P1.4 USING THE NEW GENERATION OF FLASH FLOOD WARNING TOOLS.

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1.0 INTRODUCTION

New flash flood forecast and warning tools will soon become available in all National Weather Service (NWS) forecast offices with the implementation of the Flash Flood Monitoring and Prediction (FFMP) program version 2.0 (Smith et al. 2000). FFMP computations of Average Basin Rainfall (ABR) are based on the Areal Mean Basin Estimated Rainfall Program (AMBER) developed at the Pittsburgh, PA NWS Office (Davis and Jendrowski 1996).

The new flash flood tools, developed by Paul Jendrowski (Jendrowski and Davis 1998), are graphical enhancements of the original AMBER output of digital ABR and ABR rate products. The enhanced AMBER software, created with Geographic Information System (GIS) software, is called AMBERGIS. This paper shows how the AMBERGIS tools detected a rapidly developing flash flood in Franklin, PA on 21 June 2001.

2.0 AMBERGIS STREAM DATABASE

A detailed stream database, created by the National Basin Delineation (NBD) program (Cox et al. 2001) is used to create the graphic display of ABR and ABR rate products. A sample of the NBD stream database is shown for the city of Franklin, at the confluence of French Creek and the Allegheny River in Venango County in northwest PA (Fig. 1). Figure 2 shows the NBD stream segments that are included in the Pittsburgh NWS AMBERGIS stream basin database for the Franklin area. The 11,180 defined segments are assigned a unique identification number.

Each defined stream segment has a single outflow point and may have one or more inflow points. Two small tributaries of the Allegheny River, segment 5624 (area 1.8 km^2) and segment 5622 (area 3.3 km^2) have been added locally to the NBD database. The

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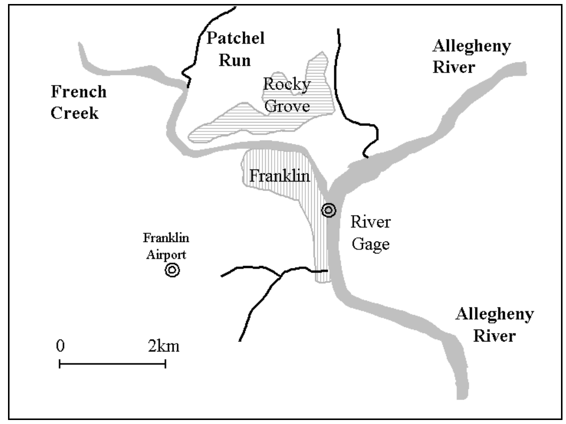

Fig. 1. Major rivers (dark gray) near Franklin, PA in Venango County. Hatched areas are urban areas. Solid dark lines are streams feeding into the major rivers.

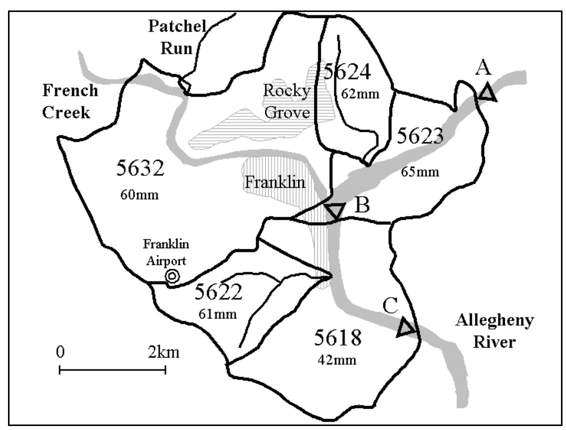

Fig. 2. AMBERGIS stream segments near Franklin, PA. ABR (mm) for 2336-0040 UTC 21-22 June 2001 for each segment. Large numbers are stream segment identification numbers. Major rivers are shown in dark gray, with urban areas hatched in light gray. Heavy solid lines are the segment boundaries.

stream segments provided by the NBD dataset have a minimum basin area of 5 km^2.

The main rivers are divided into segments, providing complete hydrologic connectivity.

For example French Creek from Patchel Run to the Allegheny River is segment 5632 (area 16 km^2). Two segments of the Allegheny River 5623 (area 5.4 km^2) and 5618 (area 5.1 km^2) are shown. The Allegheny flows into segment 5623 at Point A, flows into 5618 at point B, and exits 5618 at point C.

Tributaries of the main rivers are also divided into stream segments. Figure 3 shows how Patchel Run (total area 18 km^2) is divided into three stream segments.

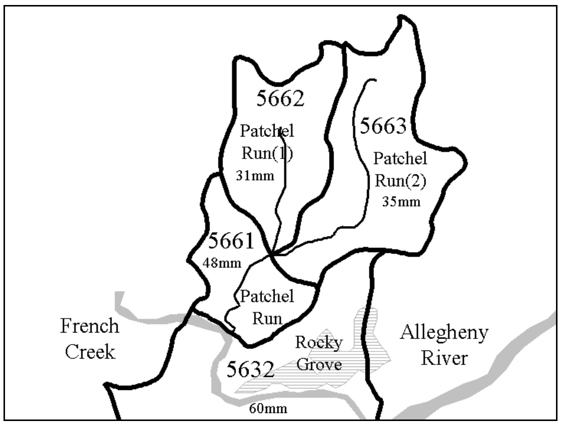

Fig. 3. AMBERGIS stream segments for Patchel Run near Rocky Grove, PA. Large numbers are stream segment identification numbers. ABR (mm) for 2336-0040 UTC 21-22 June 2001 for each stream segment. Thin dark lines are stream channels. Major rivers are dark gray, and urban areas are hatched light gray. Heavy solid lines are the segment boundaries.

3.0 AMBERGIS GRAPHIC DISPLAY

The ABR and ABR rate for each stream segment are computed for each radar volume scan (every 5 minutes). The ABR is stored in the real-time ABR database in five-minute increments, and may be summed into any time increment. AMBERGIS produces seven graphic products in the Digital Hybrid Scan Reflectivity (DHR) polar one degree by one kilometer format including ABR rate and ABR accumulations of 15, 30, 60, 90, 120 and 180 minutes. The time period for each graphic is user selectable. A time lapse of the ABR Rate product can effectively be used to show the persistent heavy rainfall over the same geographic area (training of echoes).

Figure 4 shows the DHR polar grid plotted on stream segment 5632. Notice in Figure 2 that 60 mm of ABR fell in 5632. The AMBERGIS graphic for 60 minute ABR would show all nine radar bins contained in 5632 with a color code for 60 mm of ABR.

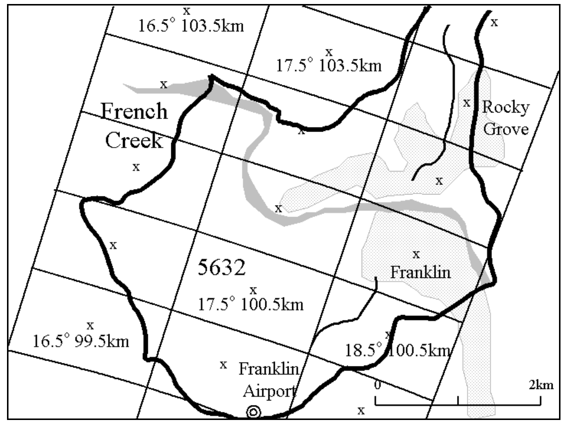

Fig. 4. DHR polar grid plotted on the French Creek stream segment (5632). Center point of each bin is shown with a small “x”. Radar azimuth (degrees) and range (km) are given for several bins. Major rivers are dark gray, while urban areas are hatched light gray.
Heavy solid lines are the segment boundaries.

4.0 FLASH FLOOD ASSESSMENT

The potential flash flood severity can be determined by comparing observed ABR with flash flood guidance (FFG). The FFG is the amount of ABR needed in a specific period of time to initiate flooding on a stream (Sweeney 1992). This county-based FFG is computed for time periods of 1,3,6,12 and 24 hours. The FFG computation assumes the stream is at low flow and no rainfall has occurred in the basin since the rainfall data cutoff time. If streams are running at high levels and/or multiple periods of rain have occurred in the basin since the last ingest of rainfall into the FFG computation, the actual FFG may be much lower that the posted FFG. Watershed segments with a large percentage of urban coverage may have actual FFG considerably below the county-based FFG. The FFG product also comes with the disclaimer that “steep terrain can greatly reduce actual FFG”.

The amount of ABR over FFG is directly related to the severity of the observed flash flooding. ABR of 25 mm over FFG may put

0.5 m of water on a bridge, causing some cars to stall in the water. ABR of 50 mm over FFG in that same watershed may result in 2.0 m of water on the bridge and wash cars off the bridge and into the stream. When ABR equals FFG typically only minor flooding problems occur as streams reach a bank full condition.

ABR must exceed FFG by a significant amount to produce serious flash flooding. Based on years of ABR observations (1990 through 2001), the Pittsburgh NWS office has found that ABR of 25 mm over FFG is often related to the start of significant flash flooding, and ABR of 50 mm or more over FFG usually results in serious flash flood occurrences. These locally observed thresholds may vary considerably in other portions of the United States.

FFG for 21 June 2001 in Venango County, PA was 53 mm hr^{-1}, with significant flash flooding expected at about 78 mm hr^{-1}. Notice the observed ABR (Figs. 2,3) ranged from 31 mm to 65 mm, indicating that no serious flash flooding should occur, but minor flash flooding might be expected.

Not all AMBERGIS stream segments have high flash flood potential. Larger rivers serve as a natural boundary to flash floods. The volume of water generated by the locally heavy rainfall producing flash flooding is usually small compared to the volume of water needed to bring a large river to flood. For example, the heavy rainfall near Franklin, PA on 21 June 2001 caused the river gage on the Allegheny River at Franklin to rise from a stage (flow) of 1.0 m (90 $m^3 s^{-1}$) to 1.2 m (144 $m^3 s^{-1}$), while flood stage at Franklin is 5.2 m (2,746 $m^3 s^{-1}$).

This is not to say that river segments are never subject to flash flooding. The Saint Charles, PA river forecast point on Redbank Creek (area 1,403 km^2) was struck with a flash flood on 19 July 1996 (Davis 2000). If heavy rainfall is spread over a large geographic area flash flooding can occur on larger watersheds.

A stream segment type designation is used to remove stream or river segments from the comparison of ABR vs. FFG. The stream segments types are determined by the local NWS office and are not supplied with the NBD database. Main river segments are usually removed from flash flood computations. Major river segments containing urban areas are included in the ABR/FFG comparison. Flash flood rainfall can quickly overwhelm the storm drainage network of urban areas causing severe urban flooding.

Most tributaries of the major rivers are typically flash flood streams, such as Patchel Run in Figure 3. These streams are divided into stream segments, as heavy rainfall and flash flooding may occur in small portion of the larger stream watershed.

The ABR/FFG comparison is only valid if both the ABR radar estimate and FFG are reasonable approximations of the actual ABR and FFG. ABR can be verified by comparing radar estimates with observed rainfall (Davis 1997). Figure 5 shows the radar estimate for the Franklin Airport rain gage was very close to the 56 mm measured at the gage site.

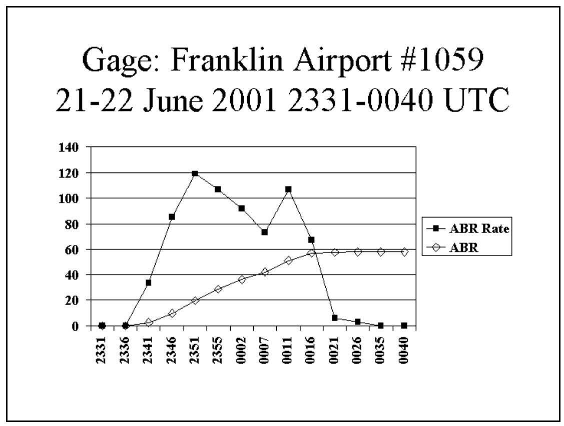

Fig. 5. Radar estimated ABR rate (mm hr^{-1}) and ABR (mm) for the Franklin Airport.

5.0 BASIN SPECIFIC WARNINGS

When AMBERGIS indicates the potential for flash flooding in a stream segment, the stream name and possible damage track along the stream can be inserted into the flash flood warning. During post-storm analysis, if the flash flood damage is accurately located, stream segments that contributed to the flash flooding can be directly identified. Figure 6 shows the areas of flood damage in the 3rd Ward north of French Creek and the length of Chubb Run along the 15th Street hill. Stream flooding from Chubb Run (Fig. 7) produced the flood damage along 15th Street. Chubb Run is contained within the river forecast segment 5632, but should be locally subdivided as a separate stream segment. No stream exists in the 3rd Ward, and flooding in this area was the result of the rapid inundation of the urban storm drainage system.

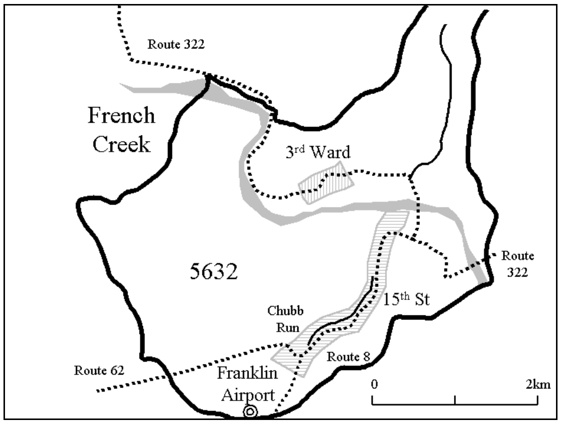

Fig. 6. French Creek stream segment 5632 showing major highways(dotted lines), major rivers (dark gray), segment boundary (heavy dark solid line), small streams (thin dark solid line), and areas is major flooding (hatched light gray).

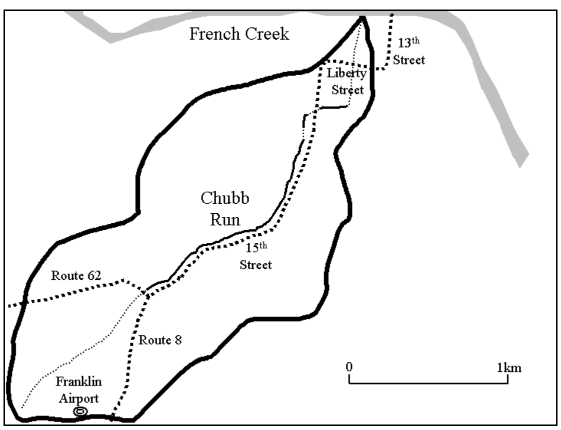

Fig. 7. Chubb Run (area 2.8 km^2) watershed showing watershed boundary (heavy solid line), major highways (heavy dotted line), stream channel (light solid line), stream underground in storm drain (light dotted line), major river (dark gray).

Two factors combined to reduce the actual FFG in portions of segment 5632, the area of urban coverage and the extreme slope of the topography. Figure 8 shows the location of two cross-sections across the areas of flood damage. Davis (2001) shows the typical slope (m/m x 1000) of "steep terrain" flash flood streams range from 10 to 30 with some extreme slopes of 100-110. The Chubb Run stream channel has a 146 m drop in 2800 m of reach for a slope of 52. The cross-section of the Chubb Run valley wall (Fig. 9) with a 150 m drop in a 1500 m reach has a slope of 100. The extreme slope of valley walls increases runoff and creates a larger flood crest in the stream flow.

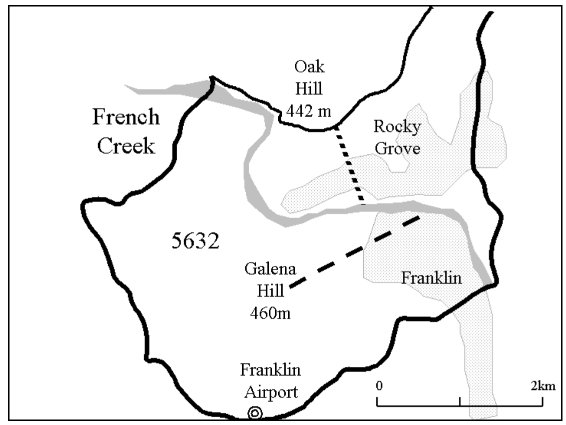

Fig. 8. French Creek stream segment 5632 showing cross section location for Chubb Run (heavy dashed line), and the 3rd Ward (heavy dotted line), major river (dark gray), and urban areas (light gray hatching).

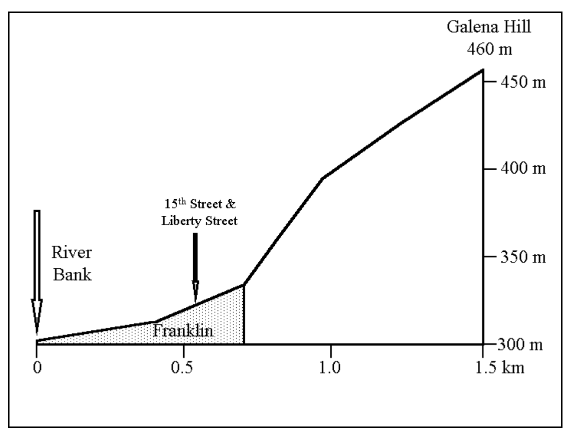

Fig. 9. Topographic cross section across Chubb Run from French Creek to Galena Hill. Urban area of Franklin, PA is shown in dark gray.

Figure 10 shows the cross-section across the 3rd Ward. Grant St through the 3rd Ward

(Route 322 in figure 6) was the center of the worst flooding north of French Creek. Atlantic St and Pacific St parallel Grant St on the south and north respectively. Notice on the cross-section that Grant St is several meters lower than the two neighboring streets. When over 60 mm of rain fell on the extreme slope of Oak Hill, a drop of 140 m in a distance of 800 for a slope of 175, Grant St was quickly inundated with chest deep water.

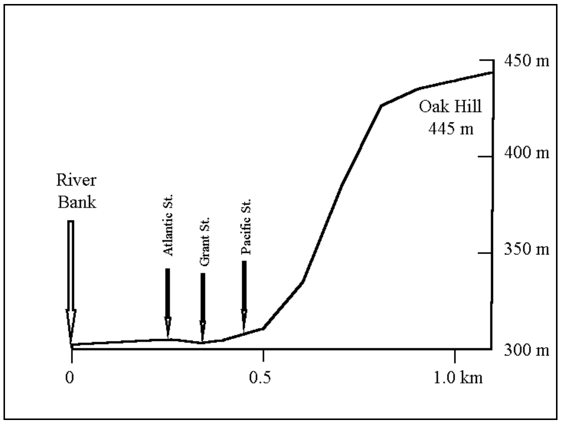

Fig. 10. Topographic cross section across the 3rd Ward from French Creek to Oak Hill. Location of west-east roads along the cross section show with small arrows.

6.0 ABR/ABR RATE PLOTS.

AMBERGIS graphic products are flash flood tools used to quickly zero in on an area of potential flash flooding. Once a specific stream segment has been located, AMBERGIS provides a line graph plot of the ABR and ABR rate for the selected stream segment. From the line graph, the duration of the heavy rainfall rates can quickly be determined along with the total ABR. Figure 11 shows that high ABR rates (>25 mm hr^{-1}) started at 2346 UTC and continued until 0026 UTC for a total of 45 minutes. ABR rates remained above 75 mm hr^{-1} from 2355 UTC to 0021 UTC, with 45 mm of the 60 mm total occurring in this 30-minute period.

While ABR rate is used to detect the developing flash flood, the accumulated ABR determines when flooding begins. Increasing values of ABR above FFG result in more serious flash flooding. When the ABR total reaches FFG, minor flooding problems should begin, with the stream near bank full.

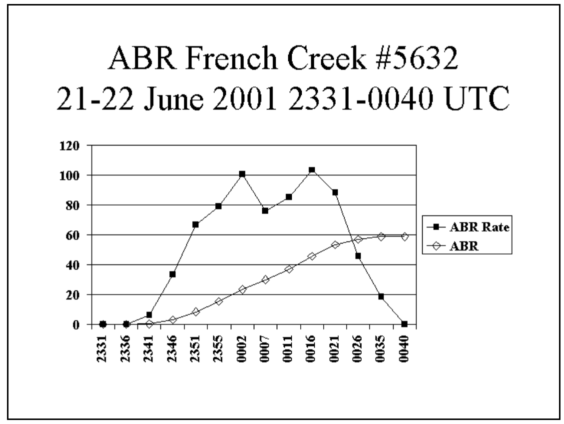

Fig. 11. ABR (mm) and ABR Rate (mm hr^{-1}) plot for French Creek segment 5632. Time in UTC.

Additional ABR over FFG will bring the stream out of its banks. As the ABR reached 50 mm with 1-hour FFG at 57 mm, a flash flood warning was issued about 0025 UTC for Venango County, mentioning urban flooding possible in the city of Franklin. Although only minor stream flooding should have occurred, the heavy rainfall in an urban area prompted the issuance of the flash flood warning. Some road flooding was reported by 0035 UTC with the urban flooding reaching a peak around 0100 UTC.

The minimum basin area of the defined watersheds is critical to the detection of flash flooding. Stream segments must be small enough to detect the heavy rainfall responsible for flash flooding. Rainfall gradients associated with thunderstorm are extreme. Figure 12 shows the ABR/ABR rate line graph for the three combined watersheds segments that make up Patchel Run. This watershed, just 2 km northwest of Franklin, received only 35 mm of ABR with no stream flooding observed in the watershed. A minimum basin area of 5 km^2 is required to detect these important spatial variations in ABR.

The maximum observed ABR occurred in segment 5623 with a 65 mm total (Fig. 13). The maximum ABR rate reached 127 mm hr^{-1} at 0002 UTC. The hourly ABR rate is capped at 127 mm hr^{-1} to help eliminate rainfall overestimation caused by hail contamination.

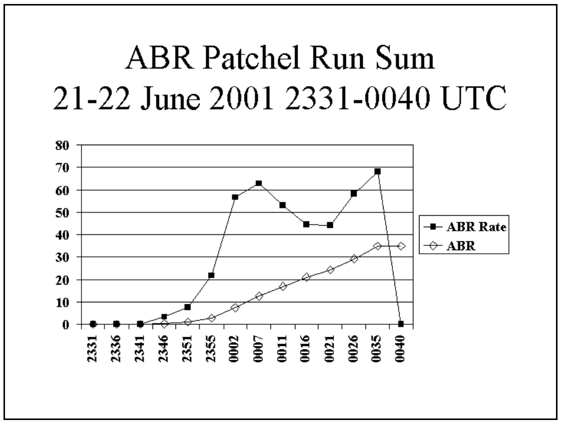

Fig. 12. ABR (mm) and ABR Rate (mm hr^{-1}) plot for Patchel Run (summation of 5661, 5662 and 5663). Time in UTC.

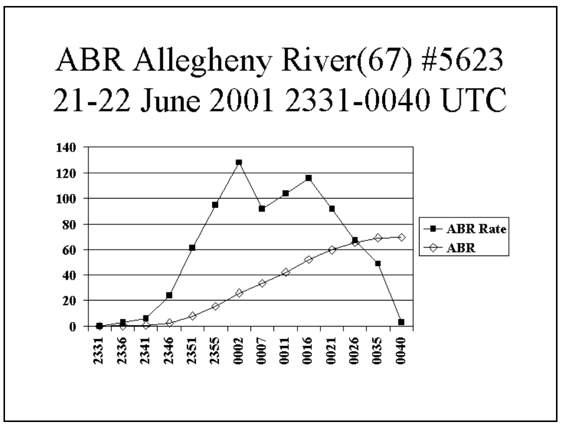

Fig. 13. ABR (mm) and ABR Rate (mm hr^{-1}) plot for Allegheny River (67). Time in UTC.

7.0 SUMMARY

ABR and ABR rate have proved to be important new flash flood tools for the early detection of flash flooding. Graphic displays of the ABR data allow quicker access to the large and detailed rainfall database. The ABR rate can be used to monitor developing flash floods before flooding begins, increasing warning lead time. Availability of the small stream database allows the inclusion of stream specific data in warnings and statements. Comparisons of ABR with FFG can provide guidance on the initiation of flooding the potential severity of the flash flooding. These flash floods tools should greatly enhance the flash flood program of the NWS as the FFMP software becomes operational in 2002.

8.0 REFERENCES

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