1996 **FLASH FLOOD** U. D. & F. C. D. PREDICTION PROGRAM **OPERATIONS REPORT**

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General Comment

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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 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.

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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 plainsfoothills-mountain interfaces of Jefferson, Boulder and Douglas Counties.

Henz Meteorological Services (HMS) of Denver was selected as the 1996 F2P2 Private Meteorological Service. HMS provided similar services for the 1990 - 1996 F2P2's. HMS forecast services were provided by John Henz, Bryan Rappolt, Frank Robitaille, and Lisa Morrison during the 1996 season. One meteorological intern, William Badini, was employed from May 15 to August 15 to assist the HMS meteorologists. Mr. Badini has a B.S. in Meteorology from the University of Wisconsin and was accepted into their Graduate School where he is currently seeking a Masters of Science in Atmospheric Science and working as a Teaching Assistant. Bill will re-join the HMS forecast team during Winter 1997 and Summer 1997 vacation seasons. xx all

2.0 **1996 Operational Season**

Service5 The F2P2 season began on 15 April 1996 and continued through 15 September 1996, for 154 operational days. An additional operations day was declared on September 25, 1996. Normal operational hours were from 0700L to 2200L and covered 2,322 hours. Overnight and/or early morning operations conducted during the period from 1000PM to 700AM added an additional 217 hours of support time for a total of 2,539 hours of F2P2 activity HMS has noted that increased nocturnal thunderstorm activity has been observed since the Summer of 1993. The increased storm activity between 1000PM and sunrise may be related to differences in the weather patterns associated with the Drought of the 1990's to the wet weather period of the El Nino dominated 1980's. The increased nocturnal activity has heightened HMS concerns that a major flash flooding event during the overnight hours could challenge the program sometime in the next three years.

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.

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Figure 1: Urban Drainage and Flood Control District

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3.0 1996 F2P2 Operational Product Production

The F2P2 is designed to offer a supplementary 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 eight District basin warning plans which exist:

- 1. Boulder Creek Warning Plan which serves Boulder/South Boulder Creeks in Boulder County
- 2. Lena Gulch Warning Plan which serves the Lena Gulch Basin and impacts Jefferson County,
- 1-plan Golden, Lakewood and Wheat Ridge Goldsmith/Harvard - South and
 - 3. Harvard Gulch Warning Plan Which impacts southern Denver
 - 4. Goldsmith Gulch Warning Plan which impacts south-central Denver
 - 4.5. Westerly Creek Warning Plan which impacts eastern Denver and western Aurora
 - 5, 6. Toll Gate Creeks Warning Plan which impacts central and southern Aurora
 - 6.7. Ralston Man Bibber Creek Warning Plan which impacts central Arvada and Jefferson County
 - 7-8. Bear Creek Warning Plan which impacts Jefferson County and southern Lakewood Morrison

Four specific F2P2 products exist in addition to voice 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 1996 season HMS delivered the following quantities of the identified F2P2 Products:

5 & you've mentioned these previous! 1754 lou HPO's: 8,642 routine HPO faxes to the 26 primary HPO reception points. 267 Message faxes and 668 Message updates, Messages: IMS's: 2,032 IMS faxes, **OPF**: 178 QPF faxes and Storm Traks: 3,604 Storm Trak products

These products were delivered 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. Use was made of the US West Broadcast Fax service network to send F2P2 products 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 528 HPO products, 162 IMS's and 15 QPF products through the District's EBB. The ondemand 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 2,000 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 US West's Broadcast Fax . These three lines were adequate to handle the volume of communications generated during peak storm periods. Despite

the increased number of District Message days, the number of verbal interactions in the program were down slightly from 1995 F2P2. The user input suggests that the quality of the faxed Storm Traks has improved sufficiently to replace some of the event verbal "hand-holding".

4.0 1996 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 Figure 2.

Figure 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 <u>and/or</u> 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 <u>and/or</u> 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 provides 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. It is issued by HMS 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. **Figure 3** shows the criteria for Message issuance based on both the rainfall potential and the anticipated response of the District basin.

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F2P2

Figure 3: UDFCD Etash 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
i.	flooding of streets and low lying areas due to thunderstorm rainfall
1. T	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.

Message 1 Rainfall	Any of the forecast rainfall intensities below prompt
Intensity Criteria:	a Message 1 issuance
	1.00"/ 60 minutes
	0.75"/ 30 minutes
	0.50"/ 10 minutes

Message 1:	Issued to identify storm events which fall just short of producing life-
RED FLAG	threatening rainfall but produce a significant impact on street and
622	stream runoff.
RED FLAG	Rainfall rates are predicted or observed to exceed 1.00"/30
Rainfall	minutes and the storm is considered imminent.
intensity:	

Message 2:	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.				
M-2 Rainfall	>3.00"/hour or a lower value based on mutual discussion				
intensity	between NWS, District and HMS due to antecedent rainfall				
criteria:	impacts on soil saturation and/or runoff characteristics.				

Message 3:	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 1996 F2P2. Three forms of Message verifications are presented. A Message 1 (M-1) Day refers to the number of days a Message 1 was issued anywhere within the District. A M-1 Day hit refers to the number of M-1 days a M-1 verifying event occurred which equaled or exceeded the rainfall criteria in Figure 3. Message 1's are issued to both County and City dispatch offices. The M-1's column refers to the number of issued M-1's which were verified by the occurrence of a heavy rainfall event which met the M-1 criteria in Figure 3. The M-1 Red Flags refers to the number of M-1 days. Red Flag criteria. 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.

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	7	6	36	29	81	3	3	100	1	1	7	7	100
June	10	7	47	27	57	4	3	75	0	0	0	0	0
July	15	12	68	44	65	28	28	100	5	0	10	0	0
August	14	9	73	47	64	41	41	100	1	1	6	4	67
September	6	3	43	26	60	33	32	97	0	0	0	0	0
Totals	52	37	267	173	65	109	107	98	7	2	23	11	48

Table 1:	Monthly	Message	Verification	for the	1996 F2P	2 Operational	Season
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Message 1's were issued on a record-setting total of 52 days or 40 percent over the 18 year average of 35 M-1 days. The 37 observed M-1 days was 21 percent over the 18 year average of 29 observed M-1 days but fell well short of breaking the record of 40 observed M-1 days set in 1987 Note seven Message 2 (M-2) days occurred in 1996. NWS issued all 7 of the 1996 Message 2's with HMS concurrence coming on the two instances the Message 2's verified. Message 1's were issued preceding Message 2's on 2 of the 7 M-2 days leaving five "pure" M-2 days to contribute to the annual total. A listing of the annual comparison of these events since 1979 can be found in Tables A-1 and A-2 in Appendix A..

The 1996 results are the third straight year of improved M-1 verification by HMS meteorologists! The 1996 season was the most active thunderstorm and urban flooding period since 1987. The tota number of M-1's (267) issued during the 1996 F2P2 was 20 percent above average. The accuracy of the 1996 M-1's was 11 percent above the five year average of 54 percent. This achievement, while notable, still leaves room for continued improvement in the years ahead. It is HMS' goal that by the year 2000 the individual M-1 verification will improve to 80 percent or better.

Encouraging as the 1996 M-1 statistics were, improvement still needs to be accomplished on National Weather Service Flash Flood Watches or Message 2's in the F2P2. HMS concurred with the issuance of NWS Flash Flood Watches on both days flash flood watches verified in May and August. On the two HMS/NWS concurrence days, 11 of 13 county/city combined M-2's verified by NWS criteria. In July, five non-concurrence flash flood watches were issued by the NWS which did not verify. The June 1996 forest fire in the Buffalo Creek basin and the deadly July 12, 1996 Buffalo Creek Flash Flood in southern Jefferson County (outside District areas) directly contributed to the diminished verification statistics for Message 2's. The non-verifying M-2's were issued by NWS for the entire Jefferson County foothills rather than only the sensitive Buffalo Creek watershed. HMS non-concurrence was based on the inclusion of the District portions of Jefferson County which were not at risk. It should be noted in defense of the NWS that definitive quantitative guidance was not provided by the hydrological community on the amounts of rainfall which could flash flood the fire-ravaged Buffalo Creek basin. Thus, rather than risk additional loss of life, NWS issued five Flash Flood Watches (Message 2's) under trying circumstances.

Only two Message 3's (*Flash Flood Warning or Flood Warning*) were issued by the National Weather Service. The first M-3 was issued on May 26th at 441PM by NWS for slow rising, agricultural lowland flooding along the South Platte River from Commerce City downstream to Kersey in Weld County. HMS concurred and issued the M-3 to Adams County. The second M-3 was issued at 1042PM the night of the July 12th Buffalo Creek flash flood. It included all of southern Jefferson County near the Buffalo Creek basin and along the South Platte drainage into Chatfield reservoir. This M-3 was forwarded to both Jefferson and Arapahoe Counties with appropriate comments on its application to the Buffalo Creek basin. Unfortunately this flash flood occurred without the benefit of a flash flood watch and caught local residents by surprise. Please note that this flash flood occurred southwest of the District's F2P2 service area.

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 can be verified as a "hit" only if a rain event meeting the M-1 criteria in Figure 3 occurs in the District portion of that county or city, not just anywhere in the county. 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.

HMS has verified this support by each of the six counties and the four cities supported by Flood Warning Plans and Flood Detection Networks. The six counties include Adams, Arapahoe, Boulder, Denver, Douglas and Jefferson Counties. With the exception of Denver County (100%), the F2P2 supports less than 50 percent of the land areas of each of these counties. Messages issued for each county is sent to a county communications dispatcher which is tasked with sending the Message to affected communities in the county. HMS does not contact each city individually in each county which is affected by a Message. Four city exceptions can be noted: Aurora, Arvada, Wheat Ridge and Lakewood. Each of these cities are served by FDN's and associated warning plans. In the case of Aurora, portions of three counties(Adams, Arapahoe and Douglas) fall within the city limits and the Westerly Creek FDN serves both Aurora and Denver. Direct notification of Aurora is viewed as simplifying an otherwise very complex communications problem. The other three cities are served by FDN's and warning plans which warrant basin-specific prediction.

Significant improvement was noted in the accuracy of the County and City level Message 1's issued during 1996 as seen in Table 2. Almost two-thirds (60%) of the county Messages verified while a record 79 percent of the City Messages hit despite the relatively small size of the verification areas. This improvement is especially notable when compared to the results of the past five years. A five year comparison of the Message verification on the county and city basis can be found in Table A-3 which includes the 1996 season statistics. The 1996 county level M-1 verification showed a 10 percent improvement through July but stumbled to just over 50 per cent verification in the last 45 days of the program which resulted in little improvement for the year. While county level verification has been stagnant near 60 percent for the past five years, a 40 percent improvement in the City M-1's has been noted since 1994. Reasons for this steady improvement will be discussed later in this section. Specific daily Message 1 verification for each of the counties and cities can be found in Appendix B, Table B-1.

Month	M-1 Days	M-1 Day Hits	Cnty M-1's	Cnty Hits	Cnty % Hits	Cty M-1's	Cty Hits	Cty % Hits	Events Missed	Event <10mi Lead
April	0	0	0	0	0	0	0	0	0	0
May	7	6	31	24	77	5	5	100	0	0
June	10	7	40	23	58	6	4	67	0	1
July	15	12	55	36	65	13	8	62	0	1
August	14	9	59	32	54	17	15	88	0	0
September	6	3	32	17	53	11	9	82	0	0
Totals*	52	37	217	132	60	52	41	79	0	2

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Table 2:	County and City	Verification for the	1996 F2P2 Operational	Season

Note: May 25 is both M-1 and M-2 day; Total* does not include two NWS M-2 only days

Of equal significance is the fact that no Message level rainfall events occurred in the District without Message issuance prior to their occurrence. In most cases lead-times of over 60 minutes were obtained. However, close calls were noted in the final column which identifies the number of Message 1's issued with less than 10 minutes lead-time. Two 1996 storm situations occurred with less than 10 minutes lead-time from the issuance of the Message 1 to the beginning of rainfall. The first such event occurred on June 13 when a strong storm "exploded" in less than 15 minutes and dropped over an inch of rain with low M-1 lead time in Denver. Message 1's were also issued for Arapahoe and Jefferson Counties which verified with over 60 minutes lead. The second event occurred from 800PM to 1000PM on July 19th when storms deluged the south side with about 0.50"-1.00"/20 min. The rainfall produced minor street flooding in portions of southeast Denver, western Arapahoe County and western Aurora. Message 1's were issued for all three affected areas with a zero lead-time for Arapahoe County and 30 minutes lead-time for Denver and Aurora. Better meteorologist use of mesonet and QCP2 could have obtained a 60 minute lead-time for both events.

The overall 1996 improvement was also evident in Message 1-Red Flag issuance as evidenced in Table 3. 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 90 percent or greater probability exists that a flooding event will occur in the next 30-60 minutes. In other words the RED FLAG means action is needed. Ninety-eight percent of the 1996 Message 1's Red Flagged verified compared to only 69 percent in 1995. As summarized in the 1994 and 1995 F2P2 Annual Reports, a significant reduction in the accuracy of M-1 Red Flags has been corrected. The problem was related to forecaster over-stimulation by the NWS WSR-88D data displays and a HMS forecaster misapplication of the 1994 Red Flag criteria change through 1995. HMS was confident that the Red Flag verification would rebound to pre-1994 levels and it has. Once again users can rely on it.

Group	M-1's	M-1 Hits	% M-1 Hits	Red Flags	RF Hits	% RF Hits	% RF M-1's
ARAP	40	26	65	12	12	100	30
ADM	40	24	60	13	13	100	33
DUG	31	19	61	9	9	100	29
BOU	28	18	64	7	6	86	25
JEF	36	20	56	15	15	100	42
DEN	38	24	63	19	18	95	50
TOTAL	213	131	62	75	73	97	35
AUR	30	19	63	11	11	100	37
LAK	8	8	100	10	10	100	125
WHT	7	7	100	8	8	100	114
ARV	7	7	100	6	6	100	86
TOTAL	52	41	79	35	35	100	67

Table 3: Verification for Red Flagged Message 1's

Several reasons for the 1996 F2P2 improvements should be noted. First, the HMS Quantitative Convective Precipitation Potential (QCP2) tool based on basin specific automated weather stations in the FDN's provided quantitative decision guidance which reliably identified the basin-specific rainfall potential on the city scale. The QCP2 uses the surface temperature, dew point, wind direction and speed as input to a 1-D cloud model which provides a peak 60-minute, 30-minute and 10-minute rainfall potential. HMS meteorologists have been able to successfully relate this rainfall potential to District Message criteria and the occurrence of basin-specific storms. Next, 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 1996 Storms

Once again cold, upslope weather systems spread copious general rains over the District from April through early-May delaying the start of the spring thunderstorm season. Once the season started on May 9th, it remained active each month through mid-September except for a brief respite in early June. Message 1's and 2's were issued on 7 days in May, 10 days in June, 15 days in July, 14 days in August and 6 days in September. Of these 52 Message days, 37 days experienced some form of urban, stream or flash flooding and 49 days experienced thunderstorm activity in the District. The number of Message days (52) and days experiencing some flooding (37) are well above the 18 year F2P2 averages of 34 Message days and 28 flooding days.

Two notable exceptions occurred in the monthly distribution of events. First, **no Message level** rainfall events occurred from June 1 to June 10 for the first time in the 18 year history of the F2P2. The first eight days in June have been notorious heavy rain producers but 1996 was the first exception. On the balancing side, the 29 Message days in July and August 1996 were 30 percent higher than the number of Message days in the same months of 1995 and 25 percent above the 18 year average.

Despite the high frequency of event days, the 1996 F2P2 season was once again uneventful in the District. The exception was the near-miss Buffalo Creek flash flood of July 12, 1996 which killed two people and caused considerable property damage to residents of the town of Buffalo Creek. The storm occurred just southwest of the District's boundary in southern Jefferson County. Research is being conducted to determine the contribution played by the deforestation of the basin by a forest fire in June and the intensity and volume of rain in producing the flash flood.

HMS meteorologists were very busy on July 12th. They issued Message 1's for Jefferson County about 600PM and then at 655PM **Red Flagged** one of the storm systems which contributed to the Buffalo Creek flash flooding as it crossed the North Turkey Creek basin between 715PM and 745PM. John Henz of HMS called NWS from North Turkey Creek with a report of heavy rain and hail to 1.25" in diameter at 702PM and the NWS issued a Severe Thunderstorm Warning immediately. The storm complex merged with another storm over Buffalo Creek Basin and became stationary from 745PM until about 845PM. Additional storms appeared to form and move over the basin between 845PM and 1000PM. Flash flooding was reported in Buffalo Creek shortly after 900PM and peaked between 930PM and 1030PM. The NWS issued a Flash Flood Warning at 1012PM which was transmitted by 1020PM on NOAA Weather Wire. The Buffalo Creek storm clearly increased Front Range awareness of the summer flash flood dangers in the foothills.

Most of the 1996 storms were quick-hitting "front-end dumpers" with a duration of less than 30 minutes and rainfall of less than 1.00 inch. The storms of July 9, July 12, 1996 July 19, August 22 and September 11th were the notable exceptions. Each of these storms produced significant urban street and stream flooding with storm total rainfalls of 1.50 inches to almost 3.00 inches. This year is the first year that June storms have not made the list.

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

- July 9 A line of strong t-storms formed over southeast Boulder County and moved into SE Arapahoe County between 630PM and 830PM. 1.42" fell in Niwot in less than 45 minutes while 0.71"/20 minutes in Thronton and 0.63"/20 minutes in Commerce City. Numerous reports of urban street flooding were reported. Eight Red Flags were issued and verified.
- July 12 The Buffalo Creek event which was described earlier. Twelve Red Flags were issued for the storms which produced 1.50" to 2.74" / < 1 hour, 2 tornadoes and hail to 1.50" in diameter. Two deaths were reported in southern Jefferson County outside the District due to flash flooding.
- July 19 The storms on July 19 deluged the south side with a "Pillar of Water" of about 0.50"-1"/20 min from 800PM to 1000PM The rainfall produced street flooding in portions of southeast Denver, southwest Arapahoe Counties and Aurora. Very frequent lightning started numerous house fires in Arapahoe and Douglas Counties. Three M-1, Red Flags were issued and verified.
- August 22 Waves of heavy thunderstorms formed on Jefferson County foothills and moved across the District producing numerous reports of urban street and small stream flooding in all counties. Thirteen Red Flags were issued and verified. Rain fell at 0.75"/45min to 2.10"/90 min rates.
- September 11 Rapidly forming thunderstorms formed along a convergence line in Jefferson and Denver Counties between 700PM and 1100PM. The storms moved to the west and dropped very heavy rainfall estimated by radar to reach 1.00 to 1.50 inches in 30-45min. Heavy rain in Morrison and Red Rocks disrupted a large crowd attending a Hootie and the Blow Fish concert. The Rockies game at Coors field was delayed for almost two hours and eventually suspended due to the storm's viciousness. Urban street flooding and vicious lightning was reported throughout the District. Ten M-1 Red Flags were issued and verified.

The **Buffalo Creek Flash Flood storm of July** 12th was only one of twelve severe storm systems which crossed the District on July 12th between 630PM and midnight. Large hail to 1.50" in diameter, 2 tornadoes and strong damaging winds accompanied the heavy thunderstorm rains which accumulated up to 2.00" to 2.74" in portions of southeastern Boulder and southwestern Adams Counties. The primary storm track across the District ranged from southeast Boulder County to downtown Denver to southwest Aurora. These storms crossed the District in two waves between 730PM and 1130PM giving HMS meteorologists a stern operational test which they passed with flying colors as all issued Message 1's and associated Red Flags verified. On-scene Boulder Sheriff' deputies identified tornado information for a severe storm approaching Broomfield provided by HMS meteorologists Lisa Morrison and Bill Badini "as having greatly enhanced public safety". Their timely predictions provided 10-20 minutes lead-time to the deputies for this dangerous storm which produced a brief but damaging tornado. In HMS' opinion the storms of July 12th were the most dangerous of the 1996 season.

These storms were the most notable of the 1996 F2P2 but clearly the District was once again **spared** "the big one". For the past three summers most of the storms have been short-duration, high intensity storms on all but four or five days. The storms on these "big days" have produced severe weather but generally less than 3.00 inches of rain in a basin. It has been six years since a strong storm either became stationary for 60-90 minutes in the Denver Cyclone's circulation or some other mesoscale weather feature, or "locked into" the foothills over the District and produced over 4.00 inches of rain. Perhaps the absence of the "big ones" is a direct result of the current drought of the 1990's over the High Plains.

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 and Message 1, Red Flags

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 have once again equaled or exceeded the 95 percent rate for the period 1991 through 1993. The primary nemesis was the use of observed thunderstorm gust fronts collisions to anticipate the formation of thunderstorm heavy rainfall in efforts to achieve a lead-time of 30 minutes. Less than 25 percent of the gust front collisions on Message days in 1994 and 1995 produced thunderstorms which dropped flooding rainfall. Similar forecaster overstimulation by the WSR-88D has been noted by the NWS researchers for the past four years. HMS will continue to strive to apply the WSR-88D technology as well as possible.

Mesonet

HMS relies very heavily on the existing ERL Mesonet and the limited District ALERT weather stations for its ability to provide basin specific flash flood prediction. Since 1993 HMS has used three key 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,
- 2. 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, and 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 13,000 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. The loss of the ERL Mesonet on October 1, 1996 has cast a shadow over the future of these techniques in the District F2P2 which could lead to a significant degradation in the short term, basin-specific forecasting capability of the F2P2. The number of District ALERT weather stations is growing too slowly to replace the ERL Mesonet data which was recently lost.

HMS requests that the District consider funding a form of the non-solicited HMS Mesonet proposal of November 1994 which addresses the minimal surface weather data needs to maintain the high level of basin-specific QPF support now given to F2P2 users. This proposal could be accomplished in time to provide input to the 1997 F2P2 season.

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 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.

Recommendations

HMS offers the following recommendations for consideration by the District in 1997:

- HMS recommends that the District consider funding a pre-operational period (PRE-OPS) which enhances user training and exercises flood warning plans. HMS will submit a proposal for such a program to the District by February 1997 with a proposed budget for possible 1998 F2P2 implementation.
- 2. HMS recommends that the UDFCD consider funding of a Mesonet evaluation and design study to insure an operational Mesonet presence for the 1997 F2P2.

APPENDIX A SUPPLEMENTARY ANNUAL VERIFICATIONS

Table A-1

UDFCD F2P2 DISTRICT-WIDE MESSAGE 1 DAY VERIFICATION <u>1979 - 1996</u>

		Message 1	Verified	Verified	Not	Percent	False	Probability
	Year	Days	Hits	Misses	Forecasted	Accuracy	Alarm %	of Detection
GRD	1979	26	17	9	3	65%	35%	85%
Weather	1980	35	23	12	0	66%	34%	100%
Center	1981	40	31	9	0	78%	23%	100%
District Era	1982	42	34	8	0	81%	19%	100%
	1983	37	32	5	0	86%	14%	100%
Henz,	1984	38	32	6	0	84%	16%	100%
Kelly &	1985	28	25	3	0	89%	11%	100%
Assoc.	1986	35	30	5	1	86%	14%	97%
County Era	1987	47	40	7	0	85%	15%	100%
	1988	28	24	4	0	86%	14%	100%
	1989	31	26	5	0	84%	16%	100%
	1990	30	26	4	2	87%	13%	93%
HMS	1991	42	31	11	0	74%	26%	100%
Red	1992	29	25	4	0	86%	14%	100%
Flag	1993	28	25	3	0	89%	11%	100%
Ега	1994	26	24	2	0	92%	8%	100%
	1995	43	35	8	1	81%	19%	97%
	1996	52	41	11	0	79%	21%	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	250	207	43	3	83%	17%	98.6%
	Total	637	521	116	7	82%	18%	98.7%

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 issued County

Miss = No verifications

~ City/County

			- 1. J.	Percent	Percent	Probability				Percent
Year	M-Days	Hits	Misses	Accuracy	False Alarm	of Detection	Total M-1's	Hits	Misses	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%
Tot	220	181	39	83%	17%	99%	1262	720	542	57%
AVG	37	30 /	$-\omega_{ID}$	83% E	17%	100%	210	120	90	57%

Table A-2: Annual Verification Comparison for UDFCD (District)

V Table A-3: County / City Message-1 Verification

	Total C	County a	and City	Cou	nty Verific	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%
Total	1262	720	57%	918	544	59%	344	176	51%

Countres :

Citles =

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

	Total			Percent	Percent	County	County	% County	City	City	% City
Year	M-1's	RF's	RF Hits	RF Hits	RF's	RF's	RF Hits	RF Hits	RF's	RF Hits	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	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%
Tot	1262	601	511	85%	48%	280	254	91%	147	99	67%

APPENDIX B

1996

COUNTY AND CITY

DAILY MESSAGE VERIFICATION

		Message 5	Not necessa
Table B-1:	Verification of All 19	996 Message the Bolded "H'	" indicato Red Flag days)

Date	ARP	ADM	DUG	BOU	JEF	DEN .	AUR	LAK	WHT	ARV	H	M
5/9	Н	H			H	Н	Н				5	0
5/22	M	H		H	H	Н		HR	HR	HR	7	1
5/23	M	M			M	М					0	4
5/25	H	H	Н	Н	H	Н	Н				7	0
5/26	Н	H	Н	Н	Н	Н					6	0
5/29	M	H	М			Н					2	2
5/31	H		Н								2	0
Н	4	5	3	3	4	5	2	1	1	1	29	
М	3	1	1	0	1	1	0	0	0	0		7
Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
6/12			М		M						0	2
6/13	H				H	HR0					3	0
6/14	M	M	М	М	M	М	M				0	7
6/15	H	H	Н	H	H	Н	Н				7	0
6/16	H	H	Н	Н	H	М	Н				6	1
6/21	H	M	М	Н	M	Н	Н				4	3
6/22	M	M	М	М	M	М	M				0	7
6/24		HR		Н	HR	HR	Н				5	0
6/26				Н							1	0
6/28				Н							1	0
Н	4	3	2	6	4	4	4	0	0	0	27	
M	2	3	4	2	4	3	2	0	0	0		20
Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
7/6	M	M	Н	Н	H		M				3	3
7/9	Н	HR	М	HR	HR	HR	Н	HR	HR	HR	9	1
7/10			Н								1	0
7/12	HR	HR	HR	HR	HR	HR	HR	HR			8	0
7/13	Н	HR	Н			HR	HR				5	0
7/15	M	M			M	М	М				0	5
7/18	N2M	N2M	N2M	N2M	N2M	N2M	N2M	N2M	N2M	N2M	0	0
7/19	HR0					HR	HR				3	0
7/23		M	Н	М	M	М					1	4
7/24	H	M	Н	M	H	М					3	3
7/25	H	M	Н	Н	H	М	М				4	3
7/26		H									1	0
7/28	M	H	М	Н	M	Н	М				3	4
7/29					N2M						0	0
7/31	H	Н				HR	М				3	1
Н	7	6	7	5	5	6	4	2	1	1	44	
M	3	5	2	2	3	4	5	0	0	0		24

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

Alpha order would be better,

Legend

H = M-1 which verifies or hits M = M-1 which does not verify or misses HR = M-1, Red Flag which verifies N2M = 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

Add . nece.

Not necessary

NM2 = NWS instrated M=2 M2 - HMS initiated M-2

Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
8/3		M			M	М					0	3
8/4	Н	Н					Н				3	0
8/6					М			•			0	1
8/7	Н		Н								2	0
8/8	М	HR	М	М	M	М					1	5
8/14	М	M	М	М	M	М	М				0	7
8/15	Н	H	Н		HR	Н	H				6	0
8/19				М	M						0	2
8/22	HR	HR	HR	М	HR	HR	HR	HR	HR	HR	9	1
8/23	HR	HR	М	М	HR	HR	HR	HR	HR	HR	8	2
8/26	HR	HR		HR	HR	HR		HR	HR	HR	8	0
8/27	HR	Н	HR		M	HR	HR				5	1
8/28	М	M				М	M				0	4
8/29	HR	Н	HR			HR	HR				5	0
Н	8	8	5	1	4	6	6	3	3	3	47	
М	3	3	3	5	6	4	2	0	0	0		26
Date	ARP	ADM	DUG	BOU	JEF	DEN	AUR	LAK	WHT	ARV	H	M
9/6	М	M	М		М	М	M				0	6
9/11	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	10	0
9/12	HR	HR	М	HR	HR	HŔ	HR				6	1
9/13	М	М	М	М	М	М	М				0	7
9/14	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	10	0
9/25			М	М	М						0	3
H	3	3	2	3	3	3	3	2	2	2	26	
М	2	2	3	1	2	2	2	0	0	0		17
TOTAL H	26	25	19	18	20	24	19	8	7	7	173	
TOTAL M	13	14	14	11	17	14	11	0	0	0		94
TOTAL Message Days	39	39	33	29	37	38	30	8	7	7		
		GR/ TOT	AND FAL:	267			MES	SSAGES				

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 N2M = 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