



2013
UDFCD FLASH FLOOD PREDICTION
PROGRAM - ANNUAL REPORT

Submitted by
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303-927-6522

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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 35th 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 2013 PMS.

Weather prediction personnel Bryan Rappolt, Tim Tonge, Brad Simmons, Jeffrey Auger, Chris Brinson, Alan Smith and David Bruggeman provided the F2P2 prediction and notification services. Bryan Rappolt was as the Project Manager and Chief Operational Meteorologist.

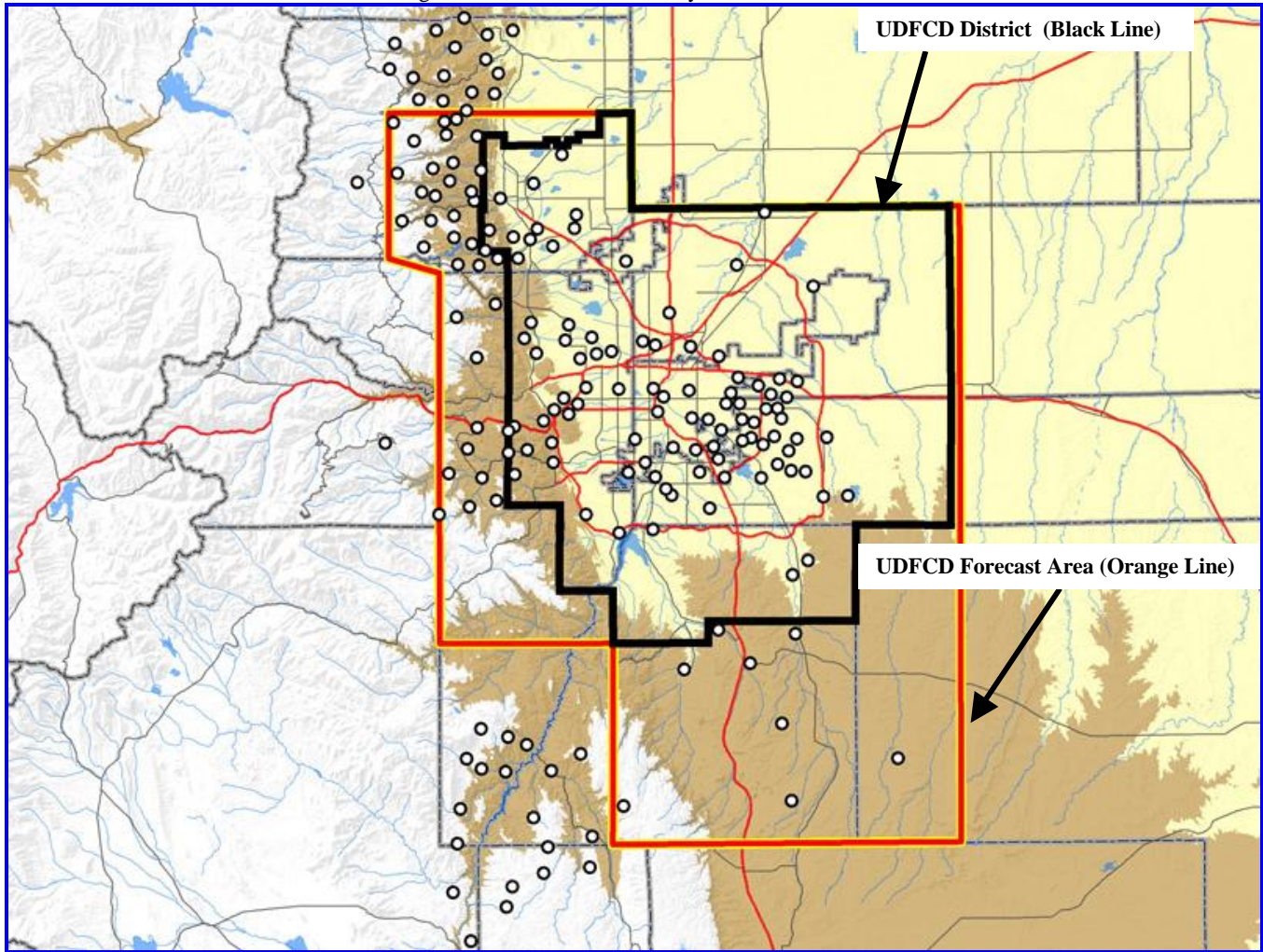
Bryan Rappolt worked his 20th season on the F2P2 while Tim Tonge worked his 8th, Brad Simmons his 7th, Jeffrey Auger his 2nd, Chris Brinson his 2nd, Alan Smith his 1st season and David Bruggeman his first season.

2.0 2013 Operational Season

The 2013 F2P2 season began on April 15th, 2013 and concluded on September 30th, 2013 for a total of **169** operational days. Normal operational hours were from 700 am to 1000 pm. A total of **1724** 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 **389** man-hours of operational support.

Normally the F2P2 end on September 15th each year. This year the F2P2 was extended until September 30th, 2013 due to a heavy rainfall and flood threat. This added an additional 15 days to the 2013 F2P2.

Figure 1: The UDFCD boundary and forecast area.



3.0 2013 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 2013.

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 fifty-five (**1,055**) 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 Flood 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.

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.

(*Low Impact Flooding*)

This language will be included as a sub-title to either a MESSAGE 1, MESSAGE 1 UPDATE, or MESSAGE 2 UPDATE to inform 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 the NWS Urban and Small Stream Flood Advisory.

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 and 2) and imminent (MESSAGE 3 and Low Impact Flooding) 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: 2013 product/communication summary.

Product/Communication	Number
Heavy Precipitation Outlook (HPO)	181
Messages and LIF's	864
Internal Message Status (IMS)	140
Basin-Specific Quantitative Precipitation Forecasts (QPF)	42
Storm Tracks (ST)	117
PMS Initiated Telephone Contacts	1,055
F2P2 Participant Initiated Telephone Contacts	74
Total	2,473

Three hundred twenty-one (**321**) short message service (SMS) emails identifying Message potential were disseminated to F2P2 participants.

4.0 2013 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 nuisance 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 **58** days during the 2013 F2P2 between April 15, 2013 and September 30, 2013. There was **5** days of the **58** Message days where only Message 2's were issued. There were **3** days of the **58** Message days where a combination of Message 2's and Message 1's were issued for portions of the District. There was a **91%** 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 2013 F2P2.

Table 4: Message Criteria.

Message 1 “Nuisance Flood Advisory” Criteria	
<ul style="list-style-type: none"> • 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	
<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 3.00"/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/drainageway (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 Days	Verified Message Days	% Verifying Message Days	Messages Issued	Verified Messages	% Verified Messages
April	0	N/A	N/A	0	N/A	N/A
May	3	3	100%	27	24	89%
June	5	5	100%	41	23	61%
July	15	13	87%	126	48	37%
August	21	19	91%	158	80	48%
September	14	13	93%	113	79	70%
Total	58	53	91%	465	254	55%

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

The **58** Message days observed was the highest number of Message days in the 35 year history of the F2P2. The second highest number of Message days is **52** days, which occurred in 1996 and 2009.

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 **25** LIF days, of which all **25** 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	51	32	63%	19	18	95%	0	0
Arapahoe	48	28	58%	15	13	87%	0	0
Aurora	47	22	47%	12	12	100%	0	0
Boulder	42	23	55%	10	8	80%	0	0
Broomfield	45	15	33%	7	6	86%	0	0
Denver	47	29	62%	14	14	100%	0	0
DIA	48	20	42%	13	10	77%	0	0
Douglas	47	29	62%	13	11	85%	0	0
Jefferson	46	31	57%	13	13	100%	0	0
Four Mile	44	25	57%	13	11	85%	0	0
TOTAL	465	254	55%	129	116	90%	0	0
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	8	100%	0	0
Lakewood	N/A	N/A	N/A	7	7	100%	0	0
Wheat Ridge	N/A	N/A	N/A	7	7	100%	0	0
TOTAL	N/A	N/A	N/A	22	22	100%	0	0
GRAND TOTAL	465	254	55%	151	138	91%	0	0

A total of **465** Messages were issued within the District. Of the **465** Messages that were issued, **254** Messages verified, resulting in a verification rate of **55%**. Adams County had the highest verification rate, **63%**, while Broomfield County had the lowest verification rate, **33%**.

A total of **151** LIF's were issued. Of the **151** LIF's issued, **138** of the LIF's verified, resulting in a verification rate of **91%**.

The PMS identified cloud-to-ground lightning days that covered the forecast period of April 15, 2013 through September 30, 2013. 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 **169** operational days of the F2P2. Of the **169** operational days, **103** of the days (**61%** of the total days) cloud-to-ground lightning was observed within or near the District. Of the **103** "thunderstorm days" within the District, **56%** of the days had Messages issued.

5.0 Notable Weather Events

The 2013 F2P2 season was well above normal in the number of thunderstorms (103 thunderstorm days), Message-days and flooding that was observed within the District. Below are some of the noteworthy weather events of the season plus the major flood event from September 9-15th observed during the 2013 F2P2.

July 13th: Multiple waves of thunderstorms moved through the District between 130 pm and 700 pm. Two strong thunderstorms moved over northeast Denver County producing very heavy rainfall of up to 2.75" in 2 hours. Two thunderstorms merged and moved very slowly to the east over central Jefferson County producing very heavy rainfall of up to 3.45" in 2 hours. As a result of the heavy rainfall a message 3's were issued for Jefferson County including the cities of Arvada, Wheat Ridge and Lakewood. Heavy and very heavy rainfall was observed across central Jefferson County and small portions of Denver and Adams Counties. Highest observed rainfall was a CoCoRaHS measurement taken at Wheat Ridge 0.9 WSW at 3.49".

August 3rd: Slow moving, strong and severe thunderstorms impacted the District during the afternoon and evening hours on August 3rd producing excessive runoff and flooding for portions of Boulder County as well as portions of Adams and Arapahoe Counties. Strong thunderstorms would exit the District between 800 pm and 900 pm. Every County in the District experienced moderate to briefly heavy rainfall with heaviest rains concentrating over SE and NW portions of the District. Message 3's were issued for Adams and Arapahoe Counties including Aurora. Highest observed rainfall was a CoCoRaHS measurement taken at Erie 1.9 WNW at 3.40".

August 8th: Converging surface winds generated a line of strong thunderstorms that extended from Douglas County all the way into far SE Wyoming. An area of low pressure to the southwest was also helping to provide additional lift. Between 500 pm and 700 pm storms began to develop becoming strong and forming a line which would remain nearly stationary oriented from SSW to NNE. Due to the lack of movement for the first few hours heavy rainfall accumulated over portions of the District. The line would eventually begin to break up after 800 pm with an overall weakening of thunderstorms through 1000 pm. Locations under the stronger thunderstorms received 2-3" of rain per UDFCD gauges and CoCoRaHS reports over northern Douglas County and portions of east Denver County and Arapahoe County including the City of Aurora. Highest observed rainfall was a UDFCD gauge at Expo Park at 2.91" with Cherry Creek below Apache Plume in northern Douglas County a close second at 2.85".

August 22nd: Scattered strong and severe thunderstorms would develop during the afternoon and evening hours on Thursday, August 22, 2013. Thunderstorms would first develop over the mountains and foothills between 100 pm and 300 pm but the stronger storms would form over the plains during the middle to late afternoon. A strong thunderstorm over Douglas County would retrograde back to the NW while a line of storms moved off of the foothills. The air between these two storms pinched off a nearly stationary strong thunderstorm over SW areas of the District which would move very little producing heavy rainfall and accumulating hail. This storm would eventually track back through northern Douglas County providing a second round of heavy rainfall. Additional strong storms of note developed over Adams County and DIA area. Thunderstorm activity would slowly decrease between 700 pm and 800 pm. Highest observed rainfall was CoCoRaHS measurements taken at Ken Caryl 0.6 WSW at 2.40” and at Castle Pines 2.2 NE at 2.48”.

Figure 2: Hail accumulating on roadways in Ken Caryl area, 8/22/2013. Photo Courtesy of: Chad Lunde



Figure 3: Workers remove hail from a parking lot in Ken Caryl area, 8/22/2013. Photo Courtesy of: Chad Lunde



September 9-15th: The one event that will forever make the 2013 flood season memorable for many years to come was the heavy rainfall event that spanned multiple days that started on September 9th and proceeded to produce heavy rainfall each day through September 15th. The perpetrator for this flood event was a slow moving upper level low pressure system with a subtropical moisture connection to both the Gulf of California and the Gulf of Mexico. This low pressure center would spin moisture into Colorado and supply upper level lift as it moved very slowly to the NE over a period of days. Rounds of moderate to heavy rainfall along with thunderstorms would occur each day through the 15th. Heavy rainfall would first develop on Monday, September 9th with generally 1-4" of rain over NW portions of the District over Jefferson and Boulder Counties. There were large breaks in the rainfall Monday night with thunderstorms developing again on Tuesday producing heavy rainfall over large portions of the District in the 0.5-2.5" range.

Extended breaks in the rain occurred again Tuesday night but the ground had become fully saturated many areas of the District by Wednesday September 11th just in time for the “Main Event”. Moderate and heavy rains with pockets of very heavy rain (3-4”/hr rates) fell over the District on Wednesday the 11th with exceptionally heavy rains occurring over Boulder County and portions of Adams and Arapahoe Counties including Aurora. Rainfall of 5-10” of accumulated in hardest hit areas. There was not a meaningful break in the rainfall overnight Wednesday into Thursday as heavy rains continued to plague the District on Thursday, September 12th with another 4-8” of rain in hard hit areas of Boulder, Jefferson, Adams, Denver, Arapahoe Counties and the City of Aurora. Rainfall began to decrease in coverage and intensity on Friday, September 13th but rainfall continued to fall over the District, lightest over Boulder County with heaviest rains of 1.0-1.5” over central Jefferson County. A lull in the storm activity occurred later Friday and Friday night into Saturday morning, September 14th. Another piece of upper level energy associated with the unseasonably strong and moist upper level low pressure system would result in strong thunderstorms and very heavy rains over portions of the District again Saturday afternoon and evening. Rainfall rates of up to 4.0”/hr were noted from the stronger thunderstorm cells. Storms would first fire along the foothills early in the afternoon with more significant storms developing over Douglas County just after 200 pm. Strong thunderstorms would grow in size and split sending strong thunderstorm activity northward into portions of Arapahoe, Denver and Adams Counties while the other piece remained nearly stationary over central and SW Douglas County. Thunderstorm activity would slowly diminish in the evening with rain showers and weaker thunderstorms continuing through the early overnight. A cold front would then move through early Sunday morning, September 15th as the back side of the system moved through resulting in an increase in rain showers, heavy at times (up to 2”/hr) with isolated thunderstorms producing locally heavier amounts. Rain would decrease through the afternoon and evening hours on Sunday the 15th.

Total rainfall amounts of 10-15” were common over Boulder County and portions of Jefferson, Adams and Arapahoe Counties including the City of Aurora. Higher amounts of 15-20” or more were measured in hardest hit areas with areas around the City of Boulder reporting the highest amounts.

Flooding of creeks and streams occurred in all Counties within the District during this time with hardest hit areas being the City of Aurora and central Jefferson County northward through all of Boulder County. Boulder Creek at Boulder crested at approximately 5,000 cfs and was the highest flows observed since 1894. There have been 9 confirmed deaths from this flood event in Colorado including Counties outside the District.

Figure 4: Home flooding in Boulder County, 9/12/2013. Photo Courtesy of Helen Richardson/Denver Post



Figure 5: Officer observes flooding in Boulder County, 9/12/2013. Photo Courtesy of Helen Richardson/Denver Post



Figure 6: High water off of Iliff Ave. east of Chambers Rd. 9/15/2013. Photo Courtesy of Eric Hurst



6.0 Recommendations

Post Flood Meetings

It is recommended that representatives from the District and the 2013 PMS meet with key members of each F2P2 jurisdiction to discuss the September 9-15 flooding that was experienced within the District. The amount of rain that was observed over the 7 day period across portions of the District is unprecedented and in some locations of the District, exceeds a 1000 year return frequency. Significant flooding was experienced due to the heavy rainfall.

Topics of discussion should include the following:

- F2P2 PMS support. What worked? What did not work?
- Observed flooding. Actions taken in response to the flooding.
- Flood Warning Response plans. Were they relied upon and if so how did they work?
- Questions/Comments