HENZ METEOROLOGICAL SERVICES
(HMS)

URBAN DRAINAGE & FLOOD CONTROL DISTRICT
FLASH FLOOD PREDICTION PROGRAM
-1991 Operational Season-

HMS FINAL REPORT 91-5
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INTRODUCTION

Urban Drainage & Flood Control District (UDFCD) has funded a Flash Flood Prediction Program (F2P2) since May 1979. Value-added forecast services of thunderstorm occurrence, rainfall, and flooding have been provided to the F2P2 by a private meteorological service (PMS). These forecasts have been issued directly to pre-arranged contact points in each of the Distrct's six counties and several large cities. The PMS forecasts are site and basin specific and supplement the normal National Weather Service (NWS) issuance of urban flooding statements and flash flood watches and warnings.

Henz Meteorological Services (HMS) was selected in a competitive bid to perform the 1990 F2P2 PMS service. After a successful 1990 season HMS was selected PMS for the 1991 F2P2 season. HMS is located in Denver, Colorado and all F2P2 forecasts were made by John Henz and Frank Robitaille. The 1991 season ran from 15 April to 15 September. The season was 153 days long with operational days extending from 0700-2200L. The program covered 2295 hours of normal weather center operation which were extended to 2438 hours of overnight operation due to thunderstorm occurrence between 2200L and 0700L. The forecast area supported by the F2P2 is shown in Figure 1.

This report will detail the degree of success achieved by the 1991 F2P2, identify significant weather events, and outline supplemental services provided.

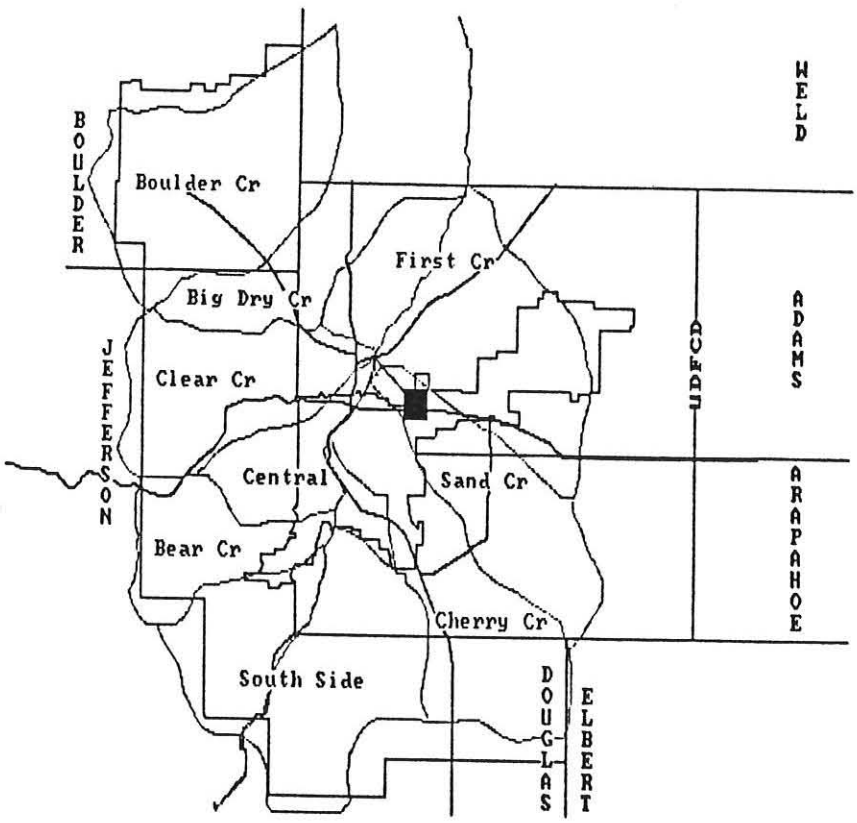

Figure 1 General map of District F2P2 Forecast Area

2.0 DEGREE OF SUCCESS

The 1991 F2P2 is regarded as a very successful program which achieved above average performance. Program success will be presented on a seasonal, District-wide and county/city basin for issuance of Message 1's (M1). Verification statistics will be provided to support the conclusions.

It will be noted that direct comparisons between the 1991 season and prior years again were not possible. In 1990 a change in the definition of a Message Day was made. The 1990 F2P2 Message 1 definition specified that a Message 1 would be issued only when the rainfall prediction called for 1 inch of rain or more to fall within a one-hour period or when the predicted intensity exceeded a 5-year frequency (i.e., 0.5 inches within 10-15 minutes). This definition was used again in 1991. Please note that Message 1 issuance in prior years was not restricted or defined by quantitative definitions but by a qualitative set of flooding definitions. However in 1991 aRed Flag tag was issued for Message 1's whenever a better than 60% chance of flooding occurrence was predicted. In effect the Message 1-Red Flag became the driving force for action in the program while the Message 1 became an internal alert of heightened flooding potential.

Seasonal/Distrct-wide

The 1991 F2P2 season experienced an above normal number of urban thunderstorm flooding potential days. The program began slowly on Sunday, April 15th and concluded in sunshine on September 15th. Most F2P2 seasons experience an average of 32 Message 1 days while in 1991 the program experienced 42 Message 1 days or 130% of the 13 year average. While the season started slowly with no M1 days in April, 4 M1 days were noted in May, 7 M1 days in June, 14 M1 days in July, 12 M1 days in August and 5 M1 days in September. The M1 day occurrences were above average in May, August and September. Speculation persists that the active August and September storminess of the past two F2P2 seasons is related to the moderate El Nino event currently in progress. If this speculation is correct we could expect a wet stormy start to 1992 season in May and July with decreasing storminess from mid-July through September as the El Nino effects begin to wane.

A seasonal comparison of the F2P2's since 1979 is presented in Table 1. The 1991 F2P2 was about average in accuracy and above average in false alarm rate compared to prior seasons while the number of observed M1 days of 31 was above average. Prior to 1990 a M1 day hit required that at least one District county reported a flooding event while since 1990 it required that a 1 inch/hour or 5-year frequency rain was observed in a District county. The close resemblance of seasons suggests the new M1 day definition was a step in the right direction. The addition of the Red Flag Message 1 criteria and the dis-continuance of the Thunderstorm Advisory may be related to the 1991 performance.

TABLE 1

VERIFICATION OF SEASON-BY-SEASON MESSAGE DAY FORECASTS (1979-1991)
FOR DENVER, COLORADO FLASH FLOOD PREDICTION PROGRAM

	Forecasts of M1 Days		Percent		
Year	Hit	Misses	M1 Accuracy	False Alarm Rate	Probability of Detection
1979	17	9	65	35	85
1980	23	12	66	34	100
1981	31	9	77	23	100
1982	34	8	81	19	100
1983	32	5	86	14	100
1984	32	6	84	16	100
1985	25	3	89	11	100
1986	30	5	86	14	97
1987	40	7	85	15	100
1988	24	4	86	14	100
E 1989	26	5	84	16	100
1990	26	4	87	13	93
1991	31	11	74	26	100
Averages:	26	6	81	19	99

E=Estimated statistics generated for the 1989 season.

It is our opinion that the dis-continuance of the Thunderstorm Advisory(TA) and adoption of the Message 1-Red Flag criteria caused the related decrease in 1991 season accuracy and increase in the false alarm rate. In previous years the TA had been used to alert users to the increased potential of thunderstorm occurrence at levels just below Message criteria. F2P2 users requested the TA's be ended and similar information be issued in a twice daily Heavy Precipitation Outlook(HPO).

The F2P2 forecaster however had lost an effective county/city-specific tool to alert users to the threat of abnormal thunderstorm activity with the demise of the TA. Additionally the Red Flag criteria was used to "red flag" Message 1 flooding potential siuations whenever the probability of occurrence exceeded 60 %. The net effect resulted in the meteorologist issuing more M1's, especially blanket M1's, on weekends or on days when a TA would have been used to "get users' attention". As experience was gained during the season the over-use of M1's was reduced. Overall the users were very pleased with the new M1 philosphy and appeared to be very pleased with the results of the support.

Table 2 shows a monthly distibution of M1 days for the District. Message 1's were issued on 28% of the days in 1991 F2P2 compared to 18% of the days during the 1990 F2P2.

TABLE 2

1990/1991 F2P2 Monthly Message 1 Day Occurrences

Month	1990	1991
April	0	0
May	1	4
June	0	7
July	12	14
August	10	12
September	7	5
Total	30	42

County/City Success

A better measure of individual user success is the verification of M1 events on a county or city basis. M1's are issued for all counties in the District and five cities served by District warning systems. The counties are Boulder, Jefferson, Adams, Arapahoe, and Douglas Counties. The cities are Denver, Aurora, Arvada, Lakewood, and Wheat Ridge. A concentrated effort was mounted to verify M1's by county and city in 1990 and 1991 as part of the Product Evaluation Program (PEP).

Prior to 1990 county/city specific M1 verification was performed in the 1987 F2P2 season. In 1987 353 individual M1's were issued on 47 M1 days. Of the 353 M1's, 155 M1's were verified while 198 M1's were not. Many of the misses were attributed to the lack of adequate rain gage networks but the fact remained on 44% of the M1's verified in 1987.

Since 1987 District has added over 60 rain gages for use in the F2P2 and the complaint still exists that more gages are needed to adequately record rainfall. The primary areas of poor data are Adams County, southern Jefferson, Denver County, southwestern Arapahoe County, and all of Douglas County. Until the areas are covered, complaints will continue.

A daily verification of M1's by county and city is recorded in Table 3. All verifications were made on the basis of raingage reports of 1" or more of rain in an hour or a rainfall intensity of equal to or greater than a 5-year frequency (i.e., 0.5" in 10-15 minutes). Many of these verifications were obtained from District ALERT gages or cooperative NWS or F2P2 observers.

Table 3

TOTAL MESSAGE DAYS: 42
TOTAL QPF DAYS: 25

DATE	HPO	M-1	M-2	M-3	IMS	QPF	MESSAGES VERIFIED BY COUNTY: ARAPCO	DOUGCO	JEFFCO	ADCO	DENCO	BOCO	AURORA	ARVADA	WHTRDGE	LKWD	
05/15/91	1	1			1	1		H		H							
05/23/91	1	1			1	1		H	H				H				
05/28/91	1	1			1			H		H	M		H				
05/31/91	1	1			1		H	H	H	H	H	H	H	H	H	H	
06/01/91	1		1	1	1	1	H	H	H	H	H	H	H	H	H	H	
06/02/91	1		1	1	1		H	H	H		H	H	H	H	H	H	
06/06/91	1	1	1	1	1	1	H	H	H	H	H	H	H	H	H	H	
06/07/91	1	1			1			M	M		M		M	M			
06/10/91	1	1			1		M	M	M	M	M		M	M	M	M	
06/21/91	1	1	1		1	1	H	H	H	H	H	H	H	H	H	H	
06/22/91	1	1			1	1	M	M	M	M	M	M	M	M	M	M	
07/08/91	1	1			1	1	H	H	M	M	M		M	M	M	M	
07/09/91	1	1			1		H	H	H	H	H	M	H	H	M	M	
07/10/91	1	1			1	1			H	M	M	H		M	M	M	
07/11/91	1	1			1							M					
07/12/91	1	1			1		H	H	H	H	H	M	H	H	H	H	
07/13/91	1	1			1	1	M		M			M		M	M	M	
07/19/91	1	1			1	1	H	H	M	M	M	M	H	M	M	M	
07/20/91	1	1			1		H		H	H	H		H				
07/21/91	1	1			1	1	M	M	M	M	M	M	M	M	M	M	
07/22/91	1	1			1	1	H	H	H	H	H	M	H	H	H	H	
07/23/91	1	1			1	1	H	H	M	M	M	M	H	M	M	M	
07/24/91	1	1			1	1			H								
07/25/91	1	1			1	1	H		H	M	H	M	H	H	H	H	
07/26/91	1	1			1	1			H	M	H	M	H	H	H	H	
08/02/91	1	1			1	1	H	H	H	H			H				
08/03/91	1	1			1		H	H	H	M	H	M	H	M	M	M	
08/05/91	1	1			1	1	H		H		H	M					
08/06/91	1	1			1	1	H	H	H	M	M		M	M	M	M	
08/08/91	1	1			1	1			M			M		M	M	M	
08/09/91	1	1			1		M	M	M		M		M				
08/11/91	1	1			1		M	M		M	M		M				
08/13/91	1	1			1	1	H	H	M	M	M	M	M	M	M	M	
08/16/91	1	1			1		M		M	H	H	M	H	M	M	M	
08/19/91	1	1			1	1	M	M	M	M	M	M	M	M	M	M	
08/27/91	1	1			1		H	H			H		H				
08/28/91	1	1			1	1	H	H	H	H	H		H			H	
09/04/91	1	1			1	1	M	M	M				M				
09/07/91	1	1			1		M		M	M	M	M	M				
09/09/91	1	1			1		M	H	H	M	M	H	M				
09/12/91	1	1			1		H						H				
09/13/91	1	1			1	1			H	H		N					
																	TOTAL
							HIT 21	21	21	14	16	13	21	10	9	10	156
							MISS 11	8	15	16	16	13	13	15	15	15	137

Table 3 shows in the 1991(1990) F2P2 293(189) M1's were issued with 185(139) issued to counties and 108(50) to cities . Of the 293 M1's, 156 M1's verified or 53% with no difference in county or city verification. A direct comparison of the 1990 and 1991 seasons may not be fair due to differences M1 definitions, the demise of the TA and a more active year in 1991 for storms.

A more appropriate comparison may be to note that Red Flags were issued for all 156 M1's which verified and only 15 Of the 137 M1's which did not verify. Since the Red Flag was designed to alert users to a "greater than 60% likelihood of a Message criteria flooding occurrence" the 91 % accuracy of the Red Flaged M1's was extraordinary while their false alarm rate was less than 10 percent. Verification of Red Flags was similar for county and city verification. Red Flags were issued for only 171 of the 293 Message 1's issued or about 58 percent.

It will be noted that "Big Bust" or over-messaging days continue to be a problem. Almost two-thirds(91) of the non-verifiying M1's occurred on 12 days. Table 4 identifies these Big Bust days which were attended by active thunderstorms, severe weather and rainfall of 0.04" to 0.47" 83% of the time. User support was enhanced on these days by the cancellation of about two-thirds of the M1's by 5:00 PM. Thus overtime requirements were not affected by the false alarms and severe weather kept emergency operations busy most of the time. However the occurrence of heavy rainfall was over-forecast.

Table 4

Identification of "Big Bust" Message 1 days for 1991 F2P2

Date	M1 Hits	M1 Misses	Rainfall (Non-verify area)
June 7	0	5	.04 - .31"
10	0	9	.08 - .47"
22	0	10	.04 - .19"
July 8	2	7	.02 - .43"
13	0	6	None
19	3	7	.04 - .16"
21	0	10	None
23	3	7	Less than 0.50"
August 8	0	6	.24 - .47"
13	2	8	.24 - .35"
19	0	10	None
Sept. 7	0	6	.04 - .24"

The most common similarities of these days and those from 1990 F2P2 are the poor forecasting or analysis of low level moisture and wind fields or the forecaster's choice to alert the District to the potential of an isolated heavy thunderstorm rainfall. It is hoped "bust reviews" will unlock other insights before the 1992 season begins.

Over two-thirds of the M1's verified in Douglas, Jefferson, and Arapahoe Counties and City of Aurora. Less than 60% of the M1's verified in Boulder (50%), Denver (50%), and Adams (47%) Counties. The disparity in the verification may be due to the lack of gages in eastern Boulder County, Denver County and eastern Adams County. In 1990 only 3 District ALERT gages were located in eastern Boulder County and 2 gages in Adams County. Verifications in these areas were largely dependent on cooperative observers. In all three locations Red Flagged M1's verified over 85: of the time indicating a heightened support level than indicated by M1 verification alone.

Given the high level of user support for the F2P2, the false alarm rates inherent in the above statistics must be balanced by the timely level of suppport delivered. In general, it appears that two out of three hits may be adequate to retain support.

Significant Storm Events

The 1991 F2P2 storm season produced a number of memorable storm dates. This section will briefly identify the primary storm event dates and a short commentary on the storm. HMS has more complete data summary on the storms and associated operations.

The 1991 F2P2 season began with a "storm-free" period from 15 April to 15 May. Few severe thunderstorms and even fewer heavy rain events were noted in this period. On May 15 post-cool front easterly winds provided the fuel for a barrage of hail and rain bearing storms District-wide. The media's heightened awareness of hail damage and street flooding from these storms led to KWGN airring a highly favorable story on the the F2P2 on their 900PM News of May 16th .

A summary of significant 1991 storms is shown in Table 5. Eleven of the 31 active storm days were selected due to either their unusual occurrence characteristics or intense rainfall. Selection to this list was the subjective choice of the HMS Project Manager.

Of these days the heaviest and most wide-spread thunderstorm rainfall occurred on June 1, 1991. On this day several clusters and bands of intense thunderstorms formed in northern Jefferson, western Arapahoe and northern Douglas Counties and moved slowly north-northwestward across the District between 1230Pm and 700PM. The initial storm barrage began in Boulder County where heavy storm rainfall estimated at 1.50 - 2.25"/30-60 minutes flooded streets and small streams between 1230PM and 130PM. The second wave began along the western Arapahoe and eastern Jefferson Counties between 200Pm and 300PM. These storms flooded streets and urban streams from Columbine Country Club through Lakewood into Golden with 4 - 12 inches of 0.75" to 1.5" diameter hail and 1.5 - 3.5" rainfall in less than 1 hour.

A thrid wave of storms moved out of northern Douglas County into western Arapahoe and denver Counties between 345PM and 500PM. Hail to 1 " diameter, funnel cloud reports and 1-2" of rainfall in less than an hour flood Littleton, Aurora, Englewood and Denver streets and streams.

Table 6
List of Significant 1991 Storm Event Dates
and Brief Storm Summaries

Date	Storm Summary
May 15	Severe t-storms barraged the southern and central portions of District from 1:30PM until sunset. Northern Douglas County hit by 1" diameter hail and an estimated 1-1.5" rainfall. Heavy rains and hail to 0.75" diameter flooded streets in Lakewood, Denver, Littleton and Englwood.
June 1	The strongest storms of the season flooded portions of Boulder, Jefferson, Denver, Arapahoe and Douglas Counties. Rainfall of 0.75" - 3.5"/30-60minutes and hail to 1" diameter accompanied the storms.
June 2	The second day of monsoonal madness brought street and urban stream flooding to Douglas, Denver and Arapahoe Counties. Goldsmith Gulch was hit quite hard.
June 6	Tornado threats and heavy rain brought rush-hour traffic to a standstill in the southern half of the District. Aurora was hit by 0.67" - 1.50" /45 minute street flooding rainfall.
June 21	Severe t-storms pelted Jefferson, Adams, Denver, Arapahoe and Douglas Counties with 1-2" hail and 0.55 - 1.73"/30-60 minute cloudbursts. Ralston Creek in Arvada was hit hard.
July 12	Very heavy foothills t-storms flooded downtown Golden on Kinney's Run with a 1-2"/30-60 minute deluge and Lena Gulch received 0.43 - 1.18" in 45 minutes in Lakewood.
July 22	Ralston Creek in Arvada and Denver's Goldsmith Gulch were hit hardest by slow-moving mosoonal t-storms about mid-afternoon.
July 25	The National Weather Service Office at Stapleton Airport recorded 1.86"/46 minutes of rainfall, the second most-intense t-storm rainfall recorded in Denver by NWS.
August 2	An intense but highly local t-storm battered the Cherry Creek Reservoir and Goldsmith Gulch basins with up to 2.5"/60 minute rainfalls. A smaller but strong storm hit Ralston Creek and Arvada at almost the same time.
August 3	Another round of very heavy storms affected most of the District with the heaviest storms dropping over 2.24" in Jefferson County and 1-2"/30-60 minutes in Douglas, Adams and Arapahoe Counties.

A more complete verification of message days, TA's, QPF's, and storm tracks can be reviewed at the HMS offices. In general, the 1991 season afforded an excellent opportunity to test new products and dissemination techniques.

3.0 SUPPLEMENTAL PROGRAMS

In addition to the F2P2 base operations, three supplemental programs were continued for 1991:

a. Storm/Archive/Video Evaluation (SAVE)
b. STORMTRAK Fax Map Program
c. Prediction Evaluation Program

This section of the report provides some information on each program and identifies key results which contributed to the success of the 1991 F2P2.

Storm/Archive/Video Evaluation Program

The Storm/Archive/Video Evaluation (SAVE) program was run from April 151 to September 15, 1991. The SAVE program's objective was to provide a video tape record (VTR) of thunderstorm activity for all days M1's were issued. A VTR was made for 28 days listed in Table 6. The VTR was made off of the District's Sony 27" color monitor rendition of the Kavouras C2R2 signal of the NWS radar in Limon, Colorado. The taped record of M1 days has provided valuable input to the following F2P2 activities:

a. Provided an opportunity to "replay" the previous day's F2P2 activity and answer F2P2 county and city questions on where storms happened.

b. Provided direct evidence of thunderstorm origin, development sequence, and storm tracks. Invaluable information on storm development was obtained.

c. Assisted in documentation of storm location and intensity over flooded basins for QPF verifcation.

d. Assisted in providing spatial coverage information for predicted thunderstorm systems.

The SAVE program provided District with a compatible archive of the source of the rainfall reported in District ALERT gages. The value of this data base should grow as District efforts to understand the spatial and temporal distribution of rainfall increase in years ahead. However its primary value is to the weather forecasting efforts. It is recommended that this program be removed the 1992 F2P2 season but that the 1992 F2P2 PMS be strongly encouraged to continue it in-house.

STORMTRAK FAX Map Program

This program was has primary products:

a. A predicted storm track fax map was to be produced for M1 days with a 30 minute leadtime.

b. The HMS Canon 850 fax was used to send copies of ECO, HPO, IMS, and QPF products directly to F2P2 users.

Storm track maps were issued for all M1 days from 15 April to 15 September 1991. The Storm Track/Fax program is strongly recommended for the 1992 F2P2 program. Fax transmission of F2P2 products will greatly enhance the ability of users to receive and re-transmit an unaltered hard copy within their county, city, or agency.

An additional initiative of HMS was to fax pre-prepared Message forms directly to dispatchers thus eliminating communication problems in verbal Message tranmission and improving accuracy of the Message. This procedure was enthusiastically embraced by dispatchers and lauded by managers and decision-makers. It is recommended for inclusion in the 1992 F2P2.

Prediction Evaluation Program (PEP)

The Prediction Evaluation Program or PEP was the least visible but possibly most productive of the three programs. PEP activities included evaluations of the timeliness or leadtime of M1's, accuracy of QPF products, and correlation of storm tracks to actual weather. It should be noted that valuable insights were gained in each of these areas within 48 hours of M1 days which were immediately used to fine-tune the program.

Verification of QPF forecasts were done for all M1 days as shown in Table 3. Each verification shows the HMS predicted storm mass curves plotted against rainfall observed in District ALERT gage networks. In each case of QPF verification, copies of the HMS QPF versus observed rainfall was presented to District within 48 hours of the event to promote timely evaluation and verification for use with local government agencies. Additionally, the QPF verification plots allowed HMS meteorologists the opportunity to adjust prediction schemes and appreciate the differences between the observed and predicted rainfall. All initial HMS QPF's are produced before noon daily or before storm clouds begin forming. While the HMS QPF's are not perfect, it is encouraging to note the general ability of the CSM to anticipate the amount and temporal precipitation distributions.

Finally, PEP funding allowed HMS the opportunity to call F2P2 users the morning after a M1 event for the purpose of eliciting immediate user feedback on F2P2 products. These informal surveys were noted in the log and used to fine-tune customer support daily.

4.0 CONCLUSION

The 1991 F2P2 can be judged as a very productive and successful storm season. The introduction of new Message 1 (M1) RED FLAG definitions affected operations very positively as evidenced by improved M1 verification on a District, county, and city basis. The use of facsimile machines to hasten the accurate transmittal of F2P2 products was extremely successful and appears poised to expand during the 1992 F2P2 season.

New fax storm track products were enthusiastically embraced by users while a video tape radar archive program recorded complete radar records of all important storms. A daily Product Evaluation Program enhanced fine-tuning of QPF, storm track, and general F2P2 products by HMS and afforded direct customer input into product evaluation. In conclusion, the prognosis for the 1992 F2P2 appears bright and very encouraging.