



Cherry Creek Recreation Area, June 3, 2005, Denver, Colorado

UDFCD Flash Flood Prediction Program –F2P2 XXVII

**Final Project Report
Urban Drainage & Flood Control District
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Denver, Colorado**

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Executive Summary

Urban Drainage & Flood Control District (UDFCD or District) has funded a Flash Flood Prediction Program (F2P2) since May 1979. The F2P2 was established as a community response to the disastrous Big Thompson Flash Flood of July 31, 1976 in Larimer County. The District contracts the unique, basin/storm-specific weather prediction services of a Private Meteorological Service (PMS) to augment the traditional forecast and warning services of the National Weather Service (NWS) for the seven-county District area. The services and products provided by the PMS are not produced or provided by NWS. HDR Engineering, Inc of Denver, Colorado was the PMS for the 2005 F2P2 operational season. 2005 was the 27th operational year for the F2P2.

The District includes over 60 percent of Colorado's population. The primary support area for response agencies is about 1600 square miles in size. F2P2 products are issued to emergency response agencies within this area. The forecast area of responsibility is an area of about 3,000 square miles that includes the headwater basins of streams that flow into the District.

The F2P2's purpose is to predict the daily flash flood and flood potential for the Denver metro area's emergency response agencies. The predictions are communicated by daily Heavy Precipitation Outlooks, Messages indicating County flooding potential and expert-to-user telephone communications before, during and after flooding events.

The 2005 F2P2 produced several notable achievements and an unusual weather pattern that provided only limited flooding opportunities. Key highlights are listed below:

1. Twenty-five Message days were predicted and 22 Message days were observed. No unpredicted Message days occurred. The annual average number of observed Message days is twenty-eight. 2005 was the fourth consecutive year of below average Message day observance.
2. Weather forecasting accuracy for Message days was 88 percent for the District-wide area or 4 percent above the annual average for the program.
3. No flooding days went un-forecast and no lives were lost due to flash flooding.
4. On Message days 59 percent of the county-specific Messages verified with a heavy rain and flooding event observed in the predicted county area. Jefferson County, Arapahoe County, City of Denver and City of Aurora verification rates were better than 60 percent.

Recommendations for the 2006 F2P2 identified the need for an upgraded telephone system, a review on the need for an update of the Bear Creek Flood Warning Plan (FWP), a review of the need for a limited FWP for the Cherry Creek bike trail and an increased use of GIS in the presentation of F2P2 products.

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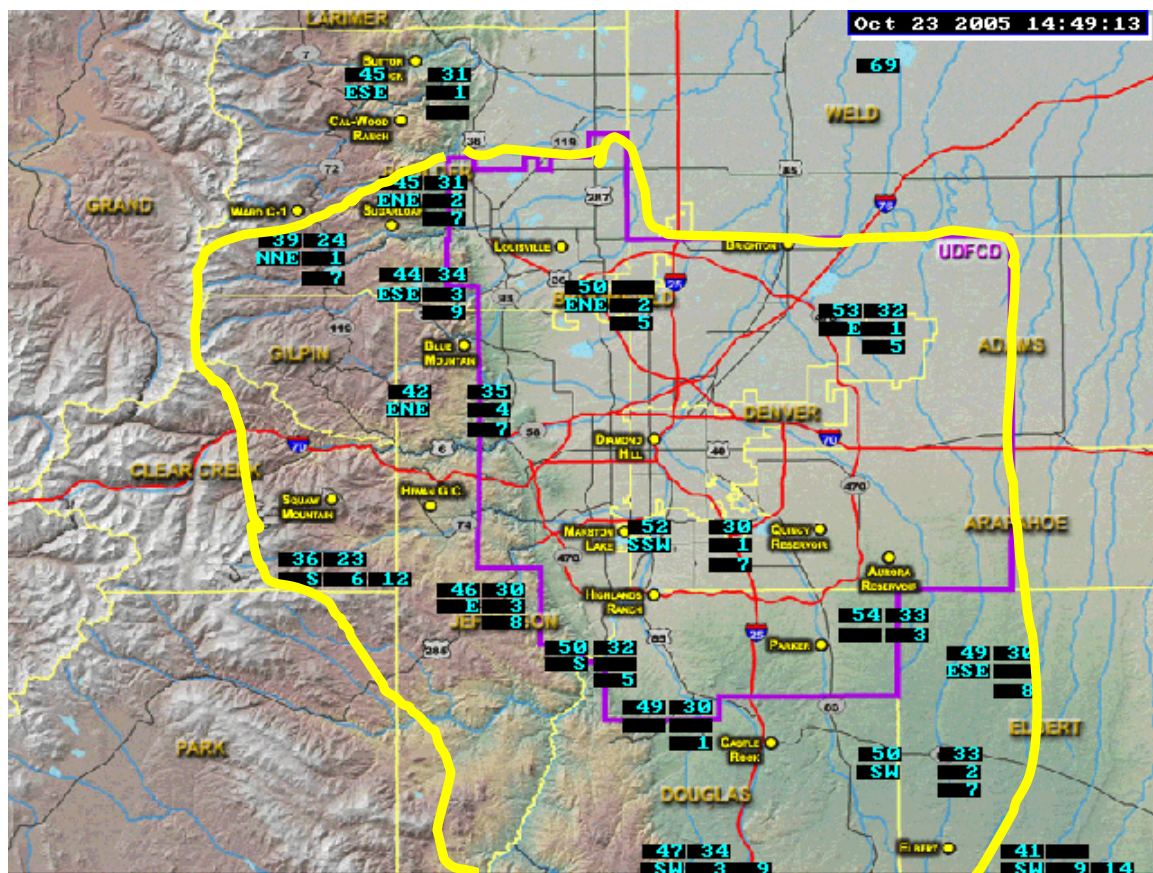
1.0 Introduction

Urban Drainage & Flood Control District (UDFCD or District) has funded a Flash Flood Prediction Program (F2P2) since May 1979. The F2P2 was established as a community response to the disastrous Big Thompson Flash Flood of July 31, 1976 in Larimer County. The District contracts the unique, basin/storm-specific weather prediction services of a Private Meteorological Service (PMS) to augment the traditional forecast and warning services of the National Weather Service (NWS) for the seven-county District area. The services and products provided by the PMS are not produced or provided by NWS. 2005 was the 27th operational year for the F2P2.

The F2P2's purpose is to predict the daily flash flood potential for the Denver metro area's emergency response agencies. In addition to the response agencies, Denver media, school districts and transportation agencies use the information.

The District is located within the magenta colored line in **Figure 1** and includes over 60 percent of Colorado's population. This **primary support area** for response agencies is about 1600 square miles in size. F2P2 products are issued to emergency response agencies within this area. The **forecast area of responsibility** is an area of about 3,000 square miles within the solid yellow boundary. The forecast area includes the headwater basins of streams that flow into the District. The F2P2's operational season extends from 15 April to 15 September.

Figure 1 UDFCD District (Magenta) and Forecast area (Yellow) boundaries.



Terrain in the forecast area varies from the rolling populated prairies of Arapahoe, Adams and Broomfield Counties to highly urbanized Denver County to the rugged plains-foothills-mountain interfaces of Jefferson, Boulder and Douglas Counties. The population in this area has increased dramatically over the last ten years within the city of Aurora, Douglas County and, recently, Adams County.

1.1 HDR – the Private Meteorological Service (PMS) provider.

The Hydro-Meteorological Services of HDR Engineering in Denver was selected as the 2005 F2P2 PMS. HDR maintains a full-service, 24/7 Weather Center at its offices at 303 East 17th Avenue. The F2P2 services were provided by operational meteorologists William Badini, Robert Rahrs and John Henz. Mr. Henz was the project manager of the 2005 F2P2 program. In addition to these three full-time meteorologists, HDR employed a meteorologist intern, Nathan Clements, a graduate meteorologist at Texas A&M.

HDR has provided the PMS services since 2001 when it acquired Henz Meteorological Services (HMS) from John Henz. The 2005 F2P2 season is HDR's fifth year as the PMS. HDR meteorologists are experienced in flash flood prediction, flood response plan development, water supply prediction and quantitative precipitation forecasting.

Mr. Henz has been involved actively in the F2P2 since it was developed in 1979. He has participated in 26 F2P2 seasons. Mr. Badini has seven years of F2P2 experience and Robert Rahrs has four years of F2P2 experience. Their 37 combined years of F2P2 experience provides continuity, creativity, insight and decision-making expertise.

1.2 PMS Forecast Services

HDR offers five special forecast services not offered by the NWS to the emergency response agencies. The special services are listed below:

1. Basin-specific probabilistic **Quantitative Precipitation Forecasts (QPFP)** that forecast the hourly rain rates and event total precipitation for each of the critical District basins.
2. Daily **Heavy Precipitation Outlooks** which identify the county flash flood and flooding threat, probabilistic peak rain rates and prime time for storm activity.
3. **StormTrak** provides storm-specific movement, speed and areal coverage of thunderstorm systems capable of producing flash flood and flooding rains in the District. This product remains one of the most popular F2P2 products.
4. **Messages** describing county/city flash flood and flood potential are issued by direct expert-to-user phone communications to local emergency response agencies before, during and after flood and flash flooding events.
5. Direct support to the seven flood warning plans developed by the District for high threat urban and foothills streams. These plans link basin hydrologic support to determination of historical flooding and evacuation concerns.

Additionally, the PMS provides direct forecast support to seven flood warning plans (FWP). Each of these FWP has specific meteorological and hydrological activities.

The District Flood Warning Plans (FWP) are identified below:

1. **Boulder Creek Flood Warning Plan:** supports Boulder/South Boulder Creeks in the City of Boulder and south Boulder County.
2. **Ralston Creek Flood Warning Plan:** supports the lower Ralston/Van Bibber/Leyden Creeks basins as they impact northern Jefferson County and the City of Arvada.
3. **Lena Gulch Flood Warning Plan:** supports the Lena Gulch basin which impacts Jefferson County, the Cities of Golden, Lakewood and Wheat Ridge and Consolidated Mutual Water.
4. **Bear Creek Flood Warning Plan:** supports the Bear Creek basins in Jefferson County and the Cities of Morrison and Lakewood. Numerous small foothills communities located along Bear Creek and its tributaries are supported by this plan.
5. **Harvard/Goldsmith Gulch Flood Warning Plan:** supports south-central Denver and south-east Denver and the Denver Technical Center. This basin is prone to urban and street flash flooding events almost annually.
6. **Westerly Creek Flood Warning Plan:** supports eastern Denver and western Aurora. This FWP is multi-jurisdictional and requires effective communication.
7. **Toll Gate Creek Flood Warning Plan:** supports central and southeastern Aurora. Both of these basins are capable of producing significant flooding events.

Provision of these PMS services is funded by the UDFCD. HDR provides all F2P2 forecast products to the National Weather Service in Boulder, Colorado. The provision of these services to users and sharing of the products with NWS assists in coordination and communication between the agencies and eliminates confusion for the user community. Basins without FWP are supported as effectively on an event basis.

2.0 2005 Operational Season – An overview

The 2005 F2P2 season can best be characterized as a “meteorological roller-coaster ride” that produced near-record highs and lows in temperature, precipitation and Message days. The F2P2 operational season runs from 15 April through 15 September. In all 22 Message days were observed during the 2005 F2P2 season or 6 below the annual average.

2.1 April-May

Despite above average April and May precipitation, no Message days were observed for only the fourth time since 1979. Most of the precipitation fell in the form of upslope rain and snow events. Only 9 thunderstorm days were observed at DIA through the end of May compared to an average of 15 during this period. The lower than normal DIA precipitation was a direct result of the upslope form of the precipitation which tends to be a minimum on the plains areas further than 15 miles from the foothills.

2.2 June-July

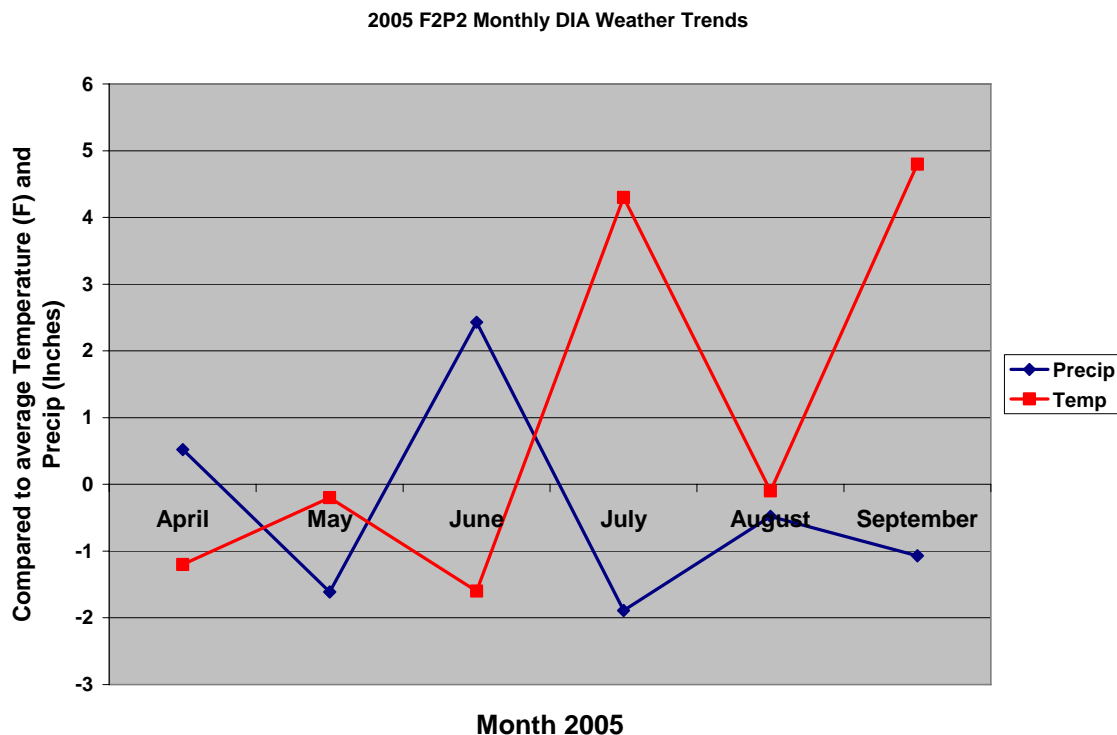
June 2005 turned stormy as Messages were issued for 11 days and the region enjoyed the fourth wettest June on record. DIA recorded 17 thunderstorm days compared to an average of 11 thunderstorm days. July proved to be the exact opposite of June as it was the second hottest and the third driest July on record. Only 7 thunderstorm days were observed at DIA compared to an average of 16 thunderstorm days. Only 4 Message days were observed in July which set a record for fewest July Message days.

The July weather was consistent with the observance of the second latest start to the Arizona monsoon (July 18) in the last 50 years. The only later start was July 25 observed in 1987. Usually the Colorado monsoon season begins 5-10 days after the onset of the Arizona monsoon. Simply put, the Colorado monsoon did not begin until early August leaving July uncharacteristically hot and dry with few thunderstorms.

2.3 August-September

August weather proved to be average in temperature and precipitation though the ten Message days was two above average for the month. DIA recorded only ten thunderstorms days compared to an average of twelve days with below normal precipitation for the month. This latter observation was in marked contrast with the rest of the Denver metro area that averaged over 2.75 inches of August rain or about an inch above average. No Message days were observed in September and only four thunderstorms days or three below average were observed at DIA (See **Figure 2**).

Figure 2 Monthly DIA temperature/precipitation averages, Apr-Sep 2005



These observations were consistent with the end of the Arizona monsoon on September 11th or about a month early. **Figure 2** shows the comparison of the DIA observed temperature and precipitation compared to average for the 2005 F2P2 season. The weather “roller-coaster” effect is quite obvious. Note how the wettest months tended to be the coolest and the driest months were the warmest.

3.0 Message day verification

The most basic verification measure of seasonal success in the F2P2 is the verification of Message day forecasts. A Message day is defined as either the observance or the prediction of locally heavy rainfall of at least 1.00 inch/hr within the District boundaries. Thus three types of Message days are possible:

1. An observed Message day where greater than or equal to 1.00"/hr rains were observed within the District.
2. A predicted Message day where greater than or equal to 1.00"/hr rains were predicted somewhere within the District.
3. A verified Message day where greater than or equal to 1.00"/hr rains were predicted and observed somewhere within the District.
4. An unpredicted Message day where greater than or equal to 1.00"/hr rains were observed but not predicted somewhere within the District.

While these terms may sound foreign or seem confusing, they are very useful in describing how effectively the F2P2's PMS forecast the heavy rainfall potential facing the District.

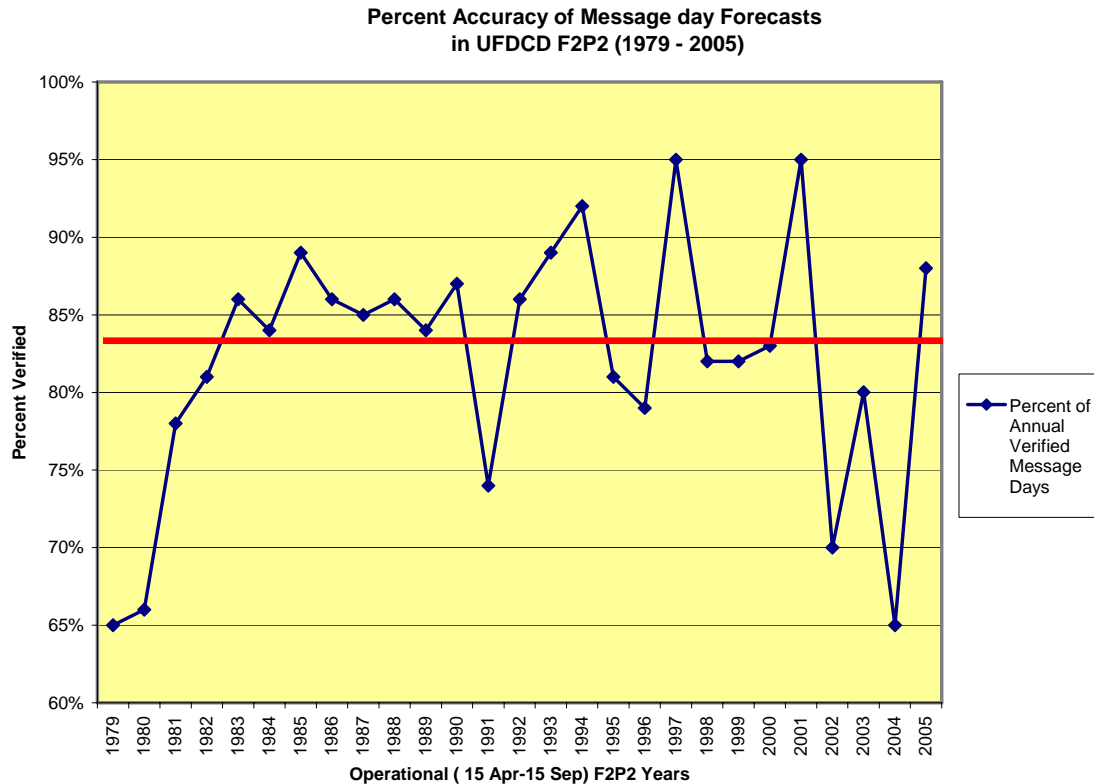
Table 1 shows the number of Message (1, 2 and/or 3) days predicted monthly, the number that verified monthly and the percent of Message day forecasts that verified during the 2005 operational year. It is quite rare to find three of the six months with no verified or predicted Message days. Message days followed the weather roller-coaster shown in **Figure 2** with June and August the only active Message months. Both the predicted and observed number of Message days in July set F2P2 records for fewest on record.

Table 1: Monthly District-Wide Message Day Verification for the 2005 F2P2.

Month	Predicted Message Days	Verified Message Days	% Verified
April	0	0	0%
May	0	0	0%
June	11	10	91%
July	4	3	75%
August	10	9	90%
September	0	0	0%
Total			
2005	25	22	88%
2004	31	20	65%

The accuracy of Message day or District-wide forecast was 88 percent compared to 65 percent in 2004. This dramatic improvement brought program verification back into line with the annual average of 84 percent accuracy after three drought years (see **Figure 3**).

Figure 3 Annual F2P2 Message day verification accuracy from 1979-2005.



The below average Message day accuracy observed from 2002 to 2004 appears to be directly related to the significantly reduced number of verified Message days during the Drought of 2000-2003. Storms were quite lethargic during this period and many potentially stormy days never were able to produce storms of note for a variety of reasons.

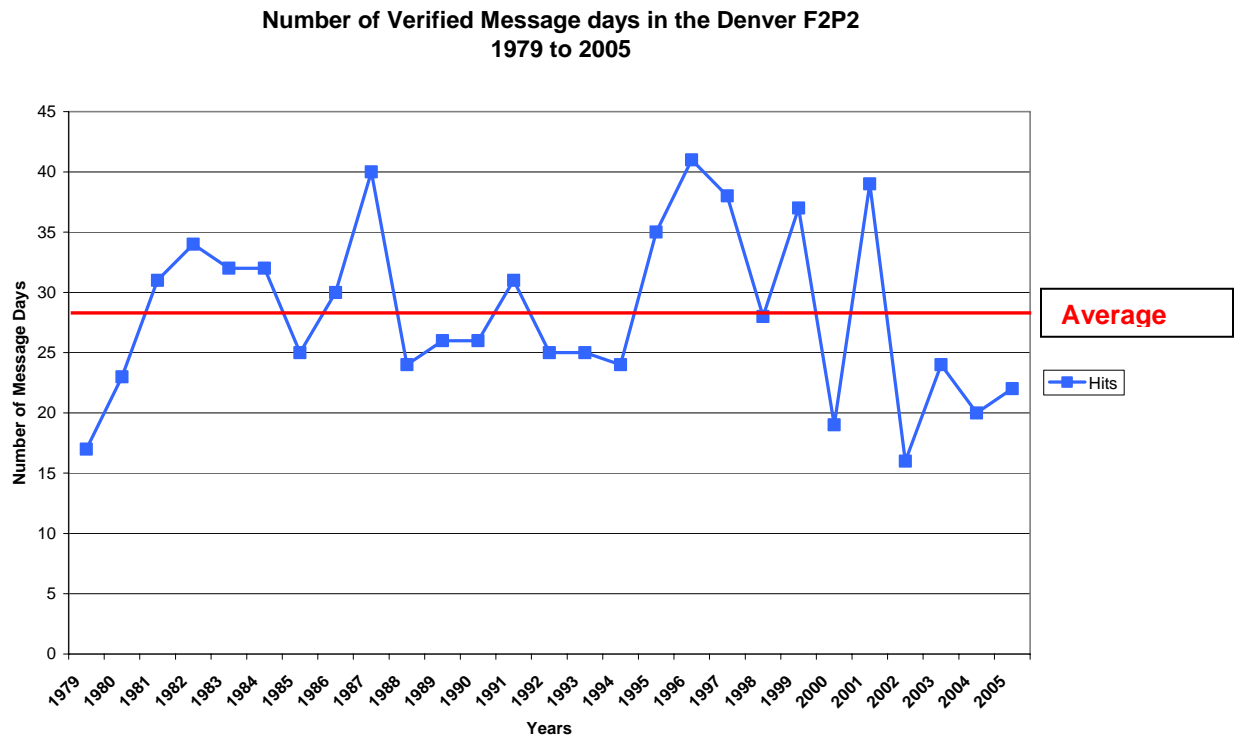
One reason of note was the lack of an active Arizona monsoon since 1998. During this period Arizona has suffered an extended drought that has produced record high temperatures and below average precipitation, especially during the summer monsoon season. The 2005 F2P2 was impacted by the second latest start to the Arizona monsoon (July 18) in the last 50 years. The only later start was July 25 observed in 1987.

This late start to the Arizona monsoon significantly reduced the number of northward intrusions of sub-tropical moisture into Colorado from New Mexico and Arizona.

Figure 4 shows the annual number of verified Message days since 1979. The annual average during this period was 28 verified Message days. The number of verified Message days has been below average for the past four years and set a record for consecutive number of below average verified Message days. Note that six out of the seven years from 1988 to 1994 also observed below average number of Message days.

The average number (20.5) of Message days for the past four years is the lowest four-year average observed since the F2P2 began. This observation also appears to be consistent with the weak or nearly non-existent Arizona monsoon during the recent drought of the 2000-2004 period.

Figure 4 **Verified F2P2 Message days from 1979 to 2005.**



The relatively quiet 2005 F2P2 season resulted in modest product totals as shown in **Table 2**. The comparison of 2005 and 2004 operational years shows the two years to be comparable relative to total F2P2 products.

It is interesting to note the difference in the number of QPF products that suggests the 2004 Message days presented a more significant QPF challenge compared to 2005 Message days. It may also reflect that relatively dry atmosphere that covered Colorado during Summer 2005. In essence, the number of locally heavy rainfall days and storms appears to have been well below normal this past year.

Table 2 **Comparison of the 2004 and 2005 F2P2 product numbers**

F2P2 Products	2005	2004
HPO	209	193
Predicted Message days	25	31
Internal Message Status	68	62
StormTrak	36	32
QPF	15	45
Total	328	332

4.0 2005 F2P2 Operational Verification

Verification of Messages issued by County is presented in this section. In general, verification improved significantly in 2005 from 2004 as most program goals were equaled or exceeded.

4.1 Message day and Message verification

Verification of F2P2 predictions is an effective way to measure the support rendered to the program's users. This section provides a verification of the District-wide Message day (M-day) forecasts and county-level Message (CM) forecasts. **Table 3** contains information on the event number, date of the event, the day of the week the event occurred, District-wide M-day hits (H) and misses (M), County Message (CM) hits (H) and misses (M) for Message 1 (M1), Message 2 (M2) and Message 3 (M3) issuances and the lead-time of the Messages from time of issuance to time of event occurrence.

Table 3 Message Day and County Message verification data for 2005

Event	Date	Day Of week	District-wide M-day	County CM Hit M1-M2-M3	County CM Miss M1-M2-M3	Lead-time Goal 30 min+
1	6-2	Thu	H	0 - 0 - 1	1 - 0 - 0	0-30min
2	6-3	Fri	H	5 - 0 - 4	3 - 0 - 0	3hr+
3	6-9	Thu	H	4 - 0 - 0	2 - 0 - 0	0-30min
4	6-10	Fri	H	6 - 0 - 0	2 - 0 - 0	>1hr
5	6-12	Sun	H	5 - 0 - 0	3 - 0 - 0	>1hr
6	6-16	Thu	H	2 - 0 - 0	2 - 0 - 0	30-60 min
7	6-20	Mon	H	4 - 0 - 0	3 - 0 - 0	>1hr
8	6-21	Tue	H	5 - 0 - 0	3 - 0 - 0	>1hr
9	6-23	Thu	H	5 - 0 - 0	3 - 0 - 0	>1hr
10	6-24	Fri	H	3 - 0 - 0	5 - 0 - 0	>1hr
11	6-25	Sat	M	0 - 0 - 0	8 - 0 - 0	>1 hr
12	7-04	Mon	M	0 - 0 - 0	4 - 0 - 0	>1hr
13	7-15	Fri	H	3 - 0 - 0	2 - 0 - 0	>1hr
14	7-24	Sun	H	4 - 0 - 0	4 - 0 - 0	>1hr
15	7-25	Mon	H	4 - 0 - 0	4 - 0 - 0	>1hr
16	8-03	Wed	H	8 - 2 - 0	0 - 1 - 0	>1hr
17	8-04am	Thurs	H	8 - 0 - 0	0 - 0 - 0	>1hr
18	8-04pm	Thurs	H	8 - 0 - 0	0 - 0 - 0	>1hr
19	8-09	Tues	H	2 - 0 - 0	6 - 0 - 0	>1hr
20	8-10	Wed	H	5 - 4 - 0	3 - 0 - 0	>1hr
21	8-11	Thurs	H	4 - 0 - 0	1 - 0 - 0	>1hr
22	8-16	Tues	H	3 - 0 - 0	1 - 0 - 0	>1hr
23	8-21	Sun	H	5 - 0 - 0	0 - 0 - 0	>1hr
24	8-22	Mon	H	7 - 0 - 0	1 - 0 - 0	>1hr
25	8-23	Tues	M	0 - 0 - 0	8 - 0 - 0	>1hr
	Totals			100 - 6 - 5	69 - 1 - 0	
Year		Percent		59%-86%-100%	41%-14%-0%	92%
2005	25	88%	22/25	111 (61.3%)	70 (38.7%)	23/25 (92%)
2004	30	65%	20/31	74 (44%)	176 (56%)	19/20 (95%)

The Message day verification improved from 65 percent in 2004 to 88 percent in 2005 as 25 Message days were forecast and 22 days experienced an event. The 2005 Message day accuracy is 4 percent above the average annual Message day accuracy of 84 percent. Message days occurred most frequently on Thursdays (7) while Saturdays (1) and Wednesdays (2) were the least active days.

The lead-time of County Messages met the goal of 30 minutes or more on all but two days. The first day was a short-duration thunderstorm that formed over DIA on June 2, 2005. This storm caused brief street-ponding on Pena Boulevard as gutters clogged with small hail. A strong low level jet from the southeast contributed to the storm's rapid intensification. However, the lack of other than hourly observations at DIA hindered early Message issuance.

The second occurrence was on June 9, 2005 when rush hour storms formed rapidly between 400PM and 500PM. Dew points increased from the mid-40's into the 50's as a surge of low level moisture entered the District from the north to east. Message 1's issued achieved a 30 min or more lead-time in all but Denver County where initial storm development occurred.

Review of both these cases indicated that the lack of automated weather sites in Weld County and eastern Arapahoe County contributed to the "surprise" arrival of moist air from the north to east of the District. Earlier studies on the value of automated weather stations in the upwind areas of Weld and Arapahoe County have described the need. These two events simply indicate the problem remains.

4.2 County Message Verification and Comparison Statistics

This section of the report provides a detailed county-by-county verification of the Messages issued during the 2005 F2P2. It should be noted that except for Denver and Broomfield Counties, the PMS predicts heavy rainfall potential only for the portions of Boulder, Adams, Arapahoe, Douglas and Jefferson Counties that are within the District boundaries.

In general, the area of each county that falls within the District is less than 275 square miles or roughly a 17 square area. Thus, the challenge of accurately predicting locally heavy rainfall in these small areas is quite significant.

The F2P2 goal for county Message verification is to equal or exceed 60 percent accuracy. The annual average for the past 15 years is 56 percent accuracy for County Messages. Verification of the individual Messages issued to counties and Aurora is shown in **Table 4**.

The accuracy goal was met in Jefferson (72.7%), Arapahoe (70.8%), and Denver (60%) Counties. Douglas County was close to goal with a 59 percent accuracy. The goal was not met in Adams (54.6%), Boulder (44.4%) and Broomfield (41.1%) Counties.

Verification of Messages improved almost across the board except in Douglas County where verification fell slightly from 61 percent to 59 percent. The greatest improvements from 2004 to 2005 were noted in Denver (+12%), Jefferson (+16.7%), Boulder (+18.4%) and Broomfield (+26.1%) Counties.

Table 4 Message Verification for 15 April to 15 September 2005 by County

Event	Date	Day	Adams H = Hit	Arap/Aurora M = Miss	Boulder	Broomfield	Denver	Douglas	Jefferson
1	6-2	Thu			M		(M3)		
2	6-3	Fri	H (M3)	H(M3)/H(M3)	M	M	H (M3)	H	M
3	6-9	Thu	H	H/H			H	M	M
4	6-10	Fri	H	H/H	M	M	H	H	H
5	6-12	Sun	H	H/H	M	M	H	H	M
6	6-16	Thu	M	H/H			M		
7	6-20	Mon	H	M/M		H	H	M	H
8	6-21	Tue	H	M/M	H	H	H	M	H
9	6-23	Thu	M	H/H	H	M	M	H	H
10	6-24	Fri	H	M/M	H	H	M	M	M
11	6-25	Sat	M	M/M	M	M	M	M	M
12	7-04	Mon	M	M/M			M		
13	7-15	Fri	M	H/H				M	H
14	7-24	Sun	M	H/M	M	M	H	H	H
15	7-25	Mon	M	H/M	H	M	M	H	H
16	8-03	Wed	H	H/H	H	H	H	H	H
17	8-04	Thu am	H	H/H	H	H	H	H	H
18	8-04	Thu pm	H	H/H	H	H	H	H	H
19	8-09	Tues	M	M/M	M	M	M	H	H
20	8-10	Wed	M	H/H	M	M	H	H	H
21	8-11	Thurs		H/H	M			H	H
22	8-16	Tues		H/H				M	H
23	8-21	Sun	H	H/H				H	H
24	8-22	Mon	H	H/H	H	H	H	M	H
25	8-23	Tues	M	M/M	M	M	M	M	M
Totals	22/25	2005	12/10	17/7 // 15/9	8/10	7/10	12/8*	13/9	16/6
Percent	88	2005	54.5%	70.8%	44.4%	41.1%	60	59	72.7
		2004	45%	62%	26%	15%	48%	61%	56%
		Change	+9.5%	+8.8%	+18.4%	+26.1%	+12%	-2%	+16.7%

Note: The Denver Message 1 verification totals do not include the 6-02-2005 Message 3 hit though it is used to verify a Message day forecast.

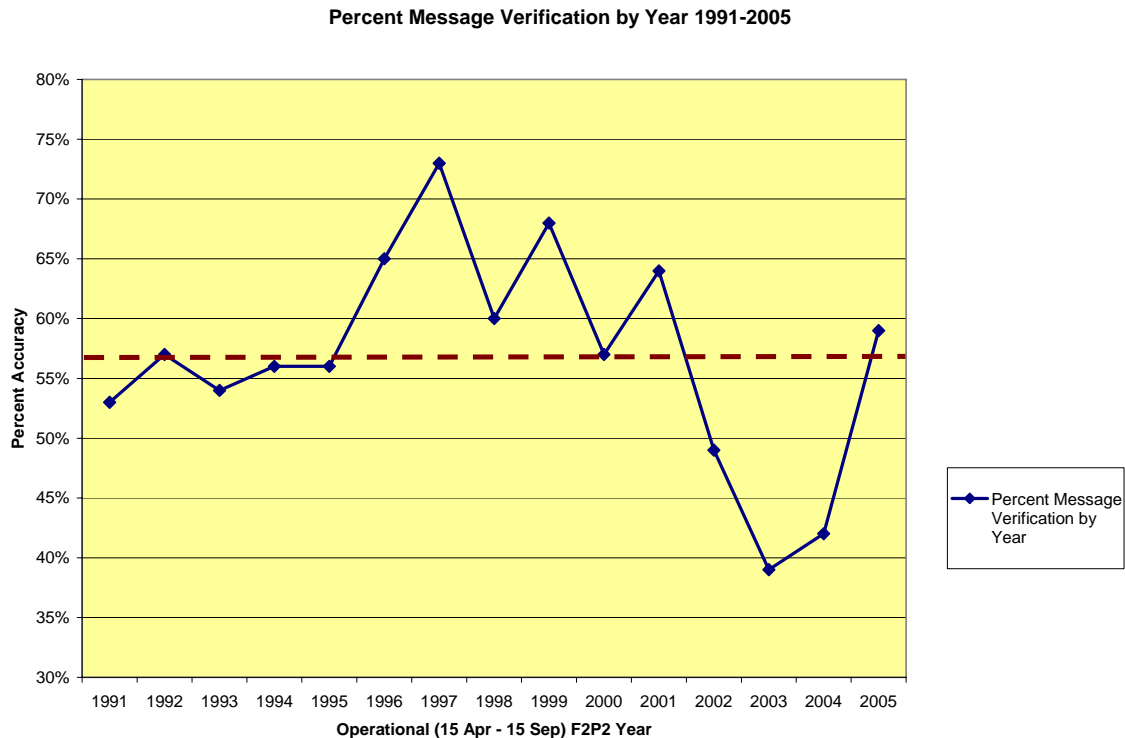
Table 4 shows Message 1 verification by County as an H and Message 3 verifications as **M3**. On June 3 some counties recorded both Message 1 and Message 3 hits due to multiple thunderstorm occurrence of varying intensity.

A comparison of 2005 Message verification to F2P2 Message verification since 1991 is shown in **Figure 5**. The annual average Message verification is 56 percent accuracy. The 59 percent accuracy attained in 2005 was slightly above average and slightly below the program goal of 60 percent. However, the 2005 accuracy demonstrated a 10-20 percent improvement over the past three years. This improvement may be attributed to increasing meteorologist experience, focused project management and the use of forecaster consensus to achieve better overall forecasting.

The consensus forecast procedure called for a 30-45 minute forecast discussion between the project manager and the duty meteorologists after an independent analysis period. The forecast decision was then based on the group evaluated information. This

“Weatherfest” was normally held between 1100AM and Noon to facilitate Message issuance early in the afternoon.

Figure 5 1991-2005 county Message verification for the F2P2.



4.3 Message 2 and Message 3 days verification

The 2005 F2P2 season featured only two Message 2 (Flash Flood Watch) days on August 3 and August 10. No Message 3's were issued on either day as storms failed to produce serious flash flooding or rain rates that approached 3.00 inches/hour. However, Message 1- Red Flags were issued and verified on both days. HDR issued Message 1's on both days prior to NWS Flash Flood Watch issuances. Minor street and urban stream flooding were observed on both days. Six of the seven (87%) County Message 2's issued on these days verified by National Weather Service criteria of observed heavy rainfall (> 1 inch/hr) or reported flooding events. By F2P2 standards the Flash Flood Watches did not verify though 24-hr rainfall totaled 2.00-4.00 inches District-wide.

Message 3 (Flash Flood Warning) days occurred on June 2 and June 3. On June 2 a localized intense thunderstorm formed over DIA and produced street flooding rain and copious amounts of pea-size hail that clogged drains. On June 3 a passing upper level disturbance and an intense Denver Cyclone spinning over SE Denver interacted to produce a line of severe thunderstorms that flooded streets and urban streams. Four Message 3's were issued in Denver, Aurora, Arapahoe and Adams Counties that all verified.

Thus all five Message 3's issued verified in 2005 with no false alarms. The two Message 2 days and two Message 3 days set records for fewest number observed since the program started.

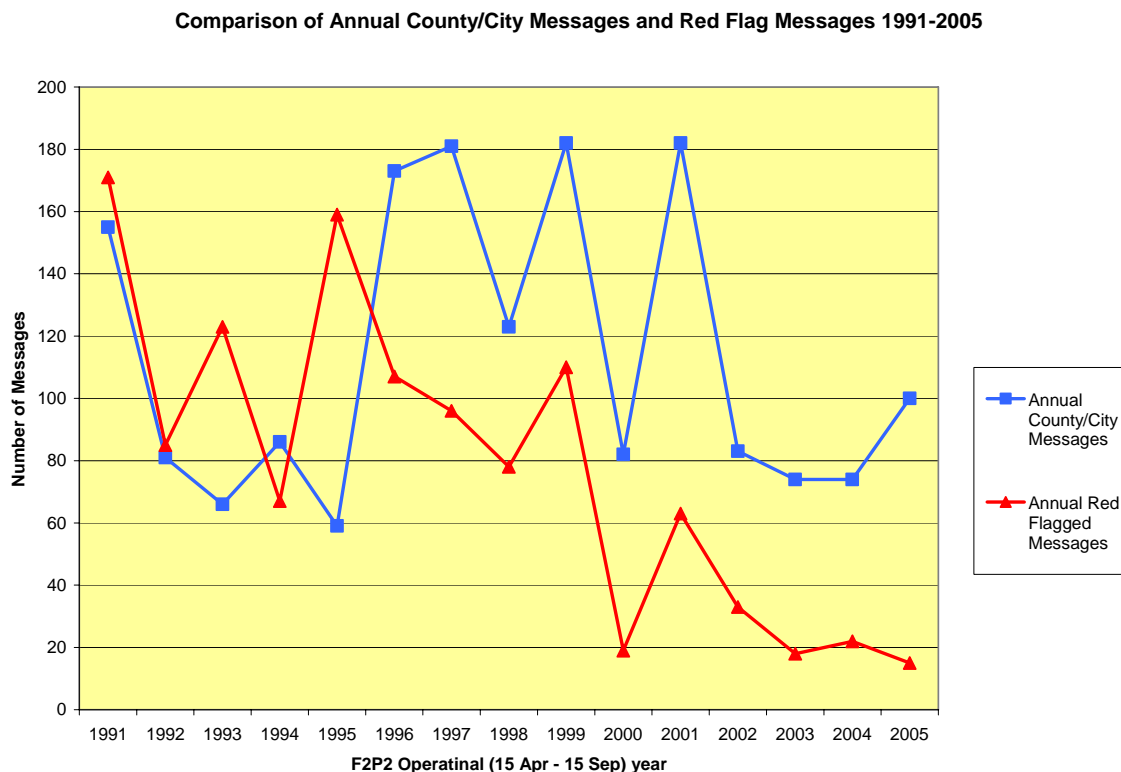
4.4 Red Flag verification

The F2P2 program issues Red Flags to Messages to indicate that a storm will produce rainfall of 1.00"/30 minutes or more (Message 1) or 3.00"/hr or more for a Flash Flood Warning (Message 3). At times, the distinction between the two products can seem blurred but F2P2 users appreciate the differences. Only 15 Message 1, Red Flags were issued in 2005 and all verified. **Figure 6** shows a comparison between the number of annual Message 1's and Red Flags issued since 1991.

The annual number of County Messages (Blue) and Red Flags (Red) issued since 1991 shows several interesting observations. First, the number of Red Flags exceeded the number of County Messages issued in 1991, 1992, 1993 and 1995. The reason for the "crossing lines" is that a Red Flag is issued on a short-duration, thunderstorm-specific basis. Thus, several thunderstorms producing locally heavy rainfall could impact a county while a single Message is valid as was frequently observed in 1995.

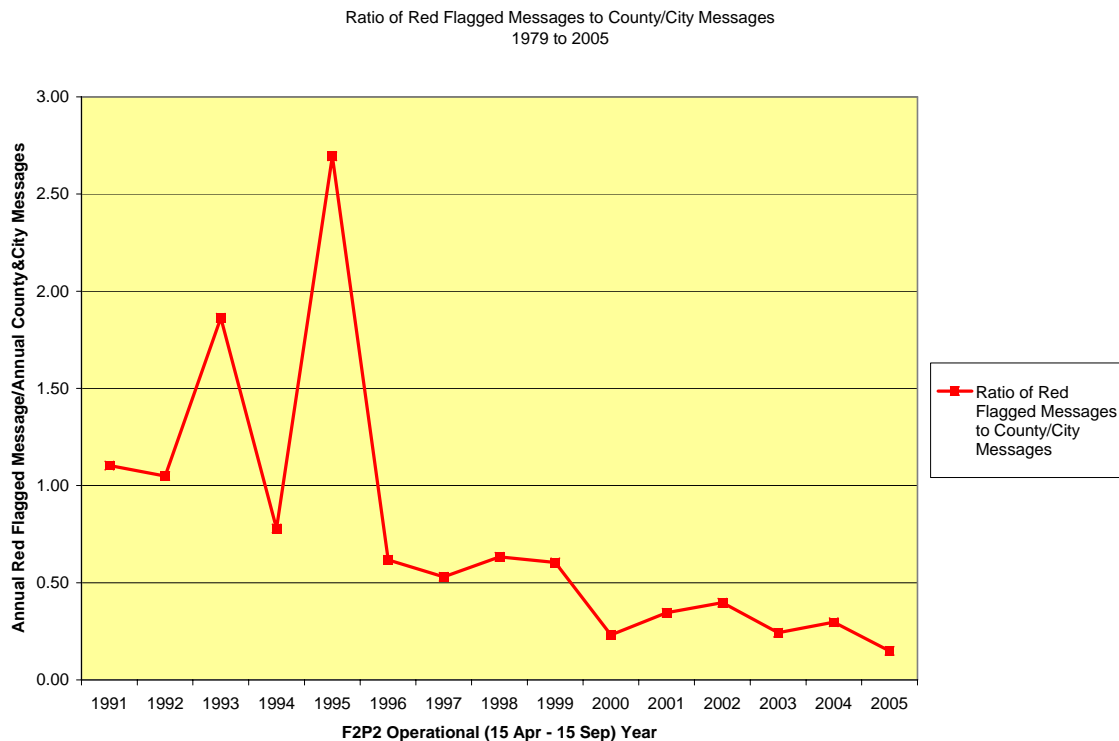
It is interesting to note the gradual decline since 1995 in the annual number of Red Flags. While it may appear related to a change in the F2P2 SOP, review of the SOP's form 1990 to present did not indicate a change in Red Flag issuance criteria.

Figure 6 Comparison of Annual County/City Message 1's and Red Flagged Messages 1991 – 2005.



If the number of Red Flags is compared to the number of Message 1's issued as a ratio (See **Figure 7**), it appears that a gradual but steady decline in the number of strong thunderstorms has been occurring for the past ten years. It is interesting to speculate on the cause for the apparent decline in the number of intense thunderstorms.

Figure 7 Comparison of Ratio of Annual Red Flagged to County/City Message 1's and 1991 – 2005.



As indicated earlier, the SOP detailing Red Flag issuance criteria has not changed since 1990 ruling out that possibility. The decline in the number of intense storms parallels both the recent 1999-2003 drought and the reduced number of Denver Cyclone occurrences since 1998. While a definitive study has not been completed, a review of weather data for the Message days of the past six years shows the following observations:

1. The average Message day Surface to 500mb precipitable water index is about 0.85 inch or about 15 percent less than the 1.00 inch average from 1979-1990.
2. The Denver Cyclone feature has appeared on less than 25 percent of Message days since 2000 compared to nearly 50 percent from 1990-1999.
3. The passage of mid-level short waves on Message days has decreased from 72 percent observed from 1990-1999 to less than 30 percent from 2000-2005.

Perhaps changes in atmospheric structure are the primary reason for the trend.

4.5 Boulder, Broomfield and Adams County verification: We're improving

The low verification rates in Boulder and Broomfield Counties appear related to a scarcity of strong storms in the southern portion of those counties from 2000 to 2005. HDR continues to explore ways to improve south Boulder County predictions. It should be noted that Message level rains were observed in other non-District parts of Boulder County on 6 of the 10 miss days. On those days the Boulder dispatchers appeared to treat the days as Message hit days instead of misses.

HDR project work in Boulder County the past two years provided a key insight into the relationship of Boulder Creek and South Boulder Creek topography to heavy rain and flood occurrence. Boulder Creek is oriented roughly SW-NE and is more open to northeasterly inflow winds in the low levels. Most flooding events observed in Boulder Creek's basin are related to long duration, low intensity general storms with occasional snowmelt enhancement of flooding stream flows.

In contrast to Boulder Creek, South Boulder Creek is open to east-southeast low level winds in the middle of the basin. It appears that South Boulder Creek is "more open" to heavy thunderstorm rainfall than Boulder Creek. These basin observations provide a quantitative insight to reduce Message issuance for Boulder County foothills areas unless low level wind conditions are supportive of storm formation.

Broomfield County is simply very small in size and almost a "point forecast". Message level storms were noted within 2-5 miles north, east and south of Broomfield on 7 of the 11 miss days. HDR meteorologists are becoming more aware of the forecast peculiarities of Broomfield County and anticipate improving support in the years ahead.

Adams County presents a different challenge in that little surface weather observation data is available in Weld County to the north or in eastern Adams County. This continuing problem will not change until more automated weather stations are installed in Weld, Adams and Arapahoe Counties as earlier noted.

4.6 Significant reduction in total bust days

Another significant positive of the 2005 season was the occurrence of only three total bust days compared to ten total bust days in 2004. A total bust day is a Message day when no Message rain event occurs in the District. The three 2005 "bust days" are outlined below:

1. **June 25:** Un-forecast drying of the afternoon atmosphere dropped dew points from the mid 50's into the low 40's ending storm threat. Upper level subsidence additionally clamped a "lid" on the atmosphere.
2. **July 4:** A line of severe thunderstorms formed in Larimer and Weld Counties and just clipped the eastern third of the District. Messages were issued because of the large holiday crowds and the potential existed that the storms could move more to south than the southeast that was observed.
3. **August 23:** A similar day to June 25 with an un-forecast drying of surface dew points from the 50's into the low 40's as dry air subsided into the region.

Rob Rahrs is doing a follow-up study to see if we can avoid these kinds of days by finding a predictable weather feature commonality. In the opinion of the HDR project manager, a few total “bust days” are to be expected every F2P2 season and represent an acceptable project attempt to not miss a potentially important storm day. The seventy percent reduction in total bust days from 2004 to 2005 aided this year’s Message verification.

5.0 Significant Storms of 2005

The F2P2 meteorologists struggled to identify the most significant “storm events” in the 2005 F2P2. The dates selected are June 3, August 3 and August 4, 2005. HDR also nominated the month of July 2005 that set a F2P2 record low number of Message days (4) for any July. As previously discussed the 2005 F2p2 was focused on only three storm months: June, July and August. For the first time since the F2P2 began in 1979, no Message days were observed in April, May and September.

A brief summary of the weather and rainfall of the three key days is presented that includes the general 24-hr CoCoRahs observed rainfall and pictures of the observed storm activity and flooding. **Appendix A** shows observed CoCoRahs 24-hr rainfall for all Message days.

5.1 June 3, 2005

An active upper level disturbance and a rapidly intensifying Denver Cyclone spinning over western Arapahoe County interacted to produce an explosive cluster of thunderstorms during a Friday afternoon rush hour. The storms exploded into street flooding rainfall and hail to 1.25 inches in diameter over Littleton, southeast Denver, Centennial and Aurora.

Weather support to the Denver metro emergency response community was aided by close co-operation between the National Weather Service and HDR meteorologists. The NWS and HDR worked together to issue four verified Flash Flood Warnings (Message 3’s) and several severe thunderstorm warnings to the emergency response agencies and the public.

HDR meteorologists Bill Badini and Rob Rahrs were present at the UDFCD Flood Prediction Center providing direct support to F2P2 users. John Henz acted as a storm spotter in SE Aurora and provided direct expert-to-user information to NWS and HDR meteorologists and dispatchers in Arapahoe and Douglas Counties and the City of Aurora. These observations assisted in placement of the Flash Flood Warning and dispelling concerns over apparent tornado formation being reported by the public. The ugly green shelf cloud leading the precipitation area gave an “Independence Day” movie look to the sky as shown in **Figure 8** taken about 445PM from SE Aurora near E-470.

Message 1’s were issued well in advance of the storm system by HDR. The storm system formed over the Jefferson County foothills and moved down the South Platte River basin. Rainfall west of the South Platte River was generally less than 0.50 inches prior to 430PM. John Henz called Bill Badini about 415PM to indicate the easterly winds over SE Aurora had increased to 20-30mph with the air becoming noticeably more humid.

Figure 8 **June 3, 2005 Severe thunderstorm complex over western Arapahoe County about 445PM as taken from SE Aurora.**

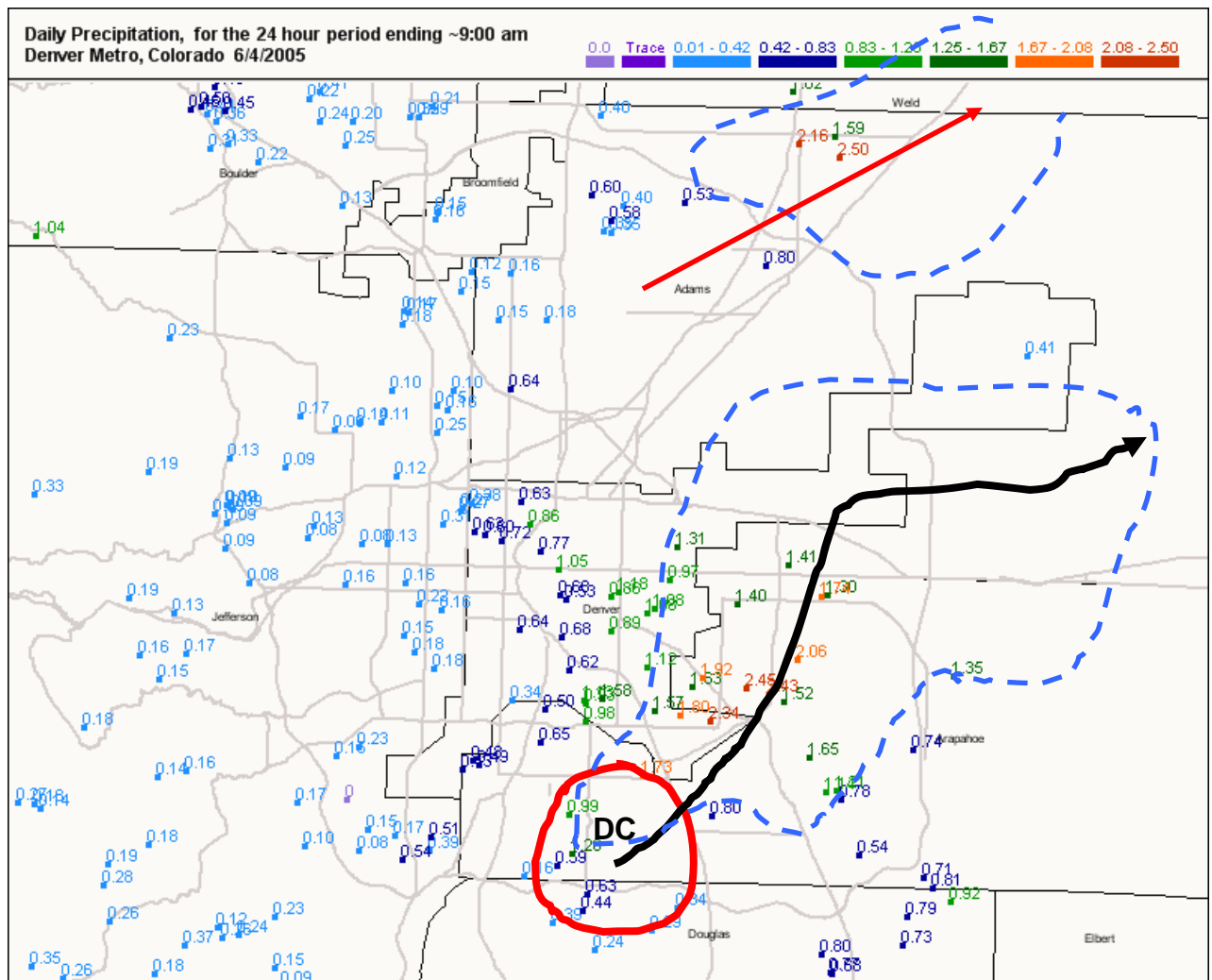


By 430PM the storm system encountered a Denver Cyclone (highlighted in red) spinning over Littleton as shown in **Figure 9**. The DC ingested the surface dew points of 50-55F lurking over eastern Arapahoe, Douglas and Elbert Counties into the storm updrafts.

Between 430PM and 445PM the thunderstorms became severe over east Littleton producing a combination of large hail, high winds, severe lightning and street flooding rainfall that continued until 530PM. Numerous reports of street flooding in east Littleton and near the Southglenn Mall were received.

Rainfall of 1.50" to 2.25 inches fell in 30-45 minutes over parts of the lower Cherry Creek, Goldsmith Gulch, Westerly Creek and Toll Gate basins (see blue dashed line in **Figure 9**). The black arrow shows the DC track. Significant street and urban stream flooding events were reported in southeast Denver along Goldsmith Gulch and Cherry Creek. Similar events were reported across Aurora along the I-225 corridor as the Denver Cyclone and the severe thunderstorm line interacted.

Figure 9 CoCoRaHS 24-hr rainfall June 3-4, 2005 observed at 7AM, June 4, 2005. Location of Denver Cyclone (DC) shown in red, track of DC in black and area of heavy rainfall > 1.50 inches (dash blue line).



Serious street and urban stream flooding was noted in SE Denver and SW Aurora. **Figures 10-12** show examples of the flash flooding that disrupted the Friday afternoon rush hour traffic. Many intersections in Aurora along the I-225 corridor were flooded between 445PM and 600PM. While rainfall totals reached only the 1.50 inch to 2.50 inch range, the rains fell in less than an hour. The volume of rainfall combined with copious amounts of hail clogged local storm sewers.

A secondary storm system (see red arrow) formed in western Adams County between 500PM and 515PM that equaled the intensity of the SE District storms but impacted a smaller area. These storms also produced large damaging hail and intense localized rainfall. The storms brought travel in the I-76 corridor to a halt for about 30 minutes. Peak rainfall in these storms was an estimated 2.50 inches in 75 minutes with about 1.75 inches falling in 45 minutes.



Figure 10 Street flooding in SW Aurora on June 3, 2005.



Figure 11 Bible Park flooding



Figure 12 Cherry Creek bike path near JFK

August 3 and 4, 2005

The combination of a cold front passage and weak steering winds prompted the NWS and HDR to confer on issuing Message 2's in the morning of August 3, 2005. The concern was that surface dew points would increase during the day into the foothills. NWS concerns were primarily with the burn areas in the foothills, none of which are in the District or in drainage basins that flow into the District. HDR concurred with the NWS concerns and Message 2's were issued for the foothills portions of the District.

The threat for heavy rainfall in the plains portion of the District was sufficient for the issuance of Message 1's for all jurisdictions. **Figure 13** shows the ominous skies that developed over Thornton just prior to front-end dumper rainfalls of 0.50"/10 min to 1.00 inch per 30-45 minutes in areas of the District along and west of the South Platte River. Message 2's were issued for Boulder, Jefferson and Douglas County about 245PM as concerns increased that overnight general rains could produce flooding in foothills basins. **Figures 14 and 15** show that 24-hr rainfall that essentially fell between 230PM, August 3 and 300PM on August 4, 2005 with totals of 2.00 inches to over 3.00 inches.

Figure 13 Ominous skies over Thornton, August 3, 2005



Figure 14 24-hour CoCoRahs rainfall observed at 7AM, August 4, 2005.

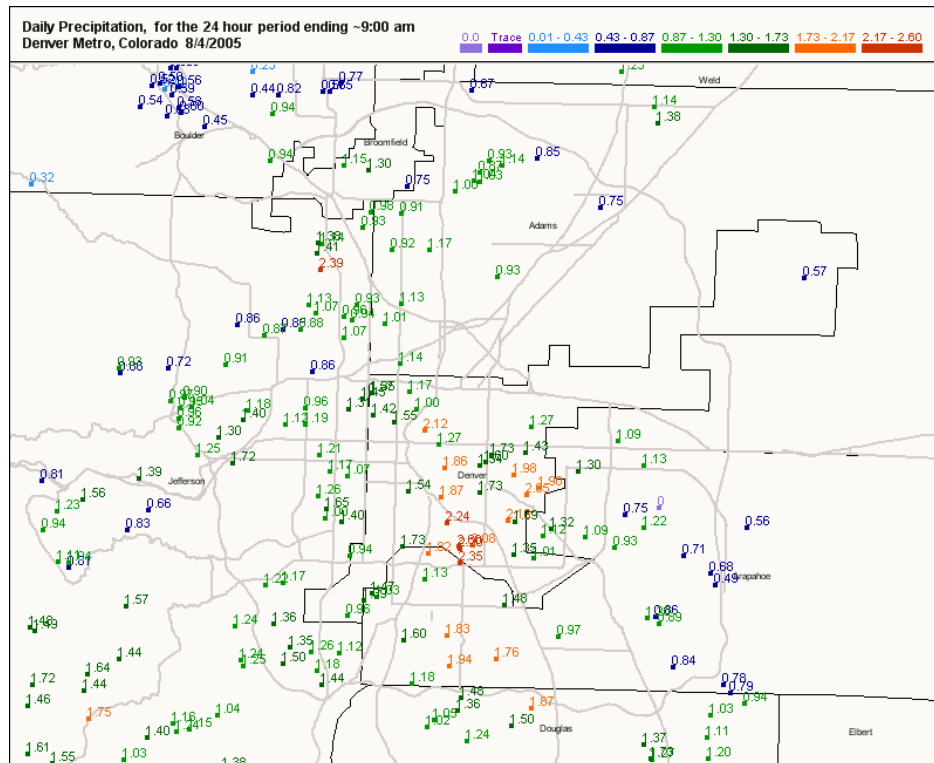
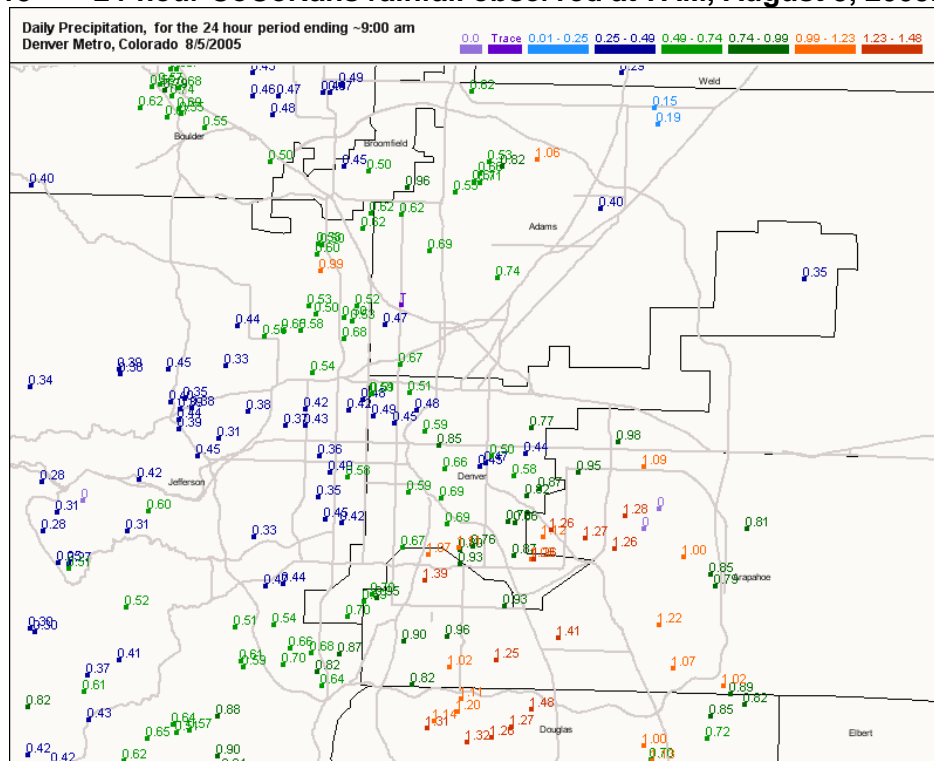


Figure 15 24-hour CoCoRahs rainfall observed at 7AM, August 5, 2005.



6.0 Recommendations and Comments

HDR offers several recommendations to UDFCD for consideration before the 2006 F2P2 season. The recommendations are listed below:

1. **Upgrade the telephone system:** The phone system used during the 2005 season was installed in the early 1990's and lacks key functional capabilities to include Caller ID, Voice Mail alert, visual keys of Call Waiting. The Flood Prediction Center needs three phone lines to accommodate the volume of communication experienced during Message event days.
2. **Flood Warning Plans:** HDR suggests that a limited flood warning plan be developed for the Cherry Creek bike path per preliminary discussions with Bill DeGroot in 2004. The June 3, 2005 flash flooding of lower Cherry Creek that inundated the bike trails provides an excellent calibration tool to quantify basin response that could be used to provide added warning to trail users. Additionally, HDR suggests that the Bear Creek FWP be reviewed for impacts on Morrison and upstream populated areas that may have developed over the past five years due to population development that may not be reflected in the existing plan.
3. **ACARS:** HDR would like to strongly encourage the District to continue to make this data source available to the F2P2 in 2006. This information was directly responsible for improved Message verification and decision-making in the 2005 F2P2.
4. **STORMTRAK:** HDR requests that a simplified script be developed for production of the StormTrak product. Rob Rahrs is key contact for this product revision.
5. **QPF:** HDR has developed a visual District QPF product for use in 2006 that could easily be incorporated into existing operations in both GIS and Excel spreadsheet formats.
6. **QCP2:** HDR recommends that the GIS-based QCP2 storm prediction tool be implemented for use in 2006 to aid in prediction of Message days.
7. **QRPM:** HDR recommends that an operational test of the QRPM tool be implemented for message day rainfall monitoring during June to August 2006.

7.0 Summary

HDR performed the PMS services for the 2005 F2P2 and produced highly accurate Message day and County Message forecasts. Significant improvements in forecast accuracy were noted despite the below average number of observed Message days. Excellent cooperation between the National Weather Service and HDR was noted on all major 2005 storm event days enhancing user support. All flooding and flash flooding events were predicted and no deaths due to flooding occurred. It was a very good year.

Appendix A

Predicted Message day CoCoRahs observed 24-hr rainfall.

Note: The CoCoRahs cooperative rainfall data is presented to enhance reader evaluation of this report. Errors in the data are possible and likely as observations are taken by volunteer observers. The rainfall data reported in this network is for the 24-hr period ending at 900AM of the report date.

