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FLASH FLOOD WARNING OPERATIONS DURING TROPICAL RAINFALL IN LOW RELIEF TERRAIN

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1. INTRODUCTION

This paper examines the flash flood that occurred over Southwest Georgia, as a result of heavy rainfall from a feeder band associated with Hurricane Dennis, after Dennis moved into Southwest Alabama late on 10 July 2005. The analysis scale of various precipitation products available to the Weather Forecast Office (WFO) forecaster over the areas flooded, and the timing of the resultant flood are reviewed. Staff warning decisions are also discussed. Field verification of the flash flood and feedback from Emergency Managers is presented.

The flood event followed the classic pattern for flash flooding with pre-event loading of urban drainage systems by moderate rainfall, followed by intense convective downbursts of rain that flashed rapid runoff through urban drainages, creeks and streams. Both Moultrie, GA and Sylvester, GA are located in relatively flat areas and received damaging floods that occurred in a matter of minutes. "In Colquitt county, flash flooding along the Okapilco Creek in Moultrie damaged many homes, washed out roads, and forced the evacuation of 100 homes. … In Worth County, a total of 300 homes were evacuated due to rising flood water, with 80 homes flooded." (NCDC 2005)

Post analysis of both events and the response of the stream channels indicate that even in relatively small towns, the combination of small scale urbanization with intense heavy rainfall can generate, flash flooding even in what is generally considered more rural flat areas in the deep south. It is the author's experience that such events can occur with weakening inland tropical cyclones, regardless of speed and direction of forward movement, and can occur far from the core of the remaining storm center as new feeder bands redevelop over inland areas. This has happened with Tropical Storms Allison, Barry, Helene and others in recent years.

2. PRE-EVENT

Hurricane Dennis originated in the Eastern Caribbean sea on July 4th and moved across the western tip of Cuba on July 8th into the eastern Gulf of

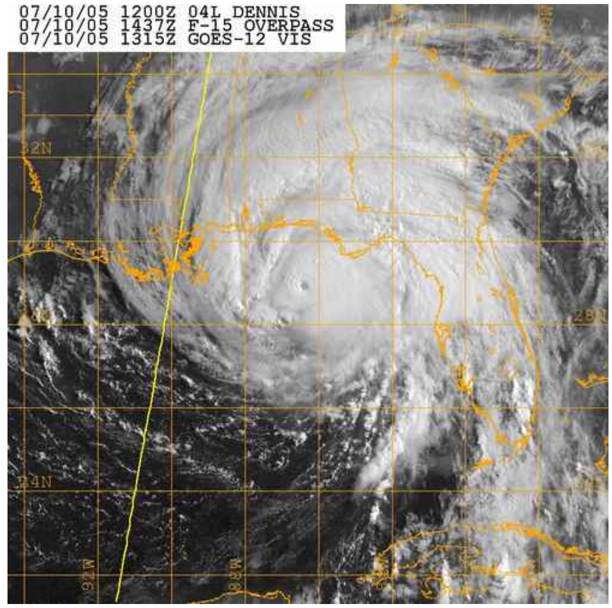

Figure 1. Hurricane Dennis GOES-12 Visual at 815am EDT on 10 Jul 2005. *GOES-12 satellite photo was provided by the Hurricane Research Division (HRD).*

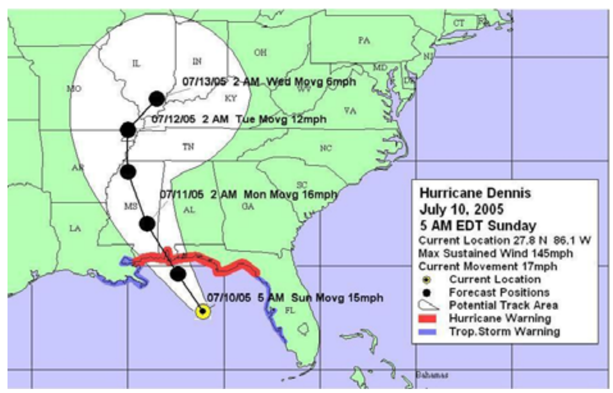

Figure 2. Hurricane Dennis location at 5am EDT Sunday 10 July 2005.

Mexico. Figure 1 shows that Dennis was a large storm with a circulation radius extending nearly 500 miles north and east of the center. By 2pm EDT Sunday afternoon as Dennis made landfall, radar rainfall estimates (not shown) from the Southeast River Forecast Center (SERFC) indicated that the precipitation shield had advanced to central Alabama and central Georgia which was well northeast of the position of Dennis. Due to the fast speed and direction of the storm the general outlook was for no

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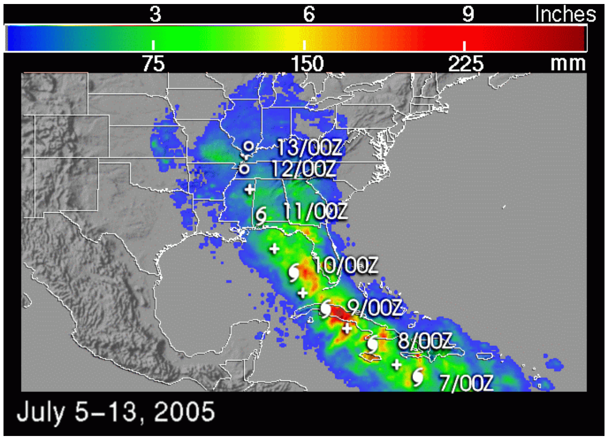

Figure 3. Hurricane Dennis rainfall totals composite from 4 through 13 July 2005. *Graphic obtained from the NASA Tropical Rainfall Measuring Mission (TRMM) Website http://trmm.gsfc,nasa.gov/ publications_dir/dennis_5-13july05_rain.html.*

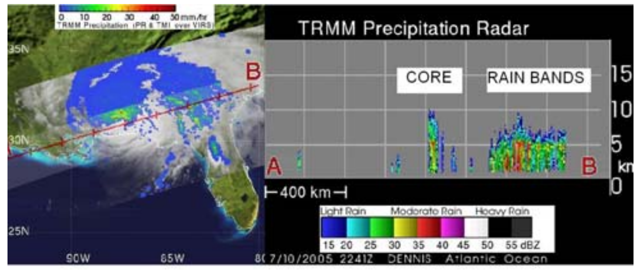

Figure 4. TRMM Radar precipitation Cross Section estimation. *Graphic obtained from the NASA Tropical Rainfall Measuring Mission (TRMM) Website http:// trmm.gsfc.nasa.gov/publications_dir/ dennis_10jul05.html*

significant precipitation over Georgia. However, the remains of Hurricane Dennis generated flash floods over much of Georgia Sunday evening. Additionally, heavy rain fell directly on the Flint River system and generated moderate riverine flooding down the Flint River.

Hurricane Dennis began to show heavy precipitation potential as it moved into the Gulf of Mexico. Figure 3 displays a satellite radar measurement of 3 to 6 inches over a wide area east of the storm track. The rain shield spread up to 300 miles northeast of the storm center as it moved inland across the western Florida Panhandle. As Dennis moved ashore, dry air wrapped around the center reducing the precipitation amounts over eastern Alabama. However the huge moisture field remained intact well east of the center, allowing for redevelopment of several intense stationary feeder bands over the Florida Big Bend and Southwest Georgia. This can be seen in the TRMM satellite radar cross section in Figure 4. Figure 5 displays the 24 hour rainfall total ending at 1200 UTC on 11 July. A dry slot is evident over eastern Alabama. Heavy rainfall from the core is apparent over western Alabama. Feeder band rainfall appears well east of the storm center over the Florida Big Bend and western Georgia. Figure 5 shows these rain accumulations in better detail. A review of One Hour Precipitation (OHP) products (not shown) reveal a series of four rain band events that impacted Florida Big Bend and western Georgia as Dennis made landfall and moved northwest overnight. The first feeder band event occurred mostly over Dixie County over 250 miles east of Hurricane Dennis as Dennis moved ashore in the western Florida Panhandle. Two more pulses arrived over the Florida Big Bend and Southwest Georgia between 8pm and 11pm EDT, which generated local flooding that affected Thomas, Colquitt and Worth Counties. The fourth and final band event began around 4am EDT over extreme western Georgia. Rainfall associated with all these bands generated strong hydrologic responses over the entire Flint River Basin. In particular, all of the bands converged in northern Georgia and generated significant flooding in the upper Flint River basin drainages around Atlanta. (Dobur and Fuchs 2005). Each band is annotated in Figure 5 below.

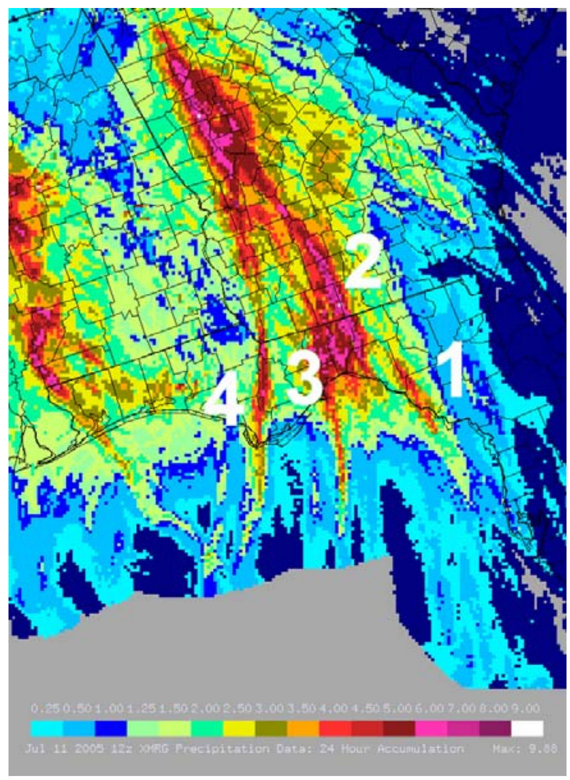

Figure 5. XMRG 24 hour rainfall total from 10/1200 to 11/1200 UTC July 2005 courtesy of the Southeast River Forecast Center. Feeder band events 1, 2, 3 and 4 are annotated

Feeder band number 2 in Figure 5 is the focus of this paper. This band setup directly over Okapilco Creek between 8pm and 11 pm EDT on 10 July 2005.

Doswell et al. (1996) discussed the importance of high precipitation efficiency with saturated moisture advection and strong convective elements needed to create conditions for intense precipitation that can lead to flash flooding. Tropical cyclone feeder bands contain those elements. A major concern is the ability of radars to accurately resolve small scale intense rain rates at distance from the radar during warm tropical rainfall events. It is interesting to note that the elevation of the most intense portion of the feeder band core as estimated by the TRMM satellite radar, over southwest Georgia, extends to about 5km in Figure 4. For this study the surface radar cross section from KTLH was not readily available, but could prove useful for gaging the effectiveness of radar performance during tropical events.

3. FLASH FLOOD FORECASTING

Forecasters have several tools to monitor rainfall which average local rainfall at different spatial scales and are available to forecasters at varying times. These include OHP available every 4-6 minutes (1/2 nm x 1 deg), HRAP XMRG files (2.2 x 2.2 nm) available every hour, Hybrid Scan Reflectivity (1/2 nm x 1 deg), Digital Hybrid Reflectivity (DHR) products (1/2 nm x 1 deg), and Flash Flood Monitoring and Prediction (FFMP) basin accumulations (5 to 10 square miles) based on DHR data typically available every 4-6 minutes.

The accuracy of methods of estimating rainfall intensity is a function of distance from the radar. This is a result of raw reflectivity beam spreading and also the way DHR precipitation grid widths widen with distance from the radar. Small FFMP basins at grater distances from the radar will have fewer DHR grids available for precipitation estimation resulting in lower resolution at long ranges. Regardless of the range associated accuracy of rainfall calculations, FFMP automation makes available to operational forecasters the high quality rainfall intensity estimates using small DHR radar reflectivity data. The ability to automatically calculate small basin mean area precipitation, and make such information available to the forecaster has proven invaluable.

4. FFMP PROCESS

The Flash Flood Monitoring and Prediction (FFMP) program is a suite of software used by WFO forecasters to assess the potential for short term flooding caused by locally heavy rain events. FFMP computes Average Basin Runoff (ABR) for small basins on the order of 5 to 10 square miles in size. These basins were developed by the National Severe Storms Laboratory (NSSL), as part of the National Basin Delineation Project using the USGS National Elevation Dataset (NED) (Arthur et al., 2005). Basin sizes are determined such that most basins within each radar umbrella are assigned at least one 256 level, 1km x 1degree Digital Hybrid Reflectivity (DHR) radar bin, either within or nearby to each basin. The FFMP basins are represented as vector lists in files located on AWIPS for use by FFMP.

Rainfall in excess of Flash Flood Guidance is assumed to generate the potential for flash flooding on small creeks and streams. Flash Flood Guidance (FFG) is issued by the supporting River Forecast Center (RFC). FFG issued by the Southeast River Forecast Center is based upon Sacramento Soil Moisture Accounting (SACSMA) Model estimates of basin soil moisture across the forecast area. FFMP calculates rainfall accumulations on time scales ranging from ½ hour to 6 hours for each small basin. Forecasters monitor FFMP basins for indications of accumulations reaching warning criteria, and issue Flash Flood warnings as appropriate. The graphics are scalable, and basins can be referenced to local areas of concern (Filiaggi 2005).

5. WFO / RFC OPERATIONS DURING THE FLOOD EVENT.

After Hurricane Dennis made landfall at the Alabama-Florida border around 230pm EDT, it continued moving rapidly northwest away from the Tallahassee forecast area. Rainfall over southwest Georgia from east-west oriented rain bands was limited to 1 to 2 inches that afternoon since the bands were moving orthogonally to the north and no training occurred. However this rainfall did help to pre-load urban drainage areas that led to flash flooding in Moultrie and Sylvester later that evening. The NWS Hydrometeorological Prediction Center (HPC) forecasted 24 hour rain totals over Southwest Georgia of one inch. The heaviest rain was forecast to occur near the storm center core in Alabama, well away from Georgia and the Florida Big Bend. Towards late Sunday afternoon, convection over Georgia and Florida appeared to be winding down. However, around 8pm EDT two new strong pulses of convective activity developed over the Gulf of Mexico and propagated rapidly north along the feeder band boundary through the Florida Big Bend and into Southwest Georgia. The first pulse (feeder band number 2 in Figure 5) affected the towns of Boston in Thomas County, Moultrie in Colquitt County and Sylvester in Worth County. The second pulse (feeder band number 3 in Figure 5) arrived slightly to the west but still over Thomas County, western Colquitt and western Worth Counties adding to local flooding in those counties.

KTLH OHP products showed rain rates of 1 1/2 to 2 1/2 inches of rain per hour from 8pm to 11pm EDT in an area extending from Jefferson County, Florida through the center of Colquitt County and northward through the center of Worth County. Storm totals of 6 to 7 inches were common. Given the rainfall that had occurred earlier in the day over the same area, rainfall totals on the order of 5 to 6 inches over the area in three hours were indicated. These amounts were verified by the NWS Cooperative Observer at Moultrie who reported a 24 hour total of 6.58 inches the next morning. This amount appears to match radar accumulations, but requires closer examination. This will be accomplished when post processing of Digital Hybrid Reflectivity products for this event is completed by the authors.

Based on radar estimates of two to three inches, FFMP monitoring and reports of high water in the Moultrie area, forecasters issued an Area Flood warning at 1021pm EDT. The warning included Brooks, Colquitt, Thomas and Worth Counties. The SERFC was updating FFG every 6 hours during the event. At around 4pm EDT the latest FFG showed a 3 hr FFG for Worth County of 3.5 inches and Colquitt County 3.1 inches. The FFG was updated at 849pm EDT by the SERFC, and showed a 3 hr FFG of 2.3 inches for Worth County and 2.2 inches for Colquitt County. The FFG was close to the accumulations which occurred during the time frame of the flood event.

6. HYDROLOGY

The flooding caused by the feeder band from the remnants of Dennis began as an urban flash flood in two separate small communities and then transitioned to longer term creek flooding. The 3 hour storm total met or exceeded the local 100 year return amount and design storm water drainage of both towns. Runoff from this event moved rapidly downstream through local stream channels and flooded numerous homes. The topography of the drainage basins that surround Moultrie and Sylvester are quite different, especially considering the two towns are separated by only twenty-five miles. However both areas are similar in that they are both predominately residential neighborhoods.

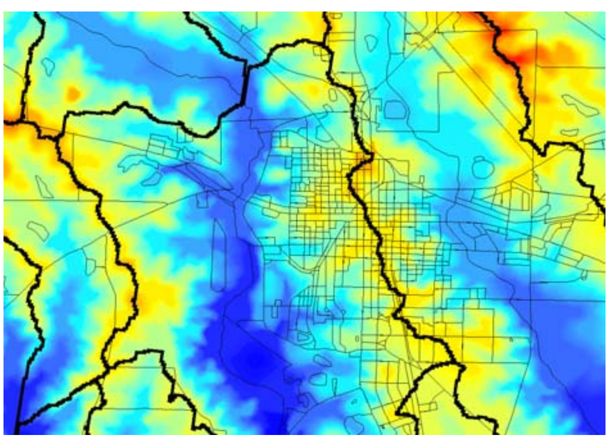

Figure 6. Digital Elevation Map of Moultrie Georgia with KTLH FFMP basin vectors in black.

Moultrie, (Figure 6) is located 25 miles south of Sylvester. The topography around Moultrie is relatively flat and is approximately 250 feet above mean sea level. Only small elevation changes determine drainage basin boundaries. This gives ample room for large flood plain footprints when compared to the waterway channel and average volume rates. The city of Moultrie resides on a small “ridge” that divides the city into two separate drainage basins (Figure 6). The western part of the city drains into the Ochlockonee River, while the rest of the city drains into Okapilco Creek.

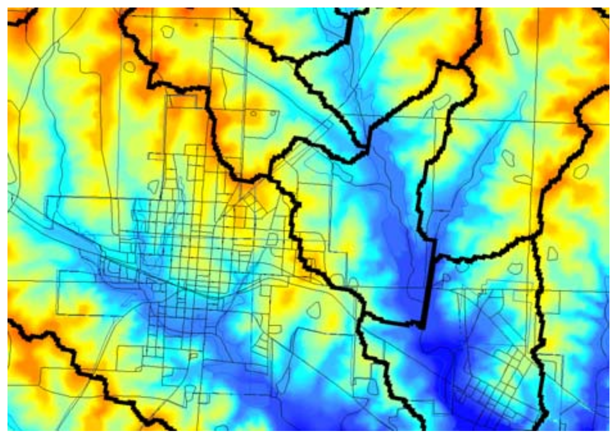

Figure 7. Digital Elevation Map of Sylvester, Georgia with KTLH FFMP basin vectors in black.

Sylvester (Figure 7) on the other hand, is in rolling foothills and sits in the headwaters for Town Creek, which drains south along the western and southern edge of the town. The tributaries for Town Creek run in a north-south direction, and divide the town into multiple smaller drainage basins with a much higher relief than that of Moultrie (Figure 7). While they both have the same bottom elevation of 250 feet above mean sea level, the foothills on which Sylvester has been built, rise quickly in excess of 330 feet, compared to the 270 foot maximum elevation cited in the Flood Insurance Study by the Federal Emergency Management Agency FEMA (1997).

As previously mentioned, precipitation had occurred earlier in the day resulting in surface saturation, and forcing any later rainfall to move to a lower elevation via overland flow for both urban areas. This effect was responsible for the flooding that occurred within 30 minutes from the time of the arrival of enhanced convective elements moving across both cities. The Flash Flood began in Moultrie around 930pm EDT and in Sylvester around 1030pm EDT. The flash flood event for both cases affected the tributary systems very quickly, since the ground surface was already saturated, allowing only for surface collection and damming to weaken and delay the overland flow event.

The City of Moultrie flash flood occurred mainly on the tributaries to the Ochlockonee River. These events started within half an hour of onset of significant precipitation, and the flooding subsided within a day of the event. All of the homes that were impacted by these events were upstream from road crossings where the culverts under the roads were not designed to handle the resulting volume of water. In these areas, the maximum height of the floodwaters was at the level of the roads, which served as dams to the water. When water reached the height of the roads, it flowed across them and continued downstream.

It should be noted that these flash flood events occurred within the flood plains determined by FEMA (1997). One area that flooded was outside the city limits of Moultrie, where the majority of homes was affected. This area involved a trailer park that is sited below two drainage ponds which were overwhelmed by the precipitation event. Both ponds overflowed their banks. The earthen dam directly above the trailer park has a low spot away from the normal streambed channel. Water flowed over that low spot and directly through the trailer park, and back to the normal stream channel. Ripples in the sand and the blown out trailer skirts gave evidence of high velocity flow that flashed through the trailer park. A road culvert downstream of the trailer park which serves as an outlet for the streambed channel, was not designed to handle the flash flood. This which resulted in the creation of a new pond that back flooded the trailer park to a depth of 4 to 7 feet.

The flash floods in the City of Sylvester occurred for the same reason. The Worth County Emergency Management Office sits in a shallow drainage basin at the start of a complex of storm water culverts that run underneath the building. Similar to what occurred upstream, the culverts could not handle the inflow rates, and the water overwhelmed the system. The Worth County Emergency Management Office was flooded with about 1 foot of fast moving water. The Emergency Management Office is located just upstream from the deepest part of the drainage basin, which is used as a city park. Flood waters in the park reached a depth of 3 to 4 feet deep. The area is far upstream from the boundary of inundation determined by FEMA (1997), and was not considered to in a flood plain.

Flash Flooding was not the only type of flooding that occurred due to this precipitation event. Riverine flooding developed well after the rainfall had subsided. Okapilco Creek in Moultrie, and Town Creek in Sylvester both subsequently overflowed their respective banks. Both events continued well after the precipitation had ended, and caused significant amounts of damage which forced evacuations and closures of roads. In Moultrie, the flooding of Okapilco Creek caused the inundation of buildings that had been erected in the flood plain. In one specific case, a bridge for a road that served as one of the town's main arteries had to be closed. Flood Damage did not occur on the Ochlockonee River, even though the flash flooding that occurred was on the tributaries of that system. In all likelihood, this was due to the fact that there is still a significant riparian zone, with little or no encroachment of permanent structures on the flood plain of this larger water system.

In Sylvester the flooding occurred along Town Creek, where low income homes had been built in the flood plain, forcing multiple evacuations. Some of the houses have since been condemned. In both cases, however, the cresting events inundated only the flood plains of the respective creeks, and did not exceed the boundaries of the 100 year flood plain.

7. FIELD VERIFICATION—SITE VISIT

Figure 8. Photograph of Flash Flood induced culvert damage in Moultrie, GA. Photo courtesy of Russell Moody, EMA Director, Colquitt County, GA.

Two of the authors, Richard Lanier and Jon Suk, conducted a post storm site visit with County Emergency Managers in Colquitt and Worth Counties in order to get a better assessment of the flooding and resulting damage. Bob Duggan, Hydrometeorological Technician, WFO Tallahassee, assisted with the site visit to Colquitt County. Due to the active Hurricane season, the site visits were not possible until just recently. However, much information was obtained, which will be useful for further investigation. We met with the Colquitt County EMA Director Mr. Russell Moody and his assistant Ms. Rene Hawkins on 11 Oct 2005. Mr. Moody explained that at 6pm EDT, conditions were dry across the area, but by 9pm EDT there were so many roads flooded that they activated the Emergency Management office. By 930pm EDT a mobile home park near Moultrie had flooded, and emergency crews including the EMA Director were rescuing people from their flooded homes. Mr. Moody explained that the flooding occurred in two main areas. The first started on the west side of town as a flash flood. He confirmed that the locations that flooded were where the rainfall runoff exceeded design storm and flow restrictions in the various culverts. See Figure 8.

Mr. Moody indicated that the second half of the flood which occurred on Okapilco Creek the next day, lasted a week. He noted that Okapilco Creek was responsible for general flooding in portions of Moultrie, and that back flooding of a housing project in the flood plain generated most of the damage to homes. Additional flood related damage occurred downstream on Okapilco creek in rural areas of the county. Around 60 roads in Colquitt county flooded during the event, and 25 roads were severely damaged.

We next met with the City of Moultrie Engineer, Mr. Roger Ruiz, who provided us with detailed city maps and storm design information. Mr. Ruiz briefed us that the town of Moultrie can handle no more than 4 inches in one hour under dry conditions, and 2 inches of rain in one hour under saturated conditions. It is apparent that conditions were saturated during the Hurricane Dennis event, leading to the flash flooding in Moultrie.

Figure 9. Worth County Flooding. Photo courtesy of Michelle McMicken, Worth County Assistant EMA.

On 13 October, two of the authors (Richard Lanier and Jon Suk) surveyed the flood damage in the town of Sylvester, GA, 25 miles north of Moultrie, GA. We visited with Ms. Michelle McMicken, Assistant Emergency Management Director for Worth County. Ms. McMicken reported that her staff received notification from the 911 office at 1030pm EDT that flooding was occurring in Sylvester. A few minutes later at 10:35pm EDT, the Worth county Emergency Management staff had to quickly evacuate the Emergency Management building as water rushed in through the doors. As discussed earlier in this paper, the Worth County EMA office is positioned over a drainage culvert that runs underneath the building. The entire office was damaged by water and is currently being refurbished. Ms. McMicken took us on a tour of the Sylvester area, with a special focus on the Town Creek drainage system. Town Creek drains the west side of Sylvester. Ms. McMicken explained that many residents needed to be rescued by boat between 1030pm and 230am EDT in the Town Creek flood plain. Continued rescue efforts were required the next day, but by Tuesday 12 July, the flooding had ended.

8. SUCCESS AND CHALLENGES

FFMP successfully provides NWS forecasters with rapid visual notifications of heavy rainfall situations capable of creating flash floods in small basins.

With the FFMP tool now available to forecasters, the main challenges are the need to increase our understanding of the limitations of the current radar precipitation processing methods and the need to find ways to apply the ground component of flash flooding (slope, urbanization, soils and soil moisture) to Flash Flood forecasting.

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