

**THE 1994 FLASH FLOOD PREDICTION PROGRAM
(F2P2) ANNUAL OPERATIONS REPORT
HMS REPORT No. 95-2**

**to
Urban Drainage and Flood Control District
Denver, Colorado
by
Henz Meteorological Services
2480 W. 26th Ave. Suite 310B
Denver, Colorado
January 1995**

TABLE OF CONTENTS

1.	Introduction.....	Page 1
2.	F2P2 Operational Product Production.....	Page 3
3.	F2P2 Operational Verification	Page 3
3.1.	Message Verification.....	Page 3
3.2.	Quantitative Precipitation Forecasts (QPF)	Page 10
4.	Significant 1994 Storms.....	Page 10
5.	Concerns and Recommendations	Page 14

LIST OF TABLES AND FIGURES

Tables

Table 1:	UDFCD F2P2 District-Wide Message-1 Day Verification	Page 6
Table 2:	Annual Verification Comparison for UDFCD (District)	Page 7
Table 3:	County / City Message-1 Verification.....	Page 7
Table 4:	Red Flagged M-1's (RF).....	Page 7
Table 5:	Verification of 1994 Message-1's by District, County and City	Page 9

Figures

Figure 1:	Urban Drainage and Flood Control District.....	Page 2
Figure 2:	UDFCD Flash Flood Prediction Program Message Criteria.....	Page 4
Figure 3:	August 10, 1994 Thunderstorm QPF Versus Observed Rainfall	Page 11

1. 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 response to the disastrous Big Thompson Flash Flood of July 31, 1976 in Larimer County. The F2P2 contracts the value-added weather forecasts of a Private Meteorological Service (PMS) to augment the traditional forecast services of the National Weather Service (NWS) for the six county District region.

The forecast area supported is shown in Figure 1 and includes over 60 per cent of Colorado's population in roughly a 1600 square mile area. Terrain in the region varies from the rolling populated prairies of Arapahoe and Adams Counties to highly urbanized Denver County to the rugged plains-foothills-mountain interfaces of Jefferson, Boulder and Douglas Counties.

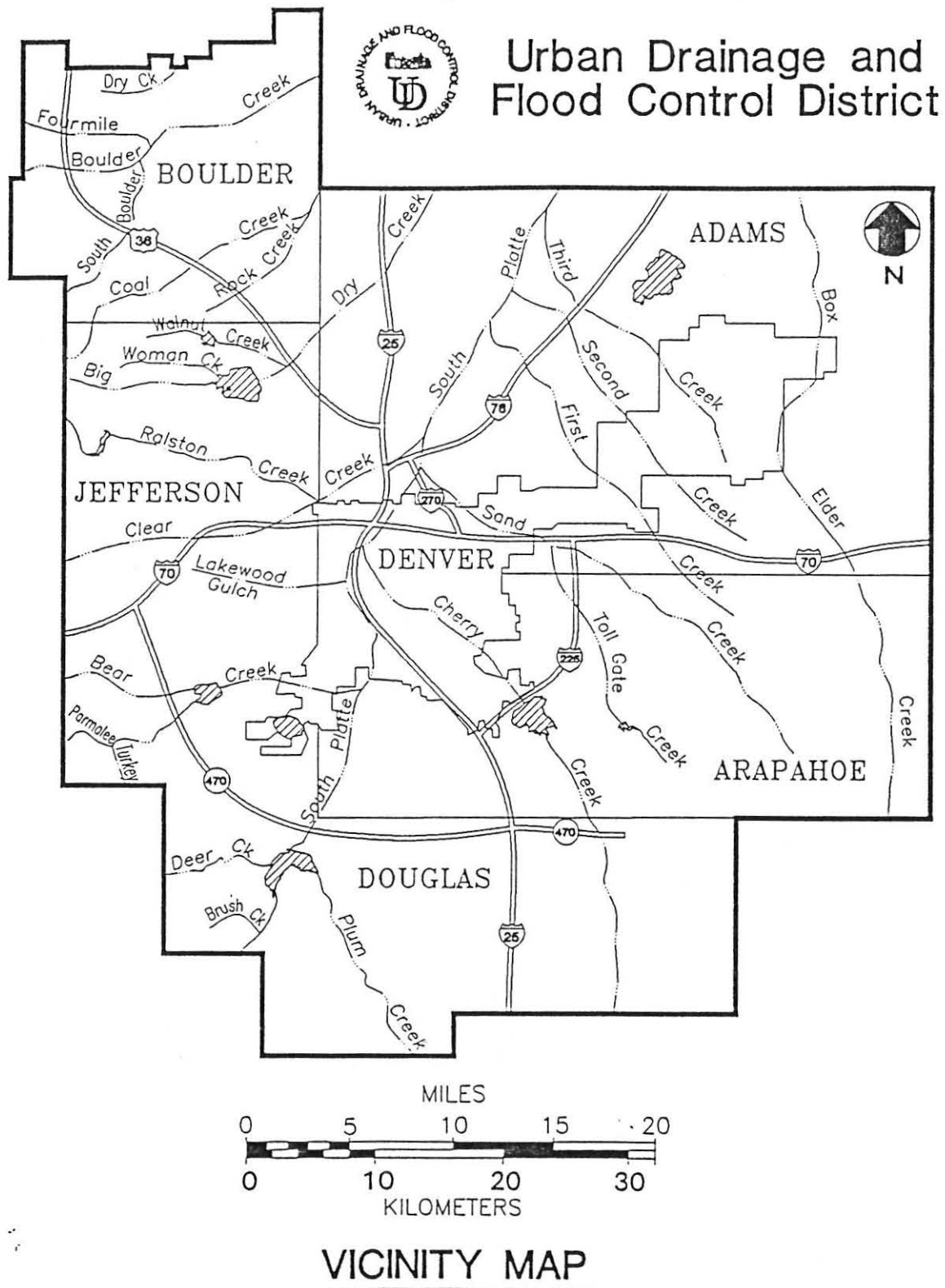
Henz Meteorological Services (HMS) of Denver was selected as the 1994 F2P2 Private Meteorological Service. HMS provided similar services for the 1990 - 1994 F2P2's. HMS forecast services were provided by John Henz, Bryan Rappolt and Frank Robitaille during the 1994 season. Significant communications improvements were made by Robert Hirsekorn the business manager of HMS. One meteorological technician was employed from May 15 to August 1 to assist the HMS meteorologists, Brenda Favario. She had three years experience as weather observer in the U.S. Navy and two years of weather radar observation experience.

The F2P2 season began on 15 April 1994 and continued through 15 September 1994 for **154 operational days**. Normal operational hours were from 0700L to 2200L and covered **2,310 hours**. Overnight and/or early morning operations conducted during the period from 1000PM to 700AM added an **additional 118 hours** of support time for a total of **2,428 hours of F2P2 activity**. The overnight hours were especially active during July August and September. A trend toward more active overnight periods has now been evidenced since 1992.

The F2P2 required a continuous Metwatch of the District for the entire period using radar, satellite, conventional surface and upper air observations and local ALERT and mesonet networks. These observations were used to prepare predictions and specialized F2P2 products. These products included daily Heavy Precipitation Outlooks (HPO), MESSAGE 1, 2, 3 and 4's, update statements, Quantitative Precipitation Forecasts (QPF), Storm-Traks and special requests from District members.

The remainder of the report will outline the operations of the 1994 F2P2, the verification of its predictions on the District-wide, county and city level, identification of significant storm events and concerns which developed during the 1994 season. Finally recommendations for the 1995 F2P2 are offered for consideration.

Figure 1: Urban Drainage and Flood Control District



2. 1994 F2P2 Operational Product Production

The F2P2 is designed to offer a supplementary weather information source concerning heavy precipitation, urban flooding and flash flooding threat to the six participating District Counties and the cities within those counties. Additionally direct basin specific support is rendered to the seven District basin warning plans which exist. Four specific F2P2 products exist in addition to voice support. These products are **Heavy Precipitation Outlooks (HPO), Internal Message Status's (IMS), Quantitative Precipitation Forecasts (QPF) and HMS StormTrack Predictions (FAX Map).**

During the 1994 season HMS delivered **8,008 routine HPO faxes** to the 26 primary HPO reception points. In turn it is estimated that the primary HPO points fax the products to an additional 200 plus locations. Additionally HMS originated **178 Message 1 faxes, 1,352 IMS faxes, 80 QPF faxes and 2,028 StormTrack products** via FAX to participating agencies. The majority of the faxes were sent on either the HMS Communications fax machine or the internal fax card on the HMS F2P2 Communications workstation. Additional use was made of the US West Broadcast Fax service network to send F2P2 graphics products such as Storm Traks.

While fax service dominated the "hard copy" F2P2 products significant electronic copy service was provided to the F2P2 via the District's Electronic Bulletin Board (EBB). All HPO, IMS and QPF products were sent to the District EBB for either re-dissemination or dial-in customer support. HMS sent **386 HPO products, 82 IMS's and 9 QPF** products through the District's EBB. The on-demand access of the EBB products to decision-makers using home computer systems is a desirable asset of the EBB service.

HMS logged over **3,500 storm-related telephone interactions** during the program, emphasizing the strong technical "touch" of the program in the local community. HMS installed three dedicated telephone lines: two for voice and one for fax and data communication in its redesigned weather center. These three lines and US West's Broadcast Fax were adequate to handle the volume of communications generated during peak storm periods. Clearly the F2P2 summer program has a more far reaching extent in the Denver metro area than the numbers alone would indicate.

3. 1994 F2P2 Operational Verification

3.1 Message Verification

The primary service rendered by the F2P2 to participating local governments is the issuance of value-added weather forecasts of urban and stream flooding and locally heavy rainfall. HMS indicates the potential for these events in a series of MESSAGES issued directly to the users by phone, FAX and EBB. The criteria for MESSAGE issuance is shown in Figure 2. These criteria were developed with the District to identify rainfall

Figure 2: UDFCD Flash Flood Prediction Program Message Criteria

UDFCD FLASH FLOOD PREDICTION PROGRAM
MESSAGE CRITERIA

Message 1: Issued primarily to alert local governments to the threat of nuisance street flooding due to thunderstorm rainfall when storm total rainfall is 0.50" - 1.00" in one hour or less. When rainfall is 1.00" to less than 3.00" in one hour or more, urban and rural street and stream flooding becomes a more significant problem. M-1 lead-times of 1 hour or more are desirable.

Rainfall intensity criteria: Any of the intensities below should prompt a Message 1 issuance

1.00"/ 60 minutes

0.75"/ 30 minutes

0.50"/ 10 minutes

Message 1,

RED FLAG: Issued whenever rainfall rates will exceed 1.00"/30 minutes and the storm is considered imminent.

Message 2: Issued to local governments when the threat of potential life threatening urban street and stream flooding is predicted. A M-2 is the equivalent of a Flash Flood Watch.

M-2 Rainfall intensity criteria: 3.00"/hour

Message 3: Issued to local governments whenever a life-threatening flash flood is imminent. M-3's are issued in accordance with basin-specific warning plans if available or at the discretion of the meteorologist.

amounts directly related to the emergency agency response to flooding events. Evaluations of program performance are based on rainfall and event occurrences which verify these criteria. An effort has been made to verify all program forecasts by these criteria and the results are presented in Table 1.

A comparison is presented in Table 1 of all F2P2 seasons since 1979. The table shows the number of days a Message 1 was issued for any of the District 's F2P2 counties (a MESSAGE 1 day) for each season, the number of Message days which recorded a heavy rain event (> 1 "/hour) or flooding event (Hit) and the number which did not record an event in the District (miss). The accuracy indicates the percentage of correct MESSAGE day forecasts while the false alarm rate indicates the percent of days incorrectly identified as a MESSAGE day. The probability of detection indicates the percentage of days which experienced a heavy rainfall or flooding event and had the appropriate Message issued.

Message 1's were issued **on 26 days during the 1994 F2P2** compared to the **16 year average of 34 days**. Twenty four Message 1 day hits were observed providing a **92 percent accuracy** during the 1994 season **compared to 16 year average of 82 percent**. The number of Message 1 hit days (24) was 15 percent below the average of 28 M-1 hit days for the 16 year period. The below average occurrences may be due to the drought weather pattern that has affected the region since 1992. The Summer of 1994 was the second hottest summer on record by the National Weather Service. In general, the District counties received only 60 percent of normal precipitation during the operational F2P2 period.

Customer support levels can best be judged by reviewing the individual Message 1 verification statistics. Table 2 shows a comparison of individual Message 1 statistics for the 1991-1994 F2P2 seasons. The verification of Messages on a county and city basis was begun experimentally in 1987 when the first ALERT Flood Detection Networks were made operationally available to the PMS. Note the steady improvement in the accuracy of County M 1's since 1987 which indicates the steady improvement made by HMS meteorologists.

A four year comparison of the Message verification on **the county and city basis** can be found in Table 3. About two-thirds (**63%**) of the county Messages verified while about only a third (**34%**) of the city MESSAGES hit. Before commenting on these statistics it should be noted that the use of the terms county and city could be misleading. UDFCD includes less than 25 percent of Boulder County, 50 percent of Jefferson County, 40 percent of Adams County, 35 percent of Arapahoe County and 25 percent of Douglas County on an area basis. It does cover all of the City and County of Denver. Therefore, a **County Message can only be verified as a "hit" if it verifies in the District portion of that county, not just anywhere in the county**. City Messages are designed to support the District Flood warning plans associated with Flood Detection Networks in Arvada, Wheat Ridge, Lakewood, Aurora and Denver. The Denver statistics are included in the 1994 county summaries instead of the city summaries.

Table 1: UDFCD F2P2 District-Wide Message-1 Day Verification

UDFCD F2P2 DISTRICT-WIDE MESSAGE 1 DAY VERIFICATION

1979 - 1994

	Year	Message 1 Days	Verified Hits	Verified Misses	Not Forecasted	Percent Accuracy	False Alarm %	Probability of Detection
GRD Weather Center (District Era)	1979	26	17	9	3	65%	35%	85%
	1980	35	23	12	0	66%	34%	100%
	1981	40	31	9	0	78%	23%	100%
	1982	42	34	8	0	81%	19%	100%
Henz, Kelly & Associates (County Era)	1983	37	32	5	0	86%	14%	100%
	1984	38	32	6	0	84%	16%	100%
	1985	28	25	3	0	89%	11%	100%
	1986	35	30	5	1	86%	14%	97%
	1987	47	40	7	0	85%	15%	100%
	1988	28	24	4	0	86%	14%	100%
	1989	31	26	5	0	84%	16%	100%
Henz Meteorological Services (Red Flag Era)	1990	30	26	4	2	87%	13%	93%
	1991	42	31	11	0	74%	26%	100%
	1992	29	25	4	0	86%	14%	100%
	1993	28	25	3	0	89%	11%	100%
	1994	26	24	2	0	92%	8%	100%
	Total District Era	143	105	38	3	73%	27%	97.2%
	Total County Era	244	209	35	1	86%	14%	99.5%
	Total Red Flag Era	155	131	24	2	85%	15%	98.5%
	Total	542	445	97	6	82%	18%	98.7%

Message Day = Issuance of a Mesage 1: Stream or Urban Flooding Forecast anywhere in District usually due to 1"/hour or more

Hit = Verification of Message in issued County

Miss = No verifications

Table 2: Annual Verification Comparison for UDFCD (District)

Year	M-Days	Hits	Misses	Percent Accuracy	Percent False Alarm	Probability of Detection	Total M-1's	Hits	Misses	Percent Accuracy
1987	47	40	7	85%	15%	100%	353	153	200	43%
1991	42	31	11	74%	26%	100%	293	155	138	53%
1992	29	25	4	86%	14%	100%	143	81	62	57%
1993	28	25	3	89%	11%	100%	123	66	57	54%
1994	26	24	2	92%	8%	100%	153	86	67	56%

Table 3: County / City Message-1 Verification

Total County and City				County Verification			City Verification		
Year	Number of M-1's	Hits	Percent Hit	County M-1's	Hits	Percent Hit	City M-1's	Hits	Percent Hit
1991	293	155	53%	185	98	53%	108	57	53%
1992	143	81	57%	109	66	61%	34	15	44%
1993	123	66	54%	100	60	60%	23	6	26%
1994	153	86	56%	112	70	63%	41	16	39%

Table 4: Red Flagged M-1's (RF)

Year	Total M-1's	RF's	RF Hits	Percent RF Hits	Percent RF's	County RF's	County RF Hits	% County RF Hits	City RF's	City RF Hits	% City RF Hits
1991	293	171	156	91%	58%	N/A	N/A	N/A	N/A	N/A	N/A
1992	143	85	81	95%	59%	69	66	96%	16	15	94%
1993	123	12	12	100%	10%	8	8	100%	2	2	100%
1994	178	67	47	70%	38%	38	32	84%	29	15	52%

The steady improvement in County M-1's from **53 percent in 1991 to 63 percent in 1994 is very significant**. Normally forecast improvement is measured in changes of 1 percent a year or less. **The 10 percent improvement in 4 years is remarkable. It may be related to the HMS efforts since 1991 to develop improved short term forecast techniques based on the Mesonet and, more recently, the NEXRAD radar.** These improvements suggest that **the utilization of these techniques gradually improved the level of service offered to our customers.**

In some respects this improvement parallels the improvements in District-wide forecasting of M-1 days experienced in the first 5 years of the program (see Table 1). If the continued level of improvement is noted over the next 3-5 years County level forecasts by the end of the 1990's will be as accurate as District -level forecasts were by the end of the 1980's. Similar progress has not yet been noted in improving the City level M-1 forecasts.

In the past four years the City level M-1 verification has dropped from 53 percent accuracy in 1991 to 26 percent in 1993 and bounced back to 34 percent during 1994. The drop in accuracy was equally evident in both the Jefferson County Flood Detection Networks serving Arvada, Lakewood and Wheat Ridge and the Aurora Flood Detection Networks. An explanation for this drop is not readily apparent. An encouraging note of improvement was apparent this season as experience in using the NEXRAD radar occurred.

From 15 April to 31 July only 10 of 29 (34%) City M-1's verified perhaps due to "forecaster over-stimulation" by the improved NEXRAD doppler radar displays. However, from August 1 to September 15 the City M-1 accuracy improved to 50% as 6 of 12 M-1's verified. Hopefully this encouraging progress will provide a stepping stone to improvement in the years ahead.

While less than 60% of the total Messages verified, their utility to the users was improved by the use of a Message 1- Red Flag issuance. A Message 1 indicates to the user that the potential exists for a flooding event later during the day. A Red Flagged Message 1 indicates that the potential of a flooding event will likely be realized in the next 30-60 minutes. In other words the RED FLAG means action is needed.

Table 4 shows the verification for the Red Flagged Messages. **Only 38 percent of the Message 1's were Red Flagged but 70 percent verified.** This high accuracy rate for the Red Flags indicates why the Message program is such a success with the users. **They can rely on it.** A summary of the individual MESSAGES and Red Flags by day, county and city are presented in Table 5. **County Red Flag M-1's verified 84 percent** of the time while City Red Flag M-1's verified only 52 percent of the time. A change in the Red Flag criteria was begun in 1993. Prior to 1993 a M-1 was Red Flagged only when heavy rainfall was imminent. In 1993 and 1994 the additional Red Flag criteria of rainfall intensity reaching 1.00 inches/30 minutes was added.

Table 5: Verification of 1994 Message-1's by District, County and City

MESSAGE DAYS FOR THE 1994 FLASH FLOOD PREDICTION PROGRAM																
DATE	FORMS ISSUED						MESSAGE VERIFICATION BY DISTRICT, COUNTY, AND CITY									
	HPO	M1	M2	M3	IMS	QPF	DISTRICT	BOCO	ARAPCO	DENCO	DOUGCO	ADCO	JEFFCO	AURORA	WHTRDGE	ARVADA
4/25/94	X	X			X		X						R			R
5/9/94	X	X			X		X	X	X	X	X	X	X	X		
5/25/94	X	X			X		X	X	X	X	R	X	R	X	R	R
5/28/94	X	X			X		X				X	X				
5/31/94	X	X			X		X		X	X	X	X	R	X		
6/1/94	X	X			X		X		R	R	X	X	R	R		
6/2/94	X	X			X		X	R	R	R	R	R	R	R	R	R
6/3/94	X	X			X	X	X	X	R	R	R	R	R	R	R	R
6/18/94	X	X	X		X	X	X	R	X	X	X	X	X	X	R	R
6/20/94	X	X			X	X	X	R	X	X	R	X	X	X		
6/21/94	X	X	X		X	X	X	X	X	X	X	X	X	X	R	R
6/22/94	X	X			X		X	X	X	X	R	X	X	X		
7/15/94	X	X			X		X		X	X	X		X	X		
7/23/94	X	X			X		X			X		X		X		
7/24/94	X	X			X		X	X	X	X		X		X		
7/31/94	X	X			X		X	X								
8/1/94	X	X			X		X				X					
8/2/94	X	X			X		X	X			X	X	X		R	R
8/3/94	X	X			X		X		X		X					
8/8/94	X	X			X		X	X	X	X	X	X		X		
8/10/94	X	X			X	X	X	X	R	R	R	R	R	R	R	R
8/11/94	X	X			X	X	X	R	X	X	X	X	X	X		
8/13/94	X	X	N		X	X	X	N/X	R	R	N/R	X	N/R	R		R
8/31/94	X	X			X	X	X	R	R	R	R	R	R	R		
9/1/94	X	X			X		X				X					
9/2/94	X	X			X		X		X		X		X			
Total Hits							24	8	13	7	20	7	15	6	3	3
Total Messages	26	26	3	0	26	8	26	16	19	18	22	19	18	18	7	8
Percentage of Total Hits to Total Messages							92%	50%	68%	39%	91%	37%	83%	33%	43%	38%

X=HMS ISSUED

R=RED FLAG

N=NWS ISSUED

 =HIT

Flash Flood Watches(MESSAGE 2's) and Flash Flood Warnings (MESSAGE 3's) issued by the National Weather Service were also included in Table 5 and were included in the HMS 1994 statistical verification. All three Message 2's verified. Please note that the coordination and cooperation between the NWS and HMS within the F2P2 has re-attained the levels of interaction achieved before 1983, while becoming mutually beneficial and productive.

3.2 Quantitative Precipitation Forecasts (QPF)

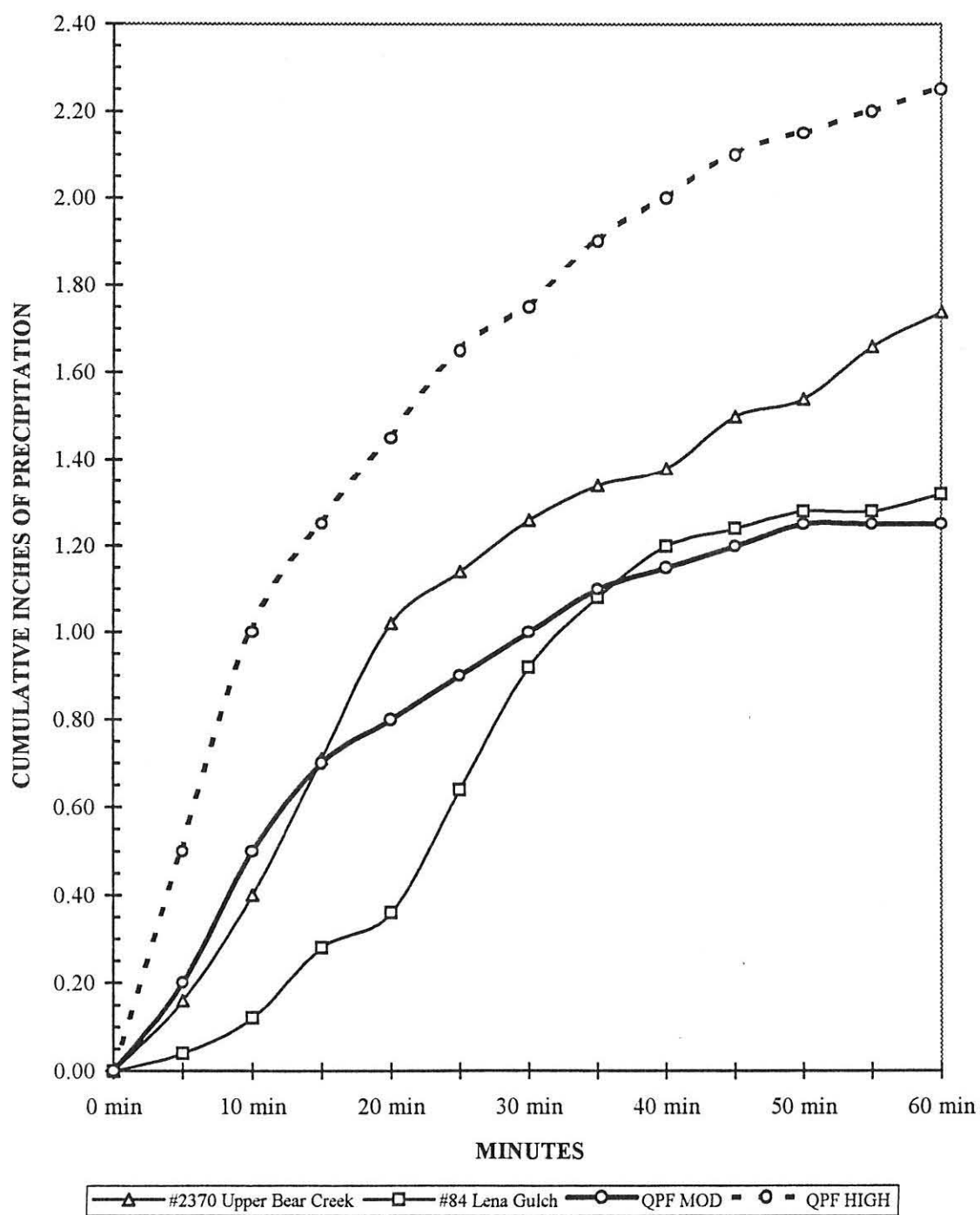
An important operational product in the F2P2 has been quantitative precipitation forecast (QPF) products. QPF products were issued in two forms: the general county QPF issued in the daily HPO and the basin-specific QPF issued whenever rainfall is expected to equal; or exceed 1.50 inches in one hour or less. **The general form of QPF is offered for each county daily in the HPO's in the form of a peak 30 minute rainfall rate and a probability of occurrence within a prime time period.** During the 1994 F2P2, daily HPO QPF's were issued while basin-specific QPF's were issued on only 8 days. An example of the verification of the QPF's is presented in Figure 3 for August 10, 1994. On this day heavy rainfall inundated the entire District between 8:00PM and 10:00PM as thunderstorms explosively developed along the Jefferson County foothills and pushed across the remainder of the District.

HMS began the QPF verification and forecast effort in a detailed manner during the 1988 F2P2. As the number of ALERT FDN's increased from one to seven, the ability to verify QPF's has understandably improved. Prior to 1990 the spotty distribution of FDN's limited QPF verification. HMS is in the process of completing a detailed verification of the QPF's since 1990 and will publish its results in 1995.

4. Significant 1994 Storms

The 1994 thunderstorm season ran "hot and cold" with long stretches of feast and famine storm development. Storm activity started abruptly during the morning rush hour on April 24, 1994 to kick off the Message 1 season. Arvada was soaked with 1.00 to 2.50 inches of rain and 6-12 inches of small hail between 8:00AM and 9:30AM. Heavy May thunderstorm rainfall was measured on only 4 days in May or about half of the normal. June storms struck early and hard on the first three days of the month but returned for an encore on only four other days for a total of only 7 days which was again half of the normal. A long hot dry spell brought record heat and reduced storm threats to the District from June 22 to July 31 with only two M-1 days observed during the period. Normally July is the greatest flash flooding month of the F2P2 season. This year's storms fizzled in the July sizzle. August was about average with 8 Message 1 days. Seven of the 8 occurred during the first 15 days of the month. Heavy storms hit on September 1 and 2 but another drought-like stretch for the rest of September ended the Message season.

Figure 3: August 10, 1994 Thunderstorm QPF Versus Observed Rainfall



The most significant storm days of the season are summarized below:

- April 24** A line of intense thunderstorms formed in the mountains west of the District at dawn. By 800AM locally heavy rainfall of 1.00 - 2.50 inches fell in 60-90 minutes accompanied by 6-12 inches of small hail. This storm was dubbed the "snowcone storm" because of accumulations of hail that piled high in ALERT FDN gauges.
- June 1, 2 and 3** A three day barrage of storms brought local cloudbursts with small hail to the entire District. The storms were especially heavy on June 1 when 30 minute rainfall rates exceeded 2.00 inches/hour on the south side during the evening hours of 7:00PM to 10:00PM.
- June 18:** NWS issues a Flash Flood watch with HMS concurrence. Waves of heavy thunderstorms form on Palmer Divide and move northwestward across the District into the Boulder and Jefferson County foothills. Street and small stream flooding was noted in all counties.
- August 10:** Violent nocturnal thunderstorms erupted over western Jefferson County inundating a ZZ Top concert at Red Rocks and the Rockies as they beat the Atlanta Braves for the first time. Rainfall was heaviest between 8:30PM and 10:30PM. Intense lightning accompanied the core of the storm. Rainfall reached 1.50 inches/30 minutes and 2.50 inches per hour. Severe flooding occurred in Larimer County to the north.
- September 2** Rapidly forming thunderstorms formed along a convergence line in southern Jefferson and Arapahoe Counties. The storms dropped very heavy rainfall estimated by radar to reach 2.00 inches in less than an hour near Chatfield Reservoir, Sedalia and Highlands Ranch. This storm line flooded the Colorado Springs metro area with 5-8 inches of rain and a foot of small hail between 9:00PM and 10:30PM.

In general the F2P2 season was uneventful with no major flash flooding events occurring. **Most of the storms were quick-hitting "front-end dumpers" of less than 30 minutes duration and less than 1.00 inches of rainfall.** The notable exceptions were the storms which occurred on April 24th, June 1, August 10th and September 2nd. The April 24th storm was small in coverage as it affected parts of Lakewood, Wheat Ridge and Arvada. It reached its peak intensity while "snow-coning" Arvada with up to 2.00+ inches of rain in 90 minutes with 6-12 inches of small hail. This storm was very hard to forecast and Message 1's and Red Flags were issued as the storm occurred with less than 15 minutes lead-time. The storm's intensity for a morning rush hour on a chilly day was exceptional and rivals the April 25, 1990 storm for early season intensity.

The early June storms were very strong on the evening of June 1, 1994 with several portions of southern Jefferson, western Arapahoe and northern Douglas Counties measuring rainfalls in excess of 2.00 inches in 30 minutes or less by cooperative observers. It was very fortunate that these storms were not able to produce a "train-echo" rainfall pattern or the District may have recorded a major urban flooding event of 4.50 to 7.00 inches of storm total rainfall in less than 3 hours. The District dodged equally potent weather bullets on August 10th and September 2nd.

On the evening of August 10th the atmosphere had been identified as "an all or nothing" night. Unstable but "dry air with dew points of less than 50F" dominated the District through 7:30PM. About that time a surge of moist, thunderstorm outflow air from storms over 50 miles east of the District arrived with dew points near 60F and easterly breezes of 15 to 25 mph. As this air mixed into the unstable Denver metro air, severe thunderstorms explosively developed in the Jefferson County foothills near Red Rocks. ZZ Top was performing a concert at Red Rocks park while the Colorado Rockies were playing the Atlanta Braves at Mile High Stadium. Both sites were directly hit with torrential rainfall and nearly continuous lightning from the storms. The potential for loss of life to either the concert or the baseball fans was significant but the relatively short duration of the storms' reduced the threat. Sixty miles to the north Fort Collins was not as lucky as heavy rainfall exceeding six inches flooded streets and plains streams in eastern Larimer County.

The final significant storm event "missed" the District the night of September 2nd. A line of vigorous storms formed across southern Jefferson and western Arapahoe Counties before moving south. The storms produced several radar rainfall estimates exceeding 2.00 inches in northern Douglas County. Once the storms reached Colorado Springs they produced 6-8 inches of rainfall accompanied by 12 inches of hail in less than 90 minutes. The rain/hail combination closed roads, flooded streets and small streams and produced minor injuries. This same storm potential could have been released over the District had the cloud steering winds been southerly instead of northerly. Once again Denver was lucky and spared a major event.

It is abundantly clear that northeastern Colorado and the District are now three years into the Drought of the 90's. It is very likely that another 1-3 years of reduced storm threat will be experienced before storms return to more normal frequency of occurrence. Keep in mind though that reduced frequency of storms does not mean reduced threat of a major flash flood.

Evidence suggests that many of the major foothills floods have occurred during periods of plains drought. The Big Thompson Flash Flood of 1976 occurred during the fourth year of the Drought of the 70's as did the significant foothills general rains of 5 to 8 inches during the Spring of 1973. Bear Creek experienced deadly flash floods in July 1933, August 1934, September 1938 and August 1957 during periods of drought in the 1930's and 1950's. The occurrence of so many significant foothills floods during drought periods should be a reminder to us not to let our guard down.

5. Concerns and Recommendations

HMS utilizes this portion of the report to identify important operational developments , operational problem areas and matters of concern which became apparent during the operational season. HMS will present pertinent comments in each of these categories.

Doppler radar

The most significant operational development was the commissioning and availability of the new National Weather Service WSR-88D (NEXRAD doppler) radar for the 1994 F2P2 season. The WSR-88D's close proximity to the District provides excellent radar coverage of the entire District and the mountains to the west. HMS is certain this enhanced radar coverage of the foothills areas will save lives when it is put to the test. **The new WSR-88D significantly enhanced the ability of HMS meteorologists to evaluate not only heavy rain producing thunderstorm's radar structure but also the structure of the pre-storm boundary layer moisture and wind profiles.** It is very likely that early season false alarm rates were so high on City level Messages because of **forecaster over-stimulation** with the new doppler data. As HMS experience increases in using this new data accuracy should improve in all F2P2 products. **In two years we predict that the new radar will make the most significant contribution to the program's success since the development of the Quantitative Convective Precipitation Forecast technique.**

Mesonet

HMS relies very heavily on the existing ERL Mesonet and the limited District Weather Detection Network (WDN) for its ability to provide basin specific flash flood prediction. During 1993 HMS developed three new short range forecast techniques based on the Mesonet. The **Quantitative Convective Precipitation Potential (QCP2)** links surface observations of temperature, dew point and winds to the HMS Convective Storm Model to produce basin-specific QPF's. The **Denver Cyclone model** makes use of the observed occurrence of severe weather and heavy rainfall in the different quadrants of the Denver Cyclone to assist in issuing Message 1's and assigning probabilities to the QPF products. Finally the **Me(so)und** technique allows an estimation of the changes in the vertical profile of temperature and moisture in the atmosphere from the surface to about 15,000 feet to assist in thunderstorm and QPF prediction. This technique makes use of elevation differences in Mesonet sites to construct a sounding of the atmosphere. All three techniques have been reported in professional papers and operationally tested. **Loss of the Mesonet would significantly degrade the short term, basin-specific forecasting capability of the F2P2.** Concerns exist that the current level of federal support of the Mesonet could evaporate in the near future which would have an immediate impact on F2P2 operational capabilities.

Training

HMS noted a continuing need for training of both dispatchers and other emergency response personnel in the understanding and utilization of F2P2 products within Flood Warning Plans and in emergency situations. These factors have become apparent when working with dispatchers and other emergency response personnel on Message days since 1990. HMS suggests that the District consider the development of a year-round F2P2 which focuses on user understanding of F2P2 products and their utility in flood warning programs continued to be a concern.

The year round F2P2 would be consist of three segments:

1. a three month pre-F2P2 operations period from January to mid-April which focused on direct PMS contact and training of County and FDN dispatchers in the use of PMS forecast products and exercising existing flood warning plans.
2. A six month F2P2 operations season from April to September, and,
3. a three month post-F2P2 evaluation and verification period when F2P2 products would be evaluated, F2P2 participants would be screened on prior season service and recommendations

Recommendations

HMS offers the following recommendations for consideration of the District:

1. **HMS recommends that the District consider funding a year-round F2P2 which adds training and evaluation components. HMS will submit a proposal for such a program to the District by May 1995 with a proposed budget for consideration of possible 1996 F2P2 implementation.**
2. **HMS recommends that the UDFCD consider future funding of the unsolicited Mesonet evaluation and design proposal submitted by HMS to insure an operational Mesonet presence for the F2P2.**
3. **HMS recommends that the HMS cellular phone be used in the 1995 F2P2 program with F2P2 phone fees reimbursable to HMS. Cellular phone rates have plunged in recent years to make commercial rates comparable to local government rates. Today's cellular phones are very lightweight and new battery technology has increased the use time of the phone. In essence the existing transportable phone has passed into F2P2 obsolescence.**