



2019
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 41st year UDFCD has funded the F2P2.

The UDFCD forecast area supported by the PMS is shown in Figure 1 and contains a population of approximately 3 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.

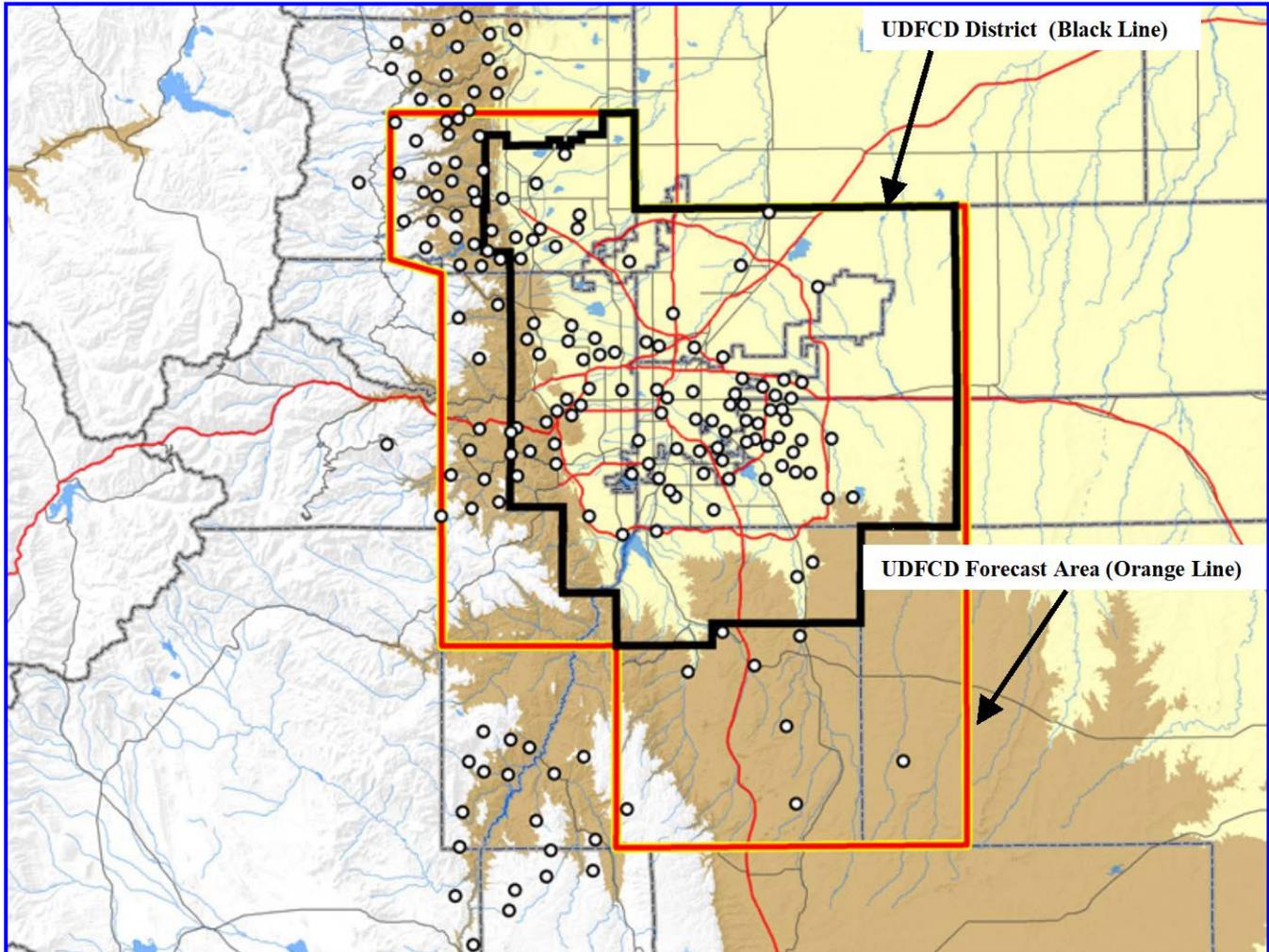
Skyview Weather, a Colorado based company was selected as the 2019 PMS.

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 14th season, Brad Simmons his 13th season, Alan Smith his 7th season, Nick Barlow his 4th season, and Justin Brooks his 4th season.

2.0 2019 Operational Season

The 2019 F2P2 season began on May 1st, 2019 and concluded on September 30th, 2019 for a total of **153** 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 10:00pm. A total of **1708.5** man-hours were expended by the PMS providing support of the F2P2 during normal operational hours. During the time period from 10:00pm to 7:00am the PMS provided an additional **29.5** man-hours of operational support.

Figure 1: UDFCD Boundary and Forecast Area



3.0 2019 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 2019.

Table 1. F2P2 Product Descriptions

Heavy Precipitation Outlook (HPO)/Internal Message Status (IMS). This HPO is available by 11:00am every day during our primary flood season as noted above and is typically issued between 9:00-10:00am. 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. The QPF product was phased out mid season and may or may not return in 2020.

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 (188) telephone or text contacts were made to F2P2 communication points by the PMS in 2019. Contacts between UDFCD and the PMS was not logged but contact was made for each Message period as well as LIF’s and Message 3’s. There were not any Message 2’s issued this year.

Table 2: Message Definitions



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 3: 2019 Product/Communication Summary

Product/Communication	Number
Heavy Precipitation Outlook (HPO)	162
Messages and LIF's	155
Internal Message Status (IMS)	70
Basin-Specific Quantitative Precipitation Forecasts (QPF)	22
Storm Tracks (ST)	81
PMS Initiated Telephone/Text Contacts	188
F2P2 Participant Initiated Telephone Contacts	2
Non Message Emails and Ham Radio Interactions are NOT Included	NA
Total	680

4.0 2019 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 49 Message periods were issued spanning 48 calendar days during the 2019 F2P2 season between May 1 and September 30. There were no Message 2's issued during the 2019 season. Message 3's were issued for portions of the District on 6/17, 7/20, 7/21, 8/21, and 9/6. 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 within the forecast area, not necessarily within District boundaries as many watercourses originate outside the District boundaries.

Table 5 depicts the number of Message periods and the number of Messages issued and verified for each month of the 2019 F2P2.

Table 4: Message Criteria

Message 1 “Low Impact Flood Advisory” Criteria
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • 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	40	71%
June	13	13	100%	101	83	82%
July	19	19	100%	149	98	66%
August	8	8	100%	64	44	69%
September	2	2	100%	16	16	100%
Total	49	49	100%	386	281	73%

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 **49** Message periods observed is above the 39-year average for the number of Message periods in the history of the F2P2, which is **37** periods. The 49 Message periods observed is also above the average for the 2007-2018 timeframe in which Skyview Weather 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
2019	7	13	19	8	2	49
2007-2018 Average	6.0	8.8	14.3	11.4	2.7	43.2

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 Flooding (LIF) imminent threat product is issued when the PMS felt that there is a **90%** or greater probability that Message level rainfall will likely occur. 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 136 LIF periods were issued and 135 verified resulting in total verification rate of **99%**.

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 main developed portion of Denver and DIA in northeast Denver County. The Four Mile Burn Area in Boulder County continued to be recognized as its own forecast zone due to its elevated potential for flooding due to a 2010 wildfire.

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	48	41	85%	23	23	100%	0	2
Arapahoe	49	39	80%	21	20	95%	0	1
Aurora	49	38	78%	18	18	100%	0	1
Boulder	47	33	70%	9	9	100%	0	0
Four Mile Burn	47	19	40%	7	7	100%	0	0
Broomfield	47	18	38%	4	4	100%	0	0
Denver	49	31	63%	10	10	100%	0	1
DIA	48	26	54%	14	14	100%	0	2
Douglas	49	39	80%	17	17	100%	0	2
Jefferson	48	42	88%	13	13	100%	0	0
TOTAL	481	326	68%	136	135	99%	0	9
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	0
Lakewood	N/A	N/A	N/A	10	10	100%	0	0
Wheat Ridge	N/A	N/A	N/A	7	6	86%	0	0
TOTAL	N/A	N/A	N/A	25	22	88%	0	0
GRAND TOTAL	481	326	68%	161	157	98%	0	9

A total of **481** Messages were issued within the District. Of the **481** Messages that were issued, **326** Messages verified, resulting in a verification rate of **68%**. Jefferson County had the highest verification rate, **88%**, while Broomfield had the lowest verification rate, **38%** due largely to its relatively small area.

A total of **161** LIF’s were issued when broken down to cities and counties. Of the **167** LIF’s issued, **157** verified, resulting in a verification rate of **98%**. There were total of **9** events in which Message 1’s were issued with a short lead time of 30 minutes or less for LIF issuance.

The PMS identified **98** lightning days comprising **64%** of the **153** day forecast period between May 1 and September 30, 2019. A lightning day is identified as any day that produces a thunderstorm cell with a cloud-to-ground (CG) lightning strike within the District forecast boundary or multiple cloud-to-cloud (CC) strikes. This was higher than the 2008-2018 annual average of 92 lightning days, but short of the 2009 record high of 108. Of the **98** “District thunderstorm days” in 2019, **49%** of these days had Messages issued. Douglas County had the highest number of lightning days with **86** total. June had the highest monthly total of **27**.

Table 8: UDFCD Lightning Statistics for Period of May1-September 30

County	2019 Lightning Days	Percent of Total Days w/Lightning	2008-2018 Average Lightning Days	Highest Yearly Total 2008-2018
Adams	68	44%	54.8	69 (2016)
Arapahoe	63	41%	51.7	70 (2015)
Boulder	73	48%	63.0	76 (2015)
Broomfield	49	32%	36.7	51 (2014)
Denver	49	32%	45.7	62 (2015)
Douglas	86	56%	72.6	87 (2014)
Jefferson	80	52%	76.3	92 (2009)
Total	98	64%	92.1	108 (2009)

5.0 Notable Weather Events

The 2019 F2P2 season featured numerous heavy rainfall days across the District. The total rainfall for the season was close to average for most areas as there were many days in which heavy rainfall was isolated in coverage. However, there were numerous severe weather events this season and there were several significant heavy rainfall events with more widespread coverage.

There were no Message 2 (NWS Flash Flood Watch) days this season, but there were 5 days in which Message 3’s (NWS Flash Flood Warnings) were issued. The majority of high flood threat days in 2019 occurred in June and July. There were a combined total of 32 Message periods during these two months, which is well above average.

The weather patterns during the 2019 F2P2 season were not typical compared to the average season. The North American Monsoon was very weak and short-lived this year, therefore the District did not receive much moisture from Mexico and the Pacific/Gulf of California region while summer precipitation across Western Colorado was well below average. However, the District received a significant amount of low level moisture from the Gulf of Mexico on a consistent basis, which resulted in a very active early to mid-summer

period. Many of the active periods across the District were driven by upper level shortwave troughs in addition to abundant low-level moisture from the east, rather than monsoonal moisture from the southwest.

May was close to average with 7 Message periods, while August was below average with only 8 Message periods. September was close to average with 2 Message periods early in the month. After a highly active stretch in June and July, the pattern was considerably drier in August and September. However, there were a few notable high threat days late in the season, most notably on August 21st and September 6th, both of which saw some of the highest single-day rainfall totals of the season for some areas.

The last Message period of the season occurred on September 8th, with much drier conditions experienced over the final 3 weeks of September. Below is a summary of the more notable days of 2019. More detailed analysis for these events can be found on the web at https://f2p2.udfcd.org/2019_summary.htm.

July 5th: A very moist and unstable environment was in place across the District on Friday with dew points in the mid to upper 50s. Thunderstorms began to develop over the foothills and Palmer Divide after noon, but a capping inversion suppressed thunderstorm development over the plains for much of the afternoon with stronger storms remaining south and west of the District.

Around 6pm, the cap finally eroded over the District and a severe thunderstorm rapidly developed over Denver and Aurora. This formed into a large of cluster of storms with no discernible movement, producing large hail and heavy rainfall between 6-7pm. Rainfall of up to 0.98” in Aurora and 0.94” in Denver fell during this time, with rainfall alarms triggered at four UDFCD gauges in this area for 0.5”/10 minute rainfall rates.

Between 7-8pm, this cluster of strong to severe thunderstorms built northward into Western Adams, Northern Jefferson, Broomfield, and Boulder Counties while weakening south. Large hail and heavy rainfall occurred in this region over the next hour with total rainfall amounts of up to 1.61” in Boulder County and up to 1.18” in the Northern Jefferson/Broomfield vicinity. Rainfall alarms were triggered at four UDFCD gauges in Boulder County during this time, with heavy rainfall impacting the city of Boulder as well.

Between 8-9pm, this cluster of thunderstorms would gradually shift north of the District. Outflow from this thunderstorm activity pushed southwest into the foothills triggering additional weaker thunderstorms along the foothills near and just west of the District between 9-11pm, but this activity was much weaker and did not survive onto the lower elevations with better rainfall remaining west of the District boundary. After 11pm, thunderstorm activity would continue to shift southwest of the District into the higher foothills and mountains with only isolated lighter showers impacting the District into the overnight period.

Below is a map showing radar-estimated rainfall for July 5th:

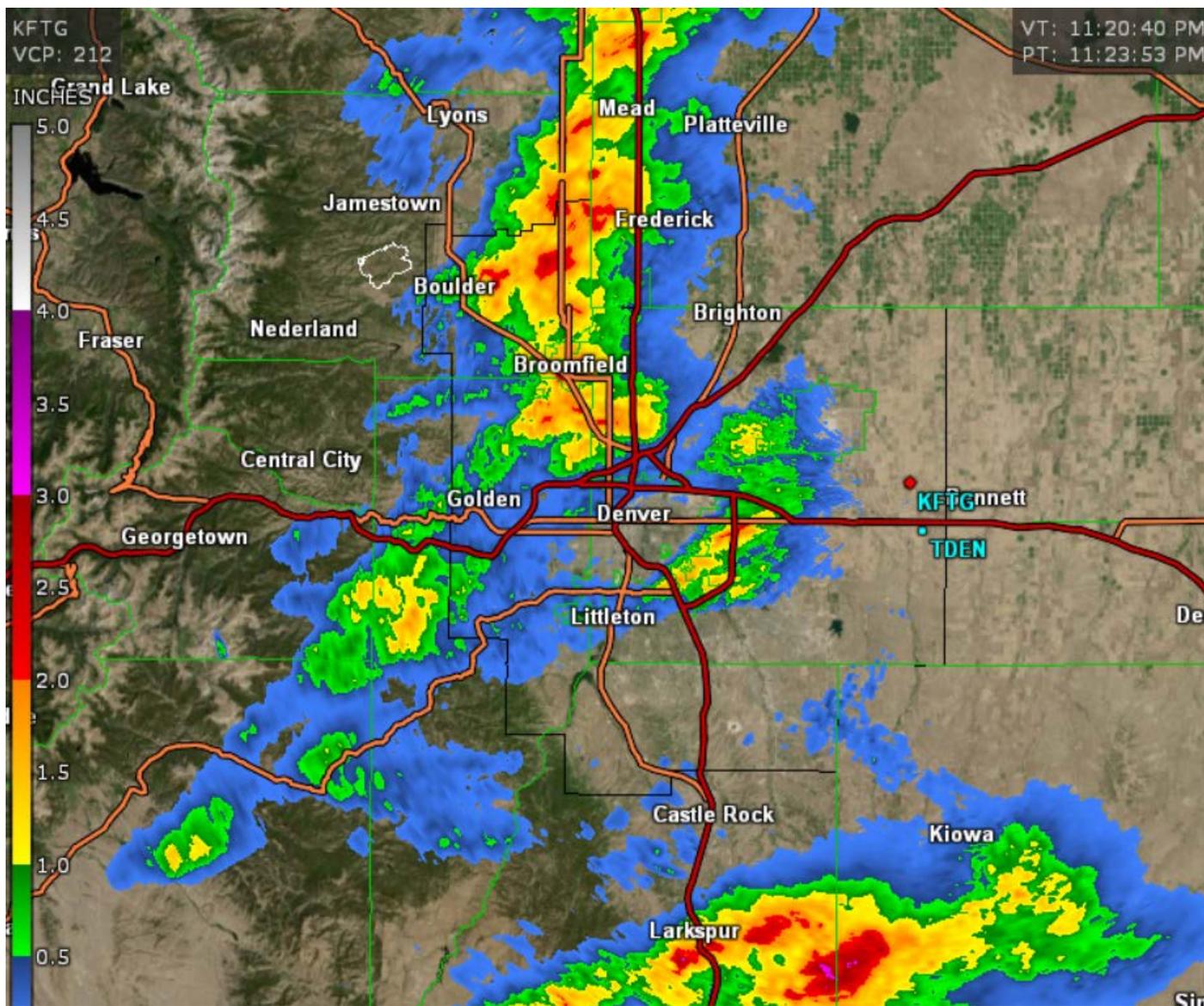


Figure 2: Radar-Estimated Rainfall on 7/5/2019

July 20th: A heat wave would come to an end on July 20th as a strong cold front would move through during the morning on Saturday capping temperatures in the 80s for highs over the plains most areas with a few lower 90s sprinkled in there. Surface moisture would slowly increase into the afternoon with dew points reaching the upper 50s to lower 60s. Precipitable water values would also increase significantly, reaching and exceeding 1.0” in the afternoon over the plains.

The increase in moisture coincided with a passing upper level disturbance to initiate 2 main waves of strong and severe thunderstorms with additional showers and weaker thunderstorms persisting into the evening. The first wave of storms initiated over the foothills between 1-2pm. Between 2-3pm thunderstorms would initiate over the plains, mainly west of I-25 and continue through roughly 4pm within the District.

The strongest storms from this first round would be over central and northern Boulder County and along and west of I-25 from roughly Westminster southward into Douglas County. The heaviest rainfall from this round was just south of the District over the Palmer Divide in Douglas County. There was then a relative lull through about 5pm then another round moved down the I-70 corridor into western and central areas of the District producing another bout of heavy rainfall.

This second round of storms resulted in the issuance of Message 3's with some rainfall rates reaching 0.7"/10 minutes and up to about 1.5-1.7" in 30 minutes. Strong storms also impacted Boulder County but the strongest storms in this area only grazed the District including the FMBA. Excessive runoff would occur under the stronger thunderstorm cells. The Lena Gulch area in Lakewood and areas along 6th Avenue into the Denver area were hit especially hard.

By 7pm the strong storms had subsided with light to moderate showers remaining. Majority of the rain had exited the District by 9pm with only isolated lingering light rain showers beyond that time. Slow storm motions with some storms nearly stationary at times resulted in extended periods of heavy rainfall.

Although heavy rainfall was observed, many areas within the District boundaries the heaviest rains of the day actually remained north and south of the District. Strong/severe thunderstorms also produced large hail and gusty winds in excess of 50mph. Unfortunately, there was 1 fatality reported in Lakewood due to the flash flooding.

Below are maps showing July 20th estimated storm total rainfall, UDFCD gauge rainfall amounts for the northern/central District and southern District, and CoCoRaHS rainfall amounts for the Jefferson, Denver, and Douglas Counties:

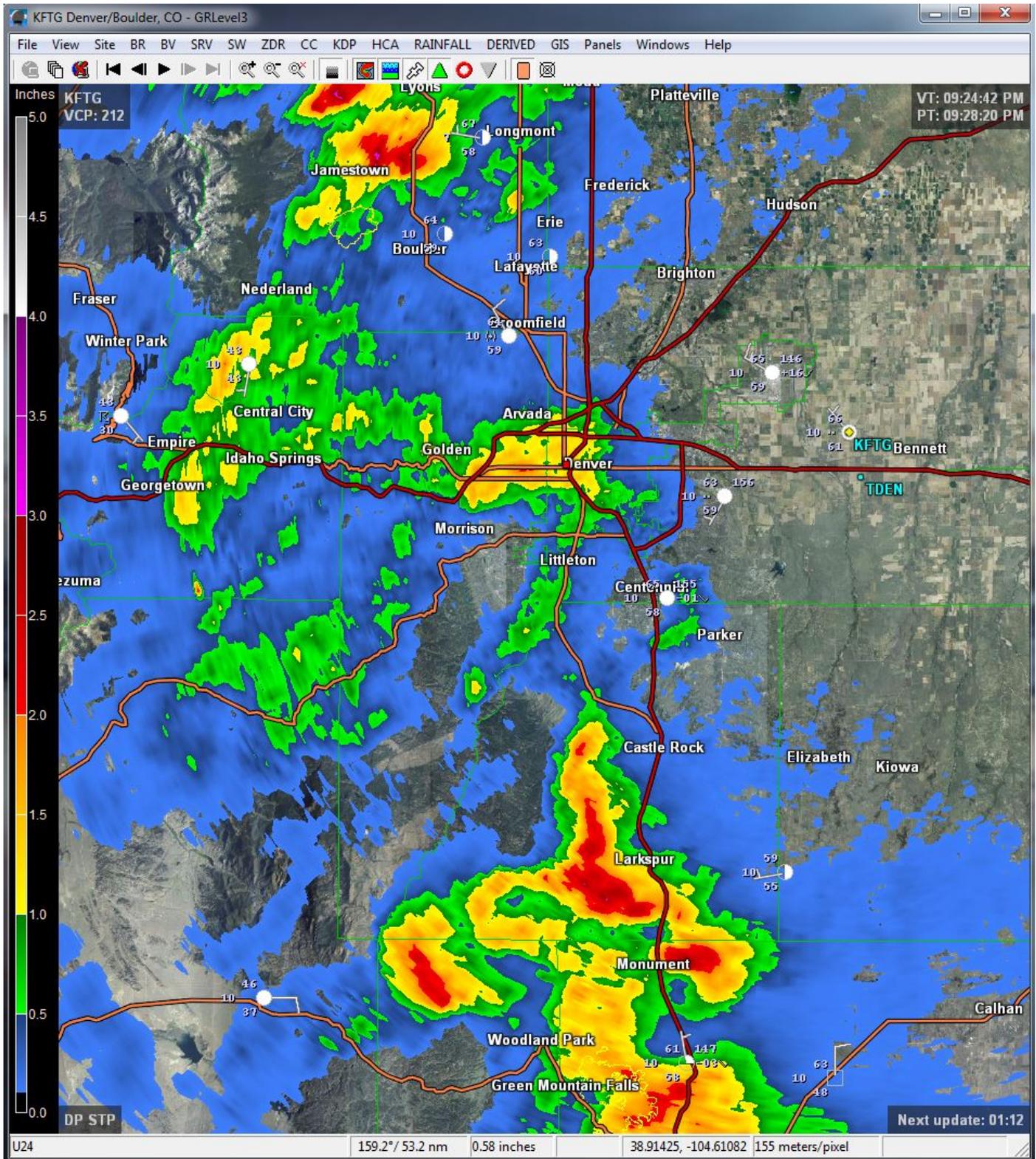


Figure 3: Rainfall-Estimated Radar on 7/20/2019

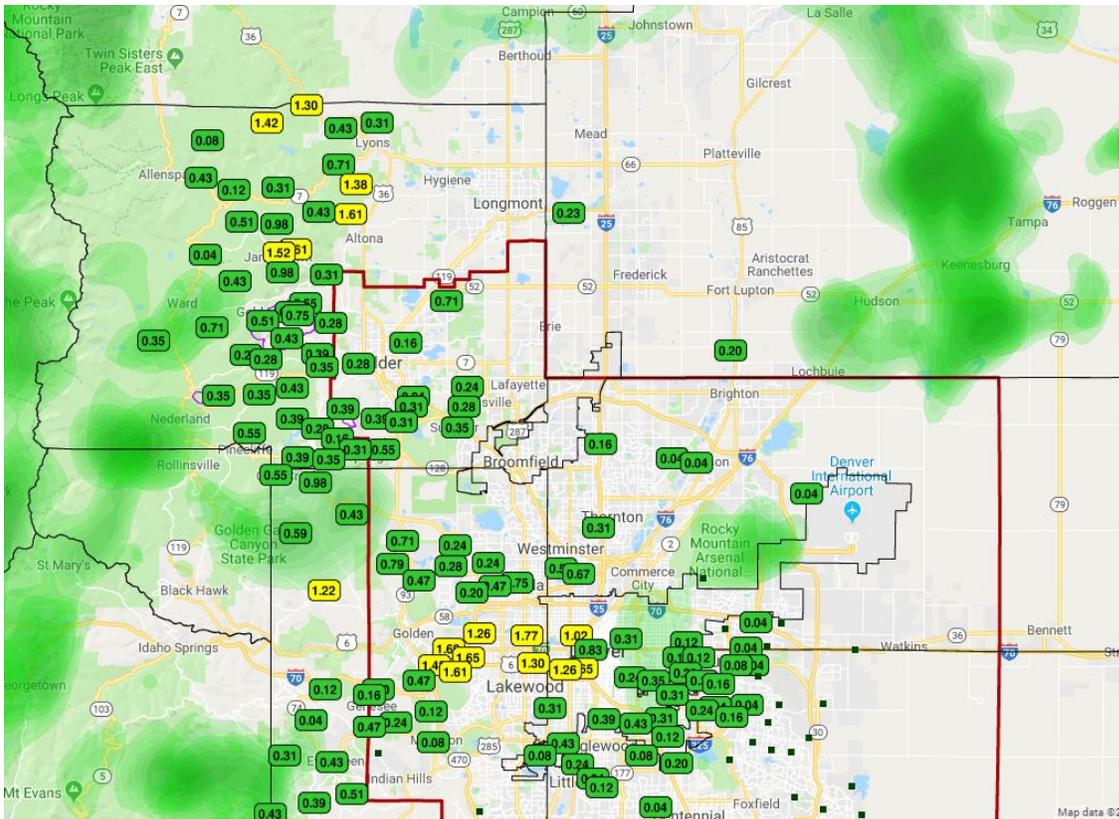


Figure 4: ALERT 24-hour Rainfall Totals for Northern/Central District on 7/20/2019

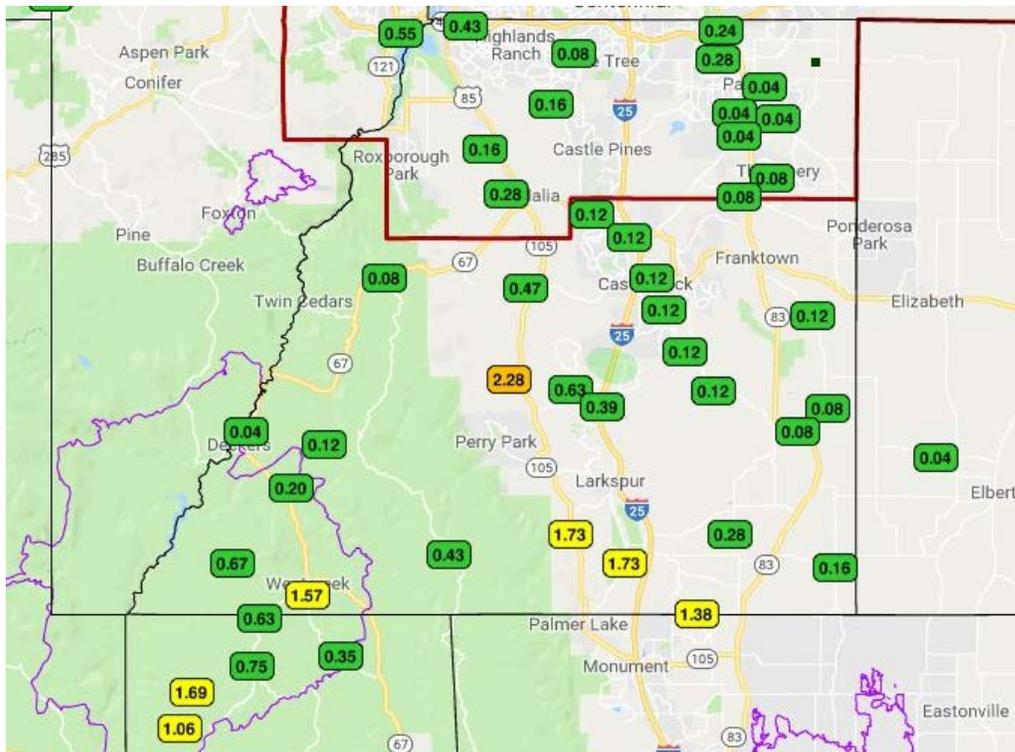


Figure 5: ALERT 24-hour Rainfall Totals for Southern District on 7/20/2019



Figure 7: Firefighters search for a missing person in Lakewood Gulch on 7/21/2019

August 21st: A cold front dropped out of the Northern Plains Tuesday evening, transporting cloud cover, cooler temperatures, and dew points in the mid to upper 50s along the Front Range by Wednesday morning, August 21st. Clockwise flow around a strong surface high anchored over the Great Lakes brought easterly winds to the area, effectively trapping low-level moisture up against the Front Range. Aloft, a ridge of high pressure remained draped over the Central Rockies, with weak steering winds throughout the mid-levels of the atmosphere. Finally, water vapor satellite observations showed a plume of subtropical moisture creeping northward underneath the ridge, pushing integrated moisture levels to around 1.00” for both the 0600 and 1800 DNR soundings.

Several ingredients were in place favoring heavy rainfall across the area, including ample convective energy and shear for strong to severe thunderstorms, elevated moisture levels, and weak steering winds. The only limiting factor was cloud cover throughout much of the day, which initially suppressed surface-based convection over the plains.

Storm activity first initiated around 1pm over the higher foothills of Teller and El Paso Counties, which produced moderate to locally-heavy rainfall as they transitioned east into the Colorado Springs area. By about 4pm, additional storm activity formed over the Larimer, Boulder, and Jefferson County foothills, while lower elevations remained dry underneath overcast skies.

This activity was finally able to break the cap over the plains around 6pm, with strong thunderstorms focusing near Arvada and Lakewood, and also over eastern Denver and portions of Aurora. These two areas of storms merged over Metro Denver around 6:30pm, forming a large, severe-warned cluster of thunderstorms. This cluster was nearly stationary, and quickly produced heavy rainfall over a large portion of the area through 7:30pm. Rainfall was heaviest along and east of Interstate 25, impacting much of central, southern, and eastern Denver, along with a good portion of Aurora. Rainfall rates underneath heavier cells in this area were measured between 2-3"/hour, prompting issuance of an NWS Flash Flood Warning for the area.

By 8pm, the strong cluster of storms over Metro Denver had transitioned to light to briefly-moderate rain showers, while an area of strong thunderstorms developed over western Douglas County. These storms eventually produced moderate to locally heavy rainfall near places like Lone Tree and Castle Pines through about 9pm, but the heaviest rainfall remained south of the District. By 10pm, storm activity had transitioned to well east of the District, with the exception of a few light rain showers for the remainder of the evening and early-overnight period.

Storm rainfall totals ranged from 1.0" to nearly 2" over favored portions of Denver and Aurora, with also several reports of rainfall between 0.50-0.75" over eastern Jefferson County. Widespread street flooding occurred on city streets and main highways throughout the Denver Metro Area, leading to one of the more-active message periods of the 2019 F2P2.

Below are August 21st radar-estimated storm total rainfall totals across the Greater Denver metro area, and UDFCD rainfall gauge amounts across central portions of the District.

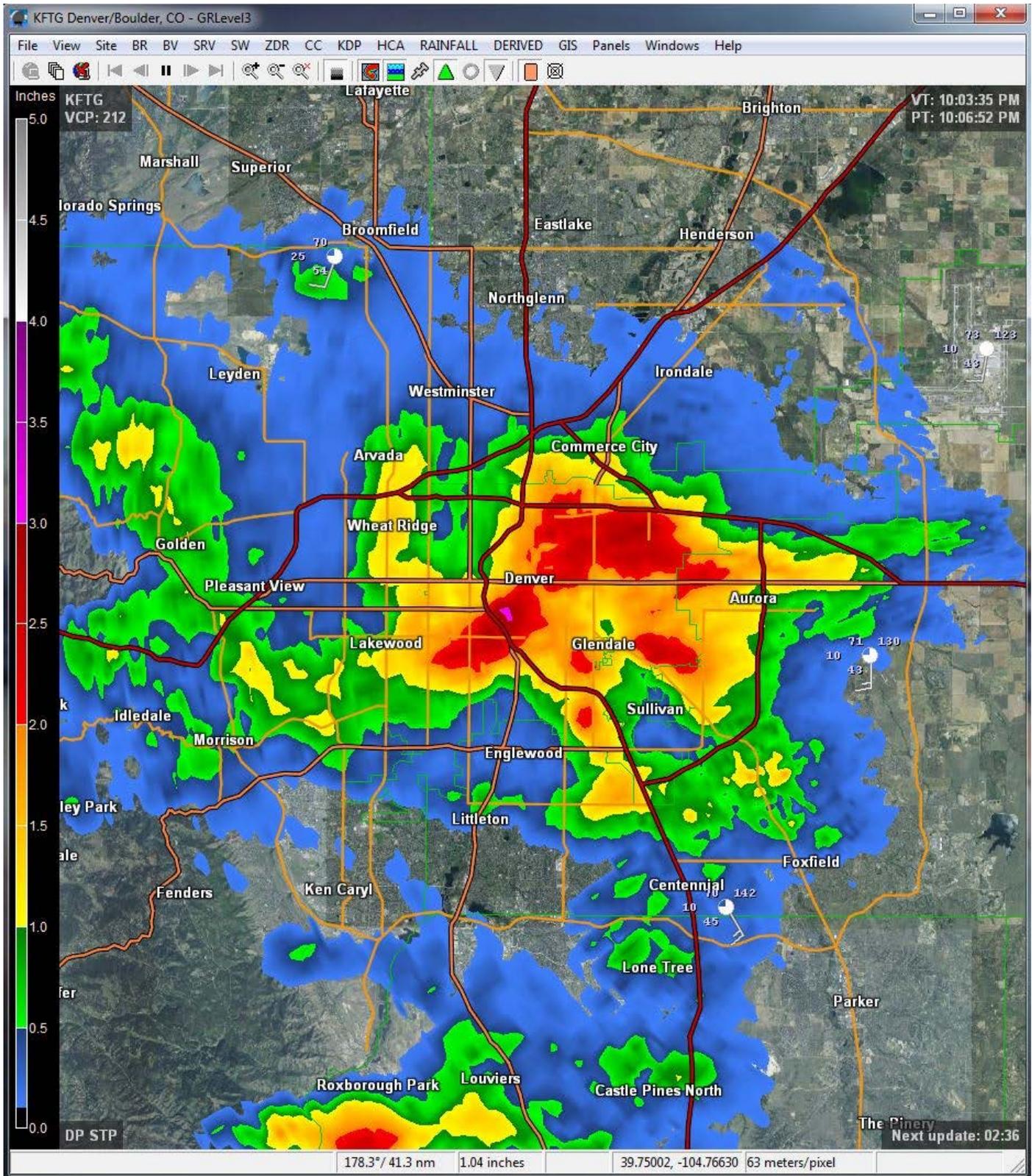


Figure 8: Radar-Estimated Rainfall on 8/21/2019

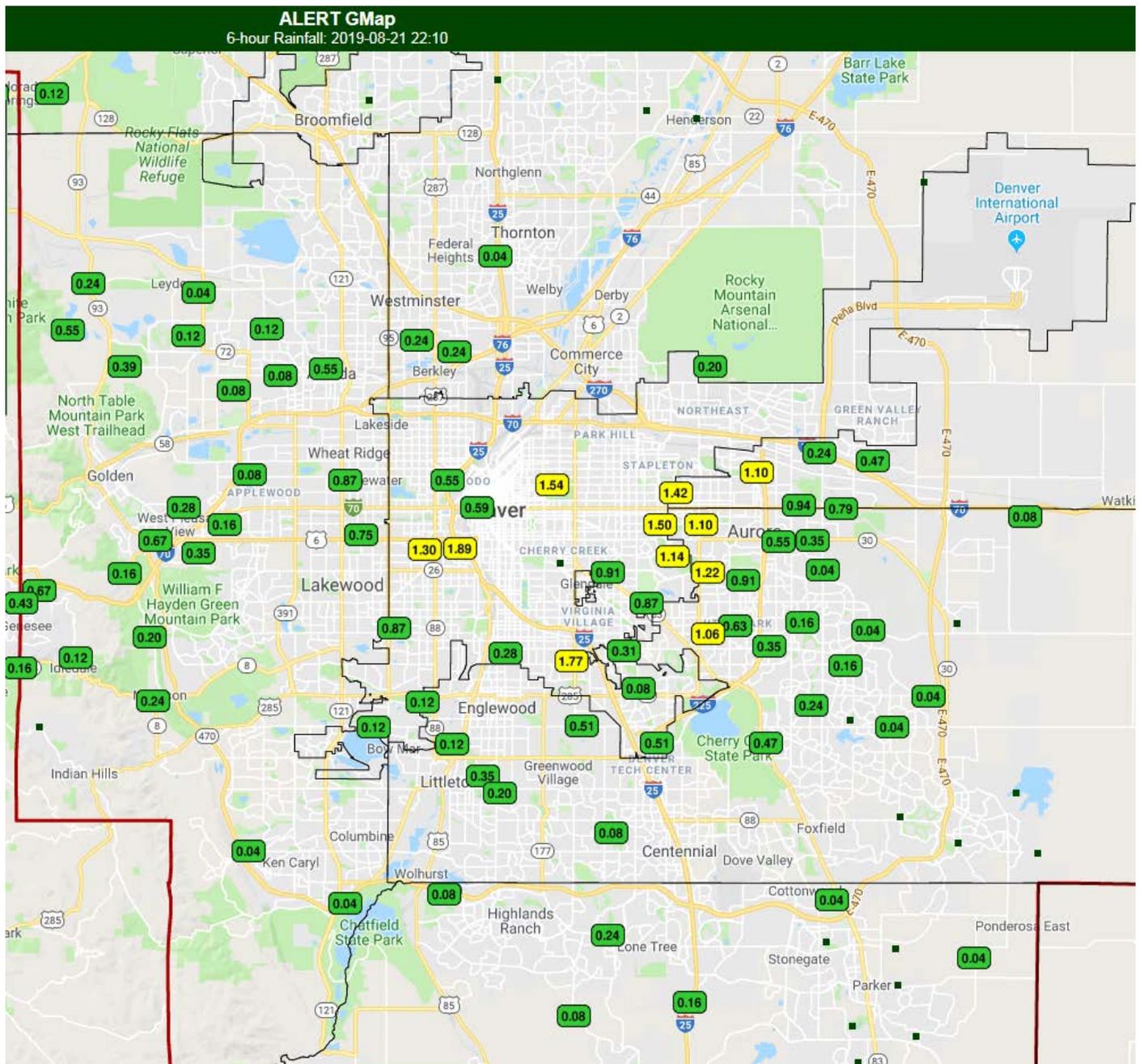


Figure 9: ALERT Rainfall Totals on 8/21/2019

September 6th: A cold front moved into NE Colorado overnight Thursday into Friday morning the 6th of September, increasing surface moisture significantly with dew points rising into the mid-50s to lower 60s and producing areas of low clouds and a few rain showers during the morning. A potent upper level disturbance would then move through during the afternoon, helping to trigger scattered to numerous strong thunderstorms through the afternoon into the early evening hours.

The first storms of the day initiated over the foothills between noon and 1pm while the plains were initially too stable. Between 2-3pm storms began to move into western areas of the District with a strong thunderstorm over Jefferson County producing heavy rainfall and accumulating hail. Floyd Hill had a spotter report of 4" of hail accumulation from this storm. As this storm moved eastward it weakened on approach to Lakewood but joined with another cell to the south, which would then spread further eastward along the Douglas/Arapahoe County line between 3-4pm. This thunderstorm would grow in size and build to the south and northeast with very heavy rainfall along the Douglas/Arapahoe County line southward into central and southern Douglas County.

Additional thunderstorm cells would develop northeastward producing heavy rainfall over portions of Aurora and just south of DIA in Adams County. Multiple LIF's were issued due to this cluster of storms with a M3 (NWS Flash Flood Warning) issued just after 4pm for a small area of Douglas and Arapahoe Counties where the storm stalled out the longest. Up to 4.5" of rain per Doppler radar was indicated but not captured well by either the ALERT or CoCoRaHS measurements due to relatively sparse gauge coverage compared to the storms geographically small heavy rain cores.

By 5-6pm thunderstorm activity had weakened over a large portion of the District with a small thunderstorm cell developing over the higher terrain of Boulder County shortly after 6pm. This Boulder County thunderstorm, although small in size, was capable of producing heavy rainfall which resulted in a LIF for the FMBA. As the storm approached the City of Boulder it diminished with only light rainfall for the lower elevations.

Storm motions were from west to east at 10-15mph but some of the stronger storms moved more erratically following outflow boundaries. Stronger storms became severe with large hail, and there was even an isolated tornado in Aurora that spawned a NWS Tornado Warning and another short-lived funnel in Douglas County.

All counties in the District with the exception of Broomfield experienced heavy rainfall that resulted in excess runoff and areas of flash flooding. Precipitable water values over the District generally ranged from 1.0-1.1" through the day. Additional lighter rain showers and a few isolated thunderstorms continued through roughly 2am Saturday morning. The heaviest rainfall rates of the 2019 season occurred during this event with 5-minute peak intensities reaching 6"/hr, 10-minute peak intensities reached 5.4"/hr and 15-minute peak intensities of 4.9"/hr.

Below are images of September 6th radar-estimated storm total rainfall and UDFCD rain gauge totals:

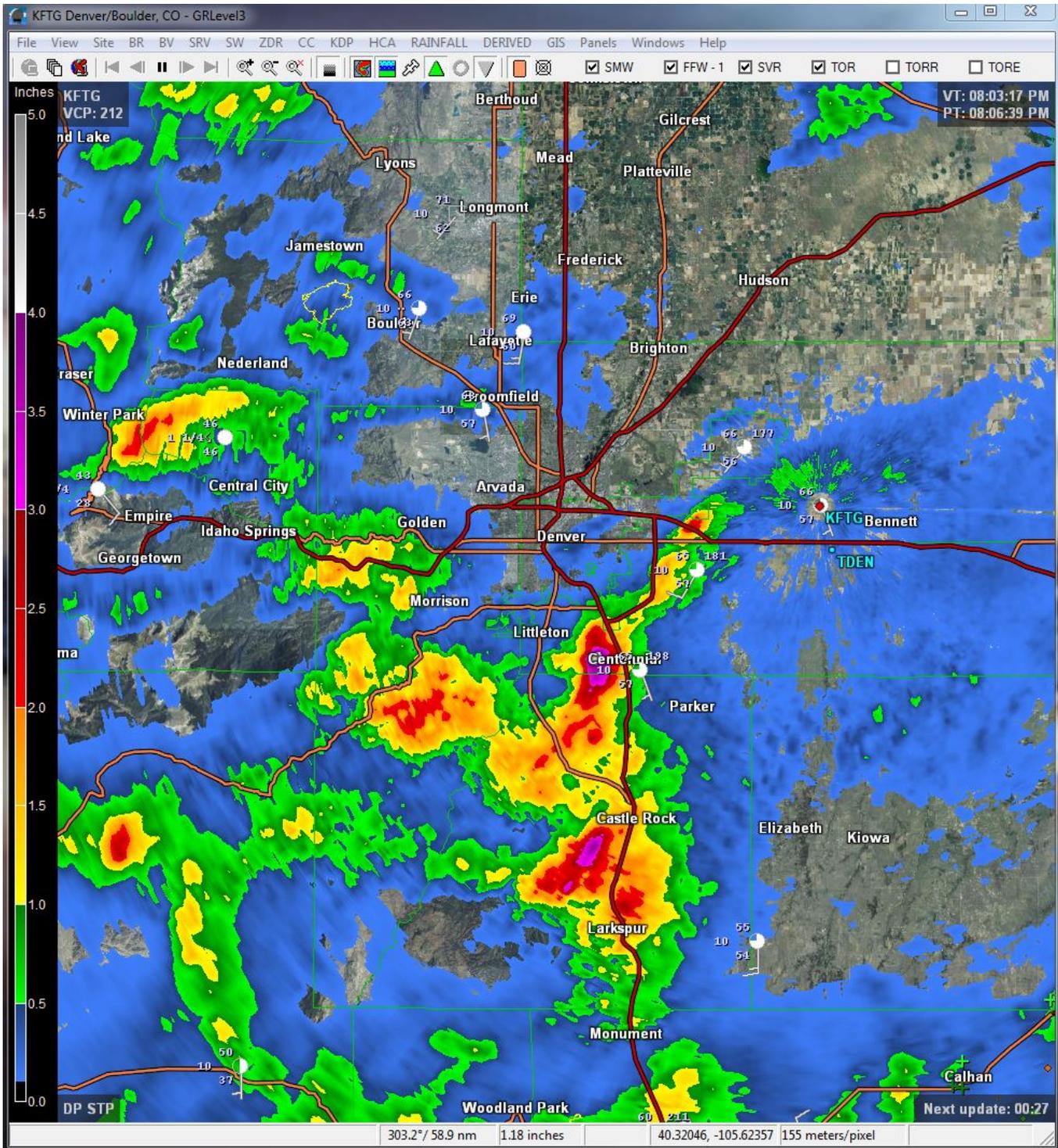


Figure 10: Radar-Estimated Rainfall on 9/6/2019



Figure 12: West Metro Fire responds to flooding on 9/6/2019, Photo Courtesy of South Metro Fire