1.5 FLASH FLOOD WARNING TECHNOLOGY AND METRICS

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1. INTRODUCTION

The Flash Flood Monitoring and Prediction (FFMP) system has been implemented throughout the National Weather Service (NWS) and will continue to evolve as both researchers and forecasters gain experience with it (Davis, 2004b). FFMP enables forecasters to view rainfall information relative to Flash Flood Guidance (FFG) on a drainage basin background (Smith et al. 2000), with basins as small as 5.1 km^2 (2 mi^2). Thus, FFMP allows interrogation of a flash flood situation on the storm scale, the scale at which important runoff processes are occurring.

Accurate remotely-sensed precipitation and representative Flash Flood Guidance (FFG) are both critical for accurate FFMP products. In addition, with higher resolution flash flood information in both time and space, FFMP is forcing us to revisit our definition of flash floods, which have been characterized by a lack of objective and quantitative criteria. There is now an effort to update the definition of flash floods with details and quantitative thresholds that will assist forecasters and policy makers with issuing forecasts and generating meaningful verification metrics.

2. FFMP CASES

Several flash flood cases in 2003 and 2004 provide an opportunity to look at the flash flood problem with respect to FFMP guidance. This paper briefly reviews two cases that both illustrate the utility of FFMP for the very small-scale nature of flash flood events. One case also illustrates issues regarding radar-derived rainfall (Kansas Turnpike, 30 August 2003) and the other provides an example of rapid-onset flooding in urbanized basins (Las Vegas, Nevada, 19 August 2003).

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2.1 Radar issues, 30 August 2003

During the evening of 30 August 2003, a quasi-stationary convective complex drenched a small area of Lyon and Chase counties in Kansas along and just upstream of Interstate 35, the Kansas Turnpike. Flooding from Jacob Creek began to seriously impact the highway by 0130 UTC (8:30 PM CDT) causing a large traffic backup as vehicles stalled in the high waters. Water completely inundated the northbound lanes as it ponded against the concrete Jersey barriers that separated the northbound from the southbound lanes. Just before 0230 UTC (9:30 PM CDT), a section of the concrete barriers gave way under the force of the water causing the floodwaters, along with seven vehicles, to be swept downstream.

FFMP products shown in Figs. 1-2 highlight the specific location of large 3-h radar-derived accumulations at 0130 UTC, about an hour before the flood surge across the turnpike. Fig. 1 shows Chase and Lyon counties highlighted with the highest 3-h accumulation. Fig. 2 shows the small Jacob Creek basin (indicated with a white "x") near the Kansas Turnpike where some of the highest accumulations occurred. The table in Fig. 2 provides additional information including rainfall rate, FFG, the ratio of accumulation to FFG, and the difference between accumulation and FFG (positive numbers show accumulation exceeding FFG). The table can be redrawn for 1-, 3-, and 6-h information. The table shows that for basin 5600, (Jacob Creek) the 3-h accumulation (column 3) was 59 mm (2.34 in) and the 3-h FFG (column 4) was 30 mm (1.18 in). The resulting ratio was nearly 200% (column 5), and the difference (column 6) indicated that the rainfall exceeded FFG by 29 mm (1.16 in).

The accumulation amounts indicated by FFMP were not exceptional given the severity of the flooding. Some ground reports indicate much higher accumulations occurred. Precipitation microphysics associated with the warm-rain process of this storm may have played an important role in this event and resulted in underestimated radar-derive rainfall rates. Witnesses reported intense rainfall rates but little or no lightning activity. AWIPS products showed relatively warm cloud-top temperatures (warmer than −40°C), strong low-level echoes (50-55 dBZ), and no lightning strikes. This is consistent with low-centroid intense rainstorms where very efficient precipitation growth is taking place in the liquid (above freezing) portion of the cloud. Fig. 3 shows a cross section through the storm complex. Note that almost all of the intense echo area is in a region below 4500 m (15 Kft) AGL where temperatures are above freezing. The 0°C isotherm is shown with the white dashed line in Fig. 3. Strong and moist low level flow was feeding this storm complex and strong low-level frontogenesis led to very efficient precipitation production in the low levels with the warm-rain process dominating. This is very similar to the powerful rainstorm that struck Fort Collins, Colorado on 28 July 1997 (Kelsch, 1998).

Convective storms in the mid latitudes often exhibit a drop size distribution (DSD) with a mixture of large and small drops. The default Weather Surveillance Radar, 1988 Doppler (WSR-88D) reflectivity-rainrate (ZR) relationship, $Z= 300R^{1.4}$, assumes such a DSD. When convection develops with a much stronger tropical maritime influence, the DSD is typically characterized by a greater density of smaller drops. This is often the case with strong, low-centroid convection in very moist environments, such as the Kansas Turnpike storm. Because reflectivity is much more sensitive to the mean diameter of drops in a volume than it is to the density of drops per volume, for a given amount water, the reflectivity returned will be greater with fewer, but larger drops. Consequently, when a DSD is characterized by a high concentration of small drops, the default ZR relationship will likely underestimate the rainfall rates. A tropical ZR, $Z= 250R^{1.2}$, results in rainfall rates much more suited to situation where the DSD is characterized by a high concentration of small drops.

The tropical ZR is often used during obvious tropical situations such as landfalling hurricanes. However, far inland from the warm ocean waters there are situations when the tropical ZR may result in more representative rainfall rates (Davis, 2004a). Unfortunately, it is not as simple as changing to the tropical ZR when unusually moist conditions prevail. In the Kansas Turnpike case, as well as in the 1997 Fort Collins case, the unique low-centroid storms in question developed concurrently with more typical deep convection nearby. Therefore, using a tropical ZR for the whole County Warning Area (CWA) could easily result in overestimated rainfall for the deep convection areas. Regardless of the ZR used, a forecaster will still be required to make a judgment about the precipitation physics of a storm complex based on an array of available data including surface observations, radar, satellite, and lightning.

2.2 Effects of urbanization, 19 August 2003

During the late afternoon of 19 August 2003, heavy thunderstorm activity deluged the city of Las Vegas, particularly the northwestern parts of the city and its northwestern suburbs. Many of the natural basins in this region are quite small and heavily urbanized resulting in a situation where the time lag from peak rainfall to peak discharge is very short. In studies done within the urbanized basins of Baltimore, Maryland, the time lag from peak rainfall to peak discharge can be as little as 0.25 h (Smith, 2004). City streets become the path of least resistance for the excess runoff and can become deadly torrents of floodwater.

Gridded FFG did not exist for this case in Clark County, Nevada (where Las Vegas is located). An AWIPS Graphical User Interface (GUI), known as the forced flash flood guidance, allows users to enter FFG values for either the entire CWA, for specific counties, or for specific basins. For the 19 August case, region-wide FFG was created and then specific basins within the urbanized areas around Las Vegas were given values to reflect the very rapid response such basins have to short-duration, intense rainfall rates. In this case the 1-h FFG was 21 mm (0.83 in). With the small urban basins of Las Vegas assigned with relatively small 1-h FFG values, the FFMP products clearly show that both Clark County and the specific small basins near Las Vegas pose the greatest risk of flooding (Figs. 4-6). Fig. 4 shows Clark County was experiencing some of the greatest accumulations according to FFMP. The table in Fig. 4 indicates that some basin in Clark County (second row) had exceeded 75 mm (3 in) of rain which is 368% of the FFG. Fig. 5 shows how zooming in to Clark County can provide information about which specific basins are experiencing the greatest rainfall. Figure 6 is similar to Fig. 5, but it shows the difference field. Thus, the red basins in Fig. 6 are exceeding FFG by more than 50 mm (2 in). Many of the natural drainages are forced into culverts under roads and structures. During a flash flood the floodwater typically surges downstream along the road grid.

The forced FFG GUI will be useful for highlighting urban areas around the nation. Its utility will likely be recognized in other special cases as well, such as fire burn and clear-cut areas which typically exhibit greater and more rapid runoff when compared to natural, unburned areas.

3. METRICS

Flash flood verification has always been quite challenging. With the FFMP tool in use there is a greater need to compile flash flood metrics that illustrate NWS successes and the impact of FFMP. However, vagaries in the definition of flash floods (and thus the verification criteria) make it difficult to compile objective metrics. The NWS Service Hydrology Program Handbook of Hydrologic Products (NOAA, 2004) defines a flash flood as:

A short-fused (i.e. less than 6 hours) flooding event that poses a threat to lives and/or property, or a flooding event that results from a dam failure or breech.

This definition does not actually define a flood and does not provide any quantitative criteria. This would be analogous to defining severe weather as “a wind and hail event that poses a threat to life and property.” A look at flash floods verified in Storm Data (NOAA, 2003) reveals that many events have no specific life-threatening danger or damage described. Specific examples include the following, all of which were associated with zero deaths, zero injuries, and no reported damages:

- Spotter reported street flooding
- Water flooded city streets as festival was underway
- Several inches of water over road.

Because the lack of specificity in the flash flood definition poses difficulties for both forecasting and verifying flash floods, both Central Region and Eastern Region of the NWS are proposing a more detailed definition that includes overland and roadway flooding, as well as numerical guidance regarding how deep the water on the roadway needs to be based on flood danger assessments done by the United State Bureau of Reclamation (USBR, 1988). An example of the proposed definition is given below.

Flash flood verification criteria is as follows: within 6 hours (often within 1 hour) of causative event such as intense rain, dam break, or ice jam release, one or more of the following occurs:

- River or stream flows out of banks and is a threat to life or property.
- Person or vehicle swept away by flowing water from runoff that inundates adjacent grounds.
- A maintained county or state road closed by high water.
- Approximately 150 mm (6 in) or more of fast-flowing water over a road or bridge. This includes low water crossings in a heavy rain event that is more than localized (i.e., radar and observer reports indicate flooding in nearby locations) and poses a threat to life or property.
- Dam break or ice jam release causes dangerous out of bank stream flows or inundates normally dry areas creating a hazard to life or property.
- Any amount of water in contact with, flowing into, or causing damage to a residence or public building as a result of above ground runoff from adjacent areas.
- Ninety-one cm (3 ft) or more of ponded water that poses a threat to life or property.
- Mud or rock slide caused by rainfall.

Although these criteria are likely to evolve, this represents an important step in developing detailed and quantitative criteria for flash flood verification.

4. SUMMARY

The FFMP software has introduced a new tool for assisting forecasters with interrogating data pertinent to flash floods and issuing flash flood forecasts that are more detailed in space and time. FFMP depends on timely, accurate, and representative gridded rainfall and FFG input. Because rainfall input is primarily from the WSR-88D network, limitations in radar-derived precipitation can introduce significant limitations to FFMP guidance. Unrepresentative FFG values will also have an impact on FFMP guidance. A forced FFG software tool will permit forecasters to create or change FFG values if necessary. This tool may be especially useful for special case basins such as those that have been altered by severe fires, deforestation, or urbanization.

As flash flood forecasts become more detailed and specific, flash flood warning and verification criteria will also need to become more specific and more objective. Progress in this area has includes the incorporation of overland and roadway flooding into the flash flood definition as well as an attempt at quantitative guidance for the depth of water necessary to be considered life threatening.

5. References

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Smith, S. B., M. Churma, J. Roe, and L. Xin, 2000.: Flash Flood Monitoring and Prediction in AWIPS build 5 and beyond. Preprints, 15th Conference on hydrology, AMS, 229-232.

USBR, 1988: Downstream hazard classification guidelines. ACER Technical memorandum No. 11, Denver, CO, 57 pp.

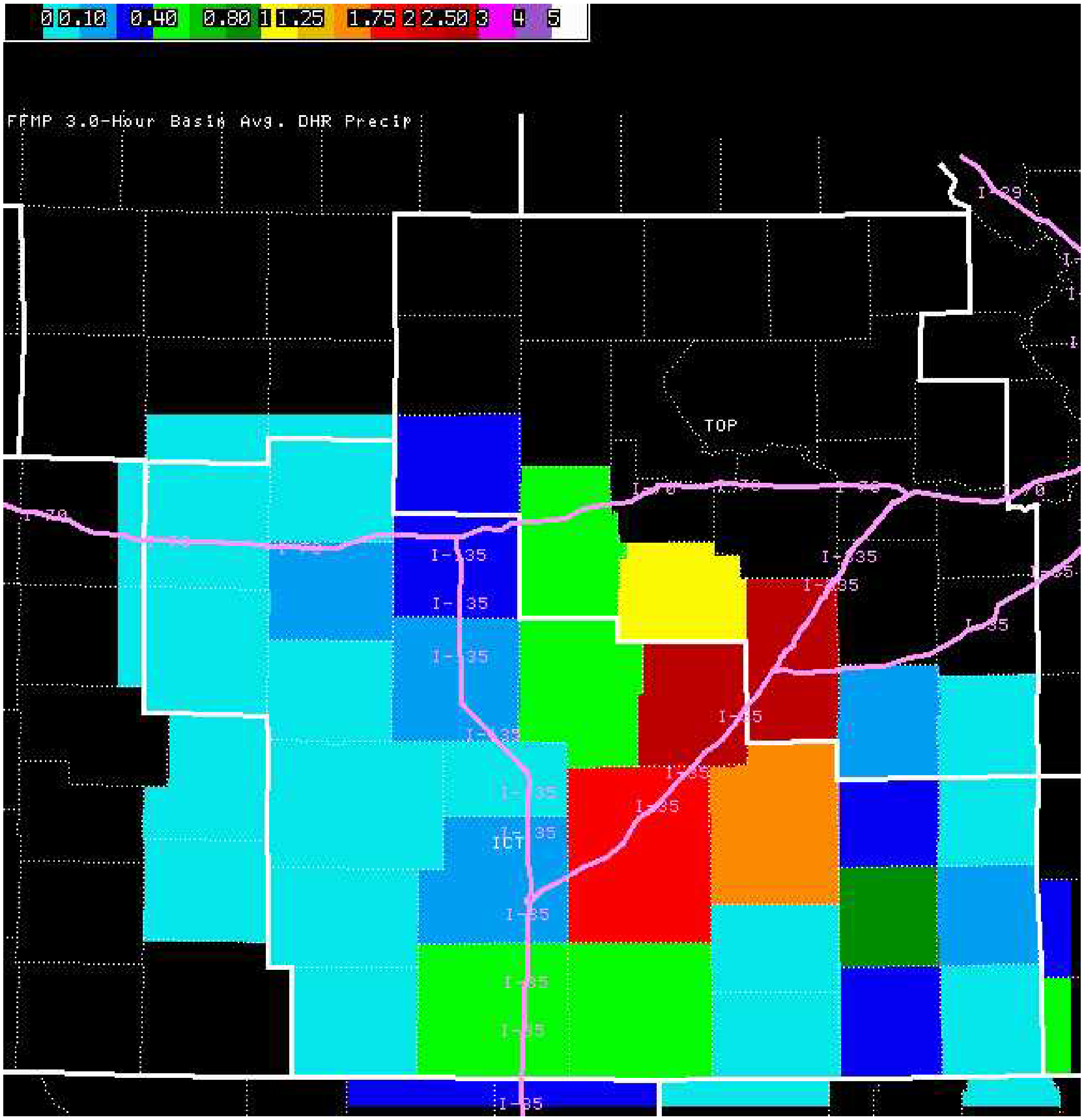

Figure 1: FFMP county image of 3-h radar-derived precipitation accumulation at 0130 UTC 31 August 2003. Color coding depicts the greatest accumulation of any basin within the county. Overlays include interstate highways (pink), county boundaries (white dotted), and NWS County Warning Area (CWA) boundaries (bold white).

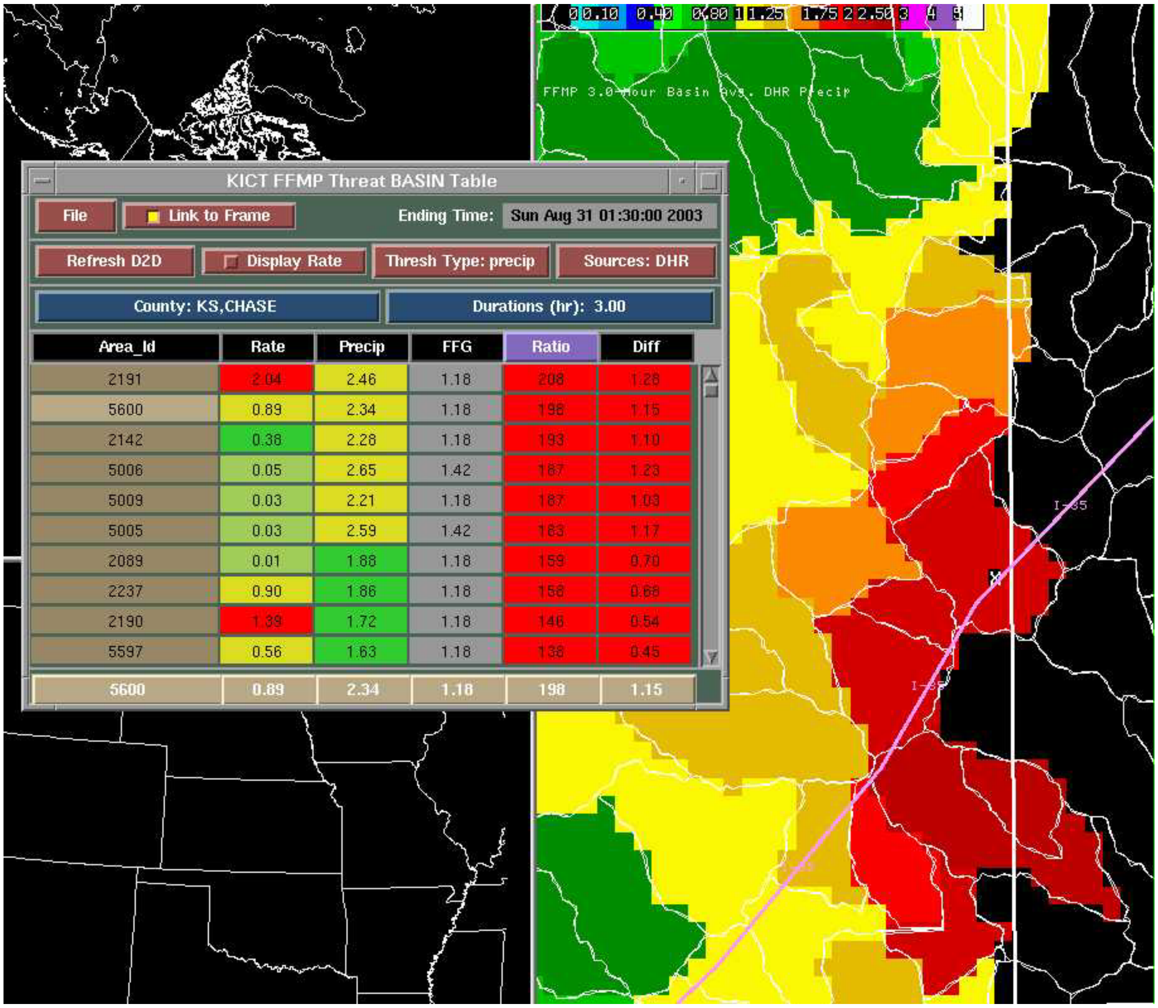

Figure 2: Basin-scale 3-h radar-derived accumulation with the Kansas Turnpike (pink), basin boundaries (white), and the Lyon/Chase county line (bold white line) as of 0130 UTC 31 August 2003. The table shows basin identification (Column 1), rainfall rates in the basin (Column 2), 3-h accumulation in the basin (column 3), 3-h FFG (column 4), the ratio of accumulation to FFG (Column 5), and the difference between accumulation and FFG (column 6). Basin 5600 (Jacon Creek), indicated by the “x” on the image, has had a 3-h accumulation of 59 mm (2.34 in) compared to the FFG of 30 mm (1.18 in). Because the county line is also an NWS CWA boundary, there are no data to the right of the line. This problem will be corrected in subsequent versions of FFMP so that basin information will be included for neighboring CWAs.

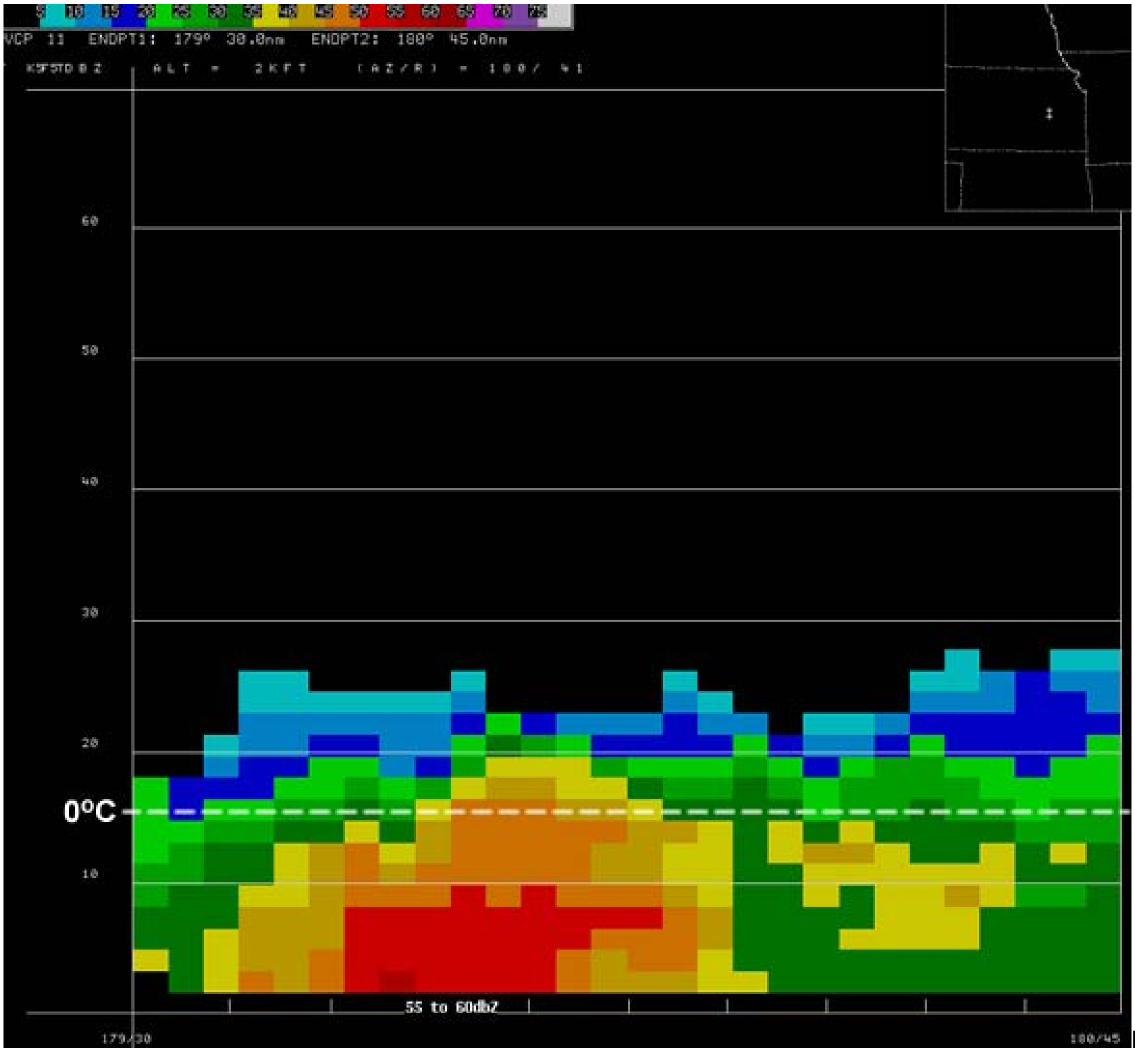

Figure 3. North to south cross section of 31 August 2003 storm. Dash line shows 0°C isotherm. Horizontal gray lines are drawn every 3048 m (10 Kft). Red colors depicts >50 dBZ.

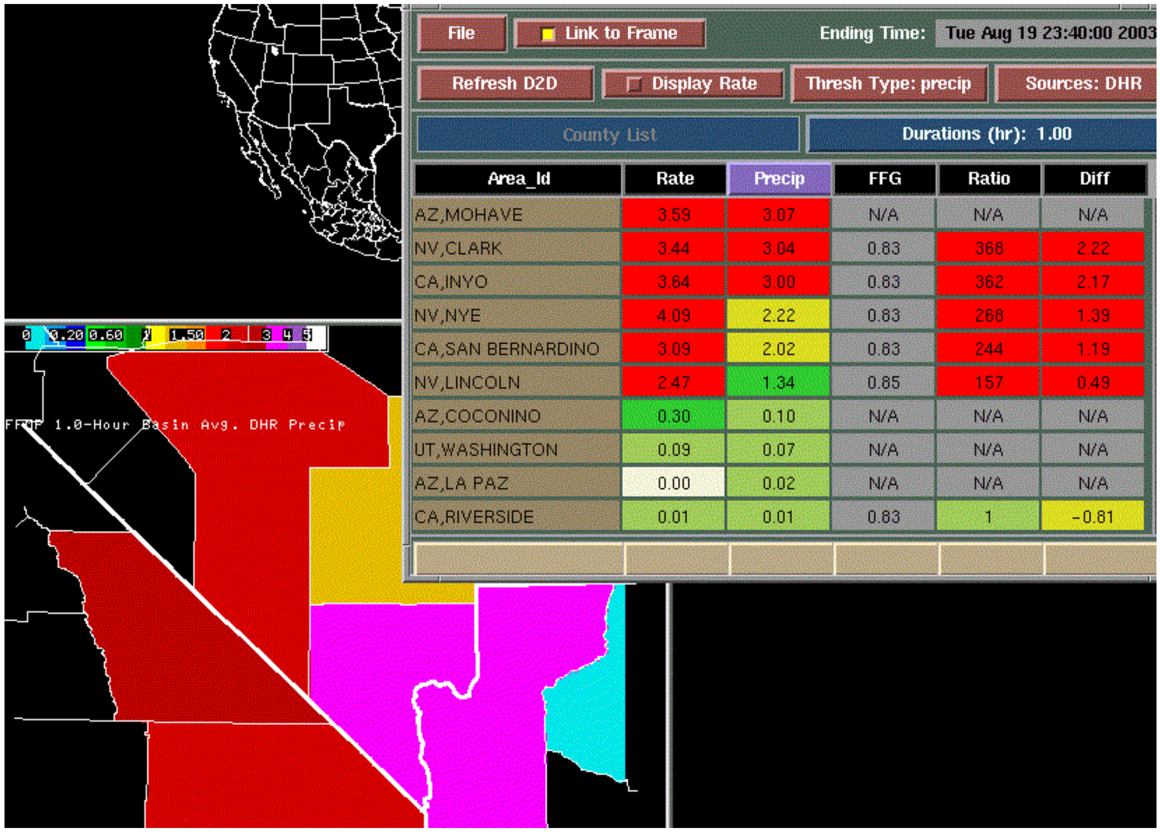

Figure 4: FFMP county 1-h radar-derived accumulation for southern Nevada as of 2340 UTC 19 August 2003. Color coding depicts the greatest accumulation of any basin within the county. Magenta color indicates the greatest accumulation of 75-100 mm (3-4 in). The table county name (Column 1), maximum rainfall rates within the county (Column 2), maximum 1-h basin accumulation within the county (column 3), 1-h FFG for the county (column 4), the highest basin ratio of accumulation to FFG within the county (Column 5), and the greatest difference between accumulation and FFG for a basin within the county (column 6). The table shows that a basin within Clark County, NV (second row) has had 77 mm (3.04) inches of rain in 1 hour, and another basin in the county (perhaps the same one) has a rate of 87 mm/h (3.44 in/h).

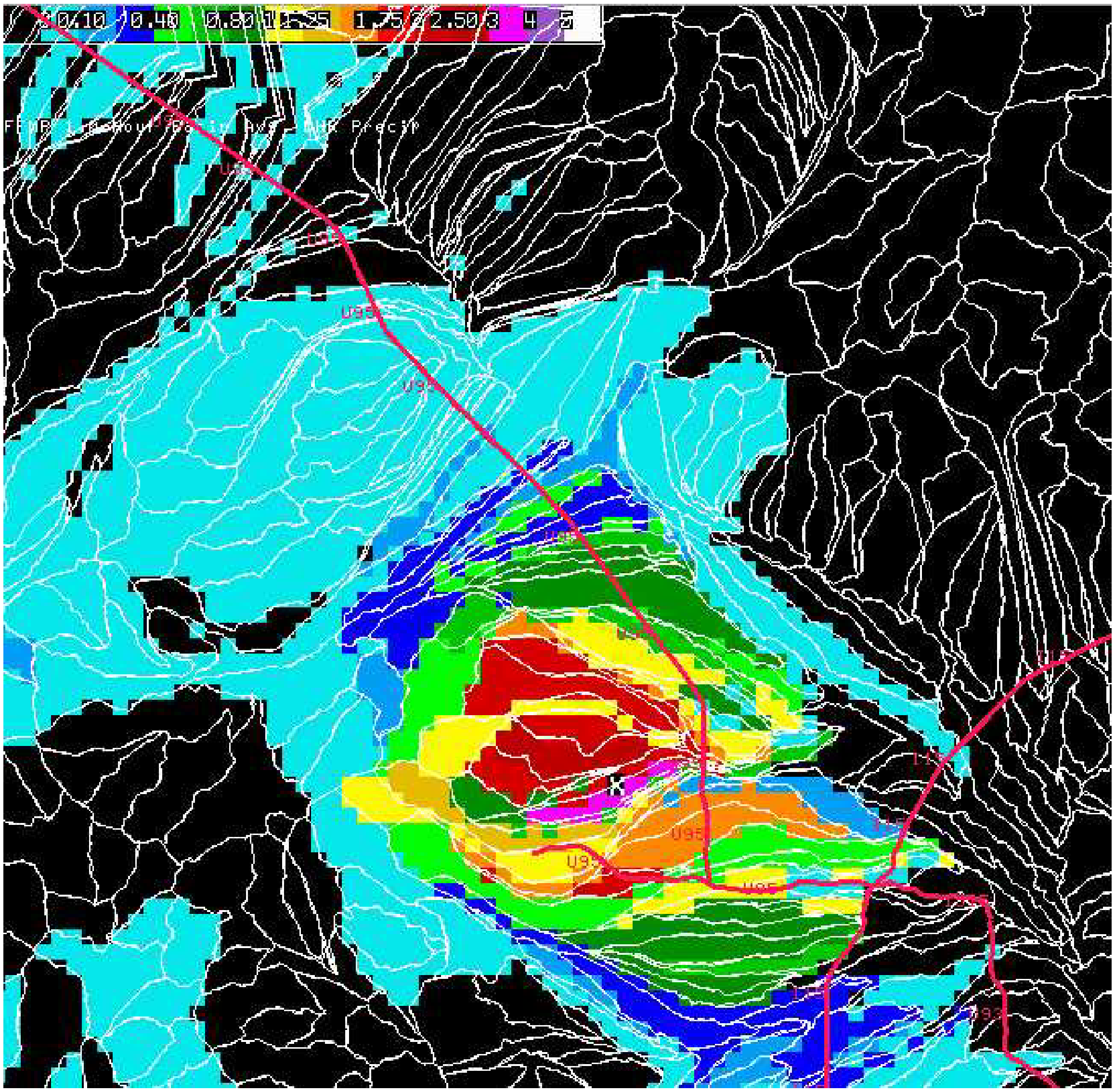

Figure 5: Basin-scale 1-h radar-derived accumulation as of 2340 UTC 19 August 2003 in the Las Vegas, Nevada area. Major highways are shown in red and basin boundaries are in white. Maximum accumulation of 75-100 mm (3-4 in) is depicted with the magenta color.

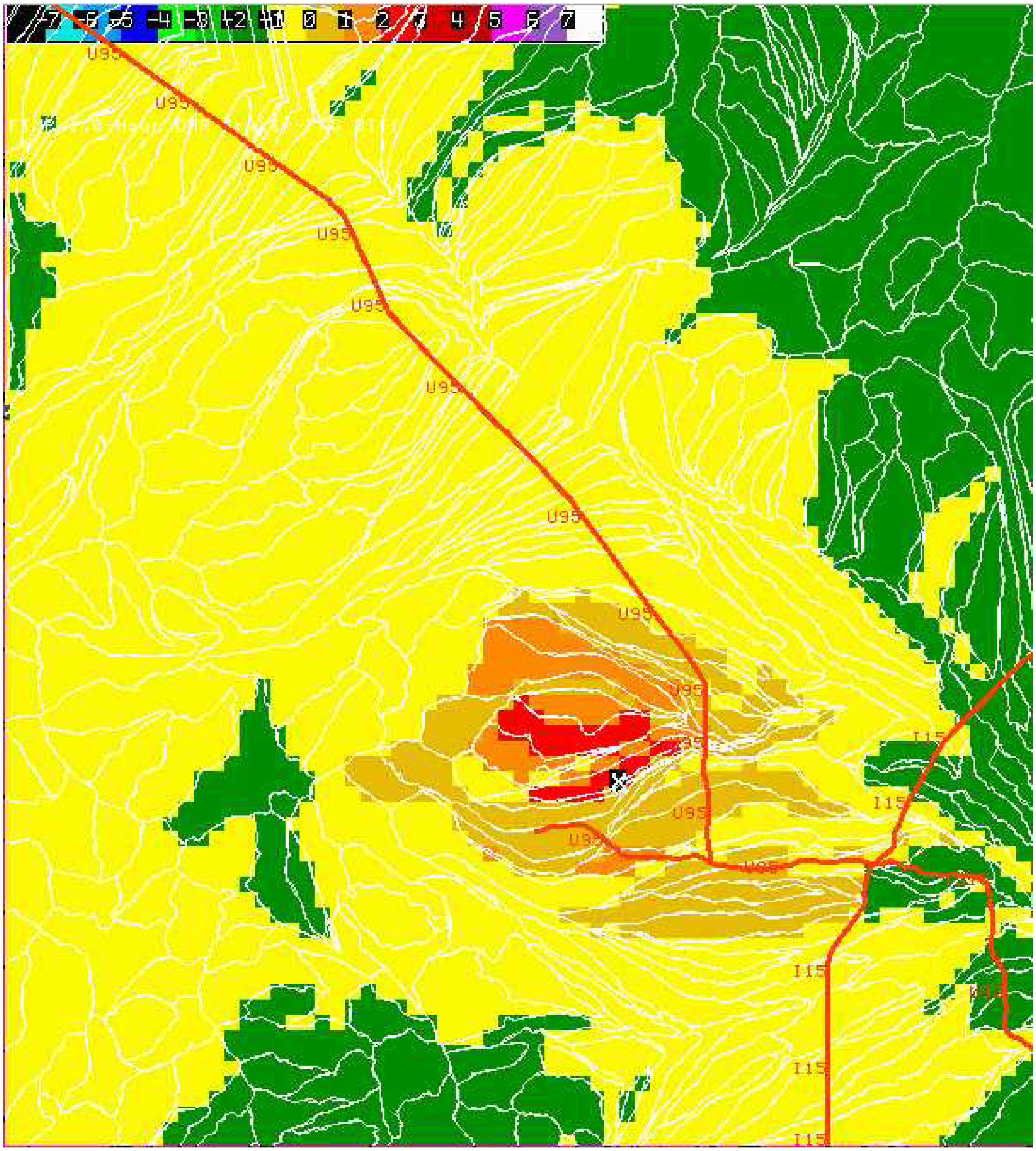

Figure 6: Same overlays and time period as Fig. 5, but image is for the difference between the 1-h accumulation and the 1-h flash flood guidance. The reds show the greatest positive difference indicating that the accumulation exceeds flash flood guidance by 50-75 mm (2-3 inches).