/10	0.88	4	0.94	4	0.83			0.94
5/11	0.31	1	0.38	2	0.34			0.38
5/12	0.12	0	0	0	0.02			0.12
5/13	0.4	1	0	0	0.11			0.40
5/14	0.04	0	0.06	0	0.15			0.06
5/15	0.24	0	0.37	2	0.81			0.37
5/16	0.56	4	0.59	4	1.11			0.59
5/17	0.16	0	0.08	0	0.4			0.16
5/18	0.91	2	0.49	1	0.4			0.91
5/19	0.12	0	NA	0	0.45			0.12
5/20	0.04	0	0.02	0	0.01			0.04
5/21	0.12	0	0	0	0			0.12
5/22	0.32	1	0.27	1	0.71			0.32
5/23	0.12	0	0.15	0	0.3			0.15
5/24	0.4	1	1.23	5	0.83	Y		1.23
5/25	0.4	1	0.08	0	1.01			0.40
5/26	0.72	3	0.87	6	4.15	Y		0.87
5/27	0.32	3	0.36	1	0.71			0.36
5/28	0.16	0	0.37	2	1.47			0.37

5/29	0.12	0	0.76	4	0.37			0.76
5/30	0.04	0	1.01	2	0.35			1.01
5/31	0.6	4	0.65	4	1.46			0.65
6/1	0.44	1	0.43	3	0.48			0.44
6/2	0.08	0	0	0	0.15			0.08
6/3	0.04	0	0.02	0	0			0.04
6/4	0.08	0	0.01	0	0			0.08
6/5	0.12	0	0.14	0	1.84			0.14
6/6	1	4	1.3	6	2.81	Y		1.30
6/7	0.6	1	0.53	4	0.83	Y		0.60
6/8	0.52	1	0.78	3	0.75			0.78
6/9	0.73	1	0.72	4	0.76			0.73
6/10	0.2	0	0.38	2	0.61			0.38
6/11	0.4	2	0.4	6	0.51			0.40
6/12	0.76	4	1.23	6	1.08			1.23
6/13	1.68	3	1.2	5	2.41	Y		1.68
6/14	0.01 (0.12)	0	0	0	0.01		Y	0.01
6/15	0.01 (0.12)	0	0	0	0.01		Y	0.01
6/16	0 (0.08)	0	0	0	0		Y	0.00
6/17	0.08	0	0.14	0	0.07			0.14
6/18	0.32	1	0	0	0.03			0.32
6/19	1	1	1.07	3	1.28	Y		1.07
6/20	0.88	3	1.25	3	1.31	Y		1.25
6/21	0.24	0	0.39	2	0.27			0.39
6/22	0.16	0	0.32	2	0.4			0.32
6/23	0.84	3	0.68	5	1.18			0.84
6/24	0.56	2	0.73	5	0.56			0.73
6/25	0.48	3	0.53	3	0.49			0.53
6/26	0.16	0	0.45	2	0.31			0.45
6/27	0.6	1	0.64	5	0.3			0.64
6/28	1.56	2	1.01	5	1.89	Y		1.56
6/29	0.32	1	0.5	4	1.27	Y		0.50
6/30	0.48	1	0.6	6	1.32			0.60
7/1	1.28	3	1.5	5	1.67	Y		1.50
7/2	0.52	2	0.66	2	0.96			0.66
7/3	0.28	1	0.4	2	0.51			0.40
7/4	0.2	0	0.67	3	0.4			0.67
7/5	0.16	0	0.92	4	0.35			0.92
7/6	0	0	0.07	0	0.02			0.07
7/7	0.16	0	0.69	2	0.6	Y		0.69
7/8	0.36	1	1.06	4	0.45			1.06
7/9	0 (0.16)	0	0	0	0		Y	0.00
7/10	0.16	0	0	0	0.02			0.16
7/11	0.12	0	0.01	0	0			0.12

7/12	0.08	0	0.28	1	0			0.28
7/13	0.12	0	0.3	1	0.24			0.30
7/14	0.12	0	0.1	0	0.22	Y		0.12
7/15	0.62	4	0.77	6	2.5	Y		0.77
7/16	0.16	0	0.03	0	0.24			0.16
7/17	0.32	1	1	3	0.66	Y		1.00
7/18	1.24	5	0.73	5	1.3			1.24
7/19	1.44	4	0.88	6	1.57			1.44
7/20	0.64	2	0.57	3	0.55			0.64
7/21	0.2	0	0.17	0	0.21			0.20
7/22	0.92	2	0.52	3	0.72			0.92
7/23	0.12	0	0.34	2	0.31			0.34
7/24	0.28	1	1.17	6	0.87			1.17
7/25	0.32	1	0.44	2	0.12			0.44
7/26	0.08	0	0.87	1	0.44			0.87
7/27	0.12	0	0.48	1	0.17			0.48
7/28	0.44	1	0.53	5	0.3	Y		0.53
7/29	0.16	0	0.94	2	0.34	Y		0.94
7/30	0.16	0	0.36	1	0.08			0.36
7/31	0.2	0	0.6	2	0.53			0.60
8/1	0.2	0	0.03	0	0.01			0.20
8/2	0.52	3	1.1	4	2.61			1.10
8/3	0.72	1	0.71	2	0.75			0.72
8/4	0.32	1	0.09	0	0.15			0.32
8/5	1.01	1	0.12	0	0.81			1.01
8/6	0.8	3	0.69	2	0.72			0.80
8/7	0.44	1	1.12	4	1.04			1.12
8/8	0.6	1	0.56	4	0.69			0.60
8/9	0.44	2	0.72	3	0.73			0.72
8/10	0.16	0	0.34	1	0.4			0.34
8/11	0.2	0	0.7	4	0.8			0.70
8/12	0.68	1	0.71	2	1.02			0.71
8/13	0.12	0	0.3	1	0.08			0.30
8/14	0.2	0	0.15	0	0			0.20
8/15	0.24	0	0.41	2	0.78			0.41
8/16	0.44	3	0.48	2	1.09			0.48
8/17	0.28	1	0.19	0	0.07			0.28
8/18	0.4	1	0.65	2	0.63			0.65
8/19	0.92	3	1.17	6	2.27			1.17
8/20	0.16	0	0.03	0	0.02			0.16
8/21	0.2	0	0.33	1	1.13			0.33
8/22	0.32	1	0.37	1	0.25			0.37
8/23	0.12	0	0.26	1	0.3			0.26
8/24	0.4	1	0.26	1	0.47			0.40
8/25	0.68	5	0.92	4	1.23			0.92

8/26	0.32	1	0.38	2	0.33			0.38
8/27	0.2	0	0.05	0	0.15			0.20
8/28	1.44	1	0.94	4	1.26			1.44
8/29	0.63	4	1	6	0.83			1.00
8/30	2.08	4	1.73	6	1.53			2.08
8/31	0.08	0	0.22	0	0.13			0.22
9/1	0.36	1	0.75	3	0.65			0.75
9/2	0.08	0	0.15	0	0.13			0.15
9/3	0.6	1	0.43	3	0.6			0.60
9/4	0.12	0	1.31	2	0.3			1.31
9/5	0.08	0	0	0	0.04			0.08
9/6	0.08	0	0.24	0	0.08			0.24
9/7	0.04	0	0.01	0	0.03			0.04
9/8	0 (0.32)	1	0	0	0		Y	0.00
9/9	0 (0.2)	0	0	0	0		Y	0.00
9/10	0 (0.08)	0	0	0	0		Y	0.00
9/11	0.12	0	0.05	0	0.08			0.12
9/12	0.32	1	0.22	0	0.4			0.32
9/13	0.44	2	0.3	1	0.47			0.44
9/14	0.28	1	1.21	4	0.56			1.21
9/15	0.28	1	0.39	1	0.35			0.39
9/16	0.2	0	0.18	0	0.27			0.20
9/17	0.08	0	0.01	0	0.01			0.08
9/18	0.12	0	0	0	0.03			0.12
9/19	0.08	0	NA	0	0.06			0.08
9/20	0.16	0	0.01	0	0.03			0.16
9/21	0.12	0	0.16	0	0.11			0.16
9/22	0.24	0	0.05	0	0.02			0.24
9/23	0.12	0	0.18	0	0.2			0.18
9/24	0.08	0	0.02	0	0			0.08
9/25	0 (0.12)	0	0	0	0		Y	0.00
9/26	0 (0.28)	1	0	0	0		Y	0.00
9/27	0 (0.08)	0	0	0	0		Y	0.00
9/28	0.12	0	NA	0	0.1			0.12
9/29	0.39	1	0.02	0	0.27			0.39
9/30	0.44	1	0.28	1	0.26			0.44

APPENDIX B – ZONE SPECIFIC THREAT LEVELS & MAX RAINFALL

The table below shows the daily threat level at each of the 6 zones, along with the highest 1-hour rainfall observed. For reference, we also show the Flash Flood Prediction Program's Message Potential obtained from the Message Generator website. Note that there were several days when Message Potential notifications were not available (presumably because of ongoing heavy rainfall activity). For those days, we assumed that the day's Message Potential is equal to the previous days.

	Zone A		Zone B		Zone C		Zone D		Zone E		Zone F		
Date	**Threat**	**Max-1hr**	**Threat**	**Max-1hr**	**Threat**	**Max-1hr**	**Threat**	**Max-1hr**	**Threat**	**Max-1hr**	**Threat**	**Max-1hr**	**F2P2-HPO**
5/1	-	0.12	-	0.12	-	0.08	-	0.09	-	0.12	-	0.12	-
5/2	-	0	-	0	-	0	-	0	-	0	-	0	-
5/3	-	0	-	0	-	0	-	0	-	0	-	0	-
5/4	-	0	-	0	-	0	-	0	-	0	-	0	-
5/5	-	0	-	0	-	0	-	0	-	0	-	0	-
5/6	-	0.38	-	0.46	-	0.04	-	0.42	-	0.9	-	0.16	-
5/7	mod	0.64	low	0.87	low	0.48	mod	1.73	mod	0.72	low	0.64	mod
5/8	-	0.12	-	0.31	-	0.04	-	0.4	-	1.12	-	0.4	-
5/9	-	0.24	-	0.31	-	0.04	-	0.1	-	0.12	-	0.04	-
5/10	-	0.1	-	0.31	-	0.37	-	0.94	-	0.88	-	0.51	low
5/11	-	0.1	-	0.31	-	0.31	-	0.13	-	0.04	-	0.38	-
5/12	-	0.12	-	0	-	0	-	0	-	0	-	0	-
5/13	-	0.4	-	0	-	0	-	0	-	0.04	-	0	-
5/14	-	0.05	-	0.06	-	0.02	-	0	-	0.05	-	0	low
5/15	-	0.24	-	0.32	-	0.37	-	0.09	-	0.23	-	0.16	low
5/16	-	0.28	-	0.32	-	0.59	-	0.2	-	0.24	-	0.32	low
5/17	-	0.16	-	0.12	-	0.08	-	0.03	-	0.06	-	0.08	-
5/18	-	0.91	-	0.49	-	0.03	-	0	-	0.32	-	0.16	-
5/19	-	0.08	-	0.04	-	0	-	0	-	0	-	0.12	-
5/20	-	0.02	-	0	-	0	-	0	-	0	-	0.04	low
5/21	-	0	-	0	-	0	-	0	-	0	-	0	-
5/22	-	0.04	-	0	-	0	-	0.18	-	0.03	-	0.32	-
5/23	-	0.12	-	0.07	-	0.04	-	0.09	-	0.15	-	0.12	-
5/24	-	0.55	-	0.83	-	0.15	-	1.23	-	0.89	-	0.85	mod
5/25	-	0.05	-	0	-	0	-	0.04	-	0.08	-	0.4	-
5/26	low	0.4	low	0.58	low	0.87	low	0.56	low	0.48	low	0.72	high
5/27	-	0.32	-	0.32	-	0.28	-	0.16	-	0.36	-	0.2	mod
5/28	-	0.04	-	0.16	-	0.14	-	0.37	-	0.16	-	0.26	-
5/29	-	0.4	-	0.18	-	0.51	-	0.46	-	0.76	-	0.23	-
5/30	-	0.05	-	0.12	-	0.22	-	1.01	-	0.26	-	0.1	-
5/31	low	0.52	mod	0.32	mod	0.65	mod	0.59	low	0.4	mod	0.6	mod
6/1	-	0.2	low	0.34	-	0.43	-	0.15	-	0.14	low	0.44	low
6/2	-	0	-	0	-	0.08	-	0	-	0	-	0.08	-
6/3	-	0	-	0.02	-	0	-	0	-	0	-	0.04	-
6/4	-	0	-	0.01	-	0	-	0	-	0	-	0.08	-
6/5	-	0.14	-	0.1	-	0	-	0.01	-	0.09	-	0.12	-
6/6	mod	0.85	mod	1.12	mod	1.3	mod	0.44	mod	0.62	mod	1.01	high
6/7	low	0.24	mod	0.41	mod	0.6	mod	0.37	mod	0.09	low	0.45	high
6/8	-	0.52	-	0.21	-	0.59	-	0.78	-	0.48	-	0.2	low
6/9	-	0.73	-	0.54	-	0.15	-	0	-	0.42	-	0.52	-

6/10	-	0.16	-	0.34	-	0.38	-	0	-	0	-	0.12	-
6/11	-	0.39	-	0.4	-	0.3	-	0.26	-	0.29	-	0.4	-
6/12	low	0.76	low	0.57	low	0.56	low	1.23	low	1.1	low	0.57	high
6/13	mod	0.25	mod	0.79	mod	1.68	high	0.97	high	0.52	mod	1.05	high
6/14	-	0	-	0	-	0	-	0	-	0	-	0	-
6/15	-	0	-	0	-	0	-	0	-	0	-	0	-
6/16	-	0	-	0	-	0	-	0	-	0	-	0	-
6/17	low	0.05	low	0	low	0	low	0	low	0.14	low	0.08	-
6/18	low	0	low	0	mod	0	low	0	low	0	low	0.32	-
6/19	-	0	-	0.62	-	1.07	-	0.38	-	0	-	0.12	-
6/20	low	0.25	mod	1.25	low	0.94	low	0.02	low	0	low	0.4	mod
6/21	-	0.02	-	0.26	-	0.16	-	0.39	-	0.22	-	0.24	-
6/22	-	0.29	-	0.32	-	0.05	-	0	-	0.19	-	0.17	low
6/23	-	0.36	-	0.84	-	0.68	-	0.52	-	0.57	-	0.44	high
6/24	-	0.46	-	0.36	-	0.73	-	0.04	-	0.25	-	0.72	-
6/25	-	0.28	-	0.43	-	0.53	-	0.04	-	0.12	-	0.48	low
6/26	-	0	-	0.25	-	0.01	-	0.41	-	0	-	0.45	-
6/27	low	0.02	low	0.33	low	0.64	low	0.59	low	0.31	low	0.43	mod
6/28	-	0.44	-	0.35	-	1.01	-	0.15	-	0.72	-	1.56	mod
6/29	-	0.1	-	0.46	-	0.5	-	0.37	-	0.06	-	0.43	mod
6/30	mod	0.48	mod	0.39	mod	0.48	mod	0.6	mod	0.41	mod	0.25	high
7/1	high	0.08	high	0.52	v. high	1.28	high	1.5	high	0.99	high	1.1	high
7/2	mod	0.52	mod	0.19	mod	0.24	mod	0.66	mod	0.27	mod	0.28	high
7/3	low	0.28	low	0.19	low	0.4	low	0.2	low	0.32	low	0.19	-
7/4	-	0.32	-	0.67	-	0.09	-	0.11	-	0.27	-	0.16	-
7/5	-	0.08	-	0.1	-	0.28	-	0.92	-	0.67	-	0.38	-
7/6	-	0	-	0	-	0	-	0.07	-	0.01	-	0	-
7/7	-	0	-	0.18	-	0.69	-	0.37	-	0.12	-	0.16	-
7/8	-	0.3	-	0.8	low	1.06	-	0.07	-	0.26	-	0.21	-
7/9	-	0	-	0	-	0	-	0	-	0	-	0	-
7/10	-	0	-	0	-	0	-	0	-	0	-	0.16	-
7/11	-	0	-	0	-	0	-	0.01	-	0	-	0.12	-
7/12	-	0	-	0	-	0	-	0.28	-	0	-	0.08	-
7/13	-	0	-	0.01	-	0.14	-	0.3	-	0	-	0.12	-
7/14	-	0.02	-	0.01	-	0.1	-	0	-	0	-	0.12	mod
7/15	-	0.77	-	0.37	-	0.73	-	0.7	-	0.61	-	0.53	-
7/16	-	0	-	0	-	0	-	0.03	-	0	-	0.16	-
7/17	-	0.04	-	0.08	-	0.37	-	0.96	-	1	-	0.32	-
7/18	-	0.72	-	1.24	-	0.76	-	0.51	-	0.45	-	0.52	high
7/19	low	0.88	low	0.82	-	0.63	-	0.51	-	0.28	low	1.44	high
7/20	-	0.3	-	0.57	-	0.64	-	0.1	-	0.05	-	0.28	high
7/21	-	0.08	-	0.17	-	0.09	-	0	-	0.01	-	0.2	mod
7/22	low	0.18	mod	0.48	low	0.92	mod	0.05	low	0.47	low	0.23	mod
7/23	-	0.14	-	0.34	-	0.11	-	0.18	-	0.06	-	0.31	low
7/24	mod	0.36	mod	0.26	high	0.54	v. high	0.62	high	1.17	mod	0.26	high
7/25	-	0	-	0.16	-	0.33	-	0.44	-	0	-	0.32	low
7/26	-	0.11	-	0.08	-	0.87	-	0.09	-	0	-	0.08	-
7/27	-	0	-	0.04	-	0	-	0.48	-	0	-	0.12	-
7/28	-	0.37	-	0.28	-	0.53	-	0.31	-	0.07	-	0.44	mod

7/29	low	0.11	low	0.06	mod	0.2	high	0.94	mod	0.58	mod	0.25	mod
7/30	-	0.08	-	0.36	-	0.1	-	0.02	-	0.05	-	0.16	low
7/31	-	0.2	-	0.17	-	0.47	-	0.6	-	0.18	-	0.2	low
8/1	-	0.03	-	0.03	-	0	-	0	-	0	-	0.2	-
8/2	-	0.28	-	0.17	low	0.44	-	1.1	-	1	-	0.42	mod
8/3	low	0.11	low	0.2	low	0.16	low	0.01	-	0.46	low	0.72	low
8/4	-	0.12	-	0.09	-	0.04	-	0.02	-	0.32	-	0.16	low
8/5	mod	0.2	mod	0.12	mod	0.03	mod	0.02	low	0.04	mod	1.01	high
8/6	low	0.44	low	0.45	mod	0.8	low	0.02	low	0.04	low	0.44	mod
8/7	high	0.49	high	1.12	high	0.6	high	0.04	mod	0.06	high	0.57	high
8/8	-	0.29	-	0.6	-	0.5	-	0.02	-	0	-	0.32	mod
8/9	-	0.22	-	0.58	-	0.72	-	0.21	-	0.44	-	0.23	-
8/10	-	0.16	-	0.11	-	0.18	-	0.04	-	0.34	-	0.12	-
8/11	-	0.18	-	0.33	-	0.2	-	0.6	-	0.7	-	0.34	-
8/12	-	0.02	-	0.37	-	0.71	-	0	-	0.01	-	0.24	-
8/13	-	0.02	-	0.02	-	0.09	-	0.3	-	0.08	-	0.12	-
8/14	-	0.01	-	0.03	-	0	-	0.15	-	0	-	0.2	-
8/15	-	0.24	-	0.08	-	0.02	-	0.26	-	0.41	-	0.12	-
8/16	-	0.28	low	0.36	low	0.48	low	0.42	-	0.21	low	0.44	low
8/17	-	0.08	-	0.28	-	0.01	-	0	-	0.16	-	0.16	low
8/18	low	0.4	low	0.3	low	0.04	low	0.08	low	0.2	low	0.65	low
8/19	mod	0.72	mod	0.56	mod	1.17	mod	0.72	mod	0.51	mod	0.92	high
8/20	-	0.12	-	0.03	-	0	-	0	-	0	-	0.16	-
8/21	-	0.04	-	0.33	-	0	-	0	-	0	-	0.2	-
8/22	-	0.16	-	0.08	-	0.13	-	0.11	-	0.05	-	0.37	-
8/23	-	0.14	-	0.26	-	0.05	-	0	-	0.15	-	0.08	-
8/24	-	0.4	-	0.2	-	0.19	-	0.09	-	0.08	-	0.24	low
8/25	-	0.36	-	0.57	-	0.92	-	0.37	-	0.32	-	0.44	low
8/26	-	0.12	-	0.38	-	0.18	-	0.03	-	0.24	-	0.32	-
8/27	-	0.12	-	0.03	-	0	-	0	-	0	-	0.2	-
8/28	-	0.4	-	0.3	-	1.44	-	0.94	-	0.01	-	0.16	low
8/29	mod	0.63	mod	0.48	mod	0.66	mod	1	mod	0.91	mod	0.77	low
8/30	high	1.84	high	1.19	high	0.58	high	0.46	high	0.29	high	2.08	mod
8/31	low	0.04	low	0.22	low	0.04	low	0	low	0	low	0.08	mod
9/1	low	0.51	low	0.75	low	0	low	0	low	0.18	low	0.25	low
9/2	-	0.15	-	0.1	low	0.04	-	0.02	-	0.08	-	0.08	mod
9/3	-	0.6	-	0.13	-	0.04	-	0.42	-	0.31	-	0.08	low
9/4	-	0.16	-	0.15	-	0.02	-	0.12	-	1.31	-	0.27	-
9/5	-	0	-	0	-	0	-	0	-	0	-	0.08	-
9/6	-	0.02	-	0.02	-	0.14	-	0.24	-	0	-	0.11	-
9/7	-	0	-	0	-	0	-	0.01	-	0	-	0.04	-
9/8	-	0	-	0	-	0	-	0	-	0	-	0	-
9/9	-	0	-	0	-	0	-	0	-	0	-	0	-
9/10	-	0	-	0	-	0	-	0	-	0	-	0	-
9/11	-	0.03	-	0.05	-	0.01	-	0	-	0	-	0.12	-
9/12	-	0.32	-	0.22	-	0.22	-	0.11	-	0.08	-	0.16	-
9/13	low	0.14	low	0.44	low	0.08	low	0.02	low	0.16	low	0.28	-
9/14	-	0.33	-	0.09	-	0.04	-	1.06	-	1.21	-	0.52	low
9/15	-	0.28	-	0	-	0	-	0.39	-	0.04	-	0.12	-

9/16	-	0.2	-	0.08	-	0.06	-	0.06	-	0.05	-	0.18	-
9/17	-	0	-	0.04	-	0	-	0	-	0	-	0.08	-
9/18	-	0	-	0.04	-	0	-	0	-	0	-	0.12	-
9/19	-	0	-	0	-	0	-	0	-	0	-	0.08	-
9/20	-	0.16	-	0.04	-	0	-	0	-	0	-	0.08	-
9/21	-	0.12	-	0.16	-	0.08	-	0	-	0	-	0.12	-
9/22	-	0.24	-	0.03	-	0	-	0	-	0.08	-	0.12	-
9/23	-	0.12	-	0.06	-	0	-	0.18	-	0.16	-	0.08	-
9/24	-	0.02	-	0.01	-	0	-	0	-	0	-	0.08	-
9/25	-	0	-	0	-	0	-	0	-	0	-	0	-
9/26	-	0	-	0	-	0	-	0	-	0	-	0	-
9/27	-	0	-	0	-	0	-	0	-	0	-	0	-
9/28	-	0	-	0	-	0	-	0	-	0	-	0.12	-
9/29	-	0.02	-	0.39	-	0	-	0	-	0	-	0.12	-
9/30	-	0.12	-	0.44	-	0.28	-	0.02	-	0.05	-	0.12	-

Comparison with F2P2 HPOs

For future refinement of the Tool, one important benchmark is to compare its performance with human-derived forecasts. To do this, below the Tool's contingency table (see Table 9, panel g) with an analogous table using the daily message potential from the Table above. **It is critical to note that this comparison is very preliminary since we do not use sub-hourly rainfall data for validation, even though that may well be relevant (e.g. 0.7 inches falling in 20 minutes but less than 1 inch in an hour, etc) from a flood risk standpoint.**

In 2015, it was shown that the Tool and the F2P2 HPO message potential had similar verification statistics. For 2016, some changes were noted. Whereas the F2P2 HPO message potential showed very similar performance to 2015 (in terms of Accuracy, False Alarm and Miss rates), the Tool showed a higher Accuracy, a sharply lower False Alarm rate but higher Miss rate. This is attributed to 2016's processing upgrades that incorporated bias correction. The Tool's increased performance from 2015 to 2016 represents an encouraging achievement, and it is surmised that more improvement is attainable given yearly updates to the scientific underpinnings on which the Tool is based.

HRG Tool Threat Level		**Heavy rainfall forecasted**		
	All zones	**NO**	**YES**	Accuracy: 80%
Heavy Rainfall Observed	**NO**	**108 (71%)**	**20 (13%)**	False Alarm: 13%
	YES	**10 (7%)**	**15 (10%)**	Miss: 7%
F2P2 HPO Message Potential				
	All zones			Accuracy: 69%
Heavy Rainfall Observed	**NO**	**87 (57%)**	**41 (27%)**	False Alarm: 27%
	YES	**6 (4%)**	**19 (12%)**	Miss: 4%

APPENDIX C – QUANTITATIVE PRECIPITATION FORECASTS

The table below shows the daily maximum forecasted 1-hour rainfall (Max; units: inches) and probability of exceeding 1 inch per hour (POP1; units: %) for each zone. This table can be compared with the table shown in Appendix A for day by day, and zone-by-zone verification.

	Zone A		Zone B		Zone C		Zone D		Zone E		Zone F	
Date	**POP1**	**Max**	**POP1**	**Max**	**POP1**	**Max**	**POP1**	**Max**	**POP1**	**Max**	**POP1**	**Max**
5/1	0	0.12	0	0.12	0	0.07	0	0.07	0	0.13	0	0.16
5/2	0	0.04	0	0.08	0	0.03	0	0.02	0	0	0	0.02
5/3	0	0	0	0	0	0	0	0	0	0	0	0
5/4	0	0	0	0.03	0	0	0	0	0	0	0	0
5/5	0	0	0	0	0	0	0	0	0	0	0	0
5/6	0	0.2	0	0.29	0	0.34	0	0.12	0	0.21	0	0.12
5/7	21.3	1.52	16.9	1.44	12.8	0.39	23.1	2.18	23.3	1.89	16.4	1.08
5/8	1.5	0.52	1.3	0.25	1.2	0.13	1.5	0.43	1.5	0.54	1.3	0.25
5/9	0	0.31	0	0.2	0	0.07	0	0.22	0	0.19	0	0.04
5/10	0	0.08	0	0.2	0	0.42	0	0.4	0	0.08	0	0.22
5/11	0	0.04	0	0.13	0	0.35	0	0.31	0	0.04	0	0.31
5/12	0	0	0	0	0	0	0	0	0	0	0	0
5/13	0	0	0	0.02	0	0.02	0	0	0	0.02	0	0
5/14	0	0.2	0	0.15	0	0.15	0	0.07	0	0.05	0	0.16
5/15	2.1	0.43	2.5	0.67	2.5	0.83	2	0.75	1.8	0.62	2.1	0.69
5/16	2.8	0.53	3.4	1.01	2.7	0.82	2.4	0.43	2.4	0.53	2.3	0.44
5/17	0	0.15	0	0.12	0	0.12	0	0.14	0	0.12	0	0.16
5/18	1.4	0.42	1.5	0.61	1	0.33	0	0.2	1.1	0.2	1.1	0.21
5/19	1.1	0.24	1.1	0.31	1	0.28	0	0.5	0	0.17	1	0.35
5/20	0	0.29	0	0.25	0	0.08	0	0.1	0	0.25	0	0.12
5/21	0	0.04	0	0	0	0.06	0	0.03	0	0.18	0	0
5/22	0	0.13	0	0.08	0	0.08	0	0.43	0	0.09	0	0.38
5/23	1.4	0.42	1.4	0.16	1.3	0.2	1.7	0.71	1.5	0.69	1.5	0.56
5/24	4.8	0.87	3.7	0.05	3.6	0.03	4.8	1.32	5.2	1.47	3.9	0.86
5/25	0	0.04	0	0.03	0	0	0	0	0	0	0	0
5/26	15.2	0.61	17.8	1.04	19.7	1.45	19.9	2.13	15	1.02	17.4	1.4
5/27	1.4	0.44	1.4	0.56	1.3	0.48	1.4	0.5	1.4	0.47	1.4	0.56
5/28	2.3	0.25	2.3	0.2	2.5	1	2.5	0.39	2.3	0.36	2.3	0.3
5/29	2.9	0.38	3	0.47	3.4	1.05	3.1	0.57	2.6	0.4	3.3	0.57
5/30	1.2	0.22	1.3	0.28	1.3	0.5	1.3	0.66	1.3	0.34	1.3	0.62
5/31	16.6	0.56	23.6	1.02	28.2	2.34	27.2	1.77	19.8	1.15	28.5	1.43
6/1	5.7	0.41	8.7	1.5	7.4	1.02	6.6	1.16	6.6	1.51	8.7	1.12
6/2	0	0	0	0	0	0	0	0	0	0.02	0	0
6/3	0	0.08	0	0.06	0	0.18	0	0.23	0	0.28	0	0.22
6/4	0	0.04	0	0.08	0	0	0	0	0	0	0	0
6/5	1.1	0.23	1.1	0.24	1.1	0.08	1.1	0.54	0	0.21	0	0.11
6/6	21.8	1.4	30	1.68	30.5	2.38	22.7	0.72	22.7	1.45	24.7	1.74
6/7	18.1	0.56	22.4	1.22	24.2	1.76	26.3	2.25	21.5	2.45	19.7	1.82
6/8	3.1	0.48	3.1	0.34	3	1.08	2.7	0.38	2.4	0.28	2.7	0.21

6/9	2.5	0.87	2.8	0.6	2.3	1.08	2.2	0.34	2.3	0.28	2.2	0.24
6/10	2	0.76	2.6	0.85	2	0.9	1.8	0.69	1.7	0.14	1.8	0.51
6/11	3.4	1.12	2.9	0.55	2.5	0.9	2.6	0.76	2.5	0.61	2.6	0.58
6/12	10.7	1.05	12.2	0.82	11.5	1.11	13.7	1.75	10.7	1.39	11	1.19
6/13	30.6	0.87	29.3	0.76	32.5	0.85	47.8	2.68	40.7	2.26	37.4	1.86
6/14	0	0.04	0	0	0	0	0	0	0	0	0	0
6/15	0	0	0	0	0	0	0	0	0	0	0	0
6/16	0	0	0	0	0	0	0	0	0	0	0	0
6/17	10.5	0.06	10.7	0.18	12.1	1.33	17.9	2.22	11.3	0.34	12.7	1.48
6/18	18.9	0.01	19	0.12	22.1	2.68	19.2	0.07	18.9	0	19	0.16
6/19	1.5	0	1.6	0.53	2	0.89	1.6	0	1.5	0	1.5	0
6/20	16.1	1.68	25.5	1.65	13.5	1.26	11.5	2.1	9.4	0.28	10	0.25
6/21	1.5	0.24	1.8	0.78	1.6	0.35	1.4	0.41	1.5	0.5	1.5	0.53
6/22	2.2	0.4	2.9	0.91	2.3	0.61	1.8	0.34	1.8	0.36	1.9	0.38
6/23	3.2	0.66	3.5	1.03	3.2	0.92	2.7	1.03	2.5	0.64	2.5	0.43
6/24	0	0.18	1.1	0.31	1.2	0.49	0	0.1	0	0.17	0	0.18
6/25	2	0.18	2.9	0.99	2.7	0.51	2.1	0.37	2	0.27	2.1	0.2
6/26	1.6	0.09	2.3	0.87	2.1	0.59	1.9	0.55	1.6	0.04	1.8	0.84
6/27	15	1.67	15.5	1.62	17	1.4	16.3	1.09	15.8	2.31	15.1	1.46
6/28	2.4	0.03	2.9	0.38	3.1	0.87	3.2	0.28	2.8	0.21	2.8	0.08
6/29	3.4	1.12	3.3	0.59	2.9	0.47	3.2	0.57	3	0.4	3	0.6
6/30	29	1.54	33	1.59	31.9	1.36	38.2	1.67	29.8	1.74	31.9	2.53
7/1	50.2	1.62	54.9	1.58	65.2	2.68	57.1	2.38	55.2	2.6	49	1.63
7/2	29	1.62	28.4	1.23	24.3	1.32	21	2.08	26.4	2.21	23.2	1.26
7/3	10.4	0.67	12.7	0.88	11	1.82	8.8	0.71	10.7	1.2	9.9	0.65
7/4	2.6	0.6	2.8	0.71	2	0.38	2	0.43	1.9	0.4	1.9	0.44
7/5	1.8	0.65	1.6	0.31	1.8	0.5	1.7	0.24	1.7	0.38	1.7	0.24
7/6	0	0	0	0	0	0	0	0	0	0	0	0
7/7	0	0	0	0	0	0	0	0	0	0	0	0
7/8	8	0.24	8.3	0.13	10.6	1.6	7.8	0.29	7.7	0.3	7.8	0.2
7/9	0	0	0	0.04	0	0.04	0	0.06	0	0	0	0.09
7/10	0	0	0	0.04	0	0.03	0	0.2	0	0.11	0	0.12
7/11	0	0	0	0	0	0	0	0.25	0	0	0	0
7/12	0	0	0	0.04	0	0	0	0.12	0	0	0	0
7/13	0	0	0	0	0	0.46	0	0	0	0	0	0
7/14	0	0	0	0.12	0	0.34	0	0.06	0	0	0	0
7/15	1.4	0.64	1.5	0.59	1.4	0.74	1.5	0.59	1.4	0.68	1.5	0.45
7/16	0	0.03	0	0	0	0	0	0	0	0.02	0	0
7/17	0	0	0	0.02	0	0.43	0	0.42	0	0.02	0	0.46
7/18	3.9	0.8	4.2	0.76	4.8	1.44	5.3	1.49	3.5	1.03	4.1	1.04
7/19	9.2	1.49	11.1	1.23	7.2	0.83	6.9	0.88	5.5	0.74	7.9	1.03
7/20	6.2	1.21	6	1.37	4.3	0.71	4	0.72	3.5	0.67	4.1	0.78
7/21	4	0.71	5.5	0.88	4.2	0.62	3.2	0.4	2.7	0.13	3.3	0.38
7/22	20.4	1.12	26.7	1.19	19.8	1.4	20.8	2.19	16.8	0.45	15.9	0.79
7/23	2.1	0.38	2.2	0.57	2.2	0.52	2.2	0.43	2.2	0.45	2.1	0.54
7/24	26.1	0.24	33.5	1.41	46.1	2.43	61	2.68	47.7	2.37	32.4	1.35

7/25	1.7	0.71	2.1	0.86	1.8	0.53	1.9	0.82	1.8	0.63	2	0.8
7/26	1	0.24	1	0.22	1.1	0.36	0	0.05	0	0.26	0	0.13
7/27	4.5	0.34	4.6	0.77	4.4	0.37	5.2	1.45	5	0.73	4.7	0.85
7/28	3.9	0.22	4.3	1.04	4.8	1.54	5.1	1.37	4.9	0.98	5.2	1.1
7/29	17.8	0.58	18.6	0.52	31.6	2.63	44.6	2.68	35	1.55	33.8	2.37
7/30	1.4	0.28	1.4	0.45	1.5	0.79	1.7	1.03	1.6	0.81	1.5	0.64
7/31	7.2	0.76	6.5	0.72	5.5	0.58	5.8	1.17	4.7	0.29	5.3	0.67
8/1	2.1	0.72	2.1	0.61	1.7	0.35	1.6	0.28	1.8	0.51	1.8	0.39
8/2	6.7	0.85	7.5	1.03	8.3	1.26	7.3	1.23	7	1.18	7.2	1.36
8/3	8.7	1.03	10.6	1.57	8.6	0.82	8.3	0.65	6.9	0.51	8.5	0.84
8/4	0	0.16	0	0.27	0	0.21	0	0.21	0	0.17	0	0.19
8/5	22.5	0.83	31.3	1.63	27.2	2.4	23.6	1.25	17.3	0.22	22.9	1.49
8/6	14.1	1.58	19.4	1.62	20.6	1.78	15.7	1.75	15.1	1.27	17.1	1.51
8/7	40.1	1.67	47.8	1.64	43.1	1.38	46.2	1.98	36.5	2.21	45	2.66
8/8	1.6	0.25	2.1	0.67	2	0.6	1.9	0.6	1.8	0.84	1.7	0.46
8/9	5.5	0.43	5.9	0.66	6.2	1.2	5.5	0.56	4.7	0.36	5.1	0.6
8/10	3.1	0.36	3.4	0.58	2.9	0.26	2.9	0.74	3	0.43	2.8	0.39
8/11	4.4	0.18	4.8	0.3	4.9	0.48	6.1	1.32	5.1	0.79	4.9	0.32
8/12	1.7	0.12	1.8	0.16	2	1.07	1.8	0.67	1.8	0.2	1.7	0.4
8/13	1.5	0.52	1.6	0.34	1.8	0.72	1.5	0.23	1.5	0.45	1.5	0.49
8/14	0	0.29	1.1	0.28	1.2	0.6	1	0.16	1	0.07	1	0.57
8/15	1.5	0.12	1.6	0.12	1.6	0.07	1.9	0.5	1.6	0.17	1.6	0.27
8/16	7.2	0.78	8.2	1.03	8.6	1.32	9.1	1.05	6.4	1.2	7.7	0.92
8/17	3.8	0.77	4.6	0.57	4	0.65	3.9	0.48	3.3	0.54	4.2	0.63
8/18	12.6	0.87	13.9	1.37	10.5	1.41	10.2	1.26	10.2	1.12	9.4	0.39
8/19	29	1.28	35	1.68	33	2.5	24.6	1.25	30.6	1.18	29.5	1.84
8/20	0	0	0	0.57	0	0.3	0	0	0	0	0	0
8/21	1.5	0	1.8	0.57	1.6	0.51	1.5	0	1.5	0	1.5	0
8/22	1.9	0.11	2.2	0.13	1.7	0.29	1.6	0	1.6	0	1.7	0.29
8/23	1.3	0.3	1.4	0.24	1	0.14	0	0.06	0	0.05	0	0.06
8/24	1.1	0.29	1.2	0.36	1.1	0.15	0	0.12	0	0.14	0	0.14
8/25	2	0.67	3.2	1.04	2.2	0.75	2.1	0.87	1.8	0.37	2.1	1
8/26	1.4	0.31	1.6	0.77	1.5	0.92	1.3	0.26	1.4	0.44	1.4	0.41
8/27	1.1	0.45	1.1	0.42	1	0.54	0	0.14	0	0.2	0	0.33
8/28	6	0.55	7.5	0.66	7.7	0.95	6.7	1.19	4.9	0.69	5.9	0.61
8/29	22.3	0.6	29.5	1.6	33.3	2.1	27.4	1.11	21	0.52	26.5	1.84
8/30	45.6	1.11	49.3	1.26	46.8	1.32	44	1.48	43.1	1.86	47.1	2.54
8/31	11.5	1.37	14.8	1.19	12.6	1.53	9.8	1.28	9	1.41	9.6	1.03
9/1	16.4	0.95	20	1.01	11.9	0.4	11	0	13.1	1.02	13.2	1.84
9/2	4.9	0.38	6.4	0.84	8.9	1.18	6.1	1.27	5	0.85	5.3	0.96
9/3	2.6	0.66	2.3	0.54	2	0.36	2.4	0.86	2.1	0.43	2.1	0.72
9/4	0	0.08	0	0.13	0	0.07	0	0.1	0	0.1	0	0.08
9/5	0	0	0	0	0	0	0	0	0	0	0	0
9/6	0	0.12	0	0.23	0	0.39	0	0.52	0	0.5	0	0.55
9/7	0	0	0	0	0	0.02	0	0	0	0	0	0
9/8	0	0	0	0	0	0	0	0	0	0	0	0

9/9	0	0	0	0.04	0	0.06	0	0.03	0	0.02	0	0.02
9/10	0	0	0	0	0	0	0	0	0	0	0	0
9/11	0	0.32	0	0.16	0	0.11	0	0.13	0	0	0	0.04
9/12	1	0.63	1	0.62	0	0.63	0	0.4	0	0.5	1	0.54
9/13	9.7	0.62	12.4	1.03	10.1	1.13	9.7	1.65	8.2	0.73	11.7	1.4
9/14	2.9	0.53	2.7	0.57	2.7	0.8	3.2	1.08	3.1	0.7	2.7	0.62
9/15	0	0.08	0	0	0	0	0	0	0	0.03	0	0
9/16	0	0.04	1	0.39	1.2	0.52	0	0.43	0	0.04	0	0.5
9/17	0	0	0	0	0	0.03	0	0	0	0	0	0
9/18	0	0	0	0	0	0	0	0	0	0	0	0
9/19	0	0	0	0	0	0	0	0	0	0	0	0
9/20	1.2	0.45	1.2	0.4	1.2	0.08	1.2	0.16	1.2	0.11	1.2	0.08
9/21	0	0.1	0	0.47	0	0.38	0	0.32	0	0.06	0	0.19
9/22	0	0.48	0	0.29	0	0.35	0	0.84	0	0.3	0	0.39
9/23	0	0.24	0	0.23	0	0	0	0.16	0	0.05	0	0.03
9/24	0	0.08	0	0.06	0	0.03	0	0.05	0	0.08	0	0.06
9/25	0	0	0	0	0	0	0	0	0	0	0	0
9/26	0	0	0	0	0	0	0	0	0	0	0	0
9/27	0	0	0	0	0	0	0	0	0	0	0	0
9/28	0	0	0	0	0	0	0	0	0	0	0	0
9/29	1.2	0.28	1.2	0.2	1.1	0	1.1	0.02	1.1	0.17	1.1	0.2
9/30	2.6	0.67	3.3	0.68	3.2	0.68	2.2	0.46	2.3	0.41	2.4	0.48

APPENDIX D – ENSEMBLE DATA

The table below shows bias-corrected (using quantile mapping; see Dewberry 2016 Technical Memo) maximum 1-hour rainfall for each day for each of the 23 ensemble members that contributes to the Tool. Gray shading indicates model data was not available that day. Light red shading indicates values exceeding 1 inch in 1 hour. The ensemble members are:

Ensemble #	Description	Operating Agency
1-9	4-km WRF based on various boundary conditions, and NMM and ARW model cores	National Severe Storm Laboratory
10 - 13	4-km WRF based on various boundary conditions, and NMM and ARW model cores	National Centers for Environmental Prediction
14-23	3-km WRF with ARW core that uses the latest data assimilation technique	National Center for Atmospheric Research

	1-hour QPF-MAX (see table above for ensemble identification; units: inches in 1 hour)																						
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
5/1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
5/2	0.2	0.3	0.3	0.2	0.4	0.2	0.1	0.3	0.2	0	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0
5/3	0	0.1	0	0.1	0.1	0.1	0	0.1	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/4	0	0.2	0.1	0	0.2	0.1	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/5	0	0	0.1	0	0.1	0.1	0.1	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/6	0.3	0.7	0.7	0.5	1	0.6	0.5	0.5	0.3	0.2	0.4	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.2	0.1	0.3	0	0.1
5/7	1.4	1.1	0.8	1.8	0.7	0.8	0.5	1.5	1	0.9	1.2	1.5	1.5	1.2	1.9	0.1	0.8	1.7	0.4	0.5	1.1	0.6	2.2
5/8	0.8	0.2	0.6	0.6	0.8	0.8	0.5	0.6	1.3	0.2	0.3	0.5	0.5	0.1	0.2	0.2	0.3	0.4	1.3	0.3	0.5	0.3	0.2
5/9	0.2	0.2	0.2	0.2	0.1	0.3	0.2	0.4	0.2	0.2	0.2	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.1	0.1	0.2	0.1
5/10	0	0.3	0.2	0.6	0.4	0.1	0.7	0	0	0	0.5	0.4	0.4	0.3	0	0.1	0.2	0.1	0	0.1	0	0.1	0.1
5/11	0.3	0.3	0.4	0.1	0.2	0.3	0.5	0.1	0.1	0.2	0.4	0.2	0.3	0.2	0	0	0.1	0.1	0.3	0.1	0	0.1	0
5/12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/13	0	0.2	0.1	0.1	0.1	0.4	0.2	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/14	0.1	0.2	0.1	0.2	0.3	0.1	0.2	0.1	0.4	0	0.1	0.1	0.2	0	0	0.1	0.2	0	0.2	0	0.1	0.2	0
5/15	0.5	0.8	1.4	0.8	0.8	0.6	0.7	0.5	0.7	0.4	0.7	0.7	0.4	0.4	0.5	0.4	0.6	0.5	0.6	0.4	0.8	0.7	0.5
5/16	0.7	0.5	0.5	0.7	0.5	0.5	0.4	0.5	0.3	0.6	0.6	1	0.5	0.4	0.5	0.5	0.5	0.4	0.8	0.4	0.8	0.5	0.7
5/17	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0	0.1
5/18		0.7	0.7	0.5	0.5	0.5	0.8	0.3	0.3	0.3	0.3	0.4	0.6	0.3	0.3	0.3	0.2	0.5	0.3	0.1	0.2	0.2	0.2
5/19	0.5	0.6	0.4	0.5	0.3	0.5	0.6	0.4	0.5	0.5	0.5	0.3	0.3	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5
5/20	0.3	0.3	0.5	0.4	0.4	0.3	0.6	0.3	0.4	0.4	0.3	0.2	0.3	0.1	0.1	0.1	0	0.1	0	0.1	0.1	0.2	0
5/21	0	0.1	0.2	0.1	0.3	0.1	0.2	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0.1
5/22	0.5	0.4	0.1	0.2	0.3	0.4	0.5	0.2	0	0.1	0.1	0	0	0	0	0	0	0	0.1	0	0	0.4	0
5/23	0.9	0.7	0.3	0.4	0.6	0.6	0.4	0.4	0.4	0.2	0.7	0.7	0.6	0.2	0.4	0.1	0.1	0.2	0.4	0.2	0.3	0.2	0.1
5/24	0.5	0.6	0.5	0.4	0.6	0.3	0.3	0.4	0.8	0.3	0.9	0.8	1.5	0	0.3	0.1	0.2	0.1	0.3	0.1	0.1	0.3	0.1
5/25	0	0	0.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/26	1	0.9	0.8	1.4	0.9	1.1	1.1	0.7	0.9	0.8	1	1.5	2.1	0.8	0.6	0.7	0.7	0.8	1	0.7	0.5	0.6	0.4
5/27	0.9	0.7	0.4	0.7	0.9	0.8	0.4	0.5	0.4	0.3	0.6	0.4	0.4	0.5	0.5	0.6	0.4	0.4	0.4	0.4	0.4	0.5	0.5
5/28	0.5	0.5	0.4	0.6	0.7	0.5	0.8	0.8	0.4	0.2	0.3	0.4	1	0.2	0.4	0.4	0.4	0.2	0.1	0.2	0.3	0.4	0.2
5/29	0.6	0.7	1.1	0.9	1	0.9	0.8	0.9	0.6	0.6	1.4	0.7	1.1	0.3	0.2	0.6	0.3	0.4	0.3	0.4	0.4	0.1	0.3
5/30	0.4	0.3	0.5	0.6	0.4	0.6	0.4	0.5	0.5	0.6	0.4	0.7	0.3	0.1	0.1	0.1	0	0.1	0.2	0.1	0.1	0.2	0.1
5/31	1.1	1.2	0.9	1.9	0.7	1.3	1	1.6	1	1.5	1.1	1.1	2.3	1.4	1.3	1	0.9	0.9	0.9	1.8	0.9	1.1	0.7
6/1	0.9	0.8	1	1	1.5	1.3	1.1	1.1	0.7	0.3	1.4	1.5	1.5	0.7	0.7	1.1	0.9	1	0.9	1	0.9	0.9	0.9
6/2	0									0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/3	0.1	0.2	0.1	0.2	0.4	0.2	0.2	0.5	0.5	0	0.1	0	0.1	0	0.3	0	0	0.1	0.1	0	0	0.2	0.1
6/4	0.1	0.1	0.2	0.3	0.2	0.3	0.2	0.8	0.7	0	0.1	0	0.1	0	0	0.1	0	0	0	0	0	0.1	0
6/5	0.3	0.5	0.4	0.5	0.4	0.5	0.6	0.4	0.7	0.3	0.4	0.5	0.1	0.1	0.1	0	0	0.1	0	0.2	0.2	0.2	0
6/6	1	1.3	2	1.4	1.2	1.3	0.8	1.4	1	0.6	1.2	2.4	1.5	0.5	0.9	1	0.6	0.7	0.6	0.8	0.8	0.7	1.4
6/7	1.6	1	1.2	0.6	0.8	0.8	1	1	1.1	0.5	0.5	1.4	2.4	0.3	0.2	0.5	0.1	0.4	0.3	0.5	0.2	0.6	0.4
6/8	0.7	1.5	1	0.5	1.4	0.5	0.8	0.8	0.7	0.2	0.3	0.5	1.1	0.2	0.3	0.2	0.2	0.2	0.3	0.4	0.4	0.4	0.4
6/9	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.3	0.8	0.4	0	0.2	0.2	0.1	0.3	0.6	1.1	0.2	0.2	0.1	0.2	0.2	0.9
6/10	0.7	0.9	0.5	1	0.6	0.5	0.5	0.5	0.6	0.4	0.6	0.8	0.9	0.2	0.2	0.1	0.2	0.3	0.2	0.1	0.3	0.1	0.2
6/11	0.3	0.7	0.5	0.6	0.7	0.6	0.4	0.2	0.5	0.4	0.5	0	0.4	0.4	0.6	0.5	0.8	0.3	1.1	0.9	0.7	0.5	0.1
6/12	1.4	0.7	1.2	0.8	1.6	1.5	0.9	1.1	1.1	1.5	0.5	1.1	1.3	0.5	0.6	1.4	1.1	0.7	0.9	0.8	0.7	1.8	1.2
6/13	1	1.2	1.1	1.4	1	1.6	1.6	0.7	0.7	1.2	1.4	0.8	2.7	0.8	1.2	2.3	1.2	1	1.1	0.4	0.9	0.7	0.6
6/14	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/15	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/17										0.4	0.1	0.1	2.2	0.3	0	0.7	0.1	0.1	0.9	1.2	0	0	1.8

6/18	0.1	0	0	0	0	0	0	0	0	0	0.4	2.7	0	0	0	0	0	0	0	0	0	0.1	0.8
6/19	0.1	0.2	0.8	0.1	0.2	0.1	0.4	0.3	0	0.3	0.9	0.8	0.7	0.9	0	0	0	0	0	0	0	0	0.1
6/20	0.7	0.7	0.7	0.6	0.9	0.8	0.7	0.8	1.5	1.5	0.9	1.7	1.7	1.6	2.1	1.4	1.7	1.4	1.5	1.1	1.4	0.6	1.6
6/21										0.1	0.1	0.3	0.8	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6/22	0.6									0.6	0.6	0.8	0.4	0.3	0.9	0.6	0.7	0.4	0.5	0.5	0.9	0.3	0.5
6/23	0.9	0	0.7		0.8	1.1	0.8	0.6	0.9	0.5	0.7	1	0.8	1	0.7	0.6	0.6	0.9	0.5	0.7	0.6	0.3	0.4
6/24	0.5	0.6	0.5	0.4	0.5	1.3	0.5	0.6	0.4	0.4	0.8	0.5	0.2	0.1	0.2	0.1	0.3	0.1	0.2	0.2	0.1	0.2	0.1
6/25	0.4	0.6	0.6	0.8	0.7	0.9	1.1	0.3	0.4	0.3	0.7	0.2	1	0.5	0.5	0.4	0.5	0.4	0.5	0.5	0.4	0.3	0.4
6/26	0.5	0.7	0.3	0.6	1	0.7	0.8	0.8	1.1	0.5	1.2	0.2	0.9	0.3	0.3	0.3	0.2	0.4	0.2	0.1	0.6	0	0.4
6/27	0.2	0.5	0.9	0.1	0.8	1	1	1.6	0.9	0.1	0.5	2.3	1.7	1.4	1.1	0.3	0.3	0	0.2	0	0.1	0	0
6/28	0.4	0.6	0.7	0.4	0.7	0.3	0.2	0.5	0.8	0.1	0.4	0.3	0.9	0.1	1.7	1.2	1.7	0	0.2	0.2	0.3	0.1	0.2
6/29	0.4	0.9	0.6	1.1	0.8	0.6	0.7	0.7	0.7	0.3	0.5	0.5	1.1	0.6	0.5	0.8	0.4	0.6	1	0.4	0.2	0.3	0.6
6/30	1.2	1.1	1.2	1.2	1.4	1.3	1.2	1.8	1.9	0.9	2.1	1.5	1	0.9	1.6	1.7	0.7	1	1.4	1.5	1.7	2.5	1.3
7/1										0.9	1.6	2.7	2.3	1.8	1.6	1.4	2.6	2.1	1.8	2	1.3	1.7	2.6
7/2										0.7	1	1	1.6	1.1	1	2.2	0.9	0.7	0.9	1	0.8	1.2	1.2
7/3										0.3	1	0.3	0.1	0.3	0.6	0.6	0.4	1.2	1.8	0.7	0.4	0.5	0.7
7/4										0.4	0.4	0.5	0.4	0.7	0.6	0.3	0.5	0.4	0.3	0.4	0.4	0.6	0.5
7/5										0.2	0.5	0.6	0.3	0.2	0	0.1	0.2	0.2	0.4	0.1	0.2	0.1	0.1
7/6										0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/7										0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/8	0.4	0.7	0.9	0.5	1.1	0.3	0.8	0.7	0.4	0.4	0.3	0.3	0.5	0.2	0.1	0.1	0	0.1	1.6	0.1	0.2	0	0
7/9	0	0	0	0	0.1	0.2	0.2	0.1	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
7/10	0	0	0	0	0	0.1	0.1	0.1	0.1	0	0	0	0	0	0.1	0	0	0.1	0	0.1	0	0.2	0.1
7/11	0	0.1	0.1	0.2	0	0	0	0.1	0.1	0.1	0.1	0.2	0	0	0	0	0	0	0	0	0	0	0
7/12	0									0	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0
7/13	0.2	0	0	0	0	0	0	0.1	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
7/14	0	0	0	0.1	0	0	0.2	0.5	0.2	0	0	0.1	0	0.1	0.3	0	0	0	0	0	0	0	0
7/15	0.9	0.5	0.4	0.5	0.5	0.4	0.9	0.5	0.3	0.4	1.2	0.5	0.1	0.6	0.1	0.1	0	0.7	0	0.1	0.7	0.2	0
7/16	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/17	0	0.4	0.2	0.2	0.5	0.3	1.5	0	0	0	0.1	0.5	0	0	0	0	0	0	0.1	0	0	0	0
7/18	1.3	0.9	1.4	1	1.1	0.8	0.9	0.2	0.6	1.1	1.4	1.4	1.5	0.4	0.5	0.3	0.6	0.4	0.5	0.5	0.3	1.1	0.4
7/19	0.9	1	0.7	0.8	1.2	1.1	1.2	0.8	1	0.8	1	1.5	0.8	0.6	0.8	0.8	1	1.1	1.2	1.1	0.8	0.4	0.8
7/20	0.9	1.3	0.9	0.8	0.8	0.4		1.2	0.8	0.7	0.9	1.4	0.7	0.8	0.7	0.8	0.8	0.7	1	0.7	0.6	0.8	0.7
7/21										0.7	1.2	0.7	0.3	0.6	0.5	0.4	0.8	0.6	0.5	0.7	0.5	0.6	0.9
7/22	0.7	0.9		0.9	1.1	1	1.2	1.4	0.8	0.4	0.4	1.7	2.2	1.2	0.9	0.6	1.1	0.6	1.1	0.5	0.5	0.8	0.5
7/23	0.7	0.6	0.8	0.8	1.3	0.4	0.4	0.6	0.6	0.4	0.6	0.6	0.4	0.3	0.5	0.4	0.4	0.3	0.4	0.5	0.3	0.2	0.2
7/24	1.2	1.7			0.8	1.5	1	1.6	1.1	0.7	1.6	2.7	2.4	0	0	0	0	0	0	0	0	0	0
7/25	0.1	0.8	0.7	1.2	0.7	0.1	0.5	0.3	1.2	0.3	0.7	0.8	0.9	0.4	0.5	0.8	0.5	0.8	0.1	0.5	0.2	0.3	0.7
7/26	0.2					0.4			0.3	0.1	0.3	0.2	0.2	0.2	0.1	0.2	0.3	0.4	0.2	0.1	0.1	0.1	0.2
7/27	0.3	0.2		0.1	0.5	0.2	0.3	0.4	0.5	0	0.1	1.5	0.5	0.3	0.1	0.5	0.3	0.4	0.2	0.4	0.2	0.1	0
7/28	0.6	1.2	0.3	0.9	0.7	0.3	0.2	1.1	0.3	0.3	0.4	0.7	1	0	1.1	0.3	1.5	1.4	0.4	0	0	0.6	0.1
7/29										0.4	2.7	2.7	1.6	0	0	1	1.2	0	0	0	0	0	1
7/30										0.2	0.3	0.1	0.1	0.1	0.1	0.3	0.8	0.2	0.7	0.6	0.8	1	0.6
7/31										0.4	0.5	0.3	0.3	0.5	1.2	0.7	0.5	0.5	0.6	0.7	0.8	0.6	0.7
8/1										0.1	0.1	0.1	0.3	0.3	0.4	0.6	0	0.7	0.3	0.5	0.3	0.3	0
8/2										0.8	1.2	0	0.3	0.6	0.6	1	0.5	0.6	1.4	1	0.2	1.2	1.2
8/3	0.5	0.8	0.7	1	1.1	0.6	0.3	0.5	0.4	0.4	0.4	0.1	0.2	0.7	0.7	0.8	0.4	0.9	0.7	1.6	0.5	0.5	0.5
8/4	0.2	0.4	0.9	0.2	0.2	0.3		0.2	0.4	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2
8/5		0.8	0.1	2.5	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.4	0.3	1.6	1.2	0.9	1	0.6	1.1	1.4	2.4	1.2	0.9
8/6	1.4	2.9	1.7	1.2	1.8	1.8	1.5	1.4	1.8	1.7	1.9	1.8	1.6	1.7	0.9	1	1.2	1.2	0.8	1.6	1.6	1.2	1.5
8/7	1.1	1	1.1	0.9	0.9	1.2	1.3	0.8	0.9	0.9	1.4	2.2	1.4	1	0.9	1.3	1.7	2.7	1.2	2	1.4	0.7	1.8
8/8	0.5	0.3	0.5	0.4	0.4	0.7	0.7	0.9	0.6	0.8	1.1	0.7	0.6	0.8	0.2	0.2	0.1	0.6	0.5	0.4	0.4	0.3	0.2
8/9	0.5	0.5	0.9	0.8	0.5	0.5	0.8	0.6	0.4	0.3	0.3	0.5	0.3	0.6	0.8	1.2	0.7	0.4	0.3	0.4	0.6	0.4	0.5
8/10	0.4									0.3	0.5	0.2	0.2	0.4	0.7	0.4	0.3	0.4	0.2	0.4	0.4	0.3	0.4
8/11	0.5	0.5	0.6	0.3	0.2	0.3	0.5	0.4	1.1	0.9	1.9	1.3	1.2	0.6	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.4	0.3
8/12	0.6	0.6	0.7	0.1	0.2	0.5	0.4	0.4	0.5	0.2	0.2	1.1	0.1	0	0.1	0.9	0.5	0.2	0.1	0.1	0.1	0	0
8/13	0.1	0.4	1.3	0.4	0.7	0.4			0.7	0.1	0	0	0.3	0.5	0	0.1	0.1	0	0	0.7	0.2	0.2	0.5
8/14	0.6	0.2	0.3	0.2	0.1	0.3	0	0	0.3	0	0.1	0	0	0.3	0.6	0.1	0	0.1	0	0.1	0.1	0.1	0.6
8/15	0.4	0.3	0.6	0.4	0.5	0.5	0.1	1.4	0.4	0.1	0.6	0.4	0.5	0.1	0	0	0	0	0.2	0.2	0	0.2	0.1
8/16	0.9	1.3	1.4	0.8	1.3	0.6	1	0.8	0.8	0.3	0.6	1.3	1.2	0.3	0.4	0.4	0.8	0.3	0.6	0.5	0.4	0.5	0.6
8/17	0.5	0.6	0.9	0.2	0.3	0.5	0.6	0.7	0.7	0.3	0.2	0.7	0.8	0.4	0.3	0.4	0.3	0.5	0.6	0.4	0.3	0.6	0.5
8/18	0.9	0.9	1	0.7	1.3	1.1	1	1	0.9	0.8	0.8	0.8	0.4	0.9	0.5	1.4	0.5	0.4	0.6	0.3	0.3	0.4	0.5
8/19	0.9	1.2	0.9	0.9	0.9	1.1	0.9	0.8	0.9	0.7	1.3	1.3	1.2	1.8	1.3	1.4	1.6	0.6	1.3	1	2.5	1.1	1.7

8/20	0.3	0.1	0	0.1	0.1	0.5	0.7	0.6	0	0.1	0.4	0.1	0	0.6	0	0.3	0.1	0	0	0.1	0.1	0.2	0.2
8/21	0.1	0.4	0.6	0.2	0.5	0.1	0.2	0	0.1	0.1	0.1	0	0	0.3	0.1	0	0.1	0.1	0	0.1	0.1	0.5	0.6
8/22	0.4	0.5	0.1	0.6	0.4	0.2	0.6	0.1	0.3	0.1	0.2	0.3	0.1	0	0	0	0	0	0	0	0	0	0
8/23	0.4	0.5	0.3	0.4	0.3	0.4	0.7	0.2	0.3	0.5	0.7	0.2	0.3	0	0	0	0	0	0	0	0	0	0
8/24	0.7	0.3	0.7	0.5	0.5	0.5	0.3	0.4	1	0.3	0.6	0.3	0.4	0	0	0	0	0	0	0	0	0	0
8/25	1.1	1	0.9	0.4	0.7	0.8	0.6	1.7	0.8	0.9	0.7	1	1	0	0	0	0	0	0	0	0	0	0
8/26	0.3	0.4	0.4	0.4	0.4	0.3	0.5	0.6	0.2	0.4	0.6	0.9	0.3	0.1	0.1	0.3	0.1	0.4	0.4	0.7	0.3	0.2	0.1
8/27	0.6	0.1	0.3	0.3	0.3	0.5	0.6	0.9	0.4	0.7	0.2	0.4	0.3	0.3	0.3	0.4	0.4	0.3	0.2	0.3	0.2	0.2	0.5
8/28	0.5	0.9	0.8	0.7	0.6	0.3	0.4	0.8	0.5	0.6	0.8	0.8	1.2	0.6	0.6	0.4	1	1.1	0.5	0.7	0.8	0.6	0.3
8/29	0.7	0.9	0.3	0.9	0.8	0.9	1	0.8	1.3	1.6	1.6	2.1	0.8	0.7	0.5	0.7	1.4	0.6	1.8	0.7	0.9	0.6	1
8/30	0.9	0.6	0.5	0.4	0.6	0.8	0.1	0.6	0.8	1	1.3	0.3	0.1	0.4	0.1	1.5	1.2	2.5	1.3	0.3	1.9	0.7	0.7
8/31	0.8	1	0.4	0.2	0.1	0.9	0.5	0.6	0.3	0.1	0.6	1.1	1.3	0.4	0.1	1.1	1.2	1.4	1	0.8	1.5	1	0.8
9/1	0.7	0.7	0.9	0.7	0.3	0.2	0.4	0.8	0.6	0.2	0.5	0.6	0.3	1	0.6	0.6	0.9	0.8	0.5	1.8	0.9	0.5	0.8
9/2	0.3	0.8	0.6	0.1	0.3	0	0.1	0.8	0.8	0.4	1.1	1.2	0.9	1.1	0.9	0.6	0.9	0.4	1.3	0.4	0.9	1	0.9
9/3	0.8	0.1	0.4	0.4	0.4	0.1	0.3	0.5	0.1	0.4	0.3	0.9	0.3	0.7	0.4	0.3	0.5	0.7	0.5	0.6	0.7	0.6	0.4
9/4	0.1	0		0		0.1	0	0.3	0	0	0.1	0	0	0.1	0	0.1	0.1	0	0	0	0.1	0.1	0
9/5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/6	0.2	0.6	0.4	0.7	0.4	0.7	0		0.6	0.5	1	0.1	0.5	0	0	0	0	0.1	0.1	0	0	0.2	0.5
9/7	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/8	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/9	0	0.2	0.3	0.2	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0
9/10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/11	0	0.1	0	0	0	0.1	0.2	0	0	0	0	0	0	0.3	0.1	0	0.1	0.2	0.1	0	0	0.1	0.2
9/12	0.3	0.6	0.4	0.6	0.5	0.4	0.4	0.8	0.3	0.1	0.7	0.3	0.2	0.5	0.5	0.1	0.3	0.6	0.4	0.3	0.4	0.6	0.4
9/13	0.9	0.7	0.6	0.7	0.5	1.1	1.5	0.5	0.6	0.3	0.3	1	0.7	0.6	0.7	0.8	0.9	1.4	0.8	0.8	0.8	1.7	1.1
9/14	0.3	0.4	0.4	0.5	0.4	0.3	0.6	1	0.2	0.3	0.4	0.5	0.5	0.6	0.4	1.1	0.4	0.2	0.7	0.8	0.5	0.4	0.6
9/15	0.1	0.1	0.2	0.1	0.2	0	0	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0.1
9/16	0.4	0.8	1		0.5			0.7	0.5	0	0.3	0.3	0.2	0.5	0.4	0.2	0.4	0.4	0.3	0.4	0.5	0.4	0.1
9/17	0.1	0.1	0.4	0.1	0.1	0.2	0.5	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/20	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0.1	0.1	0.2	0	0.4	0.2	0.1	0	0.2	0
9/21	0	0.3		0.2	0.1	0.1	0.1	0	0.3	0.1	0.2	0	0	0.1	0.3	0.3	0.5	0.1	0	0.1	0.3	0.2	0.3
9/22	0.2	0.3	0.4	0.7	0.3	0.4	0.5	0.5	0.1	0.2	0.5	0.3	0.2	0.8	0.2	0.4	0.2	0.1	0.3	0.2	0	0.3	0.5
9/23		0.3	0.1	0.2	0.1	0.1	0.5	0.2	0	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.1
9/24	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0.1	0.1	0	0.1	0
9/25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/28		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9/29	0.1	0.1	0	0.1	0.5	0.2	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0	0	0	0.2	0	0.2	0.1	0.1	0.3
9/30	0.9	0.6	1.1	0.2	0.4		0.4	0.6	0.8	0.3	0.6	0.5	0.6	0.7	0.7	0.7	0.6	0	0.4	0	0.5	0.4	0.4