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THE DENVER FLASH FLOOD PREDICTION PROGRAM

OF THE

URBAN DRAINAGE & FLOOD CONTROL DISTRICT OF DENVER

CONDUCTED BY

HENZ KELLY & ASSOCIATES
DENVER COLORADO

Final Report for the 1987 Operational Season

15 April to 15 September 1987

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INTRODUCTION

Since 1979 the Urban Drainage & Flood Control District (referred to hereafter as District) has sponsored a flash flood prediction program (F2P2) for the six county Denver metropolitan area. The six counties served directly are: Denver, Boulder, Jefferson, Adams, Arapahoe and Douglas. Additionally site-specific predictions are given to Lowry Air Force Base, Aurora, Lakewood, Wheatridge and Consolidated Mutual Water. This report presents a verification of the 1987 operational season and identifies potential improvement areas to be addressed for the 1988 season.

VERIFICATION OF THE 1987 F2P2 OPERATIONAL SEASON

A continued high level of support was achieved in the 1987 F2P2 operational season despite a record number of operational excessive convective rainfall days which challenged the program. Important new experience in providing hydro-meteorlogical support to users was gained by the mutual interaction of HKA meteorologists and District hydrologist Kevin Stewart in supporting the Lena Gulch Warning system. Three major urban flash flooding events occurred in the District which were accurately forecast but identified a number of program improvements which could be achieved.

A summary of verification statisitics achieved by the program for the 1987 operational season as compared to the previous five year average is presented in Table 1.

Table 1 1987 Operational Verification Results for the UDFCD Flash Flood Prediction Program Conducted by Henz Kelly & Associates

	1987	Average 1982-86
Number of Message Days	40	31
Percent correct District Message Day forecasts	87%	84%
District Message Day False Alarm Rate	13%	16%
Percent correct Yes/No Daily Forecasts	96%	96%
Percent correct County Message Day forecasts	60%	55%
County Message False Alarm Rate On Message Days	40%	45%
Percent of heavy rain events forecast in Messages	100%	99%

The statistics in Table 1 present 1987 F2P2 operational results on both a District-wide basis (as in past years) and on a county basis (for the first time). The reason for the expanded statistics is the improving ability of operational meteorology in general to forecast convective events. In 1979 when the F2P2 started no one in the weather profession believed storms could be forecast to occur in an area the size of the District before they occurred. The National Weather Service issued severe weather warnings for areas the size of several counties with a false alarm rates of over 80%. The District's F2P2 set a new national standard for convective forecasting over the next 9 years.

Within the F2P2 the District-wide Message day forecast continues to be 87% correct with a District-wide false alarm rate of 13%. This statistic means that on 87% of the days HKA issued a Message for all or part of the District a heavy rain or flash flooding event was observed within the portion of the District receiving the Message. It does not imply that all the counties receiving the Message experienced a heavy rain or flash flooding event.

No heavy rain events occurred within the District in 1987 that went unforecast. Messages were issued on six days for which no heavy rain events were noted. On four of these days severe weather events did occur as heavy thunderstorms crossed the District. It is possible a heavy rain event went unrecorded and verification efforts are still in progress.

Verification of Message day service in the District is evolving. An effort was made this summer to create a data base of all heavy rain events occurring in the District or reported to the F2P2 since 1979. Using this data base all Messages were verified by the occurrrence of a heavy rain event in each county for which the message was issued. Again the issuance of heavy rain or flash flooding event forecasts for small areas the size of a county is not considered the national standard at this time. However the effective use of resources in the counties requires that the forecast be as definitive in time, space and quantity as possible. Basin-specific forecasts are being routinely requested as are storm track, speed and associated weather events.

The re-verification of the Messages issued since 1979 and the 1987 operational season are discussed in detail in the next section of the report in detail. In general 60% of the Messages issued to individual counties verified with a heavy rain or flash flooding event in the county or portion of the county included in the Message. Thus the false alarm rate on a county basis was about 40% or similar to the results of the past five years.

It should be noted that the county Message day verification is based on a data base that may be full of holes, especially from years past. Many heavy rain events go un-noticed or reported each year. However we feel that it is of value to try to evaluate the service being given to each county. Thus atleast 60% of the individual county Messages verified during the 1987 season. On about 25% of the Message days severe weather events in the form of tornadoes, high winds, hail or funnel clouds were noted over the counties in the District. Forecasts and information on these associated weather events was provided upon request to the counties. The perceived value of the county Messages was enhanced, we believe, by these weather events and the support received by the counties even if a heavy rain event was not observed.

We believe that an acceptable county Message false alarm rate is 20%. So far only the Boulder and Adams County false alarm rates are this low. Denver, Jefferson and Douglas County false alarm rates are closer to 60% while Arapahoe County, Aurora and Lowry AFB are about 50%. Part of the reason for the high false alarm rate in Jefferson and Douglas Counties may be the lack of ground truth reports of flooding events that actually occurred. In Denver, Arapahoe and Douglas Counties the mesonet surface weather station coverage is much sparser than it is in the northern suburbs. More detail on the forecast implications of this weather data sparseness on the forecast problem will be entertained in the next section of the report.

Finally information is presented in Table 2 below on the monthly issuance of Messages and thunderstorm advisories(TA). The occurrence of 40 Message days in the 1987 operational season days broke the previous record of 34 set in 1982. Thunderstorm advisories were issued for another 20 days when near-Message level rainfall was expected or intense storms were likely to occur. All thunderstorm advisories verified.

Table 2 Monthly Message Day Verification for 1987

Month	# Message Days	# Hits	# Misses	# Thunderstorm Advisory Days
April	0	0	0	0
May	13	11	2	8
June	10	8	2	7
July	10	9	1	4
August	10	9	1	1
Sept	3	3	0	0
Total	46	40	6	20

Three major flash flooding event days occurred during the 1987 operational F2P2 season: May 17th, May 23rd and June 8th. On May 17th Messages were issued between 1145MDT and 1202MDT to the entire District calling for general 0.50 to 1.00"/hour storm rainfalls and isolated threat of 1-2" in a stationary storm with hail and a possible tornado in Douglas or Arapahoe County. The valid time of the Message covered from noon until 1900MDT with some slight variations by county. Severe thunderstorms crossed the District from Lakewood(1325MDT) to Aurora(1530MDT) dropping hail and 1-2" rains in 30-45 minutes. In Aurora a strong thunderstorm went stationary over Iliff and Chambers about 1515MDT. Updates to Aurora between 1506 and 1549MDT forecast 2" of rain in the next hour with hail and a brief tornado threat in the southeastern part of the city. Douglas County was warned of both the rain and tornado threat. Serious street flooding occurred in Aurora with an estimated 1.75-2.75" at Quincy and Parker Rd. A tornado touched down 2 miles north of Parker about 1515MDT. All counties receiving a Message reported street flooding. Very effective service was rendered to the counties for this event.

June 18th

About one week later on May 23rd almost a repeat performance was noted. Messages were issued to the entire District between 1330MDT and 1400MDT calling for 0.50 to 1.50" of rain in 30-45 minutes with hail. The Message was valid from 1500 to 2200MDT across the District. About 1550MDT as storms developed Update statements were sent to Arapahoe, Adams and Douglas counties calling for up to 3" of total rainfall with hail over the next 60-90 minutes. Serious flooding occurred over the Tollgate basin in Aurora and over SE Aurora. Rainfall estimates of upto 2.50" were received from Aurora. Street flooding also occurred in Denver, Arapahoe and Adams Counties. Again very effective service was delivered to the counties and all counties receiving a Message reported street flooding.

The final significant event occurred the evening of June 8th across Lena Gulch, northern Jefferson County and over most of Denver County. A general Message was issued for the entire District between 1530-1600MDT calling for 1.5"/30 minutes and up to 2.50" total rainfall from thunderstorms. The valid time for the Message was from 1600-2300MDT. Between 2000MDT and 2230MDT serious flash flooding occurred over Lena Gulch in Jefferson County and portions of downtown Denver County. Lena Gulch received about 2.00" in 90 minutes between 2030-2230MDT which caused Lena Gulch to fill and slightly overtop. Some street flooding was noted along the Gulch and evacuations were considered. At 2050MDT a very effective statement concerning the rainfall was isssued to Jefferson County and Wheatridge and at 2116MDT Lakewood was notified. Based on UDFCD written guidance of 2" in an hour creating a flooding problem and the HKA forecast calling for 1-2" basin average rainfall by 2200MDT authorities were ready. In Denver similar heavy thunderstorm rain forecasts were issued at 2036MDT for portions of the city, especially I-25 and Speer Blvd. where heavy flooding was anticipated.

Unfortunately this Update was called to Denver OEM where an unauthorized person answered the phone and took the data. Proper procedure called for Denver Fire Alarm to get the call and page Pager # 629. When OEM answered it was assumed wrongly that the OEM had been activated on the basis of the earlier Message's content and subsequent storm development The data was never received by the on-call OEM officer. Thus this update was not received and Denver experienced less than perfect support. This communications problem has since been eliminated with appropriate changes to the HKA SOP.

Several key factors emerged from the June 8th case:

a. The Message was issued at 1530MDT due to lack of confidence about the location of two key upper air features, a closed mid-level circulation and and upper level short wave trough. Both of these features are routinely monitored by use of color satellite IR animation but satellite information was not available to HKA due to vendor sector problems and 60-90 minute data transmission delays. Better satellite support could have allowed earlier Message issuance. As it was the Message was issued just before shift changes and the end of the work day and it "may have fallen into the crack" for some users.

   POINT: Satellite information needs to be received and used to improve timing.

   VISTA ~~WAST~~ ORDERED

   POINT: Improved communications is needed to speed Messages to users.

b. A communications/operations crisis hit at HKA when the radar screen lit up between 2015-2045MDT and a large portion of the District was subjected to heavy rainfall. Many users wanted to be supported simultaneously. Crucial analysis and display of mesonet and radar data was postponed to handle the communications bottleneck which ensued.

   At the present time mesonets must be acquired by manual telephone modem interaction and then manually plotted. Additionally mesonet data must be entered into the HKA Excessive Convective Rainfall model to assist in rainfall estimates and radar interpretation. While radar data is continuously received at HKA, a "poor man's" echo animation is achieved by manually entering sequential radar images into memory and manually pushing buttons to activate each memory bank and "animate" radar echo movement patterns. These crucial manual exercises were not physically possible to do during the communications crisis. The radar display was not animated and thus stationary and quasi-stationary raincell could not be quickly identified.

   RADAC UPGRADE ORDERED

   POINT: Mesonet coverage is lacking and sorely weakens the ability to support F2P2 users in Denver and the southern District. Additionally it weakens the ability to identify moisture flux focal points into the storms.

POINT: Lack of radar echo animation capability and effective radar echo basin overlays weakens the ability to issue point specific updates and storm/basin rainfall forecasts.

POINT: Communications need to be more immediate to the user during crisis situations. The system must be over -designed to handle the crises when it is really needed not the day-to-day situations.

POINT: The ability to display and plot mesonet and radar data simultaneously is needed to handle the 1 to 3 serious storm situations which hit the District every summer. This investment must be made.

c. Hydrological aids provided to HKA for use in the Lena Gulch warning plan ranged from extremely useful to barely adequate to handle the June 8th crisis. The alarms on the Lena Gulch basin alerted the duty meteorologist to the heavy rainfall rates occurring from low intensity radar echoes that could have been overlooked in the busy work environment of 2000MDT to 2100MDT. These alarms assisted in prompting the 2036MDT Update forecast to Jefferson County and Wheatridge concerning Lena Gulch flooding. On the other hand hydrological decision aids provided to HKA indicated problems on the Gulch when basin average rainfalls reached 1.96". HKA received road topping reports after less than 1.00" basin average had been reached by 2130MDT. Evacuation guidance was requested at this time and was given. It is suggested that the high intensity of the rainfall may have affected the runoff in the Gulch and resulted in the slow estimate of runoff problems in the decision aid.

POINT: Continued development of hydrological decision aids is needed. Dialogue has begun to support this effort but a commitment is needed to insure the result. Decision aids are needed for all basins in the District where potential loss of life or of significant property damage is possible. Additional basins besides Lena Gulch include Bear Creek, Turkey Creek, Ralston Creek, Tucker Gulch/Kinney's Run, Tollgate Creeks, Sand Creek and Cherry Creek could be targeted for aids.

POTENTIAL F2P2 IMPROVEMENT AREAS

Several areas in which specific improvements in F2P2 service can be achieved are: improved spatial specificity of Messages, improved communications, improved hydrological decision aids, improved mesonet data, ability for basin scenario modeling and historical recording of major storms. Suggested improvement areas are detailed below:

a. IMPROVED SPATIAL SPECIFICITY OF MESSAGES

A detailed effort to re-verify all MESSAGES issued since the start of the program in 1979 has been made. An attempt was made to identify all heavy rain events that occurred in the District for MESSAGE days. We know that the verification data base has holes but it represents "a best possible database" from which to assess the program.

The key findings of the re-assessment indicate the following:

1. From 1979-1982 heavy rain events were actually noted in only 40% of the counties issued a MESSAGE. While the District-wide MESSAGE day verification was about 73% correct, 60% of the counties issued MESSAGES did not note a heavy rain event. At the time National Weather Service had a false alarm rate of over 80% on a state-wide basis. Comparatively the District F2-P2 county false alarm rate was lower and more specific.

2. From 1983-1987 heavy rain events were noted in about 60% of the counties issued a MESSAGE on a MESSAGE day. The District-wide MESSAGE day verification improved to about 85%, however, about 40% of the counties issued a MESSAGE on a MESSAGE day still did not note a heavy rain event.

3. It is important to note that on the MESSAGE days in question those counties which did not note a heavy rain event usually experienced either severe weather events or thunderstorms in most cases. Thus the customers' perceived level of service may have been enhanced by the timely occurrence of these other events. In effect the counties were ready for whatever thunderstorm-type event occurred.

To summarize the District-wide MESSAGE day verification improved from about 72% in the 1979-1982 period to about 85% in the 1983-1987 period. In effect the District-wide false alarm rate was reduced from 28% in 1979-1982 to 15% in 1983-1987. On these MESSAGE days the individual county false alarm rate was reduced from 60% in the 1979-1982 period to 40% in the 1983-1987 period. In short the reduction in the false alarm rate is likely due to improved use of the Environmental Reserch Laboratory's Mesonet (a surface weather station network) and the development and operational application of the HKA Excessive Convective Rainfall model.

We believe that an acceptable false alarm rate on a county basis is about 20% for the prediction of a heavy rain event. Please note that achieving this goal would require a 50% reduction in the existing false alarm rate. It would require in our opinion a noteable improvement in the Mesonet weather data network, improvements in the HKA ECR model and possible availability of Profiler data (vertical resolution of temperature, moisture and wind fields).

At present we believe that the 20% county false alarm rate has been achieved in Boulder and Adams Counties. In part this is due to the heavy Mesonet station concentration in the northern half of the District. See Figure 1 and note that 9 mesonet(5minute updates) and 2 NWS(60 minute) stations exist while in the southern half of the District 4 mesonet and 3 NWS stations exist. There is a crucial disparity in available information to serve the south half of the District and the interior City/County of Denver.

The prime counties with high false alarm rates of about 50% are Denver, Jefferson, Arapahoe(exclusive of Aurora) and Douglas Counties. Improved service to these counties should be one of our primary goals in the near future. One of our proposals is directed at a solution to this improved service goal.

b. IMPROVED COMMUNICATION OF MESSAGE CONTENT AND DISSEMINATION

The number of county contact points has increased from 8 in 1979-1983 to 9 in 1984(Aurora) to 12 in 1987(Lakewood, Wheatridge and Consolidated Mutual). It is possible that the number will increase to include Arvada, Thornton, and Northglenn in the near future. As the number of county call points increases so too has the time required to issue MESSAGES. In 1987 a time study indicated that the telephone issuance of a blanket MESSAGE was about 20-25 minutes. In several short-fused situations crucial lead-time of MESSAGES was reduced by phone delays of 5-10 minutes. Communication with Denver was very slow, 8-15 minutes, for pager responses on weekends and after-hours. The dissemination of UPDATES was further slowed due to the increased workload on dispatchers during poor weather periods.

Additionally we have concerns that the content of our MESSAGES and UPDATES has been unintentionally altered by the time it is received by the end user. We believe that the electronic mail experience we have had with UDFCD indicates that such an approach using a dedicated communication line to each county focal point should be established. Our survey in 1985 indicated an interest in this form of communication existed in each county. While we do not propose to send the same statement we send to UDFCD each day, we could send other statements and all MESSAGES.

A noteable improvement was the addition of the mobile phone. It ended tha concern of local phone outages, allowed "on-the-spot support" and improved verification.

c. IMPROVED HYDROLOGICAL DECISION AIDS ARE NEEDED

The heavy rain event of June 8, 1987 on Lena Gulch and across the District demonstrated the need for improved hydrological decision aids to assist HKA in supporting Lena Gulch's Warning Plan and in reflecting the importance of storm intensity on runoff timing and volume. Discusssions were held to identify these needs during August and we are hopeful that new aids are forthcoming.

d. IMPROVED MESONET DATA NEEDED

Additional lessons in hydro-met support were learned with the over-forecasting of rainfall in Lena on the 9th of June when mesonet data and satellite data were not adequate to resolve the fine degree of specificity needed to forecast the small-scale basin rainfall event. This same problem was encountered on July 30th and August 23rd. In each case a degree of meteorlogical forecast specificity was needed that the data field existing in the District could not resolve adequately in an operational setting. The resolution of this problem may be the development of a commercial mesonet of sufficient resolution to address the forecast needs.

e. ABILITY TO DO BASIN SPECIFIC HYDRO-MET SCENARIOS

A need has been identified for an operational capability to assess the impact of forecasted rainfall in time and space on specific basins within the District. In effect the ability to assess the runoff potential of a predicted rainfall event. This scenario capability would assist in identifying "hot spots" of trouble in the District on a daily basis. The solution to this need will be the interface of meteorological and hydrological models and the professional assessment of the model output. The District and HKA took a bold step foreward the past two years by interfacing together on critical weather days without model support. An appreciation for mutual and exclusive problems inherent in scenario and operational decision-making was gained. However the need exists for the objective evolution of this interface into basin-

f. HISTORICAL RECORD OF MAJOR DISTRICT STORMS

A record of the impact and the spatial/temporal distribution of rainfall by significant rainstorms occurring within the District is needed. Such a record would enhance the development of scenarios for county exercises, the planning of flood mitigation projects and the development of a climatological record of local rainfalls for use in future construction projects.