2014
UDFCD FLASH FLOOD PREDICTION PROGRAM - ANNUAL REPORT

Submitted by
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303-927-6522

December 30st, 2014

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 36th 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 2.8 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.

A team comprised of Genesis Weather Solutions, a Colorado based company and Skyview Weather, a Colorado based company was selected as the 2014 PMS.

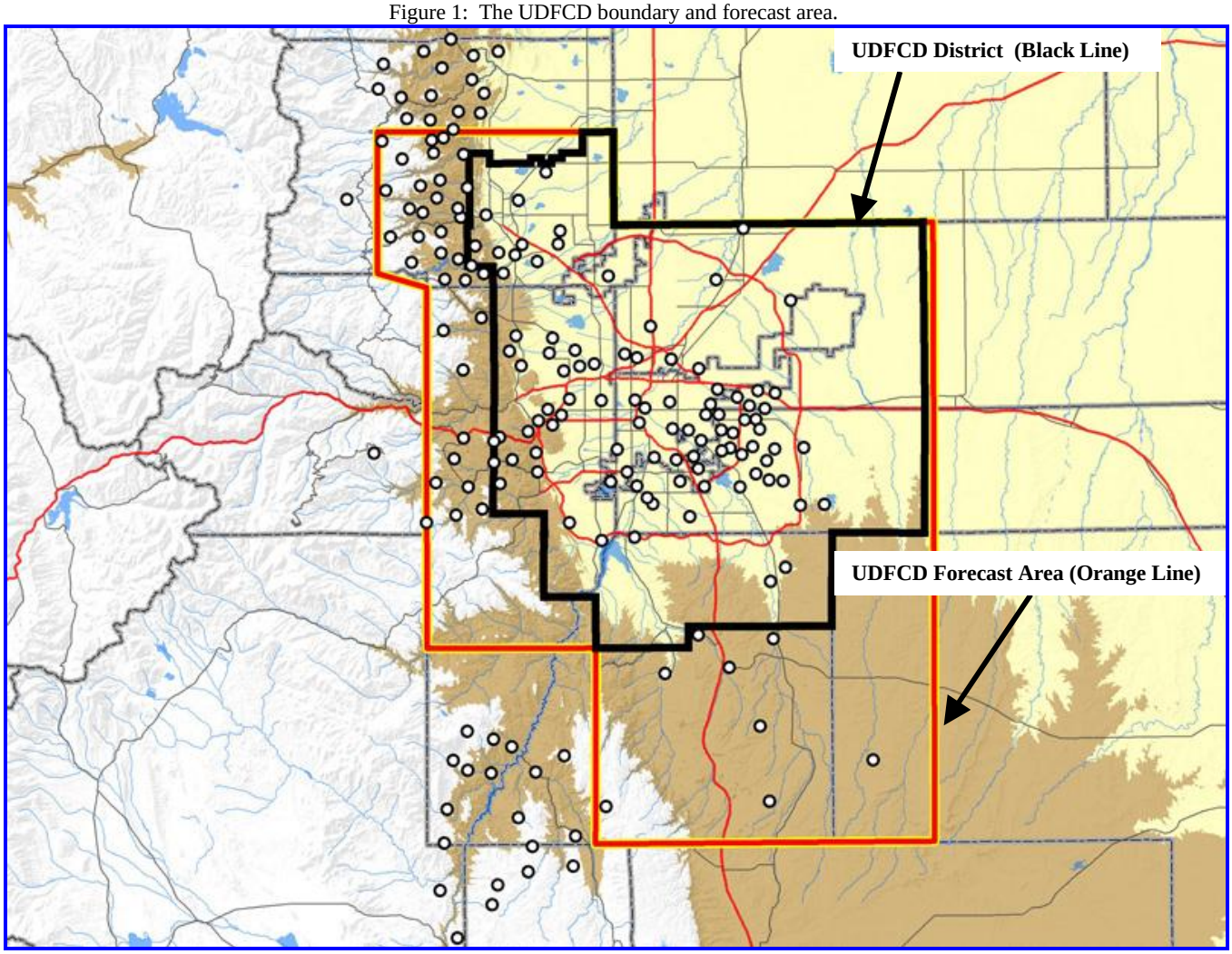
Weather prediction personnel Bryan Rappolt, Tim Tonge, Brad Simmons, Alan Smith, Andrew Muniz, Alex Trellinger and Zach Paiz provided the F2P2 prediction and notification services. Bryan Rappolt was the Project Manager and Chief Operational Meteorologist for the program.

Bryan Rappolt worked his 21st season on the F2P2 while Tim Tonge worked his 9th, Brad Simmons his 8th, Alan Smith his 2nd and Andrew, Alex and Zach all worked their first season.

2.0 2014 Operational Season

The 2014 F2P2 season began on April 15th, 2014 and concluded on September 15th, 2014 for a total of **154** operational days. Due to heavy rainfall potential the program was re-activated on the following dates: September 20th, 21st, and 22nd, 2014 and September 29th, 2014, resulting in a total of **158** operational days. Normal operational hours were from 700 am to 1000 pm. A total of **1749** man-hours were expended by the PMS providing support of the F2P2 during normal operational hours. During the time period from 1000 pm to 700 am the PMS provided an additional **346** man-hours of operational support.

Figure 1: The UDFCD boundary and forecast area.



3.0 2014 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 2014.

Table 1. F2P2 product descriptions.

Heavy Precipitation Outlook (HPO)/Internal Message Statement (IMS). This HPO is available by 11:00 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 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 probably the most-anticipated hard copy product 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 is the principal method of disseminating information within the F2P2. One thousand one hundred twenty nine (**1,129**) telephone contacts were made to F2P2 communication points by the PMS.

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: 2014 product/communication summary.

Product/Communication	**Number**
Heavy Precipitation Outlook (HPO)	239
Messages and LIF's	661
Internal Message Status (IMS)	167
Basin-Specific Quantitative Precipitation Forecasts (QPF)	52
Storm Tracks (ST)	158
PMS Initiated Telephone Contacts	1,129
F2P2 Participant Initiated Telephone Contacts	79
Total	**2,485**

Four hundred and six (**406**) short message service (SMS) emails identifying Message potential were disseminated to F2P2 participants.

4.0 2014 Message Statistics

The primary service provided to F2P2 participants is 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, facsimile, email and Internet.

4.1 Message Verification

A Message day is defined as any day in which a Message 1, Message 2 or Message 3 is issued based on the criteria depicted in Table 4. Messages were issued on **61** days during the 2014 F2P2 between April 15th, 2014 and September 29th, 2014. There were **5** days of the **61** Message days where only Message 2's were issued. There were **0** days of the **61** Message days where a combination of Message 2's and Message 1's were issued for portions of the District. Six (6) Message 3's were issued on 4 different days. There was a **97%** verification rate of Message days on a District-wide basis.

Table 5 depicts the number of Message days and the number of Messages issued and verified for each month of the 2014 F2P2.

Table 4: Message Criteria.

Message 1 "Low Impact Flood Advisory" Criteria
• **Message-1** (Street or gutter flooding): **0.50"/10 minutes or 1.00"/60 minutes**
• **Message-1** (Significant urban street and stream flooding): **1.00 to <3.00"/ 60 minutes**
• **Low Impact Flooding (LIF)**: Rainfall intensity: **0.50"/10 minutes or 1.00"/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 **3.00"/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/drainageway **(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 Days	Verified Message Days	% Verifying Message Days	Messages Issued	Verified Messages	% Verified Messages
April	**1**	**1**	**100%**	**5**	**4**	**80%**
May	**12**	**12**	**100%**	**103**	**64**	**62%**
June	**12**	**11**	**92%**	**94**	**61**	**65%**
July	**18**	**18**	**100%**	**134**	**81**	**60%**
August	**14**	**14**	**100%**	**92**	**55**	**60%**
September	**4**	**3**	**75%**	**29**	**14**	**48%**
Total	**61**	**59**	**97%**	**457**	**279**	**61%**

There was **0** days where Message level rainfall was observed within a portion of the District and no Message was issued.

The **61** Message days observed is the highest number of Message days in the 36 year history of the F2P2. The second highest number of Message days observed in a season is **58**, which occurred in 2013.

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 **29** LIF days, of which all **29** of these LIF days verified; resulting in a verification rate of **100%**.

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 was added as a new forecast zone due to its high potential for flooding from minimal 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 6: 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	**45**	**34**	**76%**	**20**	**20**	**100%**	**0**	**0**
Arapahoe	**50**	**29**	**58%**	**21**	**20**	**95%**	**0**	**1**
Aurora	**47**	**26**	**55%**	**21**	**21**	**100%**	**0**	**1**
Boulder	**44**	**23**	**53%**	**11**	**11**	**100%**	**0**	**0**
Broomfield	**38**	**12**	**32%**	**3**	**3**	**100%**	**0**	**0**
Denver	**43**	**27**	**63%**	**14**	**13**	**93%**	**0**	**0**
DIA	**42**	**25**	**60%**	**16**	**15**	**94%**	**0**	**0**
Douglas	**51**	**42**	**82%**	**18**	**18**	**100%**	**0**	**0**
Jefferson	**53**	**43**	**81%**	**15**	**15**	**100%**	**0**	**0**
Four Mile Burn	**44**	**17**	**39%**	**9**	**7**	**78%**	**0**	**0**
TOTAL	**457**	**279**	**61%**	**148**	**143**	**97%**	**0**	**2**
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	**3**	**3**	**100%**	**0**	**0**
Lakewood	N/A	N/A	N/A	**4**	**4**	**100%**	**0**	**0**
Wheat Ridge	N/A	N/A	N/A	**3**	**3**	**100%**	**0**	**0**
TOTAL	**N/A**	**N/A**	**N/A**	**10**	**10**	**100%**	**0**	**0**
GRAND TOTAL	**457**	**279**		**158**	**153**	**97%**	**0**	**2**

A total of **457** Messages were issued within the District. Of the **457** Messages that were issued, **279** Messages verified, resulting in a verification rate of **61%**. Douglas County had the highest verification rate, **82%**, while Broomfield County had the lowest verification rate, **32%**.

A total of **158** LIF's were issued. Of the **158** LIF's issued, **153** of the LIF's verified, resulting in a verification rate of **97%**.

The PMS identified cloud–to-ground lightning days that covered the forecast period of April 15, 2014 through September 30, 2014. A cloud–to-ground lightning day was identified as any day that a thunderstorm cell produced cloud to ground lightning within the District. Archived cloud–to-ground lightning data was reviewed for each of the **158** operational days of the F2P2. Of the **158** operational days, **108** of the days (**68%** of the total days) cloud–to-ground lightning was observed within the District. Of the **108** "thunderstorm days" within the District, **56%** of the days had Messages issued.

5.0 Notable Weather Events

The 2014 F2P2 season was well above normal in the number of thunderstorms (108 thunderstorm days from April 15th through September 29th) and Message-days but there were not any "signature" events of the season unlike last year with the September floods. There were however, a rather a large number of days that did indeed produce heavy rainfall and minor flooding. Below are some of the days or groups of days that that produced some of the higher rainfall totals this season.

May 21-25th: A large and slow moving upper level low pressure system would impact the District starting on Wednesday, May 21st with moderate to heavy rains each day impacting portions of the District day through Sunday, May 25th as the system slowly moved through the state. There was not a single day that stands out during this time frame but the day after day of moderate to heavy rainfall was significant. Below is a daily breakdown:

- **May 21st:** An upper level low pressure well to the west of Colorado would spin moisture and supply upper level lift over the District on Wednesday, May 21st resulting in widespread thunderstorms spawning severe weather and heavy rain. Thunderstorms would develop by early afternoon and continue well into the evening and overnight period. Heavy rainfall of up to 2" or more was reported eastern areas of the District over portions of Adams and Arapahoe Counties. Multiple severe thunderstorm warnings and multiple tornado warnings were issued for the District by NWS.

- **May 22nd:** The upper level low pressure system to the west/southwest of Colorado would spin additional moisture and supply upper level lift over the District on Thursday, May 22nd resulting in widespread thunderstorms spawning severe weather and heavy rains. Thunderstorms would develop by early afternoon and continue into the early evening. Heavy rainfall with rainfall rates in excess of 3"/hr or more was observed within the District but heavy rain would generally be brief. Heaviest rainfall totals were north of I-70 over north Denver County and Adams County. Multiple severe thunderstorm warnings and a tornado warning was issued for the District by NWS. An Urban and Small Stream flood Advisory (USSFA) was issued for the central portions of the District.

- **May 23rd**: The upper level low pressure system still to the W/SW of Colorado would continue spin moisture over the District on Friday, May 23rd resulting in multiple rounds of heavy rainfall producing thunderstorms. Thunderstorms would develop by early afternoon and continue well into the evening and overnight period. Pockets of heavy rain were observed in every County within the District with the exception of Broomfield which was brushed by the stronger storms. NWS Flash Flood Warning was issued for Four Mile Burn area (FMBA) in Boulder County.

- **May 24th:** The upper level low pressure system still impacting the weather over the District on Saturday the May 24th would produce strong thunderstorms by midafternoon with storm motions from SE to NW keeping the majority of the activity confined to areas adjacent to and over the foothills. Most of the rain was generated from one strong thunderstorm that originated over NW Douglas County and would move through Jefferson County and then weakened as it moved into Boulder County. This storm initiated 2 tornado warnings and multiple USSFA's. Heaviest rain remained west of I-25. Lighter showers would continue into the overnight period after this strong thunderstorm moved through the District. NWS Flash Flood Watch in effect for all areas of the District from 1pm to midnight.

- **May 25th:** Upper level low pressure system moving south of the District on Sunday the 25th would produce strong thunderstorms by 1pm. Storm motion would be erratic with strong storms moving from SSE to NNW while weaker showers and thunderstorms would move from ESE to WNW or E to W as the low pressure center was now to the south. Moisture had decreased slightly from previous days but storms were still very capable of producing heavy rainfall. The strongest storms of the day were hail producers which resulted in some overestimates from radar storm totals. Thunderstorms would diminish by late afternoon with generally dry conditions the remainder of the evening. Additional storms would develop overnight but would remain outside the District. All areas of the District experienced some kind of thunderstorm activity but heaviest rainfall totals were over Jefferson County and just south of the District in Douglas County. NWS issued 3 severe thunderstorm warnings for Jefferson and Douglas Counties.

May 30th: Trough of low pressure moving through the state with Precipitable Water (PWI) values just shy of 1" and dew points in the upper 40's to mid 50's supplied plenty of moisture to fuel storms. Thunderstorms would develop by 1-2pm becoming more widespread into the late afternoon. Storm motion began the day from SSE to NNW but would shift to more SSW to NNE by mid afternoon as trough axis moved through. Thunderstorm activity began to diminish by around 6pm with no significant precipitation after that time. Heaviest rainfall was recorded over Boulder County with pockets of heavier rains Jefferson/Denver Counties and very strong thunderstorms near the eastern District fringes mainly impacting Adams County. Boulder gauge reported 0.6-0.7" in 10mins with total over 1" but the heavy rains were generally brief with totals in Boulder County topping out just over 1.50". NWS issued 2 Flash Flood warnings: one for the FMBA and the other for far E Adams County.

July 7th: N/NW flow well above mountain top level with surface dew points in low 50's and PWI values around 0.90" would produce heavy rainfall producing thunderstorms late in the day. A cool front moved through the District in the evening. Deep low level moisture was advected into the District by easterly flow. A line of thunderstorm cells moved through the District between 730 PM and 1000 PM. A second line of cells moved through between 1000 PM and 1230 AM. Some portions of the District received impressive storm total rainfall amounts due to two or more thunderstorm cells. Moderate to heavy rainfall was observed across Boulder, Jefferson, Broomfield, Adams, Denver, Arapahoe and Douglas Counties with some areas in excess of 2".

July 12th: Weak northwest flow up to 55,000 feet and surface dew points upper 50's to low 60's combined with PWI of around 1.20". Deep low level moisture was in place due to thunderstorm outflow boundaries that that pushed through overnight. An area of thunderstorms developed over the central and northern portions of the District and moved slowly to the southeast. Training thunderstorm cells moved over southeast Aurora and northwest Douglas County. Flash Flood Warning was issued by NWS for training cells in NW Douglas County. Moderate to heavy rainfall was observed across south central and northeast Boulder County, northeast Denver County and DIA, central Adams County, Arapahoe County, Aurora and NE Douglas County. Very heavy rainfall was observed across east central Jefferson and northwest and central Douglas County. Peak rainfall was 3.07" in about a 2 hour period observed by the Indian Creek ALERT gage in NW Douglas County. Thirty-two rainfall rate alarms were triggered.

July 29-30th: Weak northwest flow aloft. Weak easterly flow at the surface with dew points in the middle to upper 50's and PWI at or above 1.10" indicated deep low level moisture was in place. A slow moving upper level low pressure system over Utah pumped subtropical moisture over the District on Tuesday, July 29th. The upper low provided lift and produced modest upslope flow. The result was an extended period of rain showers and embedded thunderstorms during the day and night of 7/29 and into the morning hours of 7/30. Strongest thunderstorms were experienced over the Denver Metro area during the afternoon of 7/29. Rain showers moved through the District throughout the day on 7/30. Lower atmosphere was to cool for thunderstorm development on 7/30. A general 2-4" of rain was observed across the District over the 30 hour period. SE Boulder and south Denver observed the most rainfall.

August 25th: Brisk southwesterly flow aloft, weak southeasterly flow at the surface. Surface dew points in the low to middle 50's and PWI at or above 1.0" would set the stage for strong thunderstorms with heavy rainfall. Thunderstorms developed over the higher terrain of Douglas County late in the day. Outflow from these cells initiated strong to severe thunderstorms over northern Douglas County and southeast Aurora. Outflow from these cells initiated thunderstorms over the eastern portion of the District. Moderate to heavy rainfall was observed across Arapahoe County, Aurora, northern Douglas County, DIA and Adams County. Some areas would receive in excess of 2.0" of rain.

September 29th: The F2P2 was re-activated on this date due to a high threat of heavy rainfall across the District. A strong upper level disturbance move overhead initiating a southwest to northeast propagating line of strong and severe thunderstorms. Heavy rainfall and large hail were produced across a large portion of the District. The heavy rainfall produced significant urban flooding across Denver, Arapahoe, Adams and Douglas Counties. Figure 2 depicts flooding on this day in the City of Aurora.

September 29th, 2014 is the latest "Message Day" in the 36 year history of the F2P2.

Figure 2: September 29th, 2014 flooding in the City of Aurora.

In summary the 2014 flood season did not have a signature event that stands out as the leader in the heavy rainfall department. What made this year unique was the amount of moisture that remained in place from May through August with dew points spending much of the time in the 50's. This resulted in a high number of days with a potential flood risk due to meteorological conditions. Storm motions remained fast enough through the season to keep most of the heavier rainfall brief with the higher rain totals this season resulting from training of thunderstorm cells. There was not any major flooding this season but there was a lot of low level "nuisance" type flooding. Above normal precipitation was observed in the months of May, July and August with each month more than 1" above the normal. The rainfall had many benefits one of which was the lack of wildland fire activity with no large fires in or around the District and allowing older burn scars to continue the healing process.

The 2014 F2P2 season was the second season in a row where Messages were issued after September 15. September 15 is the last day of the F2P2 season.