

**1997**

**UDCFD FLASH FLOOD PREDICTION  
PROGRAM ANNUAL REPORT**

**Henz Meteorological Services  
2480 W. 26<sup>th</sup> Avenue, Suite 310B  
Denver, Colorado 80211**

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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 response to the disastrous Big Thompson Flash Flood of July 31, 1976 in Larimer County. The F2P2 contracts the unique with basin-/storm-specific 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 percent of Colorado's population in a roughly 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. The population in this area has increased 11.8 percent in the period of 1990 to 1996 and prediction service requests have increased noticeably in the past two years in Boulder, Douglas and Arapahoe Counties.

**Henz Meteorological Services (HMS)** of Denver was selected as the 1997 F2P2 Private Meteorological Service. HMS provided similar services for the 1990 - 1997 F2P2's. HMS forecast services were provided by **John Henz, Bryan Rappolt, Frank Robitaille, Lisa Morrison and William Badini**. Mr. Badini has a B.S. in Meteorology from the University of Wisconsin and is currently seeking a Masters of Science in Atmospheric Science.

### 0 1997 Operational Season

The F2P2 season began on 15 April 1997 and continued through 15 September 1997 for **154 operational days**. Normal operational hours were from 0700L to 2200L and covered **2,322 hours**. During the period from 1000PM to 1200AM HMS meteorologists added an **additional 121 hours** of support time as storms in eastern Adams, eastern Arapahoe and northern Douglas Counties persisted in newly populated areas near Denver International Airport, Parker and eastern Aurora. Overnight forecasting from midnight to 700 AM added an **additional 113 hours** for a total of **2,556 hours of F2P2 activity**. If increasing population trends continue, a sizeable population is building east into areas notorious for nocturnal storm activity.

The F2P2 required a continuous **Metwatch** of the District for the entire period using the NWS WSR-88D Doppler radar, satellite, conventional surface and upper air observations and local ALERT and mesonet networks. These observations were used by HMS meteorologists to prepare in-house analyses, predictions and specialized F2P2 products. These products included daily **Heavy Precipitation Outlooks (HPO), MESSAGE 1, 2, 3 and 4's, Message updates, Quantitative Precipitation Forecasts (QPF) and Storm Traks**. The HPO's were issued at least once daily to describe the potential for heavy precipitation in each of the District counties. Messages were issued on those days when the potential of heavy rainfall capable of producing some form of flooding in the District or a portion of the District was deemed possible. QPF's and Storm Traks were issued on Message days to provide additional weather support to the F2P2 user community.

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT  
FLASH FLOOD PREDICTION PROGRAM (F2P2)  
BACKGROUND INFORMATION HANDOUT

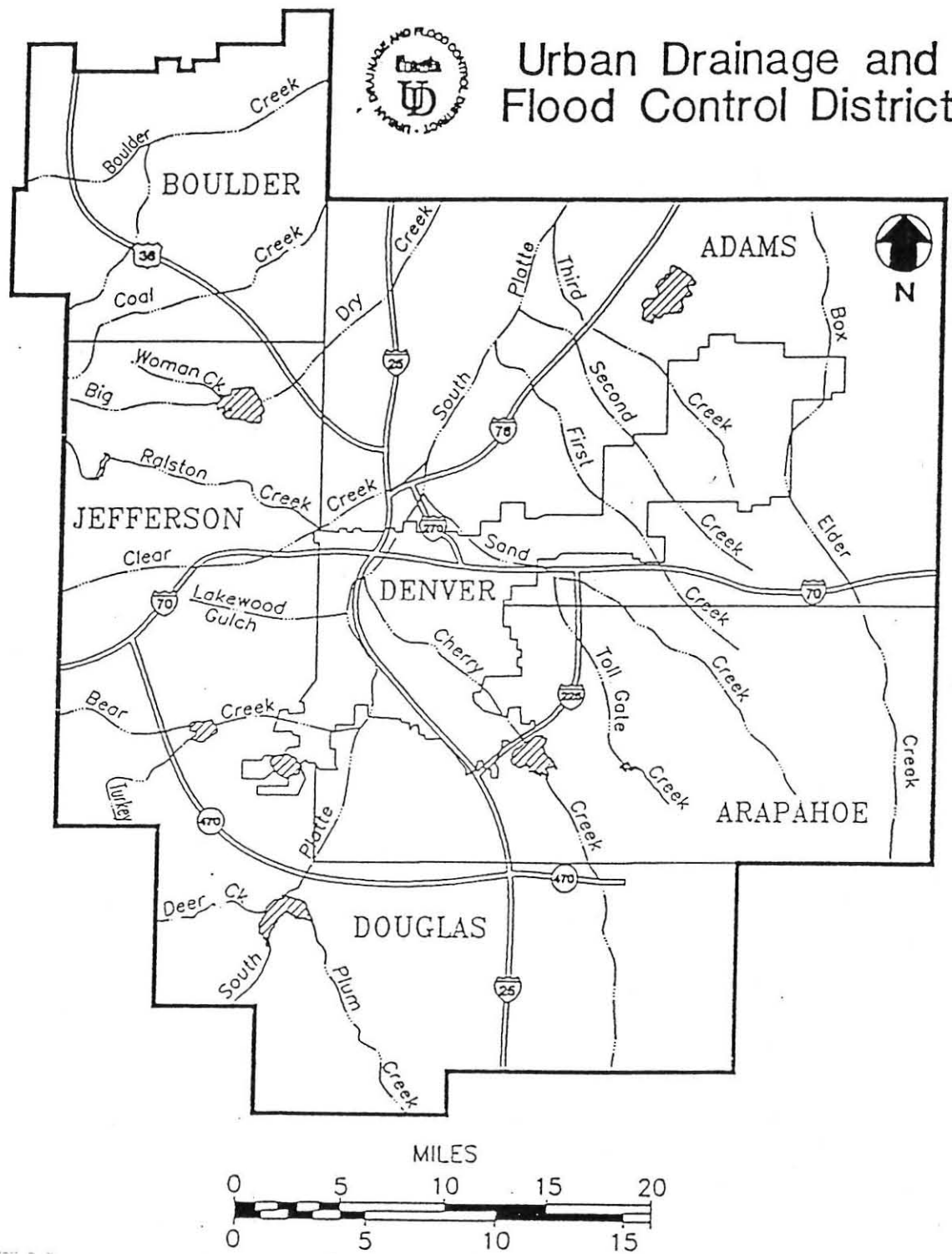


Figure 1 Flash Flood Prediction Program Area of Concern and District

### 3.0 1997 F2P2 Operational Product Production

The F2P2 is designed to offer a unique, basin-specific weather information source concerning heavy precipitation, urban flooding and flash flooding threats to the six participating District Counties and the cities within those counties. Direct basin specific support is rendered to the District basin-specific warning plans identified below:

1. **Boulder Creek Warning Plan** which serves Boulder/South Boulder Creeks in Boulder County which impacts the City of Boulder.
2. **Lena Gulch Warning Plan** which serves the Lena Gulch Basin and impacts Jefferson County, Golden, Lakewood and Wheat Ridge.
3. **Goldsmith/Harvard Gulch Warning Plan** which impacts south central Denver.
4. **Westerly Creek Warning Plan** which impacts eastern Denver and western Aurora.
5. **Toll Gate Creeks Warning Plan**, which impacts central and southern Aurora.
6. **Ralston Creek Warning Plan** which impacts central Arvada.
7. **Bear Creek Warning Plan**, which impacts Jefferson County and southern Lakewood.

Five specific F2P2 products exist as expert-to-user support. These products are **Heavy Precipitation Outlooks (HPO)**, **Messages, Internal Message Status's (IMS)**, **Quantitative Precipitation Forecasts (QPF)** and **HMS Storm Trak Predictions (FAX Map)**. During the 1997 season HMS delivered the following quantities of the identified F2P2 Fax Products:

**Table 1 1997 F2P2 Production Summary**

Product	Number issued
Heavy Precipitation Outlook (HPO)	7,607
Message Forms, Updates and Faxes	1,061
Internal Message Status (IMS)	1,938
Basin-Specific Quantitative Precipitation Forecasts (QPF)	270
StormTraks	3,652
Total	14,528

These products were delivered via fax to participating agencies. The majority of the faxes were sent on either the HMS Communications fax machine, the internal fax card on the HMS F2P2 Communications workstation or on the US West Broadcast Fax service network. Broadcast fax was used to send high impact products with a short "shelf life" such as Storm Traks and IMS's.

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 an estimated **256 HPO products, 152 IMS and 30 QPF** products through the District's EBB. The on-demand access of the EBB products to decision-makers using office and home computer systems is a desirable asset of the EBB service. HMS logged over **2,400 storm-related**

**telephone interactions** during the program, emphasizing the **strong technical "touch"** of the program in the local community. HMS used three dedicated telephone lines: two for voice and one for fax products. These three lines were adequate to handle the volume of communications generated during peak storm periods. User input indicates that the quality of the faxed Storm Traks has improved sufficiently to supplant event verbal "hand-holding" to some degree.

#### 4.0 1997 F2P2 Operational Verification

The **primary service rendered by the F2P2** to participating local governments and associated emergency response agencies **is the issuance of value-added weather forecasts of flash flooding potential, 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 definition of each Message is given below in **Table 2**.

**Table 2 Message Definitions used in the District Flash Flood Prediction Program (F2P2)**

##### **MESSAGE 1 ( Internal Alert )**

A Message 1 is an advisory message meant to inform key people in local emergency response community that weather conditions are such that flood producing storms could develop later in the day. It is issued after forecast discussions between HMS and National Weather Service ( NWS ). The advisory is preceded by the statement, " THIS IS A RED FLAG MESSAGE", when HMS deems priority handling by communications dispatchers is required.

##### **MESSAGE 2 ( Flash Flood Watch )**

This Message indicates that a Flash Flood Watch has been issued by the NWS and/or HMS feels that the risk is high that a life-threatening flood may occur later in the day. This Message requires priority handling by communications dispatchers.

##### **MESSAGE 3 ( Flash Flood Warning )**

This Message indicates that a Flash Flood Warning has been issued by the NWS and/or HMS feels that the risk is high that a life-threatening flood is imminent. This Message requires priority handling by communications dispatchers.

##### **MESSAGE UPDATE**

This Message is used by HMS to provide additional information to any of the above Messages on the developing weather situation. For example, this Message has been used to narrow a NWS Watch or Warning area, as more information becomes available or to provide more site-specific information during an event. If HMS feels that this Message requires priority handling by a communications dispatcher, it is preceded by the statement, " THIS IS A RED FLAG MESSAGE ".

##### **MESSAGE 4 ( All Clear )**

This Message cancels the flood potential status. HMS issues it after consultation with NWS and other entities involved with direct HMS communications.



The issuance of F2P2 Messages is quantitatively linked to both the rainfall potential of the weather events and the response of the District basins to the rainfall. **Table 3** shows the criteria for Message issuance based on both the rainfall potential and the anticipated response of the District basin.

**Table 3: UDFCD Flash Flood Prediction Program Message Criteria**

UDFCD FLASH FLOOD PREDICTION PROGRAM MESSAGE CRITERIA	
<b>Message 1:</b>	Issued primarily to alert local governments to the threat of nuisance flooding of streets and low lying areas due to thunderstorm rainfall when storm total rainfall is 0.50" - 1.00" in one hour or less. When rainfall is 1.00" to < 3.00" in one to three hours, urban street and stream flooding becomes a significant problem. M-1 lead-times of >1 hour are desirable.
<b>Message 1 Rainfall Intensity Criteria:</b>	<b>Any of the forecast rainfall intensities below prompt a Message 1 issuance</b>
	<b>1.00"/ 60 minutes</b>
	<b>0.75"/ 30 minutes</b>
	<b>0.50"/ 10 minutes</b>
<b>Message 1: RED FLAG RED FLAG Rainfall intensity:</b>	Issued to identify storm events which fall just short of producing life-threatening rainfall but produce a significant impact on street runoff. Rainfall rates are predicted or observed to <b>exceed 1.00"/30 minutes</b> <b>and</b> the storm is considered <b>imminent</b> .
<b>Message 2:</b>	Issued to local governments when the threat of potential life threatening flooding is predicted or the NWS issues a Flash Flood Watch. A HMS-generated M-2 is the equivalent of a Flash Flood Watch. M-2 lead-times of several hours are desirable.
<b>M-2 Rainfall intensity criteria:</b>	<b>&gt;3.00"/hour or a lower value based on mutual discussion between NWS, District and HMS due to antecedent rainfall impacts on soil saturation and/or runoff characteristics.</b>
<b>Message 3:</b>	Issued to local governments whenever a life-threatening flash flood is imminent or the NWS issues a Flash Flood Warning. M-3's are issued in accordance with basin-specific warning plans if available or at the discretion of the meteorologist.

## 4.1 Message Verification

Evaluations of program performance are based on the correct prediction of the rainfall and event occurrences, which verify the criteria presented in Figure 3. An effort has been made to verify all program forecasts by these criteria. **Table 1** presents a monthly verification of all Messages issued in the 1997 F2P2. Three forms of Message verifications are presented. A **Message 1 (M-1) Day** is any day a Message 1 was issued within the District. A **M-1 Day hit** refers to a day when a M-1 verifying event occurred which equaled or exceeded the rainfall criteria in **Table 3** within the County or City for which the Message was issued. Message 1's are issued to both County and City dispatch offices. The **M-1's** column refers to the total number of monthly M-1's which were issued on the M-1 days. The **M-1 hit** column refers to the number of issued M-1's which were verified by the occurrence of a heavy rainfall/flooding event, which met the M-1 criteria in **Table 3**. The **M-1 Red Flags (RF)** refers to the number of M-1's which were "Red Flagged" by HMS meteorologists as meeting the Red Flag rainfall and timing criteria listed in **Figure 3**. **M-1 RF hits** refers to the number of M-1 Red Flags, which were verified by heavy rainfall occurrence. The columns referring to Message 2 verification can be interpreted similarly.

**Table 4: Monthly Message Verification for the 1997 F2P2 Operational Season**

Month	M-1 Days	M-1 Day Hits	M-1's	M-1 Hits	% M-1 Hits	M-1 Red Flags	M-1 RF Hits	% RF Hits	M-2 Days	M-2 Day Hits	M-2's	M-2 Hits	% M-2 Hits
April	0	0	0	0	0	0	0	0	0	0	0	0	0
May	3	2	18	7	39	0	0	0	0	0	0	0	0
June	11	11	70	57	77	10	10	100	3	3	21	11	52
July	9	8	59	45	73	39	39	100	5	5	31	17	55
August	12	12	75	53	71	43	42	98	3	3	24	16	67
September	5	5	27	19	70	4	4	100	0	0	0	0	0
<b>Totals</b>	<b>40</b>	<b>38</b>	<b>249</b>	<b>181</b>	<b>73</b>	<b>96</b>	<b>95</b>	<b>99</b>	<b>11</b>	<b>11</b>	<b>76</b>	<b>44</b>	<b>58</b>

Message 1's were issued on a total of 40 days or 14 percent over the 19-year average of 35 M-1 days. The 38 observed M-1 days was 31 percent over the 19-year average of 29 observed M-1 days and underscored the ending of the Drought of the 1990's. In addition to the 40 M1 days, 11 Message 2 (M-2) days occurred in 1997. NWS issued all 11 of the 1997 Message 2's with HMS concurrence. Message 1's were issued preceding Message 2's on 3 of the 11 M-2 days. The total of **46 days with verifying Message 1 or 2's broke the old record of 40 verified Message days set in 1987**. A listing of the annual comparison of M1 day events since 1979 can be found in **Tables A-1 and A-2 in Appendix A**.



In 1997 73 percent of the M1's verified which was 16 percent better than the average and marked the second year in a row of significant verification improvement. The 181 verified M1 events were the highest number of M1's recorded during the past seven operational years. A M1 Red Flag was issued 96 times and verified 95 times for a 99 percent verification rate. The improvement in Red Flag ( RF ) verification marks the second straight year of 98 percent verification or better. In 1994 and 1995 RF verification rates were about 70 percent after three consecutive years of 90 percent or better verification. Concern existed that RF issuance was over-stimulated by the new NWS|WSR-88D Doppler radar usage and that customer RF expectations were not being met. HMS suggests that the two years of high verification indicate this concern has been addressed and corrected.

Another notable achievement in 1997 was **improved** National Weather Service Flash Flood Watches or **Message 2 verification** in the F2P2. Eleven Message 2's or flash flood watches were issued in 1997 and flash flooding events were reported on each of the days. **HMS and NWS concurred on all 11 Message 2's.** A total of 44 of 78 county/city combined M-2's verified by NWS criteria for an **accuracy of 58%**. This county/city M2 accuracy level for combined concurrence/non-concurrence days is the **highest** since records have been maintained (1990 ) by almost 20 percent. Unfortunately, the prior accuracy level of county/city M2's on concurrence days only has been 82 percent for the past five years. Viewed in this perspective the accuracy of county/city M2's issued on concurrence days **decreased 24 percent** below the recent average.

The primary reason for the lower M2 concurrence day verification rate this year was the lack of mesonet data available to HMS meteorologists to assist in refining the M2 product to the county/city level. This factor contributed to the lack of a flash flood watch issuance on July 19, 1997. On this date a very intense thunderstorm complex formed over and along I-70 from north Aurora across the NWS office at Stapleton to Commerce City. The NWS office was plummeted by a record 3.83" of rain in one hour and 1.50" diameter hail. Three M3 flash flood warnings were issued. HMS issued a Message 1 with 90 minutes of lead-time but was unable to identify the need for a M2. The Diamond Hill weather station dew point fluctuated between 45F ( 0.50"/30 min) and 57F ( 2.35"/30 min) from 100PM to 300PM as a tongue of moist air tried to establish itself from the north. The only other available weather observation site was at DIA. The DIA weather station reports hourly and was insufficient to refine the timing and aerial extent of the moist air.

Message 3's (**Flash Flood Warning or Flood Warning**) were issued by the National Weather Service for **16 storm events and 13 M3's verified for an 81 percent accuracy.** While the number of yearly M3's issued has not been maintained, it is believed from a review of the F2P2 logs from 1979 to present that the number of M3's issued and verified in 1997 set a F2P2 record. HMS concurred with all but one of the M3's issued. Close coordination between NWS and HMS meteorologists on storm days kept both organizations "on the same page" to the public's benefit. While day-to-day coordination between HMS and NWS is minimal, very close coordination on flash flood watch days was maintained. No flash floods occurred during the 1997 F2P2 without a timely M3 issuance.

The coordination was very timely on July 19, 1997, when the NWS office was hit by record rainfall; on July 28, 1997, the day of the Fort Collins Flash Flood; and on August 11, 1997 when downtown Denver was socked with hail, heavy rain and flash flooding. Given the intense and

frequent nature of the 1997 F2P2 season storms, anything less than close cooperation between HMS and NWS could have affected the performance of each agency. Instead, both groups benefited from each other's insight and expertise and provided outstanding support to the local populace during trying times.

## 4.2 County and City Message Verification and Service Evaluation

Each of the messages issued in the F2P2 is released to a specific county or city dispatcher in which the flooding potential has been forecast. A County or City M-1 is verified as a **"hit"** only if a rain/flooding event meeting the M-1 criteria in Figure 3 occurs in the **District portion** of that county or city. Messages are designed to support both the unique District flood warning plans associated with Flood Detection Networks ( FDN ) and other portions of the counties and cities in the District which do not have a FDN. Verification of each Message 1 by county and city provides a means of assessing the accuracy of the support given to these areas.

Continued **significant improvement** was noted in the accuracy of the County and City level Message 1's issued during 1997 as seen in **Table 5**. Over two-thirds (**72%**) of the **County Messages verified** while **77 percent** of the **City Messages verified** despite the relatively small size of the verification areas. This improvement is especially notable when one considers that little improvement was noted in verification for the past five years. A five-year comparison of the Message verification on **the county and city basis** can be found in **Table B-3** that includes the 1997 season statistics. Additionally, City level M1 verification remained at or above 75 % for the second year in a row, which is very notable. City verification for the 5 years from 1991 to 1995 was about 40% compared to the 77% average for 1996 and 1997. This **improvement in the City M-1's is especially impressive given the loss of the PROFS mesonet** and will be discussed later in this section. Specific daily Message 1 verification for each of the counties and cities during the 1997 F2P2 can be found in Appendix B, **Table A-1**.

**Table 5: County and City M1 Verification for the 1997 F2P2 Operational Season**

Month	M-1 Days	M-1 Day Hits	M-1	M-1 Hits	Cnty M-1's	Cnty Hits	Cnty % Hits	Cty M-1's	Cty Hits	Cty % Hits	Events Missed	Event< 10min Lead
April	0	0	0	0	0	0	0	0	0	0	0	0
May	3	2	18	7	15	6	40	3	1	33	1	1
June	11	11	70	57	52	40	59	18	17	94	0	1
July	9	8	59	45	47	35	70	12	10	83	0	1
August	12	12	75	53	60	42	70	15	11	73	0	2
September	5	5	27	19	23	18	78	4	1	25	0	0
Totals	40	38	249	181	197	141	72	52	40	77	1	5

Note: Table 2 does not include the 11 M-2 day statistics

The overall 1997 improvement was also evident in **Message 1-Red Flag** issuance as evidenced in **Table 6**. 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 a **flooding event is imminent**. In other words the RED FLAG means rapid information dissemination and response action is needed. **Ninety-nine percent of the 1997 Message 1's Red Flagged verified compared to 98 percent in 1996**. The Red Flag verification rebound to pre-1994 levels for two straight years indicates that **users can rely on it**.

**Table 6: Verification for 1997 Red Flagged Message 1's**

Group	M-1's	M-1 Hits	% M-1 Hits	Red Flags	RF Hits	% RF Hits	% RF M-1's
			County				
ARAP	35	27	75	12	12	100	30
ADM	34	25	74	13	13	100	33
DUG	32	20	75	9	9	100	28
BOU	30	20	67	7	6	86	23
JEF	32	25	81	15	15	100	47
DEN	34	24	71	19	18	95	56
TOTAL	197	141	72	65	65	100	33
			FDN	PLANS			
AUR	31	20	65	11	11	100	37
LAK	8	8	100	10	10	100	125
WHT	7	7	100	8	8	100	114
ARV	6	5	83	6	6	100	86
TOTAL	52	40	77	31	30	97	

In most cases lead-times of over 60 minutes were obtained. However, close calls were noted in the final column of **Table 6** which identifies the number of Message 1's issued with less than 10 minutes lead-time from the time of Message issuance to the time of storm formation. Five 1997 storm situations occurred with less than 10 minutes lead-time: May 29, June 18, July 19, August 3 and August 11. In each case the meteorologist noted in the log that lack of mesonet data to define the convective storm inversion or "cap" or the quality of the moist unstable air available to fuel storm development. The loss of the mesonet was directly responsible for the lack of a 30-minute lead-time for all events. The lack of mesonet data was especially troublesome on July 19 when a very severe rainstorm hit the north central portion of Denver, Aurora and Adams County and on August 11 when a severe rain and hail storm hit downtown Denver causing serious street flooding.

Another operational failing attributed to the loss of the mesonet was the occurrence of a minor Message 1 level rainfall in eastern Jefferson and Boulder Counties on May 24 without the issuance of a Message 1. The HPO for the day was updated three times and predicted a moderate probability of Message level rainfall. The duty forecaster chose not to issue a Message. The decision was based on lack of mesonet data, radar data ( NWS WSR-88D at Watkins was down for maintenance) and the lack of other than visual cues that heavy rainfall was possible. Short duration moderate rainfall of 0.24" - 0.39"/5-10 minutes was observed at the Morrison and Boulder Justice Center ALERT sites. Both culprit storms dissipated before M1's could be issued. No other Message level events occurred during the 1997 F2P2 without Message issuance though a few close calls were noted early in the season.

Several reasons for the 1997 F2P2 improvements should be noted. The NWS WSR-88D Doppler radar has provided verification of small-scale heavy rain events, which previously went undetected with the old Limon NWS WSR-57c, radar. The radar has also provided information on low level and vertical wind profiles, which have provided valuable guidance in storm prediction. Finally, **HMS meteorologists are improving their prediction skills** in support of F2P2 objectives by creatively using these tools.

## 5.0 Significant 1997 Storms

The 1997 F2P2 season was one of the most active on record and may have been influenced by the highly publicized El Nino climate phenomena. The season was characterized by a severe roller coaster ride of long storm-free periods followed by long periods of almost daily heavy rain events. **Message 1's/2's were issued on 3/0 days in May, 11/3 days in June, 9/5 days in July, 12/3 days in August and 5 days in September.** Message 1's and 2's were both issued on 3 days **for a total of 48 days with Messages.** Some form of urban, stream or flash flooding was experienced in the District on 46 days. The number of Message days( 48 ) and flooding days( 46 ) are **well above** the 19 year F2P2 averages of 34 Message days and 27 flooding days.

Three notable exceptions occurred in the normal monthly distribution of events. First, **no Message level rainfall events occurred until 21 May which was the latest first M1 day noted in the 19-year history of the F2P2.** The late start was balanced to some degree by the almost daily occurrence of storms from June 2 to June 25<sup>th</sup>. Three flash flood watches were issued and verified during this period. **The second notable occurrence was the lack of Message level storms from June 26<sup>th</sup> to July 18<sup>th</sup>.** The lack of any Message level storms during this period was another first. Normally the first 8 days of July are the second most active period of the F2P2.

**The final notable set of occurrences was the savage series of storm days from July 19 to August 7.** It started with the record setting 3.83" deluge in 60 minutes at the NWS WSO at Stapleton on July 19<sup>th</sup>. On July 25<sup>th</sup> 2.27" fell in 50 minutes at John Henz's Littleton home followed by 2.37" in 35 minutes at his home on July 27<sup>th</sup>. Lena Gulch experienced a minor flash flood on the 27<sup>th</sup> and 10 M1 Red Flags verified. On July 28<sup>th</sup> a severe flash flood killed 5 people in Fort Collins while dropping 10-14 inches of rain. At the same time a 6-8" radar-estimated rainfall fell in less than 2



hours over District portions of unincorporated Arapahoe County between 630PM and 830PM which washed out roads and several bridges. Twelve M1 Red Flags were issued across the District on the 3<sup>th</sup>. The severe rain events peaked on July 30<sup>th</sup> as 12 M1 Red Flags and 4 Flash Flood Warnings verified during a barrage of storms. Another seven days of Message level storms followed which prompted the issuance of 26 verified RF's. Only five M1 Red Flag level storms were noted after August 18<sup>th</sup>. The final Message level storm of the 1997 F2P2 occurred on September 11<sup>th</sup> in Arapahoe County shortly before sunset bringing a close to the active 1997 F2P2.

Unlike the high intensity/short duration storms of 1996, the storms of '97 were of longer duration, higher intensity and of greater aerial coverage. The storms of '97 took the form of either multiple organized lines or waves of storms or clusters of nearly stationary storms. Westward-moving storms were noted on five days of severe rainfall, which increased the threat of major foothill flash floods. **Table 7** shows the most notable storm days of 1997.

**Table 7 Notable 1997 Storm Days**

- July 19** A line of intense thunderstorms formed from north Aurora along I-70 to Commerce City. The NWS WFO was hit by a record setting 3.83" of rain in 60 minutes and 4.25 inches in 90 minutes with 1.50" diameter hail. Serious flash flooding was reported in NW Aurora and NE Denver in portions of the Westerly Creek basin. Five RF's and 3 FF Warnings were issued and verified.
  
- July 27** Slow moving storms formed over SW Arapahoe County and moved northwest into the central Jefferson County foothills. Littleton reported 2.35"/35min and flash flooding occurred along Lena Gulch in Golden and Lakewood. NW Douglas County experienced two waves of storms which produced a radar-estimated 2.00+ "/30 min each. Nine RF's and two FF Warnings were issued and verified.
  
- July 28** Slow moving waves of "training" storms produced the deadly Fort Collins flash flood and a 6-8 inch storm in the SE District in unincorporated Arapahoe County. Portions of Picadilly Road and three bridges were washed out. Sand Creek recorded near record flow. 13 RF's were issued and verified.
  
- July 30** Waves of heavy thunderstorms formed on Jefferson, Boulder and Douglas County foothills and moved across the District producing numerous reports of urban street and small stream flash flooding in all counties. Sixteen Red Flags and four FF Warnings were issued and verified. Aurora, Denver and Boulder Counties were especially hard hit.
  
- August 11** Rapidly forming thunderstorms formed along a convergence line in Jefferson and Denver Counties between 330PM and 600PM. The storms moved to the east and dropped very heavy rainfall estimated by radar to reach 2.00 to 2.50 inches in 20-35min. Heavy rain in W and NE Denver pooled in streets as 1-2 feet of ½" to 1 ½ " diameter hail clogged drains. The street flooding was especially bad in northern Denver. Six M-1 Red Flags were issued and verified.



These storms were the most notable of the 1997 F2P2 in the opinion of the HMS staff. It is certain that other storm days could have been included based on peak stream flows reported, intensity of attendant severe weather, vicious lightning or the potential for a major flooding event. Both the Fort Collins and the District Storms of July 28<sup>th</sup> produced over 6-8 inches of rain in less than 2 hours. The Fort Collins storm showed the deadly potential of a severe rainstorm when it occurs over a populated urban area. The Piccadilly Storm just missed producing a similar event over Parker or SE Aurora. These storms should serve as a warning to local communities to plan and exercise for the worst because some day it will happen.

## 6.0 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.

### Doppler radar: Message 1, Red Flags

As reported in 1996, the **NWS WSR-88D** Doppler radar at Watkins has become a **reliable forecaster tool** for estimating storm severity, rainfall rates and post storm verification. HMS meteorologists no longer are suffering from "Doppler-over-stimulation" when issuing Message 1, Red Flags. County and City Red Flag verification rates once again have equaled or exceeded 95 percent for the second year in a row. We believe that the concern over the "low" 1994 and 1995 RF verification statistics has been resolved.

### Mesonet

HMS had relied very heavily on the ERL Mesonet and the District ALERT weather stations for its ability to provide basin specific flash flood prediction. The loss of the ERL Mesonet on October 1, 1996 cast a shadow over the future of HMS forecast techniques based on the mesonet and led to a significant degradation in the short term, basin-specific forecasting capability of the F2P2. The results of the mesonet loss on F2P2 operations were covered in a separate HMS report and the following summary of key points from that report are offered:

1. On flash flood watch days the verification rate of county and city Message 2's for NWS/HMS concurrence days slid from over 80 percent to less than 60 percent. Forecasters cited the loss of aerial distribution of temperature/dew point fields as crucial to their ability to differentiate those counties, cities and basins that could be safely excluded from the watch area or valid time.
2. An increase in the number of zero lead-time Message 1's was alarming. HMS averaged less than 2 Message 1's per season with less than a 30 minute lead time for the past 7 years. Five M1's were issued with 10 minutes or less lead-time. Forecasters cited the loss of foothill mesonet sites crippled the use of the HMS Mesound forecast technique, which allowed accurate prediction of when the convective inversion or cap would break and allow storms to form.
3. A low-level Message 1 event was missed on May 24<sup>th</sup> due to a combination of operational factors.

more detailed discussion of these problems can be found in the HMS Mesonet Loss Study report  
**Training**

HMS continues to note the 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. HMS feels strongly that the training issue is a very necessary component of a successful flash flood warning program. Once again, HMS suggests that the District consider funding a three-month pre- operations period (PRE-OPS) from mid-January to mid-April. The PRE-OPS could have the following objectives:

1. **Provide direct person-to-person contact between dispatchers and decision-makers and HMS meteorologists to discuss communications and decision-making issues.**
2. **Exercise existing flood warning plans, and making suggestions on how they can be improved.**

HMS meteorologists have not visited the supported agencies en-masse for several years and planned F2P2 user days and Media F2P2 days have been poorly attended. HMS feels that the personal contact is needed to keep emergency response agencies motivated and able to respond in case of a major urban or foothills flash flood. Additionally HMS recommends that exercises based on the Fort Collins and Big Thompson events should be developed for the urban and foothills areas respectively.

## **Flood Warning Plans**

HMS suggests that the District consider assisting local communities without flood detection networks to develop and exercise community-specific flood warning response plans. The need would appear most acute in the Jefferson and Boulder County foothills where many new communities are developing. Additional need areas are located in rapidly developing and previously rural land around DIA and in unincorporated portions of Douglas, Arapahoe and Adams Counties.

## **Recommendations**

HMS offers the following recommendations for consideration by the District in 1998:

1. **HMS recommends that the District consider funding a pre-operational period (PRE-OPS) which enhances user training and exercises flood warning plans.**
2. **HMS recommends that the District consider the development of flood warning response plans for urban and foothills areas of Jefferson, Douglas, Boulder, Adams and Arapahoe Counties where rapidly growing communities have formed and flood detection networks and flood warning plans do not yet exist.**
3. **HMS recommends the gradual but continued effort to expand the District ALERT Mesonet to assist in the production of basin-specific Message, StormTrak and QPF products.**

**APPENDIX A**

**1997**

**COUNTY AND CITY**

**DAILY MESSAGE VERIFICATION**

**Table A-1: Verification of All 1997 Message 1's (Bolded "H's" indicate Red Flag days)**

Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
5/21	M	M				M	M				0	4
5/22	H	H	H	M	M	H	H				5	2
5/24				NMNI	NMNI							
5/29	H	M	M	M	H	M	M				2	5
H	2	1	1	0	1	1	1				7	
M	1	2	1	2	1	2	2					11
Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
6/2	M	H	M	H	H	H	M				4	3
6/6	H	H	M	H	H	H	H	H	H	H	9	1
6/7	H	H	H	M	M	M					3	3
6/8	H	H	M	H	H	H	M	HR			6	2
6/9	M2M	M2M	M2M	M2H	M2H	M2M	M2M					
6/10	H	H	H	M	H	H	H	2HR	HR		8	1
6/12	HR	H		H	M	H	HR				5	1
6/13	H	H	H	H	H	H	H				7	0
6/14	H	H	H	M	H	H	H	HR	HR		8	1
6/15		H		M							1	1
6/18	H		M				H				2	1
6/21				H	H						2	0
6/23	H	M	M		M	H	H				3	3
6/25	H	H	M	H	H	H	HR		HR	HR	8	1
H	10	10	4	7	8	9	8	4	4	2	66	
M	1	1	6	4	3	1	2	0	0	0		18
Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
7/19	HR	HR	HR	H	H	HR	HR				7	0
7/19		M3H				M3H	M3H					
7/20	M	M	M	M	M	M	M				0	7
7/21	H	M	H			H					3	1
7/23		H		H							2	0
7/24	H	H	H	M		H	H				5	1
7/25	HR	M	H	M	HR	HR	HR	HR			6	2
7/27	HR	M	2HR	M	HR	HR	HR	2HR	HR	HR	8	2
7/27					M3M							
7/28	HR	HR	H	H	2HR	HR	HR				7	0
7/28	M2HR		M2M	M2HR		M2M	M2HR		M2M			
7/29	M2M	M2M	M2HR	M2M	M2H	M2M	M2M					
7/30AM	M2M		M2H									
7/30	M	HR	H	HR	HR	M	M			HR	5	3
7/30PM	M2HR	M2HR	M2HR	M2HR	M2HR	M2HR	M2HR		M2HR	M2HR		
7/30	M3HR			M3H	M3H	2M3HR	M3H					
7/31	M2HR	M2M	M2HR	M2M	M2H	M2HR	M2HR					
H	6	5	7	4	5	6	5	2	1	2	43	
M	2	4	1	4	1	2	2	0	0	0		16

**4Legend**

H = M-1 which verifies or hits  
M = M-1 which does not verify or misses  
HR = M-1, Red Flag which verifies  
M2M = NWS M-2 which does not verify  
MR = M-1, Red Flag which does not verify  
0 = M1 with low lead time as in HR0  
M2H = NWS Message 2 which verified  
M3H = NWS Message which verified  
M3M = a NWS M3 which did not verify

ARP: Arapahoe County  
ADM: Adams County  
DUG: Douglas County  
BOU: Boulder County  
JEF: Jefferson County  
DEN: Denver County  
AUR: Aurora  
LAK: Lakewood  
WHT: Wheat Ridge  
ARV: Arvada

Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
8/01	M	HR	M	M	HR	HR	M	HR	HR		5	4
8/02	HR	HR	M			HR					3	1
8/03					HR	M		HR	HR		3	1
8/04	M2HR	2M2HR	M2HR	M2HR	M2HR	2M2HR	M2M	M2HR	M2HR	M2HR		
8/05	M2H	M2H	M2M	M2H	M2H	M2H	M2H					
8/06	M2M	M2H	M2M	M2M	M2M	M2M	M2M					
8/11	HR	H	HR		HR	HR	HR	HR			7	0
8/12	H	H	H	H	2HR	2HR	HR			MR	7	1
8/16	HR	HR	M	H	H	M	HR				5	2
8/17	M	H	M	H	H	M	M				3	4
8/18	HR	HR	HR	H	HR	M				HR	6	1
8/21				H	H						2	0
8/26	H	H	H	M	H	M	H				5	2
8/28	H	M	M	H	H	H	H				5	2
8/31	H	M	HR		M	H	M				3	3
H	8	8	5	6	10	6	5	3	2	1	54	
M	2	2	5	2	1	5	3	0	0	1		21
Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
9/01	M	H	M	H	H	H	M				4	3
9/03	HR		HR		HR	HR	M				4	1
9/04	H	H	H	H	H	H	H				7	0
9/06	M	H	H	H	M	M	M				3	4
9/11	H										1	0
H	3	3	3	3	3	3	1	0	0	0	19	
M	2	0	1	0	1	1	3	0	0	0		8
TOTAL	27	25	20	20	25	24	20	8	7	5	181	
M1 H												
TOTAL	8	9	12	10	7	10	11	0	0	1		68
M1 M												
TOTAL	35	34	32	30	32	34	31	8	7	6		249
M1												

ARP: Arapahoe County  
 ADM: Adams County  
 DUG: Douglas County  
 BOU: Boulder County  
 JEF: Jefferson County  
 DEN: Denver County  
 AUR: Aurora  
 LAK: Lakewood  
 WHT: Wheat Ridge  
 ARV: Arvada

#### Legend

H = M-1 which verifies or hits  
 M = M-1 which does not verify or misses  
 HR = M-1, Red Flag which verifies  
 M2M = NWS M-2 which does not verify  
 MR = M-1, Red Flag which does not verify  
 0 = M1 with low lead time as in HR0  
 M2H = NWS Message 2 which verified  
 M3H = NWS Message which verified  
 M3M = a NWS M3 which did not verify



**APPENDIX B**  
**SUPPLEMENTARY ANNUAL VERIFICATIONS**

**Internal Use Only**

**Table B-1**

**UDFCD F2P2 DISTRICT-WIDE MESSAGE 1 DAY ONLY VERIFICATION  
1979 - 1997**

	Year	Message 1 Days	Verified Hits	Verified Misses	Not Forecasted	Percent Accuracy	False Alarm %	Probability of Detection
<b>GRD Weather Center District Era</b>	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%
<b>Henz, Kelly &amp; Assoc. County Era</b>	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%
<b>HMS Red Flag Era</b>	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%
	1995	43	35	8	1	81%	19%	97%
	1996	52	41	11	0	79%	21%	100%
	1997	40	38	2	1	95%	5%	97%
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		290	245	43	4	84%	16%	98.4%
Total		677	559	116	8	82%	18%	98.7%
19 Year Average		36	29	11	0.4	82%	18%	98.5%

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

**Hit** = Verification of Message in District

**Miss** = No verifications

**Table B-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
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%
1995	43	35	8	81%	19%	98%	283	159	124	56%
1996	52	41	11	79%	21%	100%	267	173	94	65%
1997	40	38	2	95%	5%	100%	249	181	68	73%
Tot	260	219	41	84%	16%	99%	1513	898	615	59%
Avg	37	30	6	83%	17%	100%	210	120	90	57%

**Table B-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%
1995	283	159	56%	197	118	60%	86	41	48%
1996	267	173	65%	215	132	61%	52	41	79%
1997	249	181	73%	197	141	72%	52	40	77%
Total	1511	901	60%	1115	685	61%	396	216	55%

**Table B-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	97%	16	15	94%
1993	123	12	12	100%	10%	8	8	100%	2	2	100%
1994	153	67	47	70%	44%	38	32	84%	29	15	52%
1995	283	159	110	69%	56%	92	76	83%	66	34	52%
1996	267	107	105	98%	40%	73	72	99%	34	33	97%
1997	249	96	95	99%	38%	65	65	100%	31	30	97%
Tot	1511	697	606	87%	46%	345	319	92%	178	129	72%