

## **2021 MHFD FLASH FLOOD PREDICTION PROGRAM - ANNUAL REPORT**

Submitted by  
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# 1.0 Introduction

The Mile High Flood District (District or MHFD), 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 43<sup>rd</sup> year MHFD has funded the F2P2.

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

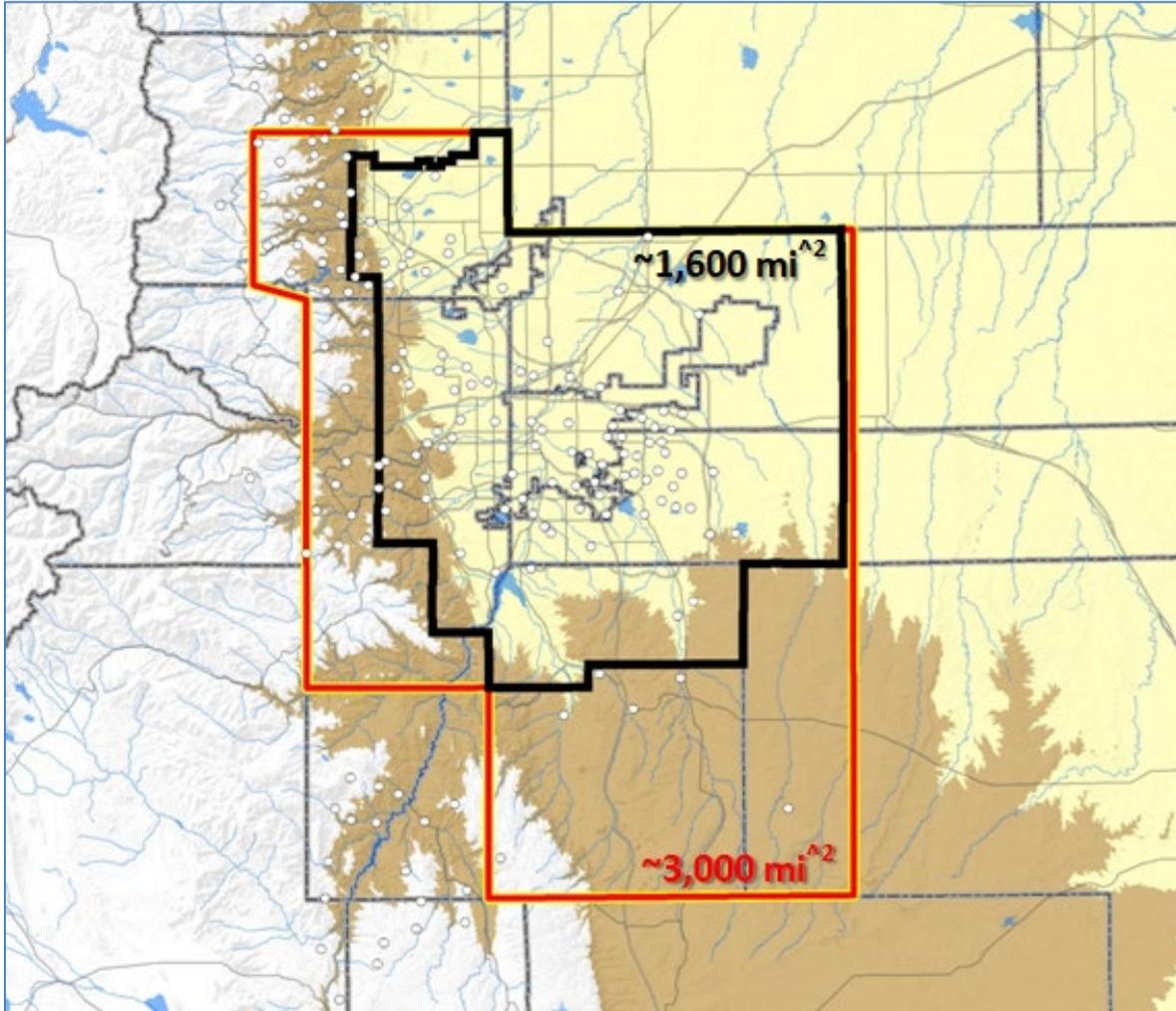
Skyview Weather, a Colorado based company was selected as the 2021 PMS.

Weather prediction personnel Tim Tonge, Brad Simmons, Justin Brooks and Laura Smith provided the F2P2 prediction and notification services. Brad Simmons was the Project Manager for the program. Tim Tonge worked his 16<sup>th</sup> season, Brad Simmons his 15<sup>th</sup> season, Justin Brooks his 6<sup>th</sup> season and Laura Smith was introduced to the program in June.

## 2.0 2021 Operational Season

The 2021 F2P2 season began ahead of the scheduled start date in late April with the first Message day on the 27<sup>th</sup> of the month just a few days ahead of the primary start date on May 1<sup>st</sup>. The F2P2 season concluded on September 30<sup>th</sup> for a total of **154** operational days. There were 2 additional days, October 1<sup>st</sup> and 2<sup>nd</sup> where a supplemental HPO forecast was provided by the PMS, but are not considered operational days as Message's did not result. Although routine daily forecast service did not begin until May 1<sup>st</sup>, the PMS was prepared to issue messages as early as April 15<sup>th</sup> and extend into October if needed. Normal operational hours were from 7:00 am to 10:00pm. A total of **1215.4** 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 **24.0** man-hours of operational support. Additional hours to prepare this annual summary are not included.

**Figure 1: MHFD Boundary and Forecast Area**



### **3.0 2021 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.

Four specific F2P2 products were produced by the PMS. The products included the daily Heavy Precipitation Outlook (HPO), the Internal Message Status (IMS), 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 2021.

**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 8:00-9:00am. It provides a weather forecast for the District with emphasis on potential higher end rainfall amounts and where storms are most likely to occur. When flood potentials threaten the District and Message 1's are issued, the HPO will be revised and renamed "Internal Message Status" or IMS. The IMS 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.

**Message 1 (Street Flood Potential).** The Message 1 product is issued when there is a threat for heavy rainfall over the District. Heavy rainfall may or may not occur but the threat is present and may result in excessive runoff or flash flooding.

**Message 1 – Low Impact Flooding (LIF).** The Message 1 LIF is issued when heavy rainfall is either imminent or already occurring and can act as a bridge between the Message 1 and the Message 3 (NWS Flash Flood Warning).

**Message 2 – NWS Flash Flood Watch.** Area and time for MHFD Message 2 may differ from NWS Flash Flood Watch.

**Message 3 – NWS Flash Flood Warning.** Area and time for MHFD Message 3 may differ from NWS Flash Flood Warning.

**Storm Track (ST).** This combination of a map/text product and 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 MHFD 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, text messaging and ham-radio communication are secondary and tertiary forms of communication. One hundred forty (**140**) telephone contacts were made to F2P2 communication points by the PMS in 2021. Contacts between MHFD and the PMS were not logged but contact was made for each Message period including individual LIF's.

**Table 2: Message Definitions**

**MILE HIGH FLOOD DISTRICT, FLASH FLOOD PREDICTION PROGRAM (F2P2) MESSAGE DEFINITIONS**



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

**MESSAGE 1 (Street Flooding Potential)**

The M1-SFP informs 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)**

The M1-LIF 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)**

The M2 informs 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)**

The M3 informs 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**

The MU may be used by PMS to update any of the previous messages except for the M1-LIF. 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 UPDATE will not be used for the short-lived M1-LIF product unless it is an extension of a current LIF already in place.**

**MESSAGE 4 (All Clear)**

The M4 cancels the flood threat 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 (M1-SFP and M2) and imminent (M1-LIF and M3) flood threats. All F2P2 messages are designed for internal use and not intended for the public. Standard forms completed by the meteorologist are sent by fax or email to designated communication fan-out points prior to making follow-up contacts by phone. Each county warning point or designated recipient should follow their respective protocol for subsequent dissemination. Beginning in 2015, M1-SFP notifications are only issued electronically unless a problem is detected.*

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

**Table 3: 2021 Product/Communication Summary**

<b>Product/Communication</b>	<b>Number</b>
Heavy Precipitation Outlook (HPO)	165
Messages and LIF's	138
Internal Message Status (IMS)	104
Storm Tracks (ST)	62
PMS Initiated Telephone/Text Contacts	140
F2P2 Participant Initiated Telephone Contacts	2
Non Message Emails and Ham Radio Interactions are NOT Included	NA
<b>Total</b>	<b>611</b>

## **4.0 2021 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. Technically, a total of 40 Message periods were issued during the 2021 F2P2 season between April 27<sup>th</sup> and September 30<sup>th</sup>. However, there was a multi-day Message period on 7/30-7/31 in which a Message 1 transitioned to a Message 2 and eventually Message 3 for Boulder and Broomfield Counties. After the Message 3's expired the Message 2's remained but there was a logical break overnight between precipitation and for this report this Message period will be broken up into (2) periods, one for the 30<sup>th</sup> and another for the 31<sup>st</sup> making for a total of **41 Message periods** when calculating the hit rates. There were 2 Message 2's (NWS Flash Flood Watch) issued during the 2021 season on 7/1 and 7/30 which carried into 7/31 and 4 Message 3's issued for portions of the District on 7/1 (2), 7/30 and 8/12. There was a **93% 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 or 38 of the 41 periods. There was a **57% verification rate when broken down to a County basis** due to the more isolated nature of the thunderstorms. The 3 Message periods where Messages were issued and did not verify for any County occurred on 6/28, 7/29 and 8/26.

Table 5 depicts the number of Message periods and the number of Messages issued and verified for each month of the 2021 F2P2.

**Table 4: Message Criteria**

<b>Message 1 “Low Impact Flood Advisory” Criteria</b>
<ul style="list-style-type: none"> <li>• <b>Message-1</b> (Street or gutter flooding): <b>0.5”/10 minutes or 1”/60 minutes</b></li> <li>• <b>Message-1</b> (Significant urban street and stream flooding): <b>1” to &lt;3”/ 60 minutes</b></li> <li>• <b>Low Impact Flooding (LIF):</b> Rainfall intensity: <b>0.5”/10 minutes or 1”/60 min AND occurrence is imminent</b></li> </ul>
<b>Message 2 Flash Flood Watch Criteria</b>
<ul style="list-style-type: none"> <li>• Option A: National Weather Service issues a Flash Flood Watch affecting the District</li> <li>• Option B: PMS predicts rainfall that will equal/exceed <b>3”/hour (No NWS Flash Flood Watch exists)</b></li> </ul>
<b>Message 3 Flash Flood Warning Criteria</b>
<ul style="list-style-type: none"> <li>• Option A: National Weather Service issues a Flash Flood Warning affecting the District</li> <li>• Option B: PMS issues a Flash Flood Warning for a specific District river/stream/drainage (<b>No NWS Flash Flood Warning exists</b>)</li> </ul>
<b>Message 4</b>
<ul style="list-style-type: none"> <li>• Message 4 (“All Clear”) is issued whenever Messages are rescinded before their expiration time.</li> </ul>

**Table 5: Monthly Message Verification**

Month	Number of Message Periods	Verified Message Periods	% Verifying Message Periods	Messages Issued	Verified Messages	% Verified Messages
April	1	1	100%	4	4	100%
May	7	7	100%	46	34	74%
June	11	10	91%	69	36	52%
July	15	14	93%	99	67	68%
August	6	5	83%	39	22	56%
September	1	1	100%	7	6	86%
<b>Total</b>	<b>41</b>	<b>38</b>	<b>93%</b>	<b>264</b>	<b>169</b>	<b>64%</b>

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 41 Message periods is only 1 Message period below the 15 year annual average of 42 Message periods.

**Table 6: Total Number of Message Periods Compared to Averages**

Month	April	May	June	July	August	September	Total
2021	1	7	11	15	6	1	41
2007-2021 Avg	0.4	5.9	8.8	14.6	10.2	2.4	42.3

## 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 7.

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. The verifications on a County basis are not performed by the PMS and can be found at: [https://f2p2.udfcd.org/2021\\_summary.html](https://f2p2.udfcd.org/2021_summary.html). Table 7 contains the results of the Message verification on a City and County basis. Message verification for the 2010 Fourmile Burn Area (FMBA), Arvada, Lakewood, Wheat Ridge and DIA was conducted by the PMS/Skyview Weather as 3<sup>rd</sup> party verification is not available from the link listed above.

A Low Impact Flooding (LIF) imminent threat product is issued when the PMS feels there is a **90%** or greater probability that Message level rainfall will occur. There was a total of **20** LIF periods where at least one LIF was issued within a Message period. All 20 LIF periods verified for at least one County/City on any given period; resulting in a verification rate of **100%**. A total of 114 LIF’s were issued when including the FMBA and DIA as well as the cities of Arvada, Lakewood and Wheat Ridge. Of the 114 individual LIF’s, 108 of the 114 LIF’s verified resulting in total verification rate of **95%**.

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 FMBA 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 Jeffcom 911, 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	40	26	65%	16	16	100%	0	0
Arapahoe	39	27	69%	16	16	100%	0	2
Aurora	39	24	62%	9	9	100%	0	2
Boulder	34	21	62%	7	7	100%	0	1
<i>Four Mile Burn</i>	<b>35</b>	<b>18</b>	<b>51%</b>	<b>3</b>	<b>1</b>	<b>33%</b>	<b>0</b>	<b>0</b>
Broomfield	35	14	40%	7	6	86%	0	0
Denver	39	22	56%	10	10	100%	0	1
<i>DIA</i>	<b>39</b>	<b>17</b>	<b>44%</b>	<b>3</b>	<b>2</b>	<b>67%</b>	<b>0</b>	<b>0</b>
Douglas	39	32	82%	13	13	100%	0	0
Jefferson	38	28	74%	14	14	100%	0	1
<b>TOTAL</b>	<b>491</b>	<b>281</b>	<b>57%</b>	<b>34</b>	<b>33</b>	<b>97%</b>	<b>0</b>	<b>7</b>
LIF Contact Points	Messages Issued	Message Hits	% Message Hits	LIFS Issued	LIF Hits	% LIF Hits	Events Missed	Event < 30 min Lead Time
Arvada	38	16	42%	9	9	100%	0	0
Lakewood	38	18	47%	5	4	80%	0	0
Wheat Ridge	38	16	42%	4	3	75%	0	0
<b>TOTAL</b>	<b>114</b>	<b>50</b>	<b>44%</b>	<b>18</b>	<b>16</b>	<b>89%</b>	<b>0</b>	<b>0</b>
<b>GRAND TOTAL</b>	<b>605</b>	<b>331</b>	<b>55%</b>	<b>52</b>	<b>49</b>	<b>94%</b>	<b>0</b>	<b>7</b>

A total of **417** Messages were issued within the District on a County basis including Aurora. DIA and the FMBA are not included in the message count but are included in the LIF count. Of the **417** Messages that were issued, **246** Messages verified, resulting in a verification rate of **59%**. Douglas County had the highest verification rate, **82%**, while Broomfield had the lowest verification rate, **40%** due largely to its relatively small geographical area.

There were 4 periods in which Message 1’s were issued with a short lead time of 30 minutes or less for LIF issuance which occurred on 4/27 for Arapahoe County including Aurora, 7/25 for Boulder and Jefferson Counties, 8/12 for Denver County and during the early morning hours on 8/20 for Arapahoe County including Aurora. **The average lead time from Message 1 issuance and the first LIF issued for the period was 116 minutes or 1 hour and 56 minutes.** Data from 7/31 was omitted as the start time was the day previous and would not represent the average lead time on a typical heavy precipitation day. This is the first season the PMS has tracked average lead times. Of the 4 Message periods with short lead time 2 of the 4 (8/12 and 8/20) occurred after normal operational hours and the 4/27 event was before the scheduled start of the F2P2 season. The 7/25 short lead time was within regular hours and resulted in a lead time of 22 minutes.

The PMS identified **93** lightning days with lightning occurring over at least one of the 7 Counties which accounted for **61%** of the **153** day forecast period between May 1 and September 30, 2021. 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 considered “normal” lightning activity compared to the 2008-2021 annual average of 92 lightning days, and short of the 2009 record high of 108. Of the **93** “District thunderstorm days” in 2021, **45%** of these days had Messages issued. All 41 Message periods contained lightning in at least one of the 7 Counties. Jefferson County had the highest number of lightning days with **75** total, followed by Douglas at 72.

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

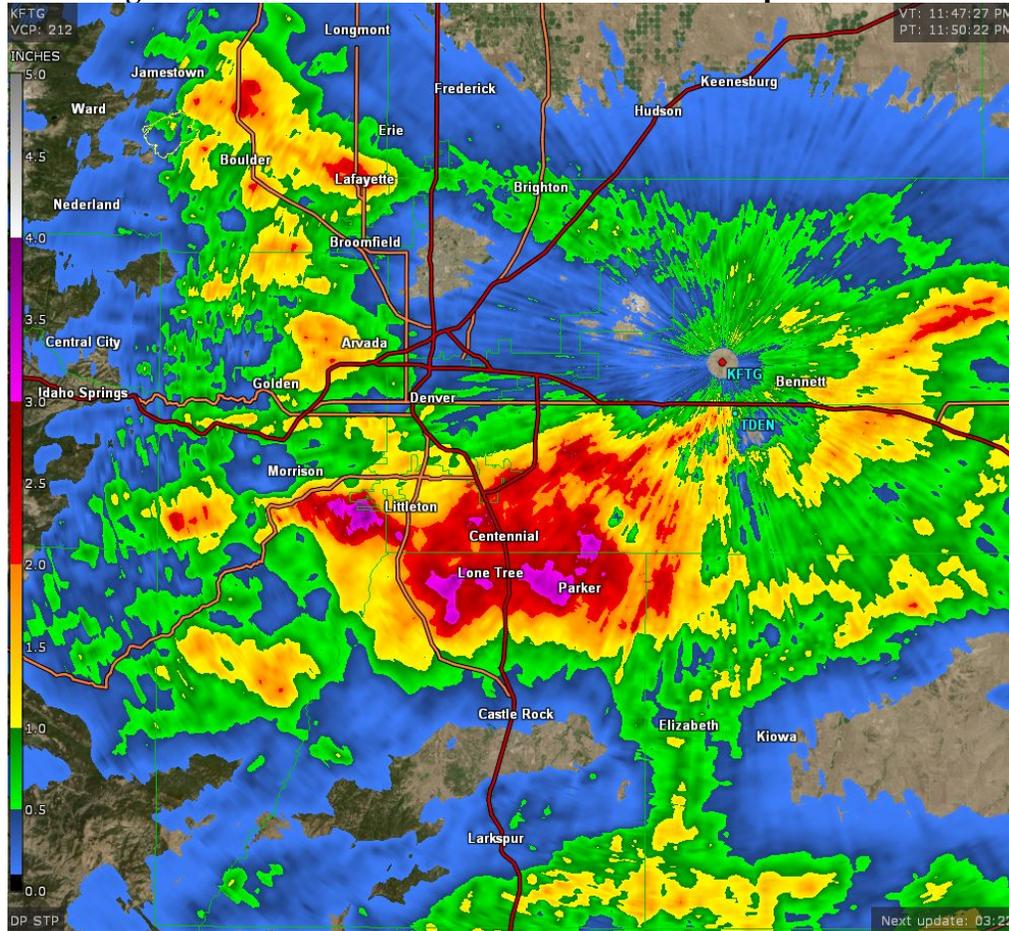
<b>County</b>	<b>2021 Lightning Days</b>	<b>Percent of Total Days w/Lightning</b>	<b>2008-2021 Average Lightning Days</b>	<b>Highest Yearly Total 2008-2021</b>
Adams	44	29%	53	69 (2016)
Arapahoe	45	29%	51	67 (2015)
Boulder	63	41%	63	76 (2013/14)
Broomfield	33	22%	36	50 (2014)
Denver	38	25%	44	62 (2015)
Douglas	62	41%	72	87 (2009)
Jefferson	69	45%	75	92 (2009)
<b>Fcst Area Total</b>	<b>93</b>	<b>61%</b>	<b>92</b>	<b>108 (2009)</b>

## 5.0 Notable Weather Events

The 2021 F2P2 season was much more active than the previous year with 41 Message periods, compared to 25 in 2020 tying the record low. The 41 Message periods is more in line with the 15-year average of 42. How we arrived at the 42 Message periods was a little different that the “average” year as the season started off early with the first heavy rainfall event occurring on the 27<sup>th</sup> of April as a line of thunderstorms moved through eastern areas of the District during the early afternoon producing heavy rainfall and hail over portions of Adams and Arapahoe Counties, clipping NE Douglas County. It’s safe to say the season was “front end loaded” as 83% or 34 of the 41 Message periods had already occurred by the end of July (see Table 5). There were only 7 additional Message periods after July: 6 in August which is 4 Message periods below the 15-year average of 10 for the month and 1 in September which occurred early in the month on the 3<sup>rd</sup>. This final Message period produced some of the season’s heaviest rainfall rates as the strong thunderstorm initiated over Jefferson County and then traversed along the Arapahoe/Douglas County line. This storm produced impressive rainfall rates of 0.5”/5 minutes and up to 1.0”/10 minutes, which is a 6.0”/hr rate! Luckily, this storm was fast moving and the total measured rainfall amounts for this storm remained under 2.0”. There were other notable weather events that we will cover below including the 6/25, 7/1, 7/30-7/31 and 8/19 events which produced more LIF’s than any other days this season. If you have interest, Message summaries can be found at: [https://f2p2.udfcd.org/2021\\_summary.html](https://f2p2.udfcd.org/2021_summary.html) which includes additional post storm analysis, maps and more information.

**June 25<sup>th</sup>:** June 25<sup>th</sup> produced 16 individual LIF’s, more than any other single day during the F2P2 season! As the day began moisture increased in earnest as the 6am Denver sounding yielded 0.85” of precipitable water (PW) and the 6pm came in at 1.03”. There were 2 separate boundaries that formed storms on their own right but these 2 boundaries (a cold front from the N and outflow from storms to the S) ended up colliding over the District during the afternoon enhancing the thunderstorm development. Thunderstorms began to form to the S/SW of the District by around noon over Jefferson/Douglas Counties. Shortly after noon thunderstorms began to develop on the leading edge of the cold front over Boulder County with a strong thunderstorm developing between 1:30-2:00pm which impacted SE Boulder County and portions of Broomfield County until roughly 3:00-3:30pm before splitting and sending one storm eastward into Adams County while a new core formed over N Jefferson County. This storm produced heavy rainfall and large hail with a small area of 1-2” or more of rain over SE Boulder County. The frontal boundary that produced strong thunderstorms over Boulder County continued to move southward while the storms to the S of the District produced a gust front that moved northward. Weaker storms fired along the gust front moving northward but when the 2 boundaries collided around 3:30-4:00pm a large thunderstorm complex developed with multiple storm cores encompassing a large area of the District. This thunderstorm complex continued to push W and SW back towards the foothills into Jefferson and Douglas Counties with additional strong thunderstorms producing heavy rainfall into the evening. Shortly after 9pm the heavy rainfall began to subside over western areas of the District and by 10pm the heavy rainfall had completely ended with lighter showers ongoing. All areas of the District experienced heavy rainfall with rainfall rates of 0.5-1.0” in 10-15minutes and up to 2” in 45-60 minutes. Many areas of the District reported between 1-2” of total moisture from multiple rounds of thunderstorms with 2 different Counties reporting over 3” of rain. High end totals of 3.14” was reported in Lafayette in Boulder County and 3.32” WNW of Parker in Douglas County. Numerous rainfall rate alarms were triggered as well as rising rate alarms on area creeks and streams. Hail accompanied the stronger storms at times initially but transitioned completely over to heavy rain producers as the afternoon progressed losing the severe weather aspect the storms contained initially. Below is the KFTG radar estimation of rainfall taken 11:47pm on 6/25.

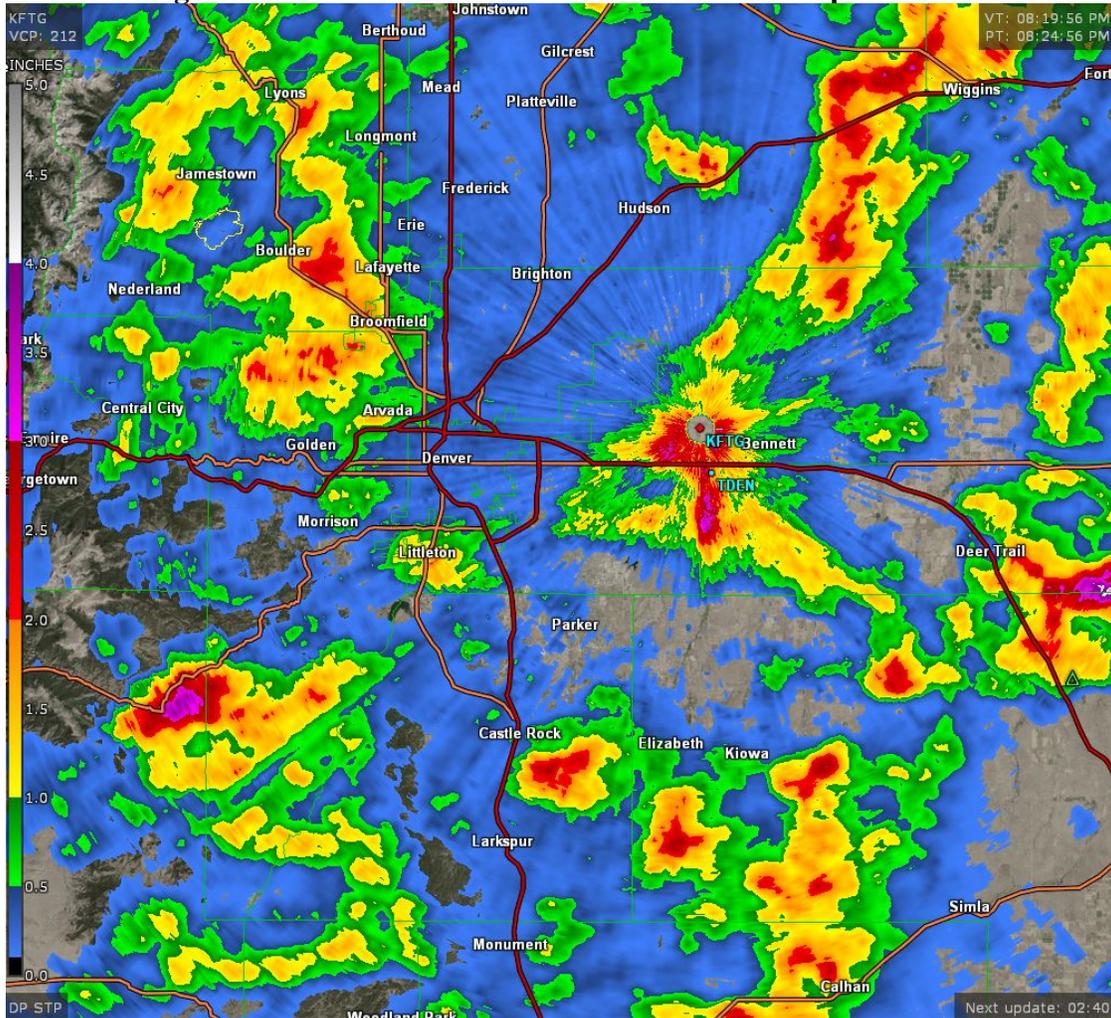
**Figure 2: KFTG Radar-Estimated Rainfall 11:47pm on 6/25.**



**July 1<sup>st</sup>:** July 1<sup>st</sup> produced 11 individual LIF's, tied for 3<sup>rd</sup> with the 19<sup>th</sup> of August and the season's first Message 3. It all started with an abnormally moist air mass in place with dew points in the upper 50's to 60 degrees which is unusually high for Front Range standards. The 6am sounding showed 1.01" of precipitable water with the 6pm sounding coming in at 1.1" of PW. Upper level steering winds were light from W to E but had little impact as the thunderstorms generally followed outflow boundaries or moved erratically along gust fronts with a couple stronger storms anchoring and raining themselves out in place. With abundant surface moisture it would only take temperatures to warm into the upper 70's to get convection going over the plains. The storms did indeed start early over portions of Elbert County and points E and W of the District between 10-11am. The initial storms E and SE of the District produced an outflow boundary that pushed back to the W into the District and would help to initiate strong thunderstorms later in the afternoon. By around 1pm the outflow boundary had reached eastern areas of the District and strong thunderstorms were forming behind it just to the E of DIA. This first strong thunderstorm within the District slowly moved southward and stalled over rural Arapahoe County over the far SE portion of the District and proceeded to produce 2-3.5" or more of rain as well as large hail at times. One spotter in Arapahoe County reported 3.71" of rain under this thunderstorm! An additional strong thunderstorm developed just south of the District over Douglas County producing a quick 1-2" of rain. Between 2-3pm strong thunderstorms had initiated over northern Boulder County and would begin their slow descent southward into the District. Isolated weak to moderate thunderstorms also began to develop over western areas of the District in Jefferson County and west Lakewood/Green Mountain area. Between 3-4pm the thunderstorm activity over northern Boulder County had sagged into southern Boulder County. This thunderstorm began to impact northern the area of Jefferson County just ahead of 4pm. Between 4-5pm this thunderstorm stalled over northern Jefferson County and proceeded to rain itself out producing 1.5-2.0" of rain or more. Highest rainfall totals over northern

Jefferson County were not captured well by gauges or spotters. Over southern Boulder County 2.39" was reported on the high end from this same storm. Between 5-6pm the strong thunderstorm activity had diminished over the District and light to moderate rain showers were ongoing. Rain shower coverage and intensity continued to decrease from 6-7pm with dry conditions all areas of the District by 8pm which allowed the Message 2's/NWS Flash Flood Watches to be cancelled early. Strong thunderstorms on Thursday, July 1<sup>st</sup> produced peak rainfall rates of 0.8-1.0" in 10 minutes per gauges and radar estimates. The strong thunderstorm over Boulder and north Jefferson County produced 1.5-2.0" or more of rain in 30-60 minutes and up to 2.5-3.5" or more of rain likely occurred in 45-75minutes in very isolated areas of Arapahoe County. A couple of the stronger thunderstorms stalled resulting in Message 3's/NWS Flash Flood Warnings being issued. All Counties within the District experienced at least brief heavy rainfall. There were rather large areas of the District that avoided the heavy rainfall which included portions of Adams, Denver and Douglas Counties. Far southern Denver County was grazed by brief heavy rainfall while the heaviest rainfall over Adams County remained well E of Hwy 85 and the strongest storms over Douglas County remained just south of the District. All strong thunderstorms contained similar high end rainfall rates with the greatest precipitation totals of the day over far SE areas of the District. The second bulls eye of precipitation was over portions of Boulder and Jefferson Counties with a small area of heavier rainfall over western Arapahoe County in the Littleton and south Englewood area. Below is the KFTG radar estimation of rainfall taken at 8:20pm on 7/1.

**Figure 3: KFTG Radar-Estimated Rainfall at 8:20pm on 7/1.**



**July 30-31<sup>st</sup>:** July 30<sup>th</sup> produced 14 individual LIF's and a Message 3 while the 30<sup>th</sup> produced 8 LIF's, combining for 22 LIF's during the 2-day period. The 30<sup>th</sup> started off as a Message 1 and was upgraded to a Message 2 which extended into the evening on the 31<sup>st</sup>. During this 2-day period monsoon moisture would increase over the District with precipitable water values coming in at their highest of the season by Saturday the 31<sup>st</sup>. As the monsoon moisture steadily increased through the day Friday with precipitable water values at the 6am sounding coming in around 0.8" and just shy of 1.1" at the 6pm sounding. The 6pm sounding was just ahead of a cold front and moisture increased behind the front likely pushing precipitable water levels to 1.2" or higher into Friday evening. Surface moisture was firmly in place with dew points in the 50's through the day and increasing to around 60 in the evening over portions of the plains. With the monsoon moisture plume poised to pass overhead and a surface cold front on the approach it was only a matter of time for thunderstorms to develop on Friday the 30<sup>th</sup>. The first storms developed along the cold front north of the District in the Fort Collins area between 3-4pm. By around 4:30pm the front had entered northern Boulder County and by 5:30pm the front had passed Broomfield County and thunderstorms were developing over the District. Thunderstorms expanded in coverage along the I-25 corridor through 6pm stretching from downtown Denver to SE Boulder County. As the cold front cleared the District shortly after 6:30pm the thunderstorm activity behind the front began to weaken and spread out, concentrating southward over Douglas County. The thunderstorm activity over Douglas County extended into Arapahoe County and continued from 6:30pm to roughly 8:00pm. After 8:00pm SE upper level winds then carried this storm activity back to the NNW over the District producing a large area of moderate to heavy rainfall from 8:00-10:30pm. After 10:30pm the heaviest rainfall had moved out of the District into Weld County. Wetting rains would continue to persist well into the evening, ending from S to N, eventually clearing the District by around 2am Saturday morning. Rainfall rates under the stronger storm cores generally peaked in the 0.6-1.8" range in 10-30 minutes, with a high of 1.2"/10 minutes was observed S of the District over Douglas County! Multiple rainfall rate alarms were triggered but the storms did a good job avoiding the MHFD gauges overall, especially through the first couple hours of the event. All Counties within the District received heavy rainfall with higher rainfall cores over Denver County, Douglas County, and a "bulls eye" of precipitation over SE Boulder County, Broomfield County extending into Weld County.

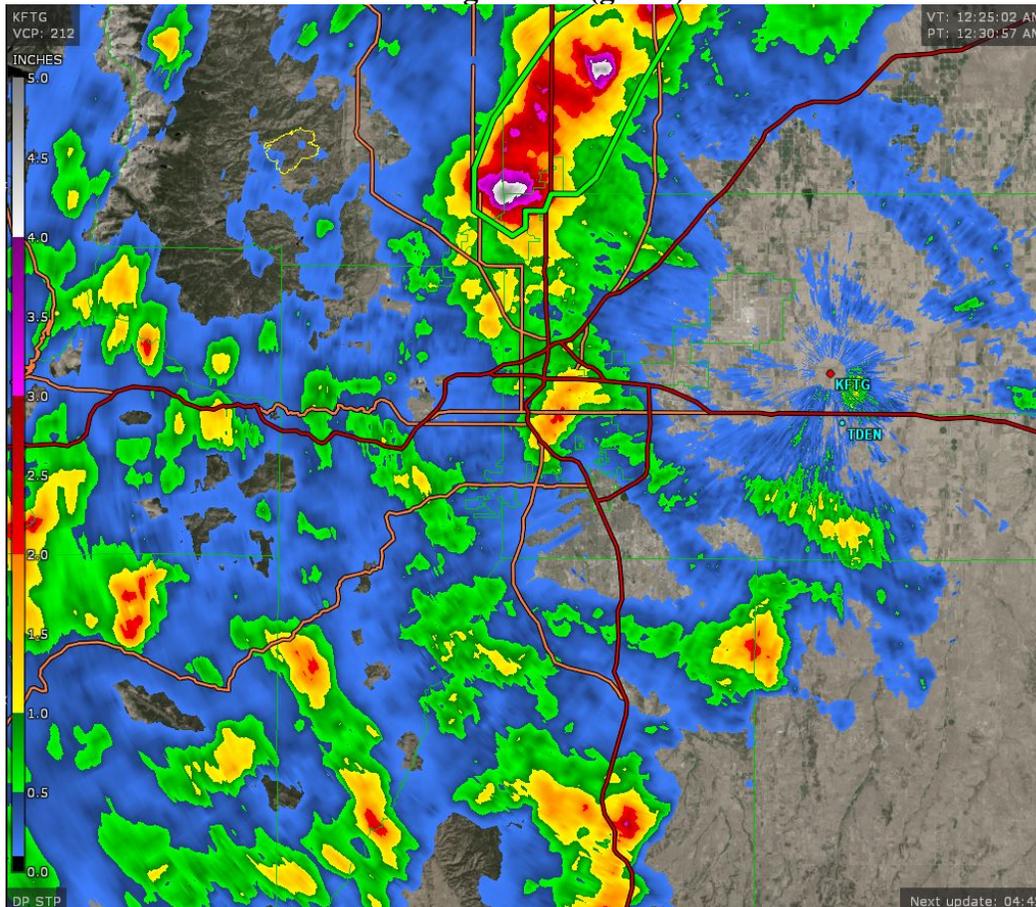
The most notable storm activity of the day that produced the "bulls eye" of precipitation was obscure at first... The initial thunderstorm activity developed as the cold front moved through around 5:30pm. This storm would be persistent and form a small circular track over SE Boulder County, Broomfield County, far NW Adams County extending into Weld County for about 4-5 hours, eventually being washed out by the line of storms that moved back to the N/NW around 10pm. This small but persistent area of thunderstorms would eventually lead to a Message 3 later in the evening as 3-4" or more of rain fell over a small area. The storm core over this zone was very small at times. As it wobbled, it would eventually concentrate most of the rainfall over a small area of only about 2 square miles just S of Erie and just E of Lafayette extending into western Broomfield County, including the far SW tip of Weld County. It is estimated, per KFTG radar, that maximum rainfall amounts likely reached between 4.5-5" of rain over a 5-hour period from 5:30-10:30pm. However, the rain was not persistent, and the heaviest rain generally fell in two separate intervals; the first heavy round started as the front passed between roughly 5:30-7:00pm, increasing a second time as the main line of storms pushed back to the NW between 9:00-10:30pm. Between these time intervals there were shorter periods of moderate to heavy rainfall as the storm meandered over the small area. This small core of heavy rainfall was the highest rainfall total of the season!

After 2:00am Saturday, July 31<sup>st</sup> a period of generally dry conditions developed beyond a few light rain showers with the first weak thunderstorms developing between 2-4pm in the afternoon. Showers and weak thunderstorms filled in over Boulder County, concentrating over the City of Boulder and over Douglas County just S/SE of the District. The weak thunderstorm over Boulder County may have produced small areas of 0.5"/10-minute type rains at its peak, and up to 1.0"/hr or more over a longer period but over a small area. Small geographical areas of heavy rainfall from weak thunderstorms but very efficient rainfall producers would be the trend for the remainder of the afternoon and evening. By 4:00pm the weak thunderstorm over the City of Boulder had reduced to light/moderate rain and began pushing into northern Jefferson County. Between 4:00-4:30pm new storm

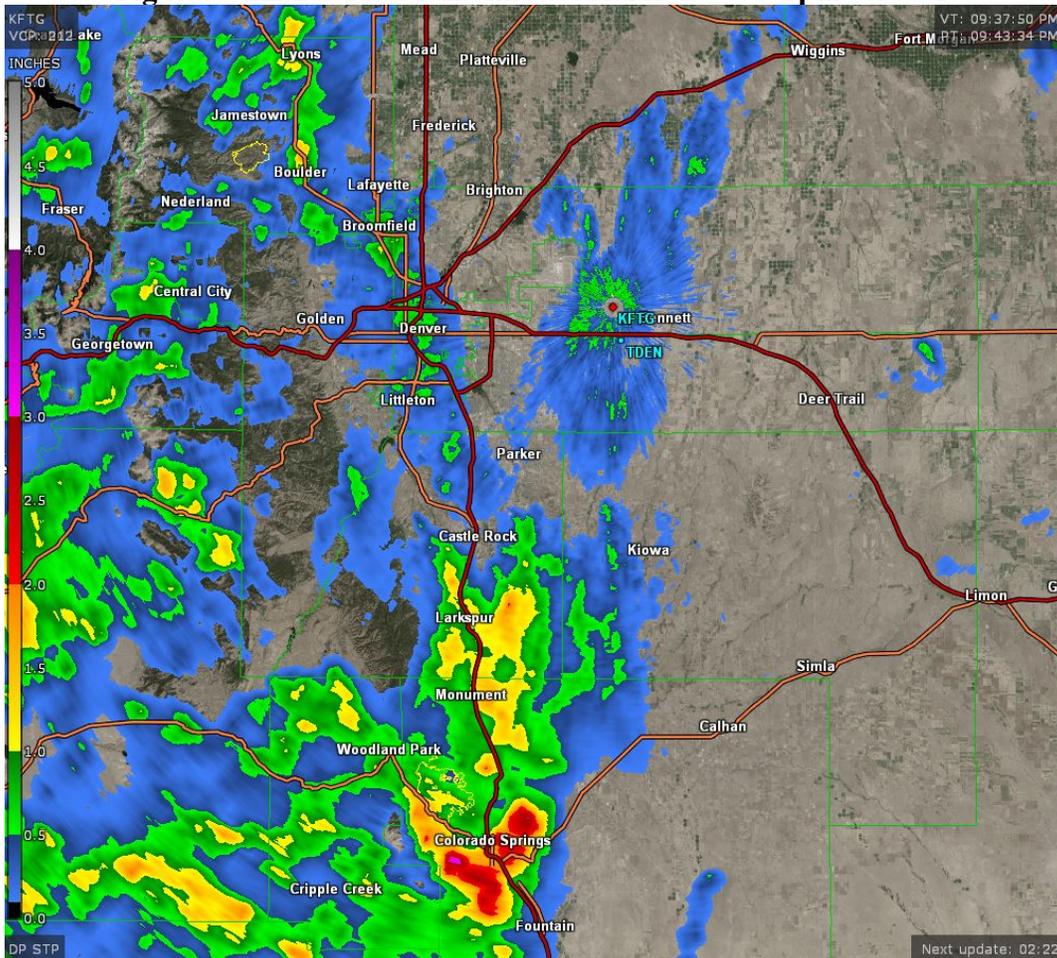
development occurred over the Denver Metro area, concentrated over NW portions of the District through roughly 6:30pm before weakening to rain showers. The heavier rainfall between 4:30-6:30pm grazed Adams, Boulder, Broomfield, Denver, and Jefferson Counties, making for difficult decisions when issuing LIF's as only small areas of the Counties listed were experiencing heavy rainfall. After 6:00pm the storm activity pushed a boundary back to the which had the potential to initiate new thunderstorms. This boundary did not result in much activity until it nearly cleared the District. A weak to briefly moderate thunderstorm developed over Adams County and tracked back to the S/SSW, just East of DIA, and into Arapahoe County from 7:30-9:00pm. By 10:00pm the majority of the rain shower activity had exited the District with a few lingering light showers persisting through about midnight. The efficient moderate to heavy rain showers and weak thunderstorms generally produced 0.3-0.8" rainfall rates in 10-30 minutes with isolated higher amounts of 0.5" per 10 minutes and up to 1.0" per hour from rain. The cooler temperatures helped to keep the thunderstorm activity weak to briefly moderate at peak, with the stronger thunderstorm activity for the day concentrated south of the Palmer Divide over El Paso County.

**Moisture levels on Saturday reached 1.28" of precipitable water at the 6pm sounding and was the peak in atmospheric moisture for the 2021 flood season!** Despite more moisture to work with on Saturday the heaviest rainfall fell the previous day on Friday. High moisture levels do not necessarily equate to heavy rainfall as many times the moisture creates cloud cover. In addition, daytime heating is a major factor in the strength of storms; sometimes the higher moisture days do not play out as the heaviest rainfall days, as was the case on Saturday, July 31<sup>st</sup>. All Counties within the District experienced at least a small area of heavy rainfall at some point through the day, with higher end amounts over the City of Boulder at nearly 1.5" reported by a CoCoRaHS spotter. Below are the KFTG radar estimates for rainfall on the 30<sup>th</sup> and 31<sup>st</sup>.

**Figure 4: KFTG Radar-Estimated Rainfall at 12:25am on 7/31 includes the NWS Flash Flood Warning outline (green).**



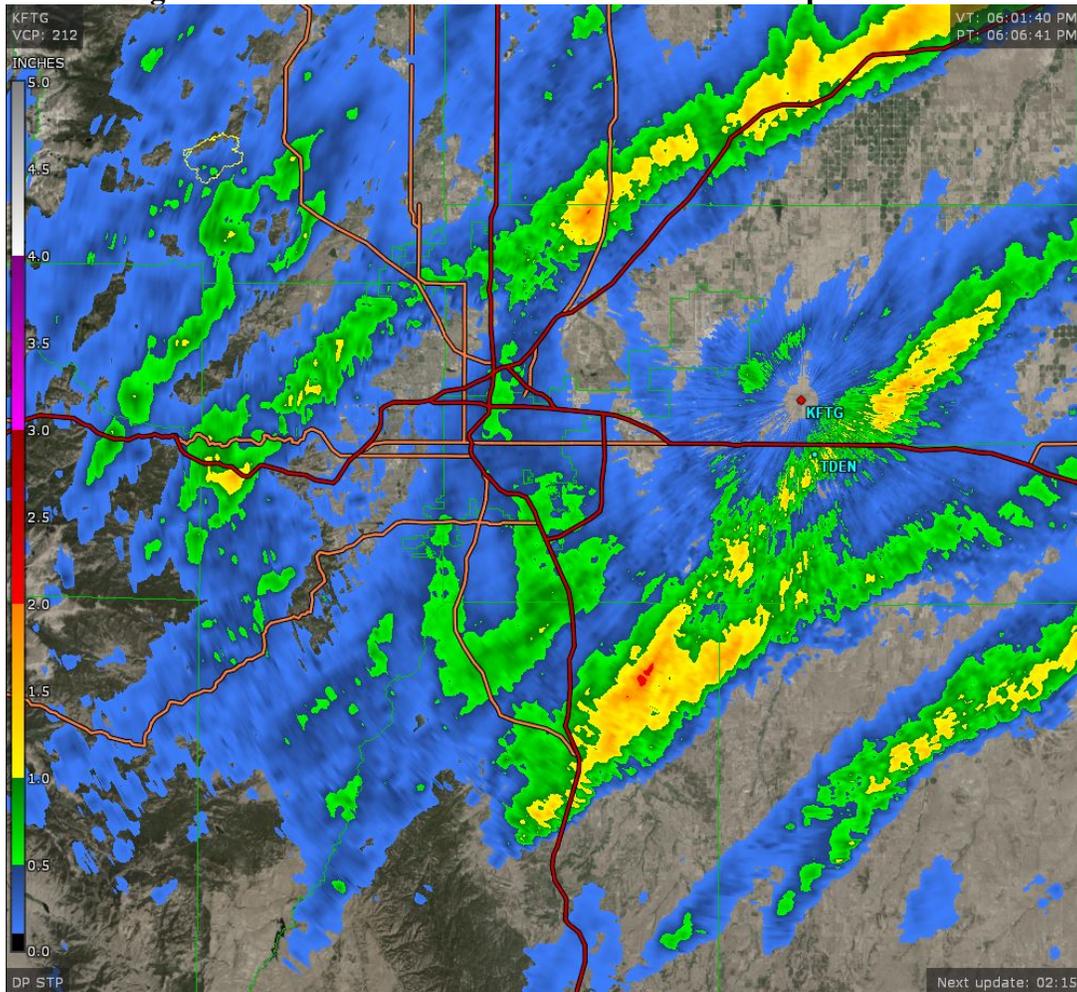
**Figure 5: KFTG Radar-Estimated Rainfall at 9:37pm on 7/31.**



**August 19<sup>th</sup>:** Thursday, August the 19<sup>th</sup> produced 11 individual LIF's impacting every County within the District as a strong low pressure system for mid August standards impacted the central Rockies. This disturbance was situated over northern UT and moved into central WY through the day spinning an upper level disturbance into the District during the early afternoon. Precipitable water values at the 6am sounding came in at 1.00" and just under 1.00" at the 6pm sounding. With precipitable water hovering around 1.00" through the day in tandem with surface dew points in the 50s to around 60 the storms that developed Thursday would be heavy rainfall producers. Relatively fast storm motions from SW to NE would help to keep the heavier rains brief during the day but also produced a favorable shear profile for thunderstorms to become severe. As the upper level disturbance approached an isolated thunderstorm developed over the Jefferson County foothills before noon but the main area of thunderstorms would begin to fill in over NW portions of the District by around 1:00pm. As the upper level disturbance pushed eastward additional thunderstorms quickly blossomed S and E of the initial storms through 2:30pm. Thunderstorms peaked in intensity between 2:30-4:00pm producing multiple LIF's and heavy rainfall rate alarms of 0.5"/10 minutes as thunderstorm activity tracked from SW to NE through the District. By 4:30pm the stronger storms had pushed N and E of the District and by 5:00pm only a few lingering weak thunderstorms persisted over the foothills. These storms dissipated as they moved onto the plains and by 6pm generally dry conditions were observed beyond a light shower or two over the foothills. All Counties within the District experienced at least brief heavy rainfall with the heaviest rains concentrating in bands over Adams, Arapahoe and Douglas Counties. Heavy rainfall generally only lasted 5-15minutes over most locations with areas that experienced longer durations or multiple thunderstorm cells experiencing totals of over 1.0" but for the most part

rainfall totals were sub 1.0” beyond a few small geographical areas. One CoCoRaHS spotter in Highlands Ranch reported 0.85” of rain in 15 minutes! There was a lull in the precipitation Thursday evening until another disturbance associated with the low pressure system passed overhead after midnight Thursday into Friday morning producing a nocturnal round of strong thunderstorms. KFTG radar estimates are over-estimating the rainfall due to the presence of large hail under the stronger storm cores resulting in hail corruption but are useful in pointing to the areas of heavier precipitation not captured by gauges.

**Figure 6: KFTG Radar-Estimated Rainfall at 6:01pm on 8/19.**



Overall the 2021 F2P2 season started strong and finished weak with drought conditions developing over NE Colorado as the season came to an end. DIA reported 3.65” of moisture in May but the following 4 months combined only produced 1.73” of precipitation! The F2P2 season total moisture at DIA of 5.38” (3.79” below normal) from May through September poorly represents the District as a whole but underscores the lack of moisture as the season wore on. Seasonal rainfall totals (May-Sept) that represent the District more appropriately typically ranged between 7-10” with locally higher and lower amounts which is closer to normal at the higher end but still below normal most areas. Each flood season has different characteristics and this year the North American monsoon was relatively brief here in Colorado and peaked in late July, weakening through August and was nowhere to be found in September. This was not the case for our southern neighbors in New Mexico and Arizona who experienced one of the wettest monsoon seasons in years! We will have to wait and see what the 2022 flood season has in store for the District but “normal” when it comes to climate typically only happens on paper here in Colorado.