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TWO CASE STUDIES OF THE OPERATIONAL USE OF STREAM BASIN AVERAGE AND MAXIMUM STREAM BASIN RAINFALL ESTIMATES

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1. INTRODUCTION

Radar estimates of the stream basin average and the maximum basin rainfall, together with the Flash Flood Guidance (FFG), can be very useful in forecasting flash floods (Davis and Drzal 1991). The stream basin average rainfall is defined as the summation of rainfall estimates for all range bins falling within a stream basin, divided by the number of range bins. The single maximum rainfall estimate for all range bins within a stream basin is the maximum basin rainfall. A forecaster can issue a timely flash flood warning, often before acquiring ground truth data, if the basin average, or maximum basin rainfall, approaches or exceeds the FFG. However, there are limitations based on basin size, that may affect the usefulness of these types of rainfall estimates. For small stream basins (less than 100 sq km), a forecaster can use both real-time stream basin averages, and maximum basin rainfall, as an aid in forecasting flash floods, because both estimates provide a realistic description of what is occurring over the basin. For larger stream basins (greater than 100 sq km), stream basin averages are useful, especially if the heavy rain falls over the entire basin. However, it may also be necessary to use maximum basin rainfall to pinpoint potential problems within smaller sub-basins, especially when the rainfall is localized.

The National Weather Forecast Office at Pittsburgh (WSFO PIT) has initiated a pilot project that makes use of radar rainfall estimates to calculate stream basin average and maximum basin precipitation estimates for 400 stream basins within the effective range of the WSR-57 radar. Software was developed to analyze base reflectivity (BSCAN) data (2° by 1 nmi) from the RADAP-II (Radar Data Processor, Version II) computer, and generate output to aid in the prediction and warning of flash floods in western Pennsylvania and the panhandle of northern West Virginia.

This paper will describe how the stream basin averages and maximums are derived, and will then present two case studies that demonstrate the successful operational use of these estimates. The need for the division of larger stream basins into smaller sub-basins will also be illustrated.

2. APPROACH AND DATA

Data are acquired from the RADAP-II computer every 10 minutes, converted to an integer format, and stored on a DEC PDP/11 computer. These data consist of base elevation observations taken every 10 minutes, and contain 180, 2°-wide radials extending from 10 to 125 nmi in range.

Each radial is then divided into 1 nmi segments. This results in 20,700 BSCAN bins, each 1 nmi by 2° azimuth (Saffle 1988; Dragomir 1990). Estimated rainfall rates are computed by using the Z-R relationship, $Z=200*r^{1.6}$, developed by Marshall and Palmer (1948). Each rainfall product is generated every 10 minutes and rainfall amounts are stored in 0.1 inch increments for each bin.

Three sets of data are calculated every 10 minutes. At the beginning of every hour, the previous 1-hour, 2-hour, and 3-hour basin average rainfalls are computed. For 10-minute intervals after the hour, the current hour, the running 1-2 hour, and the running 2-3 hour basin average rainfalls are generated. Also, the maximum rainfall for each stream basin is calculated. The software outputs the computed data for a stream basin to a printer whenever the maximum basin rainfall exceeds 60% of the FFG value for that basin. Figure 1 is an example of the output. The 1-hour FFG is used for the current hour and previous hour rainfall products, a locally calculated 2-hour FFG value is used for the running 1-2 hour and previous 2-hour rainfall products, while the 3-hour FFG is used for the running 2-3 hour and previous 3-hour rainfall products. The 2-hour FFG value is not generated by the Ohio River Forecast Center (RFC) in Cincinnati, rather it is an approximation generated at WSFO PIT. This value is simply the average of the 1- and 3-hour FFG.

This approach is used to calculate 400 stream basin averages. The boundaries of the stream basins were manually determined from USGS (United States Geological Survey) topographic maps. The number of RADAP-II BSCAN boxes in each stream basin was calculated and stored for use by the averaging program. The number of bins ranges from one in some of the smaller stream basins, to over 500 bins for the Conquessnesing Creek basin.

3. EXAMPLES

3.1 Flash Flooding of July 15, 1990

A flash flood event occurred in eastern Ohio, the northern panhandle of West Virginia, and western Pennsylvania during the evening of July 14, and the early morning of July 15, 1990 (Figure 2a). Areas of moderate to heavy rain "trained" across these regions during an 8-10 hour period. Some locations received rainfall at a rate of 1.0 to 1.5 inches per hour causing widespread flooding, especially in Jefferson County of eastern Ohio. By making use of the maximum basin rainfall amounts that were generated from radar rainfall estimates and observer reports, WSFO Pittsburgh was able to alert the Weather Service Office in Akron, Ohio (WSO CAK) to the possibility of flooding. WSO CAK issued a flash flood warning for Jefferson County in eastern Ohio. Widespread flooding occurred throughout the county and evacuations were required along Wills Creek. Figure 2b shows the Wills Creek stream basin in Jefferson County.

The FFG issued by the Ohio River Forecast Center (OHRFC) in Cincinnati on July 14, 1990, indicated that a basin average rainfall of 0.8 inches in 1 hour, or 1.3 inches in 3 hours, was needed to begin flooding. By 0020 UTC, July 15 (Figure 3), a maximum basin rainfall of 0.40 inches (since 2300 UTC) was indicated in central Jefferson County over the Cross and Wills Creek basins. The airmass producing the rain was tropical in nature. From past experience and studies, such as the Shadyside, OH, flash flood of June 14, 1990 (Department of Commerce, 1991), rainfall estimates from RADAP-II often need to be multiplied by 1.5 to 2.0 in these "warm top" circumstances, possibly because of the abundant moisture available. Based on this assumption, it was estimated that 0.6-0.8 inches of rain had fallen in an hour and 20 minutes over central Jefferson County.

At 0030 UTC (Figure 4), the maximum basin rainfall during the past hour was 0.5 inches over Wills and Cross Creeks. During the same time, WSFO PIT received a report that the New Cumberland Dam rain gauge on the Ohio River near northeastern Jefferson County, recorded 0.70 inches of rain between 0000 and 0025 UTC. This report confirmed that the radar estimates should be multiplied by a factor of two. Hence, it appeared that about 0.75 to 1.0 inches of rain had fallen in 30 minutes. This rate of rainfall exceeded the 1-hour FFG. By 0100 UTC (Figure 5), the program indicated that a maximum of 1.80 inches of rain (after incorporating the "warm top" rainfall enhancement factor) had fallen over the Cross and Wills Creek basins in 2-hours which exceeded the 2-hour FFG. (Recall, the 2-hour FFG is an approximation determined by averaging the 1- and 3-hour FFG values.)

During the hour from 0000-0100 UTC, WSFO PIT made several calls to WSO CAK and informed them of the rainfall estimates. This information was very helpful to WSO CAK, since they had not received rain gauge reports from the area. Based on this radar information, WSO CAK issued a flood warning for Jefferson County. While ground-truth reports of flooding, or observed rainfall reports from Jefferson County were not received in real-time, flooding was reported later.

For this event, the maximum basin rainfall was more helpful than the stream basin average as an indication of excessive rainfall because of the small size of the creek basins. At 0100 UTC, the basin average rainfall in the Wills and Cross Creeks were 0.22 and 0.36 inches in 2-hours, respectively (Figure 5). After multiplying these amounts by the factor of two mentioned earlier, the values were still well below the 2-hour FFG of 1.10 inches. However, the maximum basin rainfall of 1.80 inches in 2 hours was much greater than the 2-hour FFG. In this case, the stream basin averages would not have indicated any potential problems in Wills and Cross Creeks. However, the maximum basin rainfall indicated that rainfall amounts in those basins actually exceeded the FFG. The smaller sub-basins of the Wills and Cross Creeks flooded.

3.2 Flooding of September 6-7, 1990

Flooding occurred in Washington County of Pennsylvania and Brooke County in the northern panhandle of West Virginia on September 6-7, 1990 (Figure 2b). Three separate Mesoscale Convective Systems (MCS) formed over the Great Lakes region and moved from the northwest to the southeast across the area. The first MCS moved across the region between 2100 and 2200 UTC on September 6; the second between 0200 and 0400 UTC on September 7; and the last MCS from 0700-0900 UTC on September 7. As each MCS moved across the region, it dropped rain at a rate of 1.0 to 2.0 inches per hour.

The hardest hit cities were Follansbee in Brooke County, WV, and Avella and Houston in Washington County, PA, all of which are in the Cross and Chartiers Creek basins (Figure 2b). By the early morning of September 7, over 5 ft of water covered the roads in Follansbee, and houses had been damaged by flooding in the Houston and Avella areas. A traveling circus in the Houston area was also impacted by the high water. The circus animals had to be removed from their cages and chained to parking meters in the streets of Houston.

Figure 6 shows the basin average, maximum basin rainfall, and running total for each stream basin from 0100 to 0900 UTC, September 7. The FFG for Brooke County, WV, and Washington County, PA, was 1.8 inches in 1 hour, and 2.9 inches in 3 hours. By 0100 UTC on September 7, about 1.0 to 1.5 inches of rain from the first MCS had fallen in 2 hours over the Cross and Chartiers Creek basins. Another 1.5 to 2.5 inches of rain fell over these basins from the second MCS between 0200 and 0400 UTC. Over the Cross Creek basin, 1.5 inches fell between 0200 and 0300 UTC. A Flash Flood Warning was issued at 0406 UTC that included Brooke County, WV, and Washington County, PA. Some minor flooding had already occurred when this warning was issued.

Maximum basin rainfall estimates of 4.0-5.0 inches of rain were indicated for sections of each basin. Ground truth information from rain gauges in the area verified these estimates. Canonsburg, which is just north of Houston, reported 6 inches during this period.

We noticed that the basin averages for Cross Creek were higher than those for Chartiers Creek. This may have been produced by the relative size of the two basins. Since Chartiers Creek is much larger, more RADAP-II range bins are used in the calculations. This would result in lower basin-averages if the heavy precipitation is localized. Therefore, if only the stream basin averages are used for larger basins, a forecaster may not recognize the potential for flooding in smaller sub-basins.

Also, the program produced stream basin average rainfall estimates for Cross Creek that approached the 3-hour FFG, and indicated that the heaviest rainfall fell in the headwaters of Cross Creek, which flows through Avella, and Allegheny Steel Run, which flows through the middle of Follansbee. Therefore, the basin average estimates alerted the forecaster to the potential of flooding, and the maximum basin average values helped pinpoint the smaller sub-basins that would be most affected.

Finally, the flooding in the Houston area occurred on Chartiers Run, which is a sub-basin of Chartiers Creek. The maximum basin rainfall data (Figure 6) indicated that the heaviest rain fell over this sub-basin. The basin averages for Chartiers Creek alone would not have indicated flooding on the smaller Chartiers Run basin. Therefore, the maximum basin rainfall was a better forecasting tool than the stream basin average because of the size of the basin.

4. SUMMARY

These two cases illustrate how the streams basin average and the maximum basin rainfall estimates can be used as an aid in the forecasting of flash floods. In the case of July 15, WSO CAK used the information to issue a timely and accurate flash flood warning for Jefferson County in Ohio. This case also illustrated that for a large stream basin, maximum basin rainfall can be a better indicator of potential flooding than stream basin averages.

For September 6-7, 1990, because of the size of the primary basin, the maximum basin rainfall data indicated a potential flooding problem in the Chartiers Run sub-basin of the larger Chartiers Creek, while the basin average did not. For the smaller Cross Creek basin, the stream basin averages approached 3-hour FFG values and the maximum basin rainfall data then pinpointed a potential problem on the Allegheny Steel Run in Follansbee.

These two cases indicate that both the stream basin average rainfall and the maximum basin rainfall estimates are important, and depending on the size of the basin, must be used in different ways. The stream basin average rainfall may not be a good indicator of flooding in smaller sub-basins if the rain does not fall across the entire basin. Therefore, the forecaster must also review the maximum basin values. In addition, these cases illustrate the need to subdivide larger basins and calculate basin averages for the smaller basins.

6. ACKNOWLEDGMENTS

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References

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 CURRENT HOUR RAINFALL FROM 00Z TO 0030Z  AND DATE = 7/15/90
a)        b)                               c)           d)     BASIN
#     STREAM BASIN                     CTY OF MOUTH    ST.    AVG. AMT.
23    SAMPLE CREEK                     ALLEGHENY       PA       0.11 e)
MAX. AMT. WAS 0.50 IN. AT 256/29  f)
1 HR. FFG IS 0.8 INCHES    g)

*******************************************************************
 RUNNING 1-2 HOUR RAINFALL FROM 2300Z TO 0030Z  AND DATE = 7/15/90
                                                               BASIN
#     STREAM BASIN                     CTY OF MOUTH    ST.    AVG. AMT.
23    SAMPLE CREEK                      ALLEGHENY        PA       0.20

MAX. AMT. WAS 0.90 IN. AT 256/29
1 HR. FFG IS 0.8 INCHES
2 HR. FFG IS 1.1 INCHES

*******************************************************************
 RUNNING 2-3 HOUR RAINFALL FROM 2200Z TO 0030Z  AND DATE = 7/15/90
                                                               BASIN
#     STREAM BASIN                     CTY OF MOUTH    ST.    AVG. AMT.
23    SAMPLE CREEK                      ALLEGHENY        PA       0.29

MAX. AMT. WAS 1.20 IN. AT 256/29
2 HR. FFG IS 1.1 INCHES
3 HR. FFG IS 1.4 INCHES

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<u>LEGEND:</u>

a) stream number; used to find stream on county map
b) name of stream basin
c) county of mouth of stream
d) state of mouth of stream
e) basin average
f) maximum point value in stream basin given by azimuth (degrees)/range (nm)
g) Flash Flood Guidance

Figure 1. Sample output from rainfall estimation program.

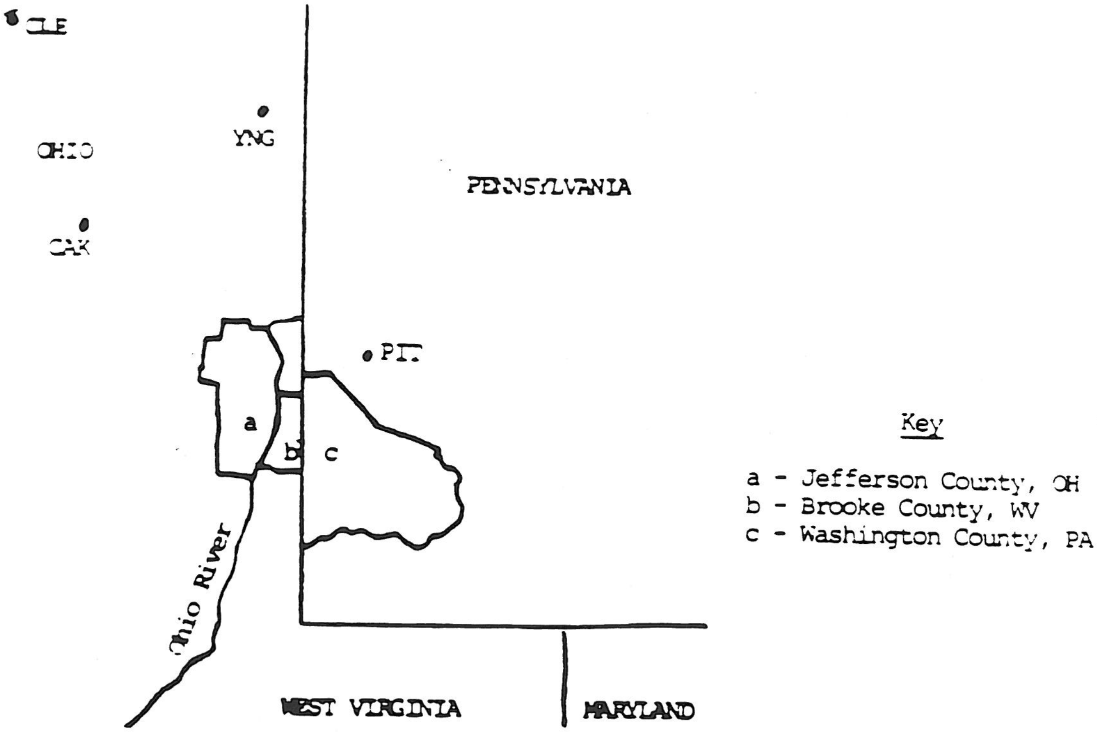

Figure 2a. Regional map with counties affected by the flash flood events described in this paper.

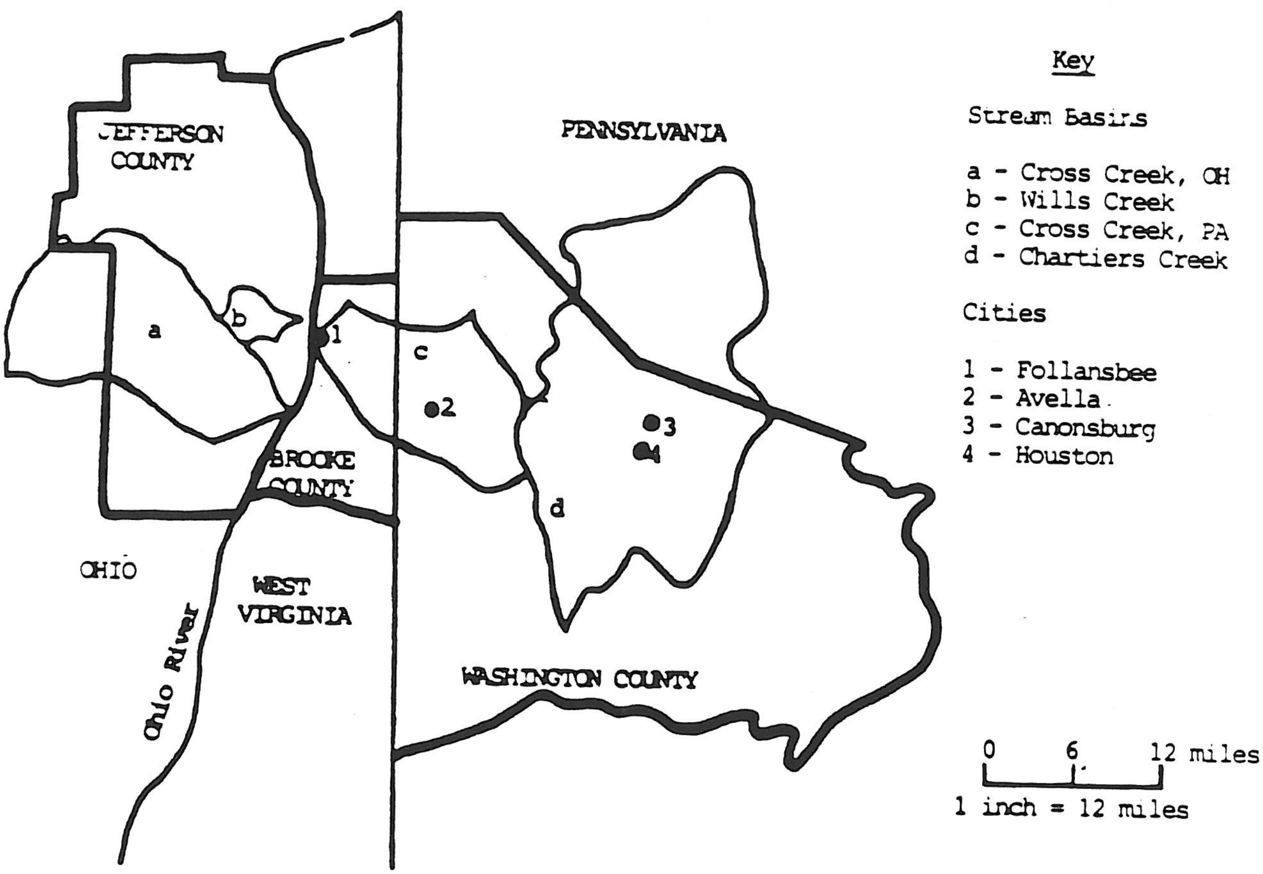

Figure 2b. Local map of stream basins affected by the flash flood events described in this paper.

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CURRENT HOUR RAINFALL ENDING AT 0020Z  AND DATE= 7/15/90
                                                                 BASIN
#   STREAM BASIN                        CTY OF MOUTH    ST.     AVG. AMT.

NO MAXIMUM AMOUNT OR BASIN AVERAGE EXCEEDED FFG
**********************************************************************
RUNNING 1-2 HOUR RAINFALL FROM 23Z TO 0020Z AND DATE= 7/15/90
                                                                 BASIN
#   STREAM BASIN                        CTY OF MOUTH    ST.     AVG. AMT.
28    CROSS CREEK                        JEFFERSON      OH          .12

MAX. AMT. WAS 0.40 IN. AT AZRAN       256/29
1 HR. FFG IS 0.8 INCHES
2 HR. FFG IS 1.1 INCHES

32    WILLS CREEK                       JEFFERSON       OH         .09
MAX. AMT. WAS 0.40 IN. AT AZRAN       250/23
1 HR. FFG IS 0.8 INCHES
2 HR. FFG IS 1.1 INCHES

**********************************************************************
RUNNING 2-3 HOUR RAINFALL FROM 22Z  TO 0020Z AND DATE= 7/15/90

#   STREAM BASIN                        CTY OF MOUTH    ST.     AVG. AMT.
28    CROSS CREEK                        JEFFERSON      OH          .19
MAX. AMT. WAS 0.60 IN. AT AZRAN       256/29
2 HR. FFG IS 1.1 INCHES
3 HR. FFG IS 1.3 INCHES

32    WILLS CREEK                       JEFFERSON       OH          .10
MAX. AMT. WAS 0.60 IN. AT AZRAN       250/23
2 HR. FFG IS 1.1 INCHES
3 HR. FFG IS 1.3 INCHES
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Figure 3. 0020 UTC output for July 15, 1990.

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CURRENT HOUR RAINFALL ENDING AT 0030Z  AND DATE= 7/15/90
                                                                BASIN
#   STREAM BASIN                      CTY OF MOUTH     ST.    AVG. AMT.
28   CROSS CREEK                       JEFFERSON       OH        .06
MAX. AMT. WAS 0.50  IN. AT AZRAN  250/24
1 HR. FFG IS 0.8 INCHES

32   WILLS CREEK                      JEFFERSON        OH        .17
MAX. AMT. WAS 0.50 IN. AT AZRAN  250/23
1 HR. FFG IS 0.8 INCHES

************************************************************************
RUNNING 1-2 HOUR RAINFALL FROM 23Z TO 0030Z AND DATE= 7/15/90
                                                                BASIN
#   STREAM BASIN                      CTY OF MOUTH     ST.    AVG. AMT.
28   CROSS CREEK                       JEFFERSON       OH        .16

MAX. AMT. WAS 0.50 IN. AT AZRAN 250/24
1 HR. FFG IS 0.8 INCHES
2 HR. FFG IS 1.1 INCHES

32   WILLS CREEK                      JEFFERSON        OH        .17
MAX. AMT. WAS 0.50 IN. AT AZRAN 250/27
1 HR. FFG IS 0.8 INCHES
2 HR. FFG IS 1.1 INCHES

************************************************************************
RUNNING 2-3 HOUR RAINFALL FROM 22Z  TO 0030Z AND DATE= 7/15/90

#   STREAM BASIN                      CTY OF MOUTH     ST.    AVG. AMT.
28   CROSS CREEK                       JEFFERSON       OH        .22
MAX. AMT. WAS 0.60 IN. AT AZRAN  250/24
2 HR. FFG IS 1.1 INCHES
3 HR. FFG IS 1.3 INCHES

32   WILLS CREEK                      JEFFERSON        OH        .18
MAX. AMT. WAS 0.60 IN. AT AZRAN  250/23
2 HR. FFG IS 1.1 INCHES
3 HR. FFG IS 1.3 INCHES
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Figure 4. 0030 UTC output for July 15, 1990.

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PREVIOUS ONE HOUR RAINFALL ENDING AT 0100Z  AND DATE= 7/15/90
                                                            BASIN
#   STREAM BASIN                      CTY OF MOUTH    ST.     AVG. AMT.
28   CROSS CREEK                       JEFFERSON       OH         .11

MAX. AMT. WAS 0.90 IN. AT AZRAN 250/24
1 HR. FFG IS 0.8 INCHES

32   WILLS CREEK                      JEFFERSON       OH          .22
MAX. AMT. WAS 0.90 IN. AT AZRAN 250/23
1 HR. FFG IS 0.8 INCHES

**********************************************************************
PREVIOUS TWO HOUR RAINFALL ENDING AT 0100Z  AND DATE= 7/15/90
                                                            BASIN
#   STREAM BASIN                      CTY OF MOUTH    ST.     AVG. AMT.
28   CROSS CREEK                      JEFFERSON       OH         .22
MAX. AMT. WAS 0.90 IN. AT AZRAN 250/24
2 HR. FFG IS 1.1 INCHES

32   WILLS CREEK                      JEFFERSON       OH         .36
MAX. AMT. WAS 0.90 IN. AT AZRAN 250/23
2 HR. FFG IS 1.1 INCHES

**********************************************************************
PREVIOUS THREE HOUR RAINFALL ENDING AT 0100Z AND DATE= 7/15/90
                                                            BASIN
#   STREAM BASIN                      CTY OF MOUTH    ST.     AVG. AMT.
28   CROSS CREEK                      JEFFERSON       OH         .28

MAX. AMT. WAS 1.00 IN. AT AZRAN 250/24
3 HR. FFG IS 1.3 INCHES

32   WILLS CREEK                      JEFFERSON       OH         .37
MAX. AMT. WAS 0.90 IN. AT AZRAN 250/23
3 HR. FFG IS 1.3 INCHES
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Figure 5. 0100 UTC output for July 15, 1990.

STREAM BASIN AVERAGES

	CHARTIERS CREEK		CROSS CREEK	
	BASIN AVERAGE	RUNNING TOTAL	BASIN AVERAGE	RUNNING TOTAL
0200 UTC	.03	.03	.12	.12
0300 UTC	.16	.19	.81	.99
0400 UTC	.16	.35	.27	1.26
0500 UTC	.27	.62	.97	2.23
0600 UTC	.17	.79	.10	2.33
0700 UTC	.00	.00	.00	2.33
0800 UTC	.27	1.06	.41	2.74
0900 UTC	.04	1.10	.06	2.80

MAXIMUM BASIN RAINFALL - CROSS CREEK

	AMOUNT	RUNNING TOTAL	AMOUNT	RUNNING TOTAL
AZIMUTH/RANGE	208/21 (headwaters near Avella)		224/21 (near Follansbee)	
0200 UTC	.40	.40	.20	.20
0300 UTC	1.50	1.90	1.50	1.70
0400 UTC	.40	2.30	.50	2.20
0500 UTC	1.00	3.30	1.70	3.90
0600 UTC	.30	3.60	.10	4.00
0700 UTC	.00	3.60	.00	4.00
0800 UTC	.60	4.20	.30	4.30
0900 UTC	.00	4.20	.00	4.30

MAXIMUM BASIN RAINFALL - CHARTIERS CREEK

	AMOUNT	RUNNING TOTAL
AZIMUTH/RANGE	190/15 (on Chartiers Run near Houston)	
0200 UTC	.10	.10
0300 UTC	.60	.70
0400 UTC	.70	1.40
0500 UTC	.90	2.30
0600 UTC	.50	2.80
0700 UTC	.00	2.80
0800 UTC	.90	3.70
0900 UTC	.90	4.60

Figure 6. Calculations of stream basin averages (inches), maximum basin rainfalls (inches), and azimuth/range (degrees/nmi) of the maximum basin rainfall for September 6-7, 1990.