2018
UDFCD FLASH FLOOD PREDICTION PROGRAM - ANNUAL REPORT

Submitted by
Skyview Weather

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1.0 Introduction

The Urban Drainage and Flood Control District (District or UDFCD) has used the forecasting and notification services of a private sector meteorologist for the Flash Flood Prediction Program (F2P2) since 1979. The services of a Private Meteorological Service (PMS) supplement the forecast and warning services of the National Weather Service (NWS) in Boulder, Colorado for the seven-county District area. This is the 40th year the UDFCD has funded the F2P2.

The UDFCD forecast area supported by the PMS is shown in Figure 1 and contains a population of approximately 2.9 million people. The forecast area of approximately 3,000 square miles includes the upper basin areas of watercourses that flow into the District. Terrain in the forecast area varies in elevation of around 5,000 feet above sea level to as high as 10,500 feet above sea level.

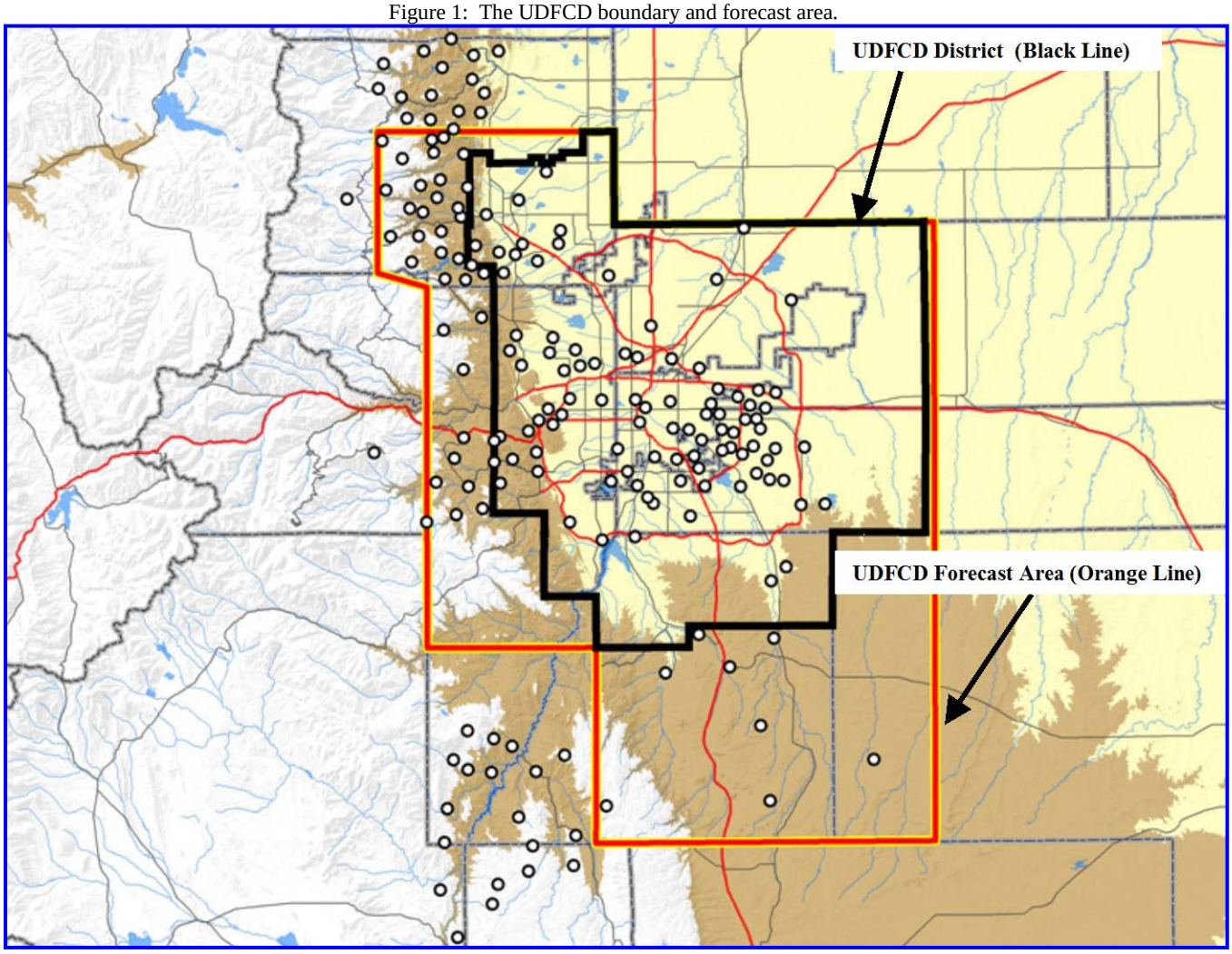
Skyview Weather, a Colorado based company was selected as the 2018 PMS.

Weather prediction personnel Tim Tonge, Brad Simmons, Alan Smith, Nick Barlow and Justin Brooks provided the F2P2 prediction and notification services. Brad Simmons was the Project Manager for the program. Tim Tonge worked his 13th, Brad Simmons his 12th season, Alan Smith his 6th season, Nick Barlow his 3rd season, and Justin Brooks his 3rd season.

2.0 2018 Operational Season

The 2018 F2P2 season began on May 1st, 2018 and concluded on September 30th, 2018 for a total of **152** operational days. Although routine daily forecast service did not begin until May 1st, the PMS was prepared to issue messages between April 15th and April 30th. Normal operational hours were from 7:00 am to 10:00 pm. A total of **1509** man-hours were expended by the PMS providing support of the F2P2 during normal operational hours. During the time period from 10:00 pm to 7:00 am the PMS provided an additional **69.5** man-hours of operational support.

Figure 1: The UDFCD boundary and forecast area.



3.0 2018 Operational Products

The F2P2 is designed to provide rainfall prediction and notification services of urban flooding and flash flooding threats to the seven District counties and the cities and towns within those counties. Direct support is provided to the District basin-specific flood warning plans, which include the Westerly Creek, Boulder Creek, Toll Gate Creek, Lena Gulch, Ralston Creek, Goldsmith/Harvard Gulch, and the Bear Creek drainage basins.

Five specific F2P2 products were produced by the PMS. The products included the Heavy Precipitation Outlook (HPO), the Internal Message Status (IMS), the Quantitative Precipitation Forecast (QPF), Storm Track (ST), and Messages. Table 1 provides a description of the first four products and Table 2 provides a description of Messages. Table 3 depicts the number of F2P2 products that were produced and the number of communication contacts made or received by the PMS in 2018.

Table 1. F2P2 product descriptions.

Heavy Precipitation Outlook (HPO)/Internal Message Status (IMS). This HPO is available by 1100 AM every day during our primary flood season as noted above. It provides a weather forecast for the District with emphasis on possible rainfall amounts and where storms are most likely to occur. When flood potentials threaten the District, the HPO will be revised and renamed "Internal Message Status" or IMS. This report will indicate the message status for each primary contact point within the District. The contact points include the counties of Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas and Jefferson, and the City of Aurora.

Quantitative Precipitation Forecast (QPF). This text product is only available on days when the rainfall potential exceeds 1.5 inches in one-hour or less. The QPF product contains more basin-specific information than the HPO or IMS, and requires some knowledge of the regional major drainage basins, streams and associated flood hazards that impact the District. Storm types, expected rainfall totals, storm duration, peak intensities and associated probabilities of occurrence are presented in this forecast product.

Storm Track (ST). This combination of map/text product is a short lead-time forecast showing where a storm has formed or is forming, the approximate size of the storm(s), the direction (or track) of the storm(s), and the estimated arrival times along the forecast track(s). This is one of the most-anticipated products of the F2P2, but keep in mind that generally it is only available within an hour or less of storm impact. Also, the Storm Track is not prepared for storms that do not pose a flood threat.

All of the above products were produced and delivered to F2P2 participants using the UDFCD F2P2 Internet-based Product Generator Interface (PGI). All F2P2 products were made available on the PGI in both HTML and PDF format, with exception of the Storm Track product, which is only available in PDF format.

Voice communication continues to be the principal method of disseminating information within the F2P2 once LIF updates are issued. Email and ham-radio communication are secondary and tertiary forms of communication and are not logged at this time. Two hundred ninety two (292) telephone or text contacts were made to F2P2 communication points by the PMS in 2018.

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT FLASH FLOOD PREDICTION PROGRAM (F2P2) MESSAGE DEFINITIONS

MESSAGE 1 (*Street Flooding Potential*)

This message is to inform key people that weather conditions are such that low impact street flooding may occur later in the day. Streets, low-lying areas, normally dry gulches, small urban streams, and recreational trails located along streams are areas most likely to be affected. Mud, debris and rock slides are the primary concern in the mountains and foothills. This product is comparable to a **NWS Hazardous Weather Outlook** concerning heavy rainfall.

MESSAGE 1 (Low Impact Flooding)

This message informs key people that low impact flooding is either imminent or occurring. Streets, low-lying areas, normally dry gulches, small urban streams, and recreational trails located along streams are areas most likely to be affected. Mud, debris and rock slides are the primary concern in the mountains and foothills. This product is comparable to a **NWS Flood Advisory**.

MESSAGE 2 (*Flash Flood Watch*)

This message is to inform key people that a Flash Flood Watch has been issued by NWS indicating that weather conditions are such that a life-threatening flash flood may occur later in the day. Significant stream flooding and property damage is possible. PMS will add any additional information available.

MESSAGE 3 (*Flash Flood Warning*)

This message will be issued to inform key people that a Flash Flood Warning has been issued by NWS or PMS feels that a life-threatening flash flood is imminent or occurring. Significant stream flooding and property damage is expected. PMS will add any additional information available. This warning message should be disseminated as quickly as possible.

MESSAGE # UPDATE

This message will be used by PMS to update any of the previous messages. For example, this message can be used to narrow a watch or warning area as more information becomes available, or to provide more site-specific data and direction during an event.

MESSAGE 4 *(All Clear)*

This message cancels the flood potential status. It is issued by PMS after consultation with NWS and other entities involved with direct PMS communications.

***SUPPLEMENTAL**: F2P2 messages are used to notify local governments of potential (MESSAGES 1-Street Flooding Potential and MESSAGE 2) and imminent (MESSAGE 1- Low Impact Flooding and MESSAGE 3) flood threats. All F2P2 messages are designed for internal use and not intended for the general public. Standard message forms completed by the meteorologist are sent by fax or email to designated communication fan-out points prior to making contact by telephone. Each county warning point or designated recipient should follow their respective protocol for subsequent dissemination of messages.*

ABBREVIATIONS: NWS...National Weather Service PMS...Private Meteorological Service

Table 2: Message definitions

Table 3: 2018 product/communication summary.

Product/Communication	**Number**
Heavy Precipitation Outlook (HPO)	161
Messages and LIF's	149
Internal Message Status (IMS)	70
Basin-Specific Quantitative Precipitation Forecasts (QPF)	35
Storm Tracks (ST)	82
PMS Initiated Telephone/Text Contacts	292
F2P2 Participant Initiated Telephone Contacts	6
Non Message Emails and Ham Radio Interactions are NOT Included	NA
Total	**795**

4.0 2018 Message Statistics

The primary services provided to F2P2 participants include early prediction and notification of the potential for flash flooding, urban and small stream flooding, and locally heavy rainfall events that can initiate low impact flooding. The PMS indicated the potential for these events in a series of products issued to F2P2 participants by phone, SMS text message, facsimile, email and Internet.

4.1 Message Verification

A Message period is defined as any time period in which a Message 1, Message 2 or Message 3 is issued based on the criteria depicted in Table 4. A total of 42 Message periods were issued spanning 40 calendar days during the 2018 F2P2 season between May 1st and September 30th. Message 2's were issued on 5/18, 7/5, 7/15 and 7/25. On 5/18 and 7/25 all areas were included in the Message 2 with 7/7 and 7/15 being issued for foothill areas only (Boulder, Douglas and Jefferson Counties). A Message 3 was issued on 5/18 for Boulder County and on 7/24 Adams, Denver, Arapahoe/Aurora were included in a Message 3. There was a **100%** verification rate of Message periods on a District-wide basis where at least 1 of the 7 Counties experienced message level rainfall.

Table 5 depicts the number of Message periods and the number of Messages issued and verified for each month of the 2018 F2P2.

Table 4: Message Criteria.

Message 1 "Low Impact Flood Advisory" Criteria
• **Message-1** (Street or gutter flooding): **0.5"/10 minutes or 1"/60 minutes**
• **Message-1** (Significant urban street and stream flooding): **1" to <3"/ 60 minutes**
• **Low Impact Flooding (LIF)**: Rainfall intensity: **0.5"/10 minutes or 1"/60 min AND occurrence is imminent**
Message 2 Flash Flood Watch Criteria
• Option A: National Weather Service issues a Flash Flood Watch affecting the District
• Option B: PMS predicts rainfall that will equal/exceed **3"/hour (No NWS Flash Flood Watch exists)**
Message 3 Flash Flood Warning Criteria
• Option A: National Weather Service issues a Flash Flood Warning affecting the District
• Option B: PMS issues a Flash Flood Warning for a specific District river/stream/drainage **(No NWS Flash Flood Warning exists)**
Message 4
• Message 4 ("All Clear") is issued whenever Messages are rescinded before their expiration time.

Table 5: Monthly Message verification.

Month	Number of Message Periods	Verified Message Periods	% Verifying Message Periods	Messages Issued	Verified Messages	% Verified Messages
May	**7**	**7**	**100%**	**56**	**48**	**86%**
June	**6**	**6**	**100%**	**42**	**35**	**83%**
July	**17**	**17**	**100%**	**131**	**90**	**69%**
August	**8**	**8**	**100%**	**61**	**45**	**74%**
September	**4**	**4**	**100%**	**32**	**26**	**81%**
Total	**42**	**42**	**100%**	**322**	**244**	**76%**

There were no periods where Message 1 level rainfall (0.5"/10mins or 1"/60mins) was observed within a portion of the District and no Message was issued.

The **42** Message periods observed is slightly above the 38-year average for the number of Message periods in the history of the F2P2, which is **37** periods. However, the 42 Message periods observed is slightly below average for the 2007-2017 timeframe in which Skyview's records are available, which is **43** Message periods.

Table 6: Total Number of Message Periods Compared to Average.

Month	May	June	July	August	September	Total
2018	**7**	**6**	**17**	**8**	**4**	**42**
2007-2017 Average	**5.8**	**9.0**	**14.1**	**11.7**	**2.7**	**43.4**

4.2 County/City Message Statistics

Each Message issued within the F2P2 is disseminated to a primary contact point in which flooding potential has been predicted. The counties and cities that receive Messages are listed in Table 6.

A Message is verified as a "hit" when a rainfall event meeting the Message criteria depicted in Table 4 is observed in the District-portion of that City/County or in the drainage area of a watercourse that flows into the jurisdiction. Table 6 contains the results of the Message verification on a City and County basis.

A Low Impact Flood (LIF) product is issued when the PMS felt that there is a **90%** or greater probability that Message level rainfall would be observed within a portion of the District. There were a total of **32** LIF periods where at least one LIF was issued within a Message period. All 32 LIF periods verified for at least one County/City on any given period; resulting in a verification rate of **100%**. A total of 143 LIF periods were issued and 135 verified resulting in total verification rate of **94%.**

Verification of Messages issued for the City of Aurora and Denver International Airport (DIA) are included in the County statistics because Aurora is a primary contact point and Denver County is segmented into two sections which includes the City and County of Denver and northeast Denver County; DIA. The Four Mile burn area continues to be its own forecast zone due to its higher potential for flooding from less intense rainfall caused by a wildfire in the fall of 2010.

The cities of Arvada, Lakewood and Wheat Ridge receive Message 1 notifications from Jefferson County dispatch, but also receive LIFs, Message 2's and Message 3's directly from the PMS.

Table 7: County/City Message Verification.

Primary Message Contact Points	Messages Issued	Message Hits	% Message Hits	LIFS Issued	LIF Hits	% LIF Hits	Events Missed	Event < 30 min Lead Time
Adams	41	32	78%	24	22	92%	0	2
Arapahoe	40	32	80%	20	20	100%	0	0
Aurora	39	29	74%	15	15	100%	0	0
Boulder	37	25	68%	13	13	100%	0	4
Four Mile Burn	37	13	35%	5	3	60%	0	1
Broomfield	37	16	43%	7	6	86%	0	1
Denver	40	27	68%	13	13	100%	0	0
DIA	40	18	45%	12	9	75%	0	1
Douglas	40	39	98%	18	18	100%	0	0
Jefferson	40	35	88%	16	16	100%	0	2
TOTAL	391	266	68%	143	135	94%	0	11
LIF Contact Points	**Messages Issued**	**Message Hits**	**% Message Hits**	**LIFS Issued**	**LIF Hits**	**% LIF Hits**	**Events Missed**	**Event < 30 min Lead Time**
Arvada	N/A	N/A	N/A	8	6	75%	0	2
Lakewood	N/A	N/A	N/A	8	7	88%	0	0
Wheat Ridge	N/A	N/A	N/A	8	5	63%	0	1
TOTAL	N/A	N/A	N/A	24	18	75%	0	3
GRAND TOTAL	391	266	68%	167	153	92%	0	14

A total of **391** Messages were issued within the District. Of the **391** Messages that were issued, **266** Messages verified, resulting in a verification rate of **68%**. Douglas County had the highest verification rate, **98%**, while the Four Mile Burn Area had the lowest verification rate, **35%** due largely to its relatively small forecast area.

A total of **167** LIF's were issued when broken down to Cities and Counties. Of the **167** LIF's issued, **153** of the LIF's verified, resulting in a verification rate of **92%**. There were total of **14** events in which Message 1's were issued with a short lead time of 30 minutes or less for LIF issuance.

The PMS identified **89** lightning days that covered the forecast period of May 1st, 2018 through September 30th, 2018. A lightning day is identified as any day that a thunderstorm cell produced a cloud-to-ground (CG) lightning strike within the forecast District boundary or multiple cloud-to-cloud (CC) strikes. Archived CG and CC lightning data was reviewed for each of the **152** operational days in 2018. Of the **152** operational days in 2018, 89 of these days, or **59%** of the total days, CG lightning was observed or multiple CC lightning strikes were observed within the forecast District. This was lower than the 2008-2017 annual average of 92 lightning days. Of the **89** "thunderstorm days" within the forecast District, **48%** of days had Messages issued. Douglas County had the highest number of lightning days with **69** total. July had the highest monthly total of **22** lightning days.

Table 8: UDFCD Lightning Statistics for period May1-September 30

County	2018 Lightning Days	Percent of Total Days w/Lightning	2008-2017 Average Lightning Days	Highest Yearly Total 2008-2018
Adams	**55**	**36%**	**54.8**	**69 (2016)**
Arapahoe	**46**	**30%**	**52.3**	**70 (2015)**
Boulder	**56**	**37%**	**63.7**	**76 (2015)**
Broomfield	**35**	**23%**	**36.9**	**51 (2014)**
Denver	**43**	**28%**	**46.0**	**62 (2015)**
Douglas	**69**	**45%**	**73.0**	**87 (2014)**
Jefferson	**67**	**44%**	**77.2**	**92 (2009)**
Total	**89**	**59%**	**92.4**	**108 (2009)**

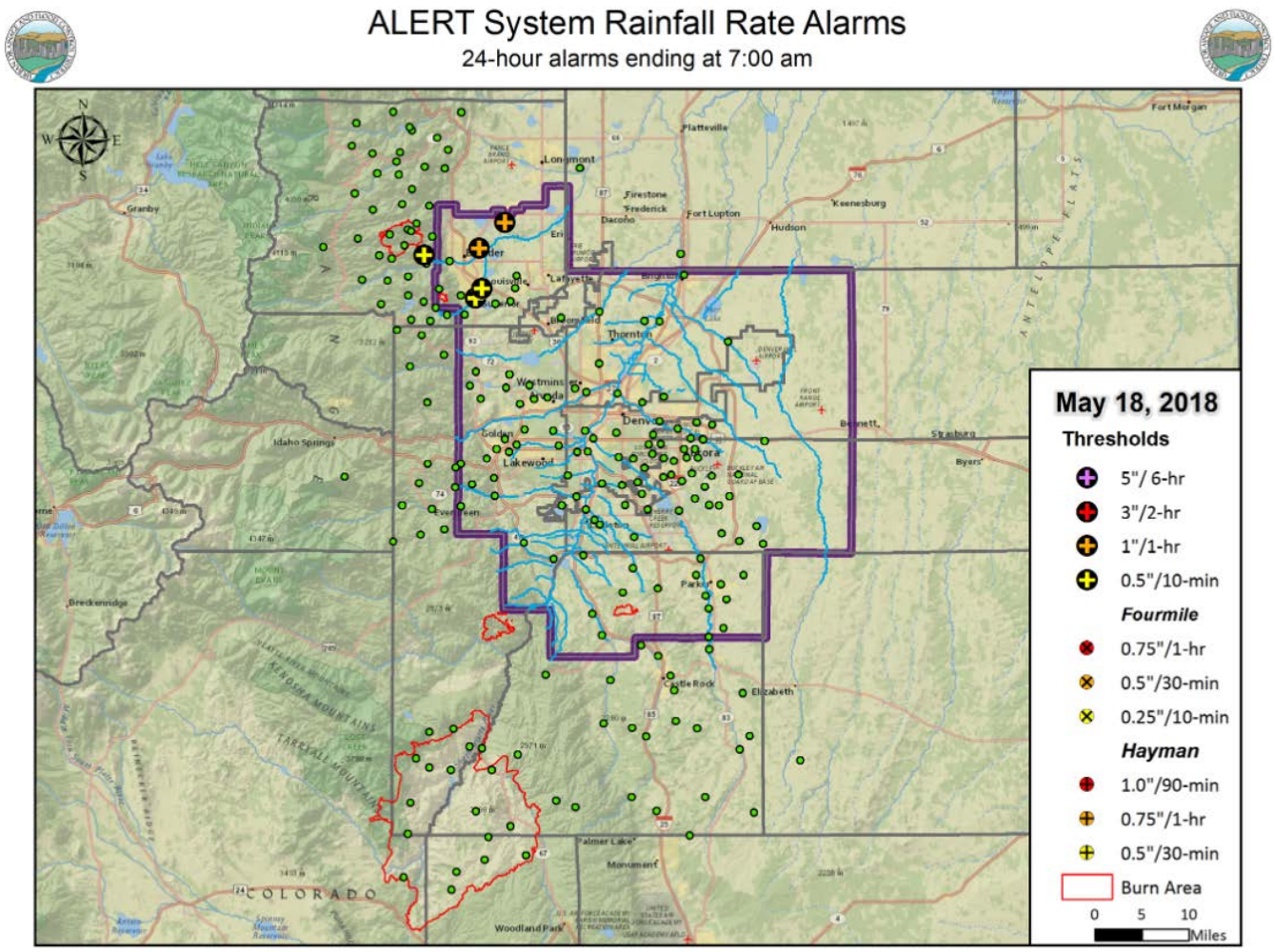
5.0 Notable Weather Events

The 2018 F2P2 season featured numerous heavy rainfall days across the District but the most severe events which produced significant flooding were relatively small in geographical area. There was one Message 3 (NWS Flash Flood Warning) in May over Boulder County on the 18th then June was relatively benign with only 6 Message periods with the heaviest rainfall days on the 17th and 18th. The majority of the high threat flood days were in July with 17 Message days in total. There was a very active period from the 15th through the 28th of July where 12 Message periods were observed over a 14 calendar day span. There was 1 Message 3 (NWS Flash Flood Warning) on July 24th, which resulted in the only human death of the flood season. There were not any Message 3 days beyond the 24th. The heaviest rainfall rates of 2018 were observed on the 23rd and 24th of July with upwards of 6"/hr rainfall rates. August was below normal in Message days with 8 in 2018 versus 12 on a 10-year average. The flood season ended in September with a significant rainfall event on the 4-5th which produced a relatively rare nocturnal heavy rainfall over a large area of the

District. The last Message period of the season was September the 19th. Below is a meteorological summary of the more notable days of 2018. More detailed analysis for these events and more can be found on the web at the UDFCD website: https://udfcd.org/FWP/floodhistory/2018storms/

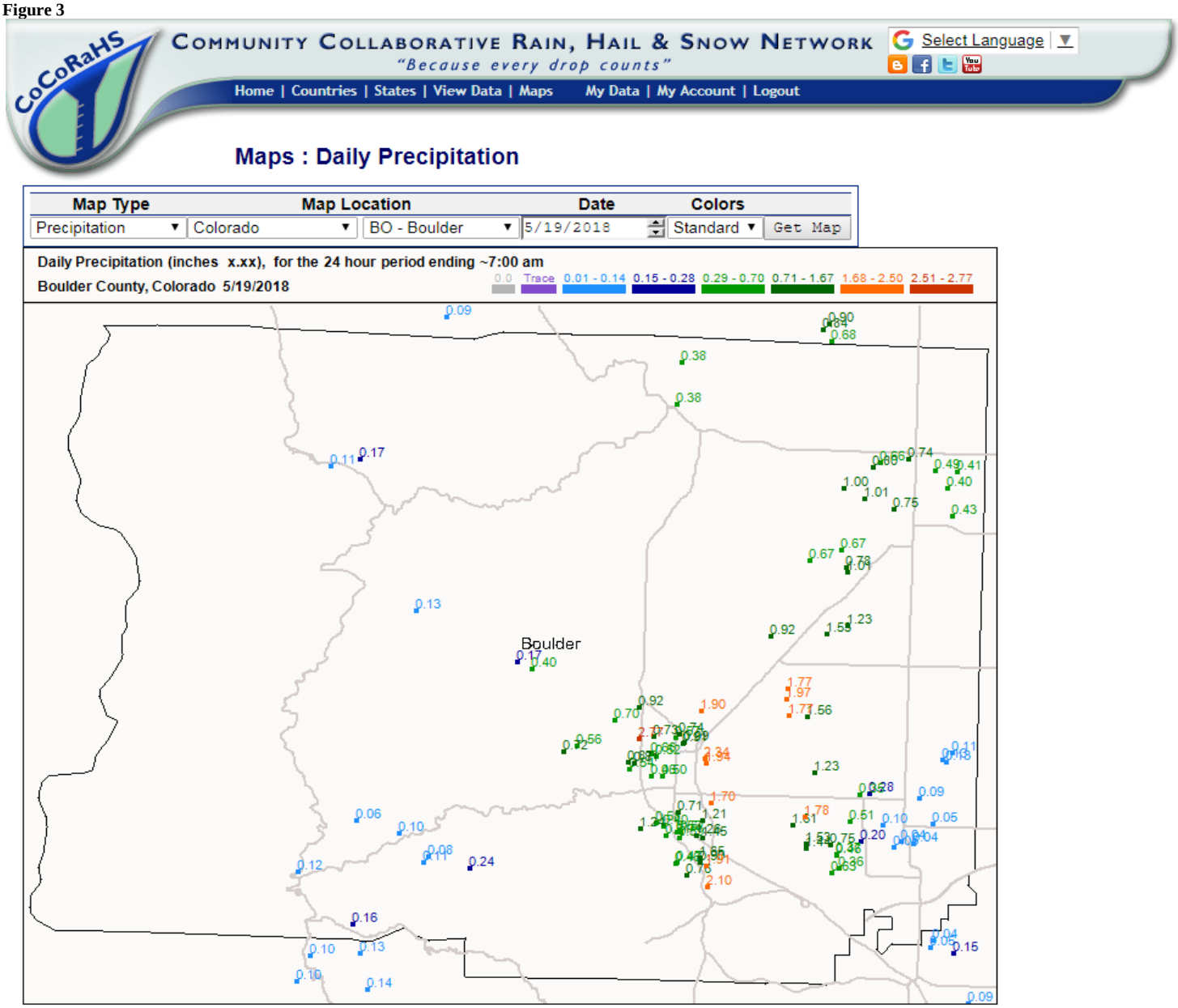
May 18th: Spring like upper level low pressure system would move into Colorado on Friday, May 18th with good upper level support on top of deep low level moisture with dew points in the 50-54 range and precipitable water values from upper air soundings in the 0.60-0.75" range which was relatively high for the date. A cold front moved through during the very early morning hours on Friday increasing the low level moisture. Message 2's were issued for all areas of the District at 1118am valid from 3pm until midnight Saturday. The upper level low itself would begin to move overhead in the afternoon generating thunderstorms over the higher terrain west of the District between 1-3pm. These storms would propagate onto the plains after 3pm and increase in strength. The strongest storms initially developed over Boulder County between 3-5pm producing heavy rainfall and hail as well as significant accumulating hail. Up to nearly 3" of rain was produced in about 2 hours resulting in NWS issuing a Flash Flood Warning for central and eastern Boulder County. Significant Street flooding was observed in and around the City of Boulder with conditions improving by 7pm. Additional strong thunderstorms developed over portions of Jefferson and Adams Counties around 5pm continuing for a couple hours producing small pockets of heavy rain and hail resulting in additional LIF's being issued. Outside of the stronger storms rainfall remained light to moderate with relatively minimal amounts. There was then a lull that developed into the evening with more rain expected to fill in as the low pressure center emerged onto the plains with wrap around moisture expected to produce a prolonged period of moderate to heavy rain. The potential for theses showers resulted in an extension of the Message 2's through 9am on Tuesday the 19th. The surface low ended up positioning itself about 100 miles too far NE of the District for this wrap around moisture to fill back in with any intensity with rain generally being on the light side overnight into Saturday morning. Due to the placement of the low pressure the Message 2's (NWS Flash Flood Watch) was cancelled over the District at 444am on the 19th. Below is a rainfall alarm map (figure 1) from the ALERT system on May 18th showing how the heaviest rainfall was limited to SE Boulder County (Figure 2).

Figure 2



Below is an additional map from CoCoRaHS showing the 24-hour rainfall totals over Boulder County, much of which fell during a 2-hour period (Figure 3):

Figure 3

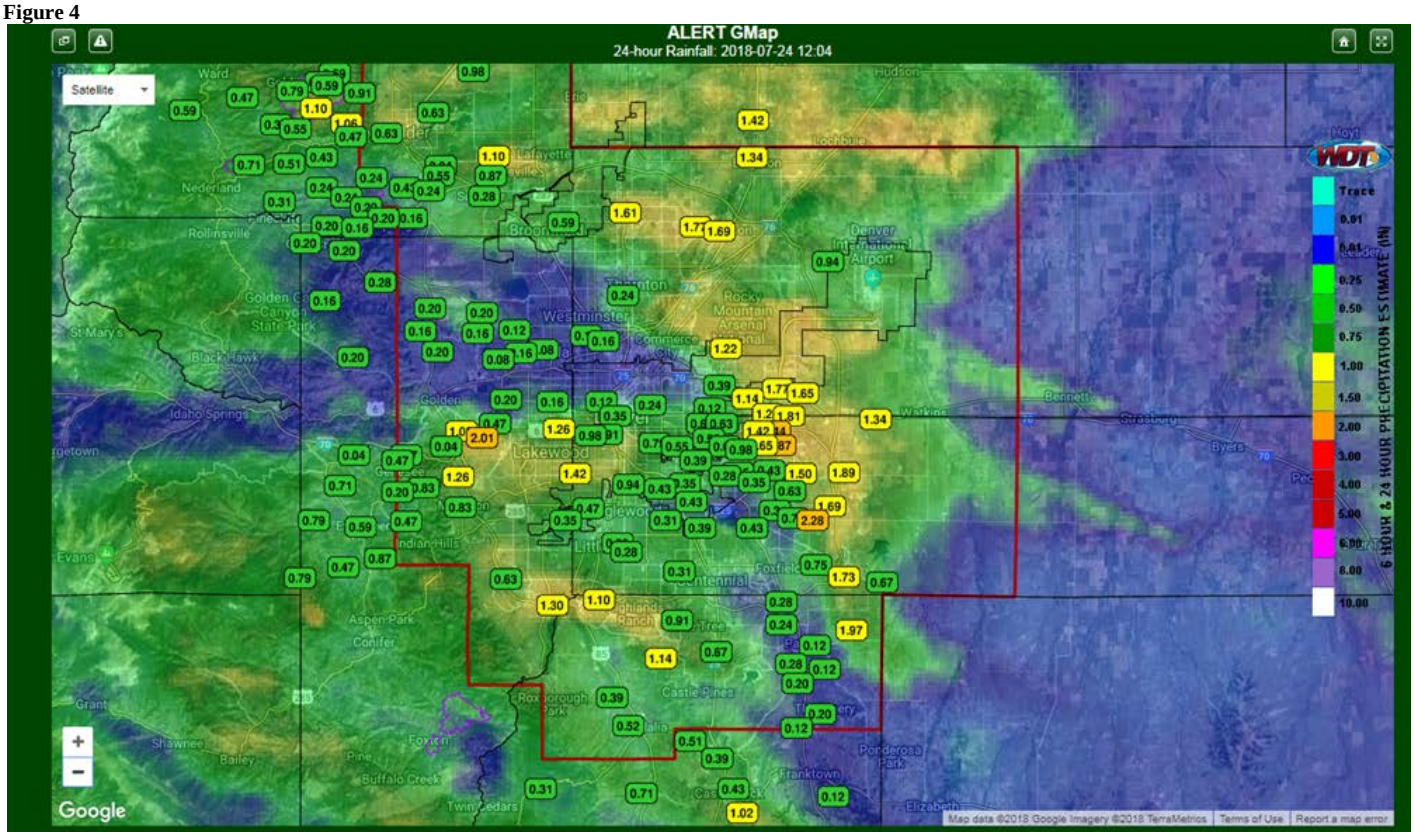


July 15-28th: July was the most active month during the 2018 flood season with 17 Message periods compared to 14 on average. Between the 15-28th of the month 12 Message periods were observed. The heaviest and most intense rainfall fell on the 23rd and 24th of July with a Message 3 (NWS Flash Flood Warning) issued on the 24th.

On Monday the 23rd of July the upper level pattern featured high pressure centered to the west of the District, with a northwest flow aloft transporting monsoonal moisture into the area at the mid to upper levels. A cold front arrived during the overnight period Sunday night, ushering in much cooler temperatures and a significant increase in low level moisture on Monday. These factors combined with several embedded upper level disturbances set the stage for a very active afternoon. Dew points were generally in the low 60s across the District for most of the afternoon, with PW values ranging from 1.21" in the morning to 1.41" in

the afternoon. Thunderstorms began to develop over the mountains and higher foothills between noon-2pm, before spreading into western portions of the District between 2-3pm. Multiple rounds of moderate to strong thunderstorms would then continue to move across the District to the E/SE at 10-20mph through 8pm. Given the deep moisture in place, thunderstorms produced widespread heavy rainfall across the District. The greatest number of rainfall alarms for the entire flood season were triggered for both 0.5”/10 minutes and 1”/hour rates on this day. The peak rainfall intensities were the highest during the entire 2018 flood season with 5-minute peak intensities of 9.9”/hr and 10-minute peak intensities of 7.8”/hr and 30-minute peak intensities of 6.8”/hr. Many locations in the District recorded rainfall amounts of over 1.0” in 15 minutes. Rainfall rates with thunderstorms began to decrease after 8pm as storm activity weakened with the loss of daylight. Additional scattered showers and weak thunderstorms would continue to move across portions of the District through 11pm, before drying out during the remainder of the overnight period. Total rainfall amounts of 1-2” were common under the stronger thunderstorm cells, with all counties (except Broomfield) in the District having at least one rain gauge record over 1”. The most widespread 1” plus rainfall totals occurred in Arapahoe and Adams Counties. The highest rainfall total occurred at the East Toll Gate at Buckley gauge where 2.87” of rain was recorded. Below is a 24 hour rainfall map (figure 4) of the 23rd from the UDFCD ALERT system, much of the rainfall measured occurred in 60 minutes or less.

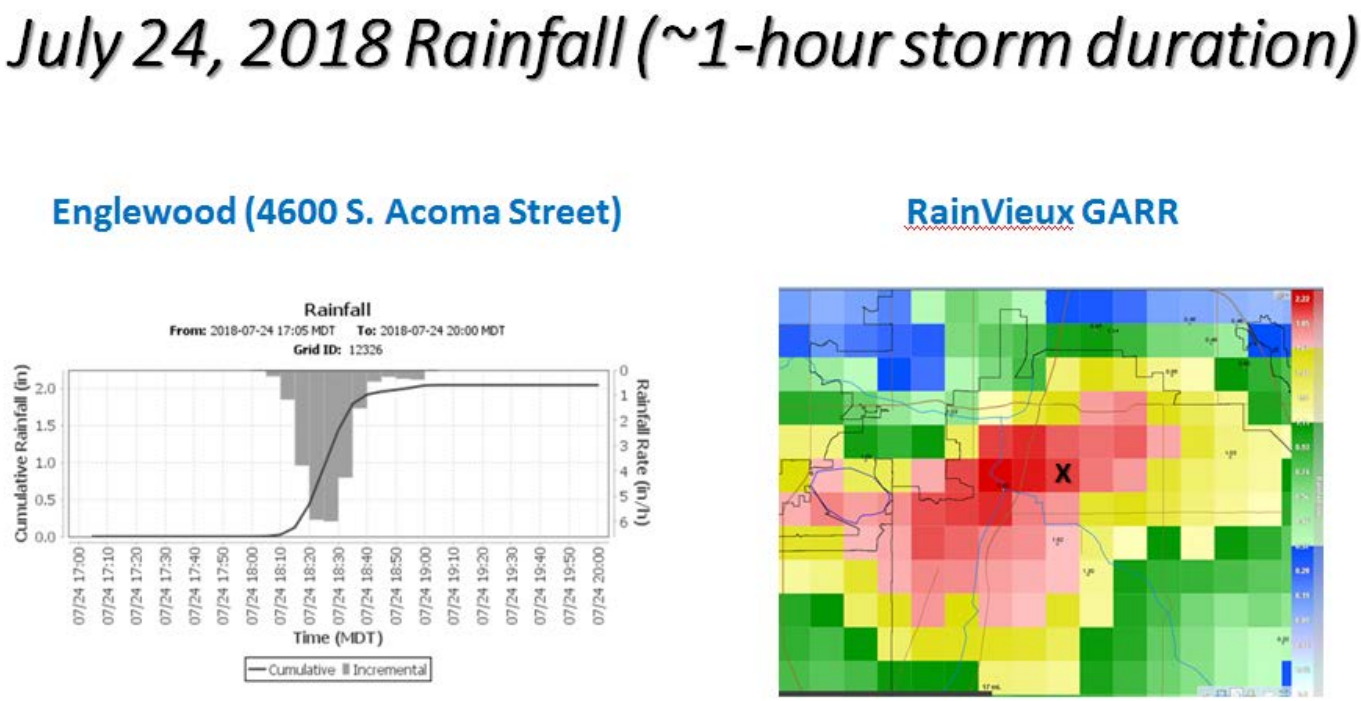
Figure 4



The heavy rainfall that occurred on the 23rd would set the stage for a Flash Flood on the 24th which would result in the only human death during the 2018 flood season. The meteorological set up for the 24th was a ridge of high pressure positioned over the Four Corners region allowing subtropical moisture to stream N over Colorado. Precipitable water was measured at 0.96” at the 0600 GMT Denver sounding, which increased to 1.05” by 1800 GMT. Afternoon dew points were in the low 50s, while high temperatures

climbed into the upper 80s to around 90 over the plains. Upper air observations showed a capped atmosphere over the plains, which initially confined showers and thunderstorms to the mountains and higher foothills through the mid-afternoon hours. However, there was concern an arriving upper-level disturbance could help trigger potentially-strong storms at lower elevations by late afternoon or early evening. A strong thunderstorm formed over the Boulder County foothills near the Four Mile Burn Area early in the afternoon but his storm was unable to transition to lower elevations. Scattered shower and thunderstorm activity continued over the foothills into the mid/late afternoon hours before the strongest thunderstorm of the day formed over central Jefferson County after 5pm. This thunderstorm strengthened rapidly as it tracked E into the District and turned severe. The storm steadily tracked E through the District over the next hour, impacting large portions of Jefferson, Douglas, Denver, Adams, and Arapahoe Counties with heavy rainfall, large hail, and damaging winds. As the storm passed over southern areas of the District it triggered a Message 3 (Flash Flood Warning) prior to 7pm for Adams, Arapahoe and Denver Counties. This severe storm complex eventually exited the District before 8pm, and only light precipitation was observed for the remainder of the evening. A total of 44 individual Alert Gauge alarms were triggered between 6:20pm and 7:00pm at 12 different gauge sites, both for rainfall at or exceeding 0.50”/10 minutes and 1.00”/hour. The heaviest rainfall was not captured by gauges and fell over a small portion of Englewood in Arapahoe County (see figure 5). It was this area of heavy rainfall with up to 0.9” in only 10 minutes that produced flash flooding and trapped a woman on the block of 4600 S. Acoma Street in a basement while flood waters blocked a doorway not allowing her to escape. The pocket of heavy rainfall in Englewood and parts of Littleton was quite small in geographical area and literally fell between UDFCD ALERT gauges.

Figure 5



September 4-5th: As the flood season was coming to a close in September there was a relatively rare nocturnal heavy rainfall event that began to take shape late in the evening on Tuesday, September 4th into the early morning hours on the Wednesday the 5th with another round of storms Wednesday afternoon and

evening which resulted in 2 Message periods during one calendar day. The meteorological setup was a trio of factors, the first being a cold front moving through during the evening on the 4th increasing surface moisture behind the front with the second being an upper level disturbance moving in from the SW Colorado. The third factor was light steering winds aloft which allowed storms to move very slowly and produce heavy rainfall amounts of 0.5-2.0" in 10-40 minutes with lingering rains increasing totals further in some isolated areas. Conditions during the day Tuesday the 4th were generally dry with no activity at all later afternoon into mid evening. As the front moved into the foothills thunderstorms rapidly developed shortly after 10pm over the higher terrain west of the District. These storms continued to intensify through 11pm and remained nearly stationary along and just W of the District boundaries. As these initial cells rained themselves out new storms began to develop further E into the District (likely due to outflow) with additional moderate to strong thunderstorms impacting the District through about 4am Wednesday the 5th. Thunderstorm coverage was widespread with all but Douglas County reporting heavy rainfall. Storms were nearly stationary initially and then began to move from N/NNW to S/SSE at 5-15mph as the event unfolded. Numerous rainfall rate alarms were triggered and the FMBA even got in on the act with a strong thunderstorm grazing the W flanks of the burn scar producing upwards of 1.2" in less than 1hr. Mid to upper end rainfall totals were from 0.5-2" with isolated higher amounts. Highest total from UDFCD was 2.09" at Blue Mountain in Jefferson County but a CoCoRaHS report from Co-DN-122 in Denver County reported 2.14". There were certainly higher amounts outside of gauge coverage but likely remained under 3". All Metro area creeks and streams were running high or out of banks due to this event with numerous LIF's issued as well as Aerial Flood Advisories from the NWS. The last heavy rainfall alarm was hit at 0349 on the 5th with no heavy rain alarms after that time. After 4am rain shower activity was rapidly on the decrease with dry conditions during the morning. Precipitable water at the 6am sounding was around 0.70" with the 6pm sounding ahead of the front coming in even lighter in the low 0.60's. PW values increased after 6pm to around 0.90" by early AM Wednesday with the 6am sounding on the 5th yielding 0.85". Dew points during the rainfall event ranged from the low to mid 50's. This was a rather rare nocturnal heavy rainfall event considering the breadth of the heavy rain and the intensity for 30 minute periods. After a break in the storm activity additional strong thunderstorms would develop Wednesday afternoon as a broad trough of low pressure remained over the Four Corners, pumping mid and upper-level moisture NE into the Central and Southern Rockies. Tuesday evening's cold front left moist easterly winds in its wake, pushing dew points into the low to mid 50s over the plains, with afternoon highs in the upper 60s to low 70s. Precipitable water values increased to 1.03" by noon Wednesday. Showers and thunderstorms developed over the mountains and foothills shortly after noon, and also along the Palmer Divide by about 1pm. A line of slow-moving storms then intensified over the Palmer Divide and tracked N into southern portions of the District. This line of heavy thunderstorms reached peak strength over Jefferson, W Arapahoe, and SW Denver Counties producing heavy rainfall throughout the SW quadrant of the District. Slow storm motion greatly contributed to extended periods of moderate and heavy rainfall, as storms moved at 10mph or less. This line of storms dissipated slightly, but eventually tracked N to impact Arvada with heavy rainfall around 330pm. Thunderstorm activity largely decreased by 4pm, but light to moderate rain showers were slow to clear out of the District through early evening. A total of (66) Alert Gauge alarms were triggered at (14) unique gauge sites, for rainfall at/exceeding 0.50"/10 minutes and also 1.00"/hour. The heaviest rainfall was over western Portions of the District. UDFCD ALERT gauges at West Metro Fire Station near Ken Caryl reported 1.14", Maple Grove Reservoir 1.89", and Lakewood Country Club 1.65". Additionally, CoCoRaHS observers reported rainfall of 2.11" near Ken Caryl, 2.15" near Applewood, and 1.94" ENE of Golden. Although there were additional message days on the 6th and 19th of September this was the last notable heavy rainfall event of the season. Below are maps for rainfall totals starting late on the 4th through 5am on the 5th (figure 6) and the additional rainfall on the 5th through the afternoon and evening (figure 7).

Figure 6

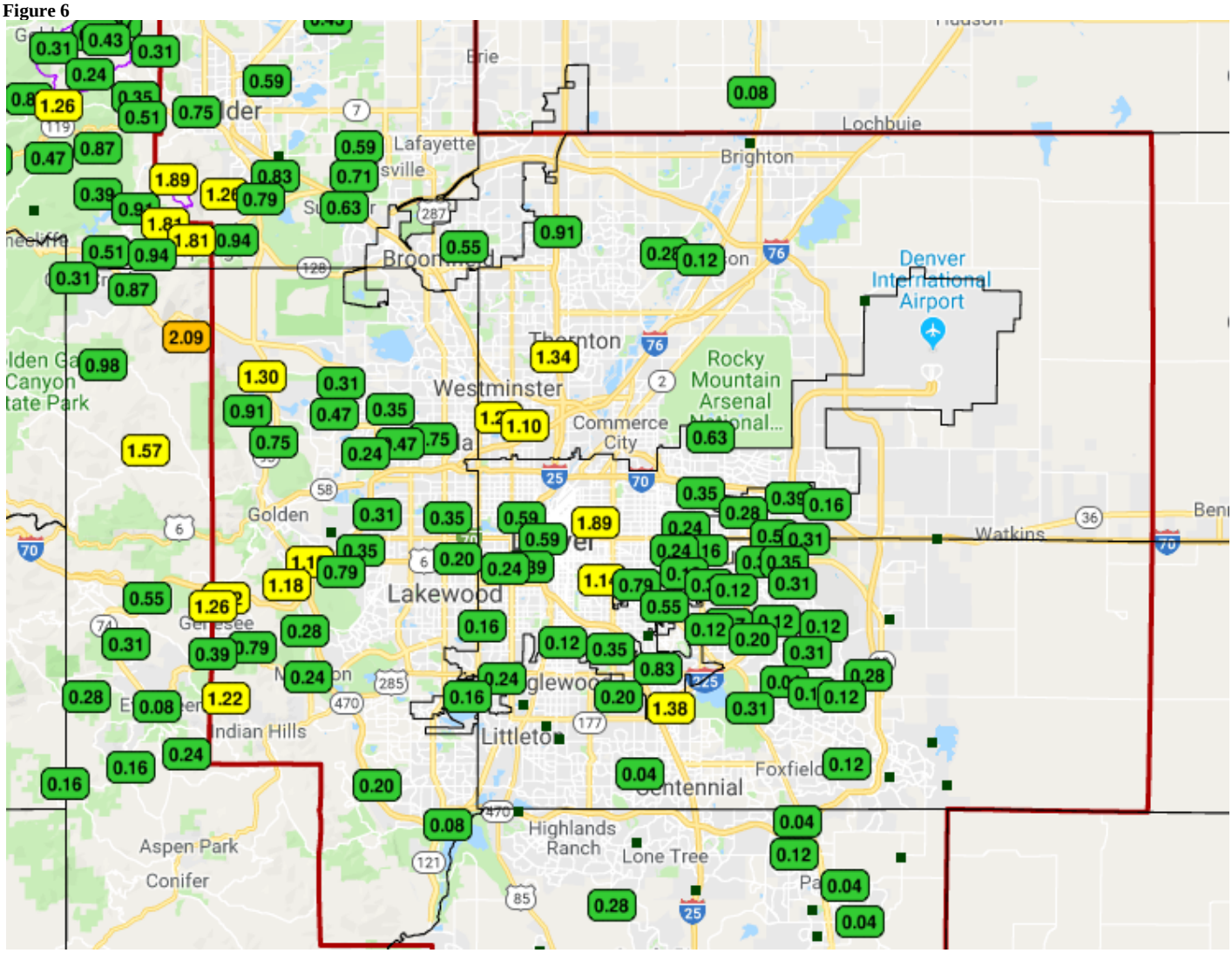
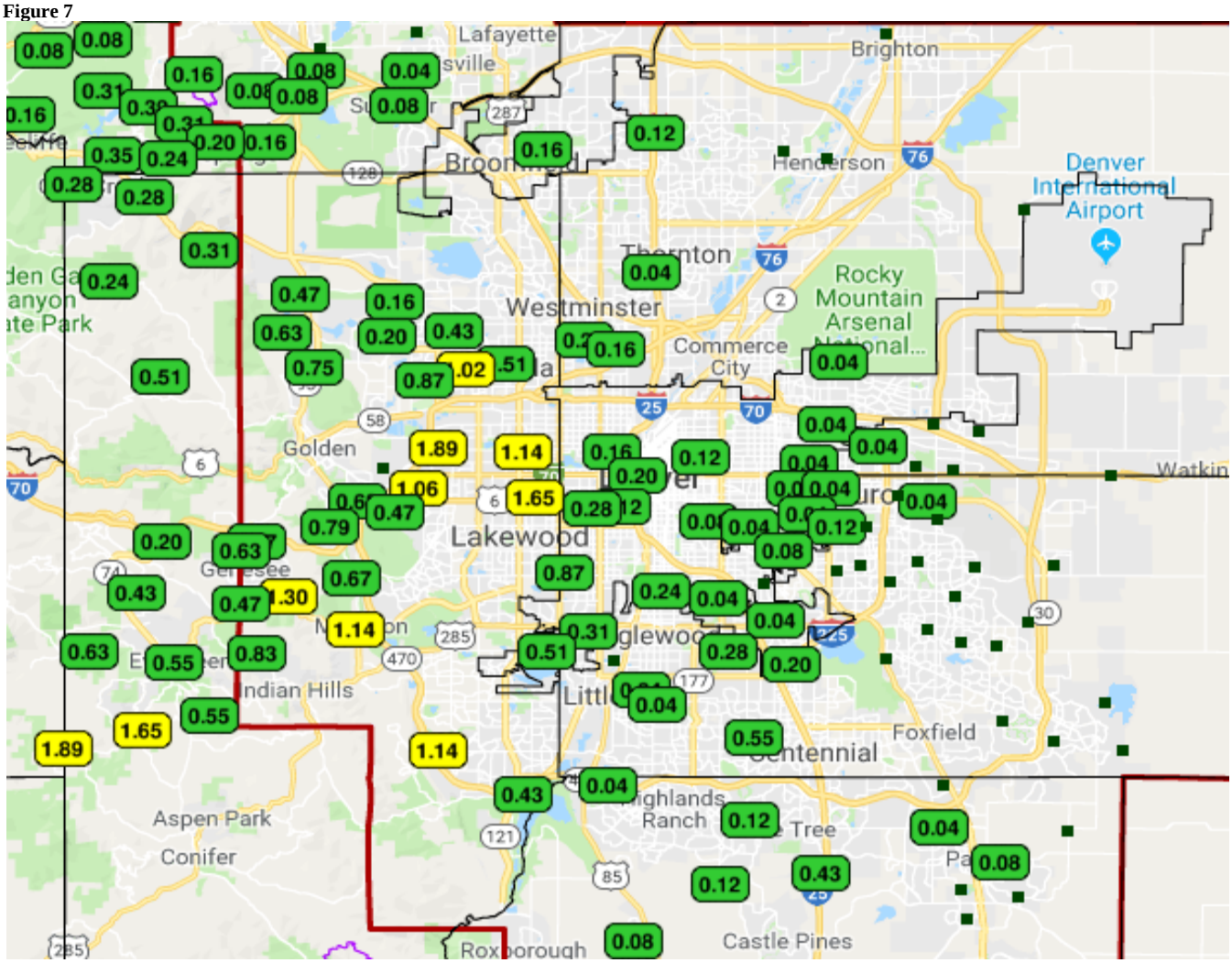

Erie
Lafayette
Brighton
Lochbuie
Denver International Airport
Rocky Mountain Arsenal National...
Thornton
Westminster
Commerce City
Golden
Lakewood
Littleton
Indian Hills
Foxfield
Centennial
Highlands Ranch
Lone Tree
Aspen Park
Conifer
Watkins

Figure 7


Lafayette
Brighton
Henderson
Denver International Airport
Rocky Mountain Arsenal National...
Westminster
Commerce City
Golden
Lakewood
Indian Hills
Foxfield
Aspen Park
Conifer
Highlands Ranch
Castle Pines