VALIDATION OF THE ON-SITE FLASH FLOOD POTENTIAL SYSTEM FOR NEXRAD*

Mark L. Walton, Edward R. Johnson, and Robert C. Shedd

Hydrologic Research Laboratory
National Weather Service, NOAA
Silver Spring, MD 20910 USA

ABSTRACT

A Flash Flood Potential System has been developed for use in NEXRAD (Next Generation Weather Radar). The system, consisting of a precipitation projection procedure as well as a flash flood potential assessment procedure, has been tested on a storm in Colorado. Test results indicate that the projection procedure forecasts a one-hour precipitation accumulation with 66 - 83 percent of the grid points within 2.5mm of what was observed during the forecast hour. The flash flood potential assessment procedure accurately forecasts areas where flooding did occur. In addition, use of the Flash Flood Potential System could have resulted in flash flood warnings three hours earlier than the National Weather Service warning issued during the actual storm.

I. INTRODUCTION

Flooding during the 1986 fiscal year resulted in over 175 lives lost and a record $5.5 billion in flood damages. Flood damage will continue to increase as development in flood plains and upstream watersheds increases. Over the past ten years, floods and flash floods have become the major cause of weather-related fatalities within the United States. Unfortunately, about half of the National Weather Service's (NWS) flash flood warnings have no lead time; i.e., they are issued after flooding has begun.

The NWS's Hydrologic Research Laboratory (HRL) has developed a Flash Flood Potential (FFP) System for the Next Generation Weather Radar (NEXRAD). The NEXRAD FFP System consists of a precipitation projection procedure and a flash flood potential assessment procedure. The precipitation projection procedure forecasts up to one hour of precipitation accumulation. The forecasts are updated every volume scan (approximately every five minutes). The procedure also produces projected total precipitation accumulations and associated error variances. The projected total accumulation is composed of the previously observed accumulation and the projected accumulation. A more detailed description of the procedure is given by Walton et al. (1986). The observed precipitation data used by the FFP comes from the NEXRAD Precipitation Processing Subsystem (PPS) developed by HRL (Ahnert et al., 1983). These projections, accumulations, and error variances are then input to the flash flood potential assessment procedure.

The flash flood potential assessment procedure uses flash flood guidance values developed by the River Forecast Centers (RFC), and observed and projected precipitation accumulations output from the precipitation projection procedure to produce observed and projected Critical Rainfall Probabilities (CRP). The CRP is an estimate of the probability that the actual precipitation for some time during the rainfall event has exceeded or will exceed the flash flood guidance value. The flash flood guidance values are

*Presented at the Twenty-First International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, October 26-30, 1987.

based on hydrologic models run by the RFC's. They determine how much rainfall would be required over specified durations to produce flooding, given the current hydrologic conditions, at one or more locations within a zone or county. A more detailed discussion of the flash flood potential assessment procedure is given by Walton et al. (1985), although certain changes have subsequently been adopted.

Figure 1 contains a generalized block diagram of the current NEXRAD FFP System. This updated version shows the new projection procedure which uses a spatial moving average for the mean and variance of the precipitation rate and a pattern matching technique for the localized storm velocity determination (Walton et al., 1986). The probability products have also been changed from instantaneous products to composite probability products (i.e., integrated over the storm event) with the observed probability product being monotone nondecreasing. Product names have also been changed to more adequately describe the data present. The Observed and Projected Flash Flood Probabilities have been changed to Observed and Projected Critical Rainfall Probabilities. It is important to note that the information displayed by the probability products has not changed.

II. VALIDATION PROCEDURE

Validation of the algorithms included testing the total system with actual data and testing each component for computational accuracy. The code was informally verified, after being implemented, by manually comparing the final code to the functional descriptions. In addition, each major computational step was checked by manually computing intermediate results for selected time periods and locations and comparing these with values output by the system. Testing with actual data was done for a 5¼ hour case acquired by the National Center for Atmospheric Research (NCAR) CP2 Doppler radar.

III. DATA

The NCAR CP2 Doppler radar, located approximately 25 km east of Boulder, Colorado, was operated by the Prototype Regional Observing and Forecasting Service (PROFS) during the summer of 1983, for its operational forecast exercise and for the purpose of evaluating selected NEXRAD algorithms. In consultation with PROFS (Smart, 1983), the July 23, 1983, case was selected because of the existence of a flash flood producing storm to the south of Denver, Colorado, which produced over a half-million dollars in damages from heavy rain alone (NOAA, 1983) . The following, taken from Storm Data (NOAA, 1983), summarizes the nature and severity of the storm:

> Storm Data - July 23
>
> Another round of heavy thunderstorms blasted Denver and areas just to the south of the city. Douglas County was hardest hit; golfball sized hail fell in and to the north of Parker between 1:30 and 2:15 PM MST. Many homes at Pinery, a subdivision just north of Parker, had windows broken and paint stripped by the storm; some vehicles were dented by the large stones. In Parker, 1.90 inches of rain fell in just 30 minutes. Many roads in Douglas County were washed out, and at least one bridge was damaged. Up to two inches of rain fell in Lakewood and Littleton was drenched by 1.60 inches in 15 minutes. A department store in Lakewood suffered water damage when a pipe handling runoff broke, sending four inches of water onto the floor of the store. The rain also spread to Brighton, north of Denver, and to the east as far as Deer Trail; both spots had about an inch of rain in 30 minutes.

NCAR CP2 data were collected from 18:13Z (12:13 MDT) to 23:26Z (17:26 MDT) July 23, 1983. The characteristics of the data collected by the NCAR CP2 radar are similar to those planned for NEXRAD data collected during periods of

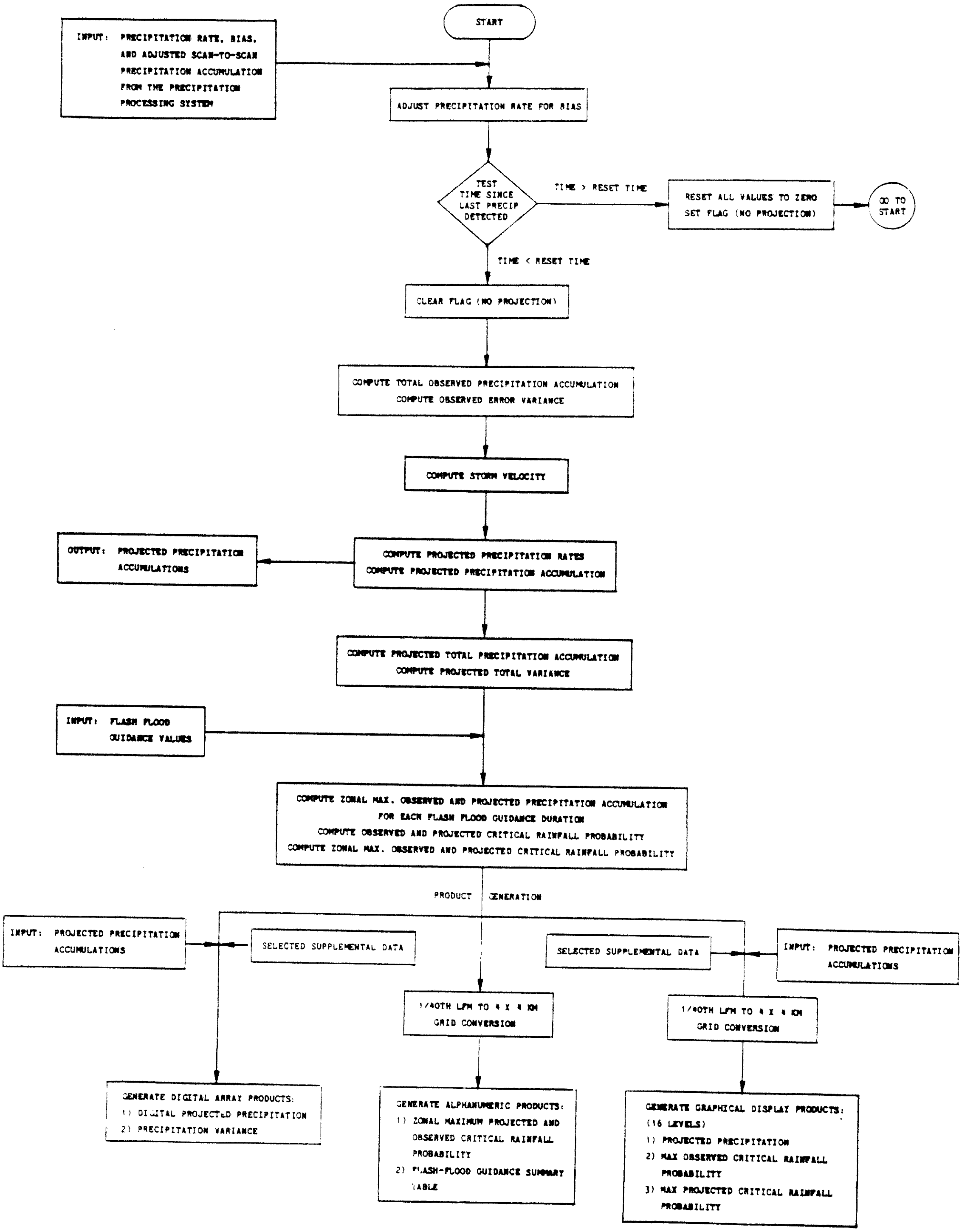

Figure 1. Generalized Block Diagram of the On-Site Flash Flood Potential System.

	Minimum NEXRAD Requirements (during precipitation)	CP2 (Storm mode)
Bin size	1° x 1 km	1° x 150 m
Range	1 km to 230 km	1 km to 160 km
Elevations (approx.)	0.5, 1.5, 2.5, 3.5, ...	0.5, 1.5, 2.5, 3.5, ...
Scanning	Sequential, 4 complete scans within approx. 2 min.	Sequential, 4 complete scans within approx. 1.5 min.
Frequency	Approx. once every 5 min. during normal operation	Approx. once every 5 min. occasionally once every 10 min.
Dynamic Range	0 to 71 dBZe	-10 to 80 dBZe
Precision	1 dBZe	0.01 dBZe
Number of Samples	Not specified	64/gate
Clutter Suppression	Applied in known clutter areas	Not applied

Table 1. (Ahnert et al., 1984)

precipitation (Table 1). In order that the input data better match minimal NEXRAD requirements, the CP2 data were averaged from 1° x 150 m values to 1° x 1 km values. In addition, the dynamic range was reduced to between 0 and 71 dBZe (dBZe = equivalent radar reflectivity factor, in decibels) and the precision was degraded to 0.5 dBZe. A major difference in the NEXRAD and CP2 radar data characteristics, important in areas affected by ground clutter, is the absence of clutter suppression in the CP2 data. Clutter suppression may result in improvements in NEXRAD precipitation estimates in clutter areas. However, care will have to be taken to ensure that good data are not being eliminated along with the clutter. Clutter supression would have been particularly helpful in this case since mountain echoes to the west of Denver were contained in the data even after quality control preprocessing by the PPS.

In addition to the radar data, verification data were collected by the PROFS' chase teams and spotter network. Additional independent data were obtained from the National Climatic Data Center on flash flood watches/warnings issued by the NWS local forecast office for July 23, 1983.

An example of the data collected by PROFS is shown below:

Time of occurrence (MDT)	23-JUL-1983 15:30
Time report received (MDT)	1-AUG-1983 10:00
Type of event:	Flood
Severity:	1
Observer:	Public Official

Text description of report:
JUNCTION OF US 85 AND I-25 CLOSED DUE TO FLOODING FROM APPROXIMATELY 15:30-18:30, DOUGLAS COUNTY

The NWS Weather Service Forecast Office in Denver issued the following watches and warnings for the July 23, 1983 event:

BULLETIN
FLASH FLOOD STATEMENT
NATIONAL WEATHER SERVICE DENVER CO
3230 MDT SAT JUL 23 1983
...FLASH FLOOD WATCH IN EFFECT ALONG FRONT RANGE...
RAINS OF 2 TO 3 INCHES AN HOUR HAVE BEEN REPORTED IN DOUGLAS COUNTY AND IN THE SOUTHEASTERN DENVER AREA AS STORMS CONTINUE TO DEVELOP IN THE WATCH AREA. ROAD AND STREET FLOODING AS WELL AS SOME SMALL

STREAM FLOODING HAS BEEN REPORTED IN DOUGLAS AND ARAPAHOE COUNTIES.
AT 330PM HEAVIEST STORMS WERE IN CENTRAL ARAPAHOE AND NORTHERN ELBERT COUNTIES BUT THERE WERE MODERATE TO HEAVY SHOWERS THROUGHOUT THE WATCH AREA. AS AN UPPER AIR DISTURBANCE MOVES THROUGH THE AREA LATER THIS EVENING ACTIVITY IS EXPECTED TO INCREASE FROM THE WEST AND SOUTHWEST AND ALL INTERESTS SHOULD BE ALERT FOR THE POSSIBILITY OF MINOR TO MODERATE FLOODING OF SMALL STREAMS AND CONSIDERABLE ROAD AND STREET FLOODING.
STREAM RISES WITH THESE STORMS WILL BE QUITE RAPID IN SOME CASES AND ALL INTERESTS ARE ADVISED TO STAY AWAY FROM STREAM BANKS AND LOW LYING AREAS AND REFRAIN FROM CROSSING WATER-FILLED UNDERPASSES AND CULVERTS.
FURTHER STATEMENTS OR WARNINGS WILL BE ISSUED AS CONDITIONS REQUIRE.
TUNNELL

BULLETIN...EBS ACTIVATION REQUESTED
FLASH FLOOD WARNING
NATIONAL WEATHER SERVICE DENVER CO
520PM MDT SAT JUL 23 1983 EXPIRES 8PM MDT
COUNTIES AFFECTED CO DOUGLAS ARAPAHOE
THE NATIONAL WEATHER SERVICE HAS ISSUED A FLASH FLOOD WARNING EFFECTIVE UNTIL 8PM MDT FOR PERSONS ALONG CHERRY CREEK AND TRIBUTARIES FROM NORTH OF FRANKTOWN TO CHERRY CREEK RESERVOIR.
A FLASH FLOOD WARNING MEANS FLOODING IS IMMINENT/HAS BEEN REPORTED.
TAKE NECESSARY PRECAUTIONS IMMEDIATELY.
CHERRY CREEK IS OUT OF ITS BANKS IN SOME LOCATIONS IN THE WARNING AREA AND MORE HEAVY RAIN IS MOVING INTO THE AREA. SOME ROADS ARE ALREADY CLOSED.
FURTHER STATEMENTS WILL BE ISSUED AS CONDITIONS REQUIRE.

TUNNELL

IV. RESULTS

Table 2 compares the hourly precipitation accumulations generated by the PPS with the projected hourly precipitation accumulations from the FFP. All calculations within the FFP are done over a 1/40 LFM (Limited Fine Mesh) grid used by the NWS. The difference fields, calculated by subtracting the one-hour projected precipitation from the one-hour observed precipitation, show that from 66 to 83 percent of differences were within ±2.5 millimeters and 89 to 96 percent of differences were within ±10 millimeters. The mean difference (PPS-FFP) over the precipitation field for the 20 representative scans varied from 3.52 mm (underestimation) to -1.85 mm (overestimation) with an average of 1.1 mm (underestimation). Due to the nature of the projection procedure within the FFP System, the underestimation occurred during storm growth and the overestimation occurred as the storm began to decline. Figure 2 graphically illustrates the one-hour precipitation difference field for one of the scan times within Table 2. The figure and table show the precipitation projection procedure within the FFP to be working reasonably well; however, there are some areas showing underestimation of high precipitation rates and overestimation of low precipitation. Some of the over and underestimation of precipitation by the projection procedure resulted from errors in estimating the localized storm speed and direction. This was evidenced in Figure 2 where areas of over and underestimation are adjacent to one another. It is expected that this form of storm, with multiple cells and rapid growth and decline, would give the FFP the most problems since the FFP is unable to account for new cells. However, even in this case, the projection was a fairly accurate representation of what actually occurred. Testing is being currently conducted on a stratiform rain case over Oklahoma. It is expected that this case will provide an even stronger correlation between projected and observed precipitation.

	Difference Interval (mm) \ SCAN TIME(Z)	19:11	19:16	19:21	19:26	19:41	19:46	19:51	20:16	20:21	20:26	20:31	20:41	20:46	20:51	21:21	21:26	21:31	22:11	22:21	22:26
UNDERESTIMATION	> 76.2	0	0	0	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0
	50.8 → 76.2	0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0
	25.4 → 50.8	2	2	2	2	2	1	1	2	1	2	2	1	2	1	1	1	1	1	0	0
	19.1 → 25.4	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0
	12.7 → 19.1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	1	0	1	0	0	0
	10.2 → 12.7	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
	7.6 → 10.2	1	1	1	2	1	1	1	1	2	2	2	2	2	2	1	0	1	1	1	1
	5.1 → 7.6	3	3	4	3	3	2	1	2	2	2	3	2	3	3	2	2	2	2	1	1
	2.5 → 5.1	6	7	9	7	6	4	2	3	4	6	6	7	6	6	3	2	3	3	3	2
	-2.5 → 2.5	83	81	79	79	77	81	73	77	71	71	76	72	78	75	72	66	76	77	74	73
OVERESTIMATION	-2.5 → -5.1	0	0	1	2	2	5	11	5	8	5	2	4	2	4	9	10	5	7	6	8
	-5.1 → -7.6	0	0	0	1	2	2	3	2	2	2	1	2	1	1	4	6	2	3	4	5
	-7.6 → -10.2	0	0	0	0	0	1	2	1	2	1	0	1	0	1	2	2	1	1	3	3
	-10.2 → -12.7	0	0	0	0	0	0	2	2	1	1	0	1	0	0	1	2	1	1	2	2
	-12.7 → -19.1	0	0	0	0	1	0	2	2	2	1	1	1	0	1	1	3	1	1	2	2
	-19.1 → -25.4	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	0	1	1
	-25.4 → -50.8	0	0	0	0	1	0	0	0	0	2	0	0	0	1	1	2	2	1	1	1
	-50.8 → -76.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	< -76.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Table 2. Percentage of boxes (1/40th LFM Grid) within the various difference (PPS-FFP) intervals for 20 selected scan times.

	Difference Interval (%) \ SCAN TIME(Z)	19:11	19:16	19:21	19:26	19:41	19:46	19:51	20:16	20:21	20:26	20:31	20:41	20:46	20:51	21:21	21:26	21:31	22:11	22:21	22:26
UNDERESTIMATION	> 500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	400 → 500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	300 → 400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	200 → 300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	100 → 200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	75 → 100	62	56	64	40	45	21	8	21	30	35	47	41	37	41	15	14	22	21	22	18
	50 → 75	16	16	12	16	15	14	5	13	12	13	14	12	15	12	9	7	11	13	14	12
	25 → 50	6	8	8	11	7	12	5	10	9	9	7	8	10	7	8	7	9	10	10	9
	-25 → 25	6	7	5	9	9	10	11	11	10	10	9	10	12	7	11	12	14	12	10	12
OVERESTIMATION	-25 → -50	1	2	1	2	2	3	5	3	3	4	3	3	4	3	4	4	4	4	4	4
	-50 → -75	1	1	1	1	2	2	4	3	3	2	3	1	2	2	4	3	3	4	3	3
	-75 → -100	1	1	1	1	2	1	4	2	3	2	2	1	1	2	3	3	3	3	2	3
	-100 → -200	2	2	2	2	3	4	8	4	6	5	3	3	3	4	7	8	8	7	7	7
	-200 → -300	0	1	0	1	2	2	5	2	3	2	2	2	1	2	5	5	5	4	4	4
	-300 → -400	0	0	0	1	1	1	1	1	1	1	1	1	1	1	3	4	2	3	2	3
	-400 → -500	0	0	0	1	1	0	2	2	1	0	1	1	1	1	2	3	1	2	2	1
	< -500	4	4	6	15	11	28	42	27	20	17	8	15	13	18	30	31	18	18	19	23

Table 3. Percentage of boxes (1/40th LFM Grid) within the various percent difference (((PPS - FFP)/PPS) x 100) intervals for 20 selected scan times.

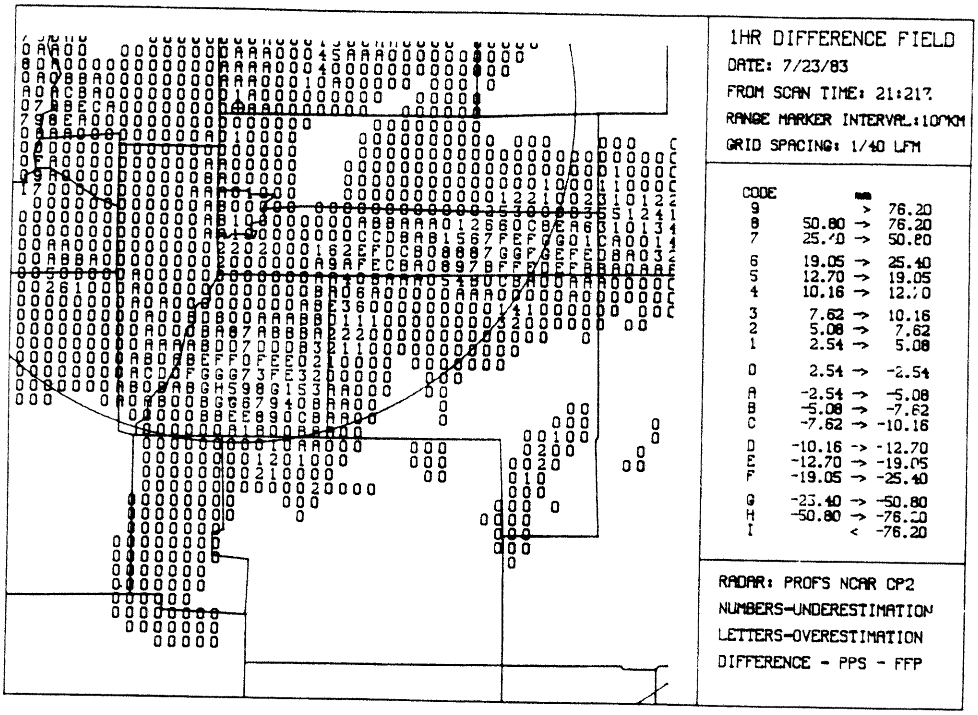

Figure 2. One hour precipitation difference field (PPS-FFP) for 21:21 Z.

Figures 3 and 4 graphically illustrate the observed and projected precipitation fields used in Figure 2. It is important to remember that the projected precipitation (Figure 4) is calculated one hour before the observed precipitation shown in Figure 3. The graphic displays are strikingly similar.

Table 3 illustrates the percent difference between the hourly precipitation accumulations from the PPS and the projected hourly precipitation accumulations generated by the FFP. Values are calculated by subtracting the one-hour projected precipitation (FFP) from the one-hour observed precipitation (PPS), and then dividing by the one-hour observed precipitation (PPS) and multiplying by 100. For the 20 representative scans in Table 3, 42 to 94 percent of the grid points were within ±100%, with a mean of 72 percent. Although Table 3 also shows a large number of locations with very large percentage overestimations, these resulted from points at which the projection procedure forecast precipitation but none was observed. Clearly (from Table 2) the projection procedure rarely overestimates rainfall accumulations by more than 20 mm in absolute terms.

The NWS definition of a flash flood is a flood caused by a rapid rise, usually within 6 hours of the onset of the causative event, on a river or creek. A flash flood watch is used to inform the public and cooperative agencies that current and developing hydrometeorological conditions are such that the area designated in this watch message is subject to possible flash flooding. A flash flood warning is a public warning issued for specific communities, streams, or areas by the NWS to alert the public of flooding which is imminent or in progress.

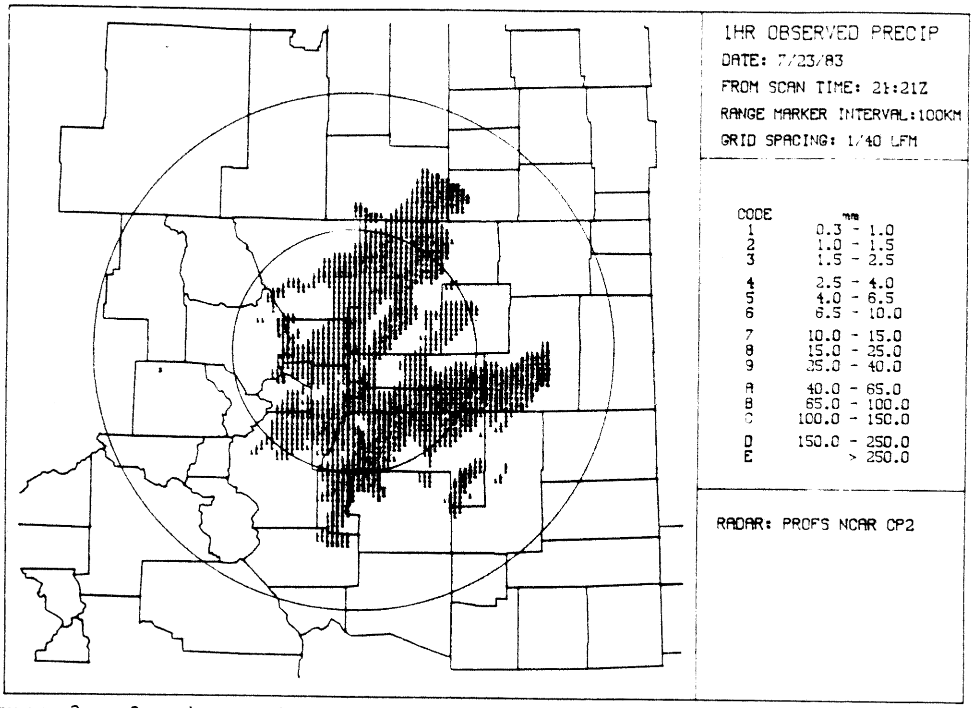

Figure 3. One hour observed precipitation accumulation for 21:21 Z to 22:21 Z, calculated at 22:21 Z.

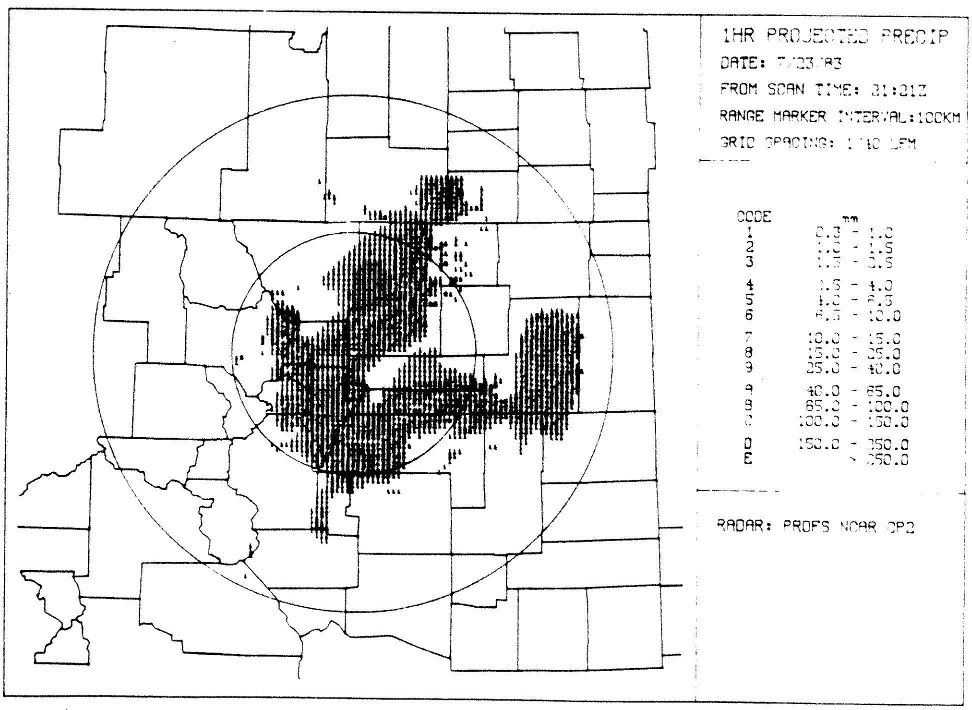

Figure 4. One hour projected precipitation accumulation for 21:21 Z to 22:21 Z, calculated at 21:21 Z.

The NWS flash flood watch had been in effect from the previous day and was not changed to a flash flood warning until 5:20 p.m. MDT (23:20 Z) on the 23rd. Figures 5 through 8 show the critical rainfall probability (observed) and the projected critical rainfall probability for Douglas and the surrounding counties for two selected scan times. Clutter from the Rocky Mountains caused the high probabilities just to the west of the radar.

The plots of CRP show that the FFP forecast flash flooding beginning in Douglas County and then extending to the northeast into Arapahoe County. If the forecaster had access to the NEXRAD FFP data, and if flash flood warnings were issued whenever the observed probability reached 76-100 percent, the warning could have been issued over 3 hours earlier for Douglas county. The figures clearly show the severity of the situation and would have been invaluable to the forecaster.

V. LIMITATIONS

The FFP System does not explicitly take the following conditions into account:

- Storm systems moving faster than approximately 50 km/hr.
- Curvilinear storm motions.
- Individual cell dynamics other than that accounted for by the current residual field.
- Initiation of precipitation other than that due to the motion of existing precipitation areas.
- Orographic effects.

Other limitations arise from the use of flash flood guidance values which presently:

- Do not reflect criteria for urban areas.
- Are not calculated the same way at all RFC's.
- Are calculated from data bases that may not allow the RFC's hydrologic models to accurately reflect soil moisture conditions for all areas within a zone or county.
- Are updated only once a day and do not have an updating procedure to reflect changes brought about by multiple rainfall events.

VI. SUMMARY/CONCLUSIONS/RECOMMENDATIONS

With the products from the FFP system, and the observed precipitation accumulation products from the PPS, the forecaster can monitor the accumulated precipitation for various durations up to the current time, evaluate precipitation forecasts for short periods into the future, noting areas of potential heavy rainfall, and assess flash-flood potential through the use of the flash-flood potential products and other information. Map backgrounds stored at the NEXRAD Principal User Processor (PUP), e.g., county and basin boundaries and stream locations, will further enhance the usefulness of the graphic displays produced by the FFP system. The products produced by this procedure should be viewed by the forecasters as very useful guidance, but not as definitive identification of flash flooding until interpreted together with other information at their disposal. The products will alert the forecasters to potential trouble spots and allow them to focus their time and resources where they are needed most. Time lapse display of the various FFP products

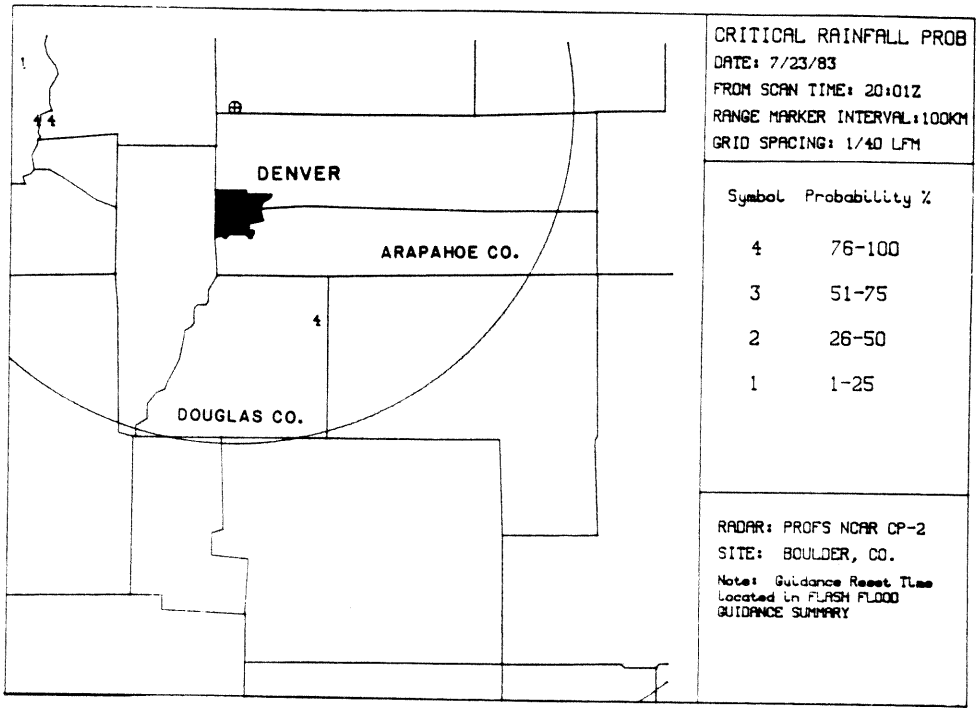

Figure 5. Observed Critical Rainfall Probability for 20:01 Z.

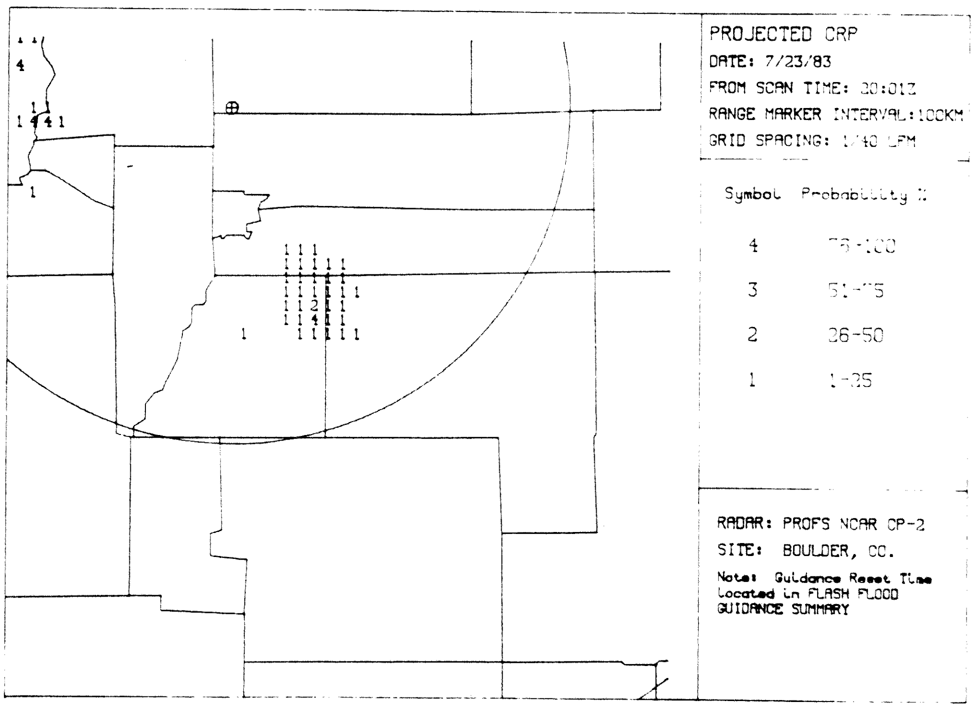

Figure 6. Projected Critical Rainfall Probability for 21:01 Z, calculated at 20:01 Z.

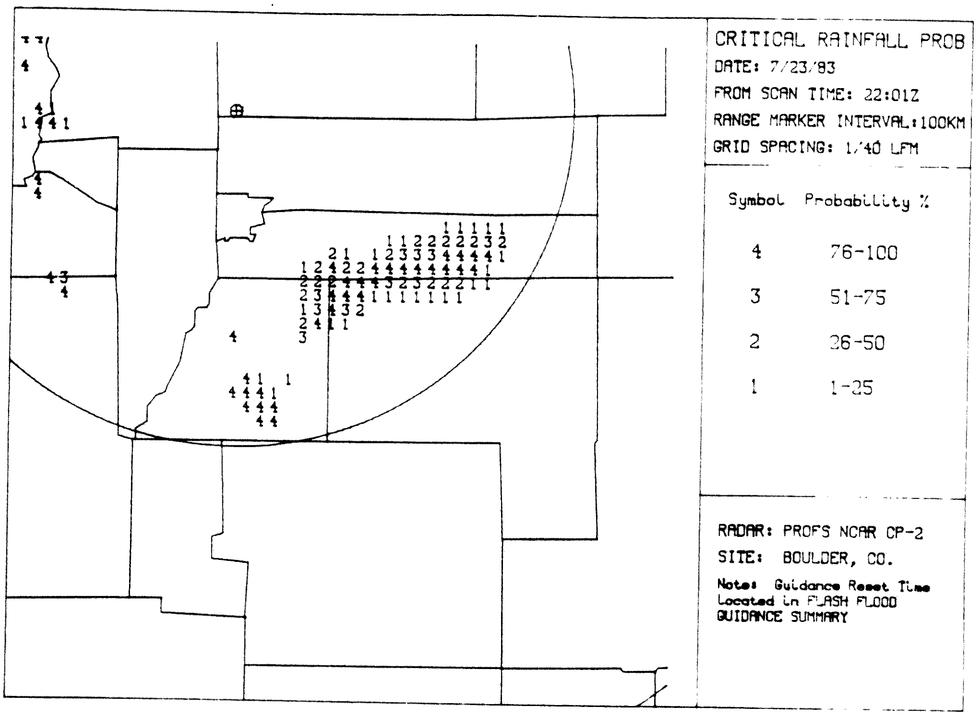

Figure 7. Observed Critical Rainfall Probability for 22:01 Z.

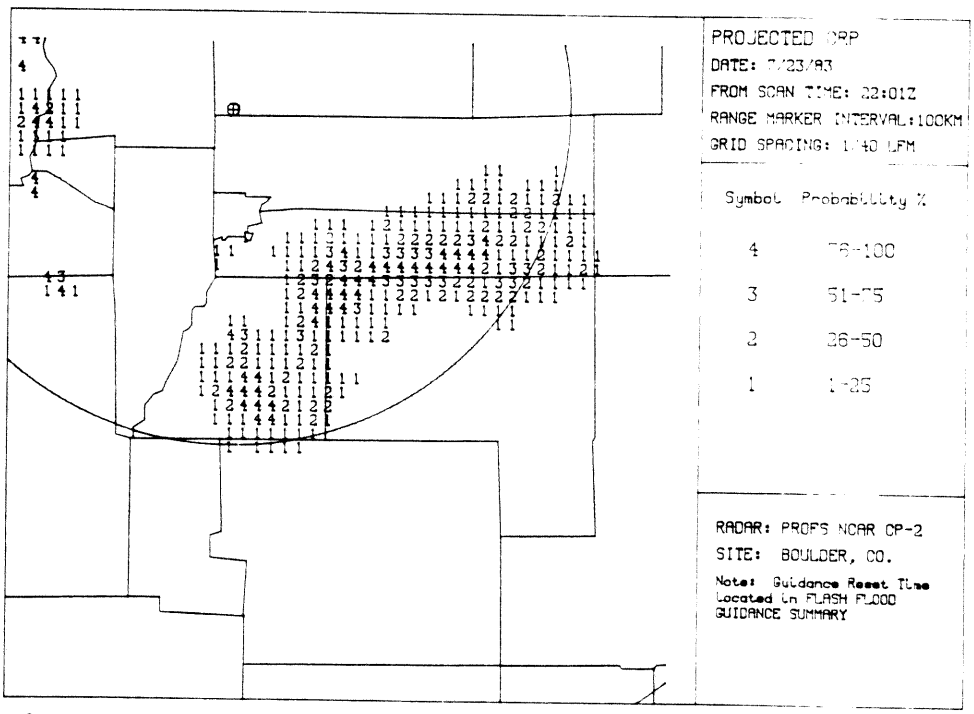

Figure 8. Projected Critical Rainfall Probability for 23:01 Z, calculated at 22:01 Z.

should prove to be extremely valuable for monitoring and forecasting flash flood events.

While the results presented on the July 23, 1983, storm show great promise, a single storm is not sufficient to establish the reliability of the NEXRAD FFP System or establish appropriate criteria for issuance of flash flood watches/warnings based on FFP products. The Hydrologic Research Laboratory recommends continued testing of the FFP system on as many different data sets and weather regimes as possible. Sensitivity analysis studies should also be conducted on the various adaptation parameters within the FFP system. The Hydrologic Research Laboratory feels the FFP system is ready for NEXRAD implementation and will provide very useful data in a form not presently available to the forecaster.

VII. ACKNOWLEDGEMENTS

The authors would like to thank the NEXRAD Joint System Program Office for providing partial support for the coding of the algorithms, and Paul Tilles of Automated Sciences Group for an excellent job of coding the algorithms. Appreciation also is expressed to the PROFS office for assistance in providing the excellent NCAR CP2 radar test data. The authors would also like to thank Elaine Hauschildt and Virginia Radcliffe for their expert typing of this manuscript and Lianne Iseley, who assisted with much of the editorial and graphics work.

VIII. REFERENCES

Ahnert, P. R., M. D. Hudlow, and E. R. Johnson, 1984: Validation of the On-site Precipitation Processing System for NEXRAD, Preprints, 22nd Conference on Radar Meteorology, AMS, Boston, Massachusetts, 192-201.

Ahnert, P. R., M. D. Hudlow, E. R. Johnson, and D. R. Greene, 1983: Proposed On-site Precipitation Processing System for NEXRAD, Preprints, 21st Conference on Radar Meteorology, AMS, Boston, Massachusetts, 378-385.

NOAA, 1983: Storm Data, Vol. 25, No. 7, National Climatic Data Center, NESDIS, NOAA, Asheville, North Carolina.

Smart, J., 1983: Discussion of CP2 data collected during the PROFS summer 1983 exercise. Personal communication, PROFS, NOAA, Environmental Research Laboratories, Boulder, Colorado.

Walton, M. L. and E. R. Johnson, 1986: An Improved Precipitation Projection Procedure for the NEXRAD Flash-Flood Potential System, Preprints, 23rd Conference on Radar Meteorology and the Conference on Cloud Physics, AMS, Boston, Massachusetts, JP62-JP65.

Walton, M. L., E. R. Johnson, P. R. Ahnert, and M. D. Hudlow, 1985: Proposed On-site Flash Flood Potential System for NEXRAD, Preprints, Sixth Conference on Hydrometeorology, AMS, Boston, Massachusetts, 122-129.