

## Introduction:

Cummins Falls State Park has become a very popular tourist attraction since being designated as a state recreation area, while it has been a popular swimming hole for locals to Jackson and Putnam counties for over a century. This increased popularity results in many guests hiking the 0.7 km path along the stream to the bottom of the falls to enjoy the swimming and beauty of the natural area. The dangers come from the sudden increases in the stream levels caused by heavy rains upstream in the watershed. These flash flooding events have resulted in fatalities and rescue operations in past years. Beginning in October 2019 a state operated rainfall and stream gauging system has been in place at points along tributary streams above Cummins Falls State Park. This network of gauges provides park rangers with a warning when rain or stream conditions may pose a danger to visitors at both parks, and records historical rain and stream gauge data. The purpose of this study was to analyze gauge data collected by this system to determine thresholds in rainfall and stream level rises in order to predict flooding at Cummins Falls. Secondly, a model of the lower West Fork and Blackburn Fork streams was created in HEC-RAS to simulate flood peak travel times between upstream areas and Cummins Falls.

## Methods:

### Field Measurements:

Photographs of the streams in various sections which are contained in the study are invaluable for determining the Manning's  $n$  factor to use and understanding the geomorphology of the stream. In addition to the photographs from the ground, a UAV was utilized to obtain vertical air photographs of the stream bed in difficult to reach areas. Discharge measurements were made to develop rating curves at each gauge location. The rating curve allows for calculation of discharge by stream gauge reading. Most discharges were measured via wading rod set to 60% depth and velocity measured by a Flo-Mate 2000 electronic flowmeter. One discharge measurement at the West Fork station was made during high water using a float method with the velocities measured being factored by 80%. The cross-section area for the high flow event was measured by marking high water marks and returning later to make the measurement.

### Stream Gauge Data:

The Cummins Falls flash flood monitoring system consists of 5 stream gauges and 6 rain gauges spread throughout the watershed. Data from these gauges was downloaded and entered in a spreadsheet allowing for filtering and sorting based upon date/time, rainfall amount, or stream levels. Storm events were selected by filtering for rainfall above 0.05" in 5-mins or a stream depth over 1.5' at Cummins Bridge station. Data for these events were graphed to allow analysis of rainfall-runoff peak lag times. (Figure 5 Bottom Right)

### HEC-RAS Modeling:

HEC-RAS 5.07 and 6.0 BETA 2 were both used to develop partial watershed models. A DEM of the watershed area was created from the Tennessee 2015 LiDAR data project, having a 2.5' horizontal resolution and 0.01' vertical resolution. The watershed area and basic statistics were delineated and retrieved from the USGS StreamStats online service (USGS 2020). Once the terrain is established a river reach is created following the channel of the geometry file. Cross sections (XS) were spaced at 30' intervals and interpolated by HEC-RAS, with some slight adjustments to cover the floodplains. All XS were georeferenced and cut from the terrain DEM for elevation measurements. Each XS has a bank line position which determines where a change in Manning's  $n$  will occur. Manning's  $n$  roughness coefficients were then set for each XS. Using our experience in the field with this stream and the aerial photographs taken, we then applied the USGS recommended method (Arcement and Schneider 1989) for selecting the coefficient. The overbanks Manning's  $n$  values were set to 0.18 based upon the vegetation and roughness characteristics of floodplains while the channel  $n$ -value was set to 0.05 based upon the mostly bedrock nature of the channel, with some roughness from gravel bottom areas. Setting up an Unsteady Flow Analysis is using known or imagined conditions to simulate how the water will move down the stream system. This analysis can not only show maximum water depths based upon given conditions, but also the time intervals of water flowing down the stream. (Figure 4 Right) This model was set up using the conditions from a rainfall event recorded on 2/28/2021 beginning at 20:00 and continuing through 3/1/21 at 03:00 CST. A flow hydrograph determined by rating curve application to stream gauges measurements provided the input for the West and East Fork streams. Once set up properly, the model will record calculated flows, gauges and timings of each interval of the simulation which can then be studied.

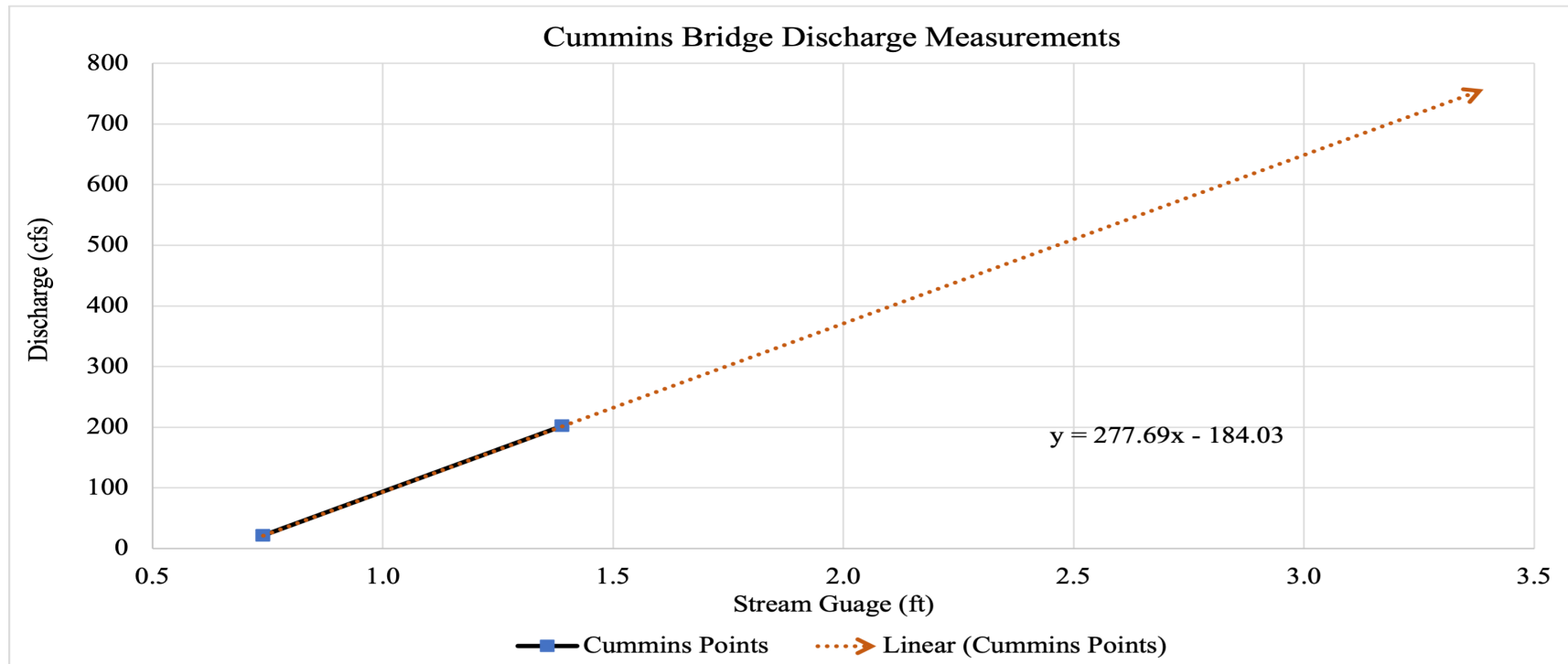
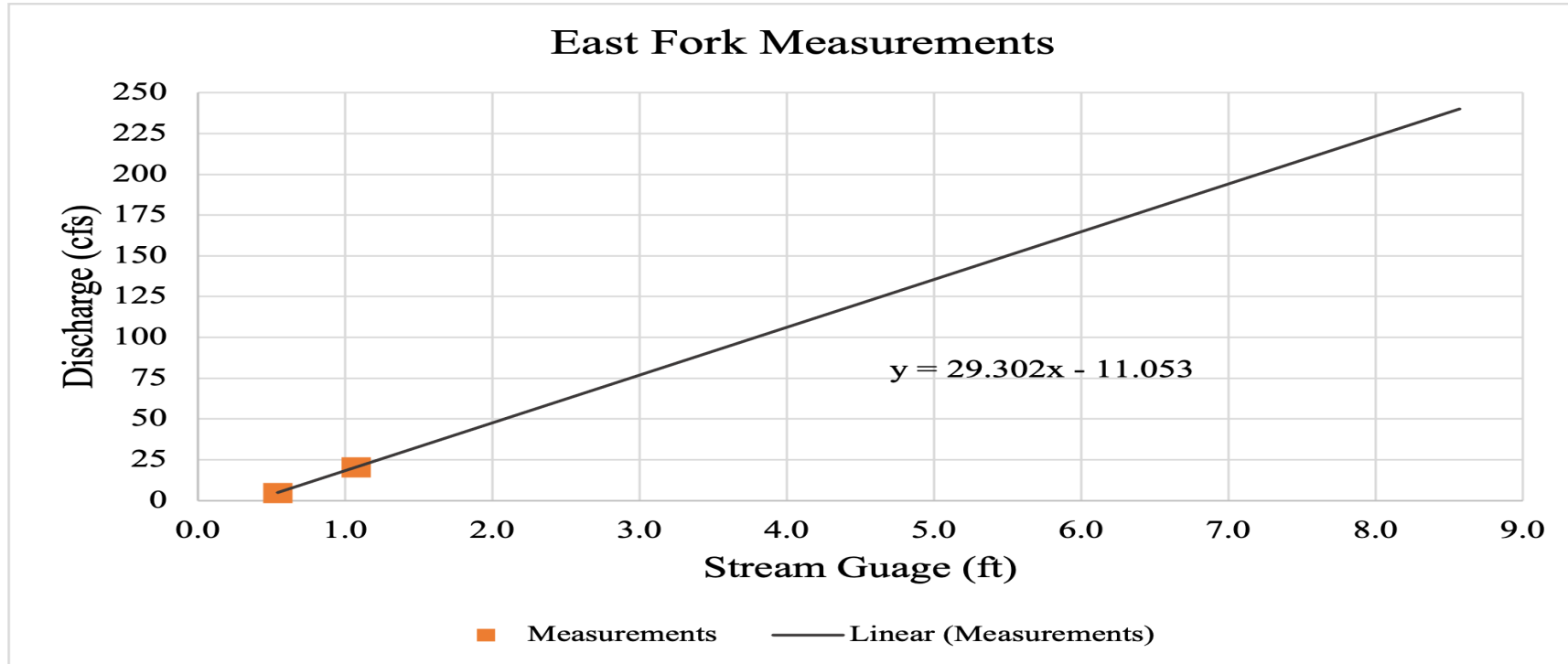
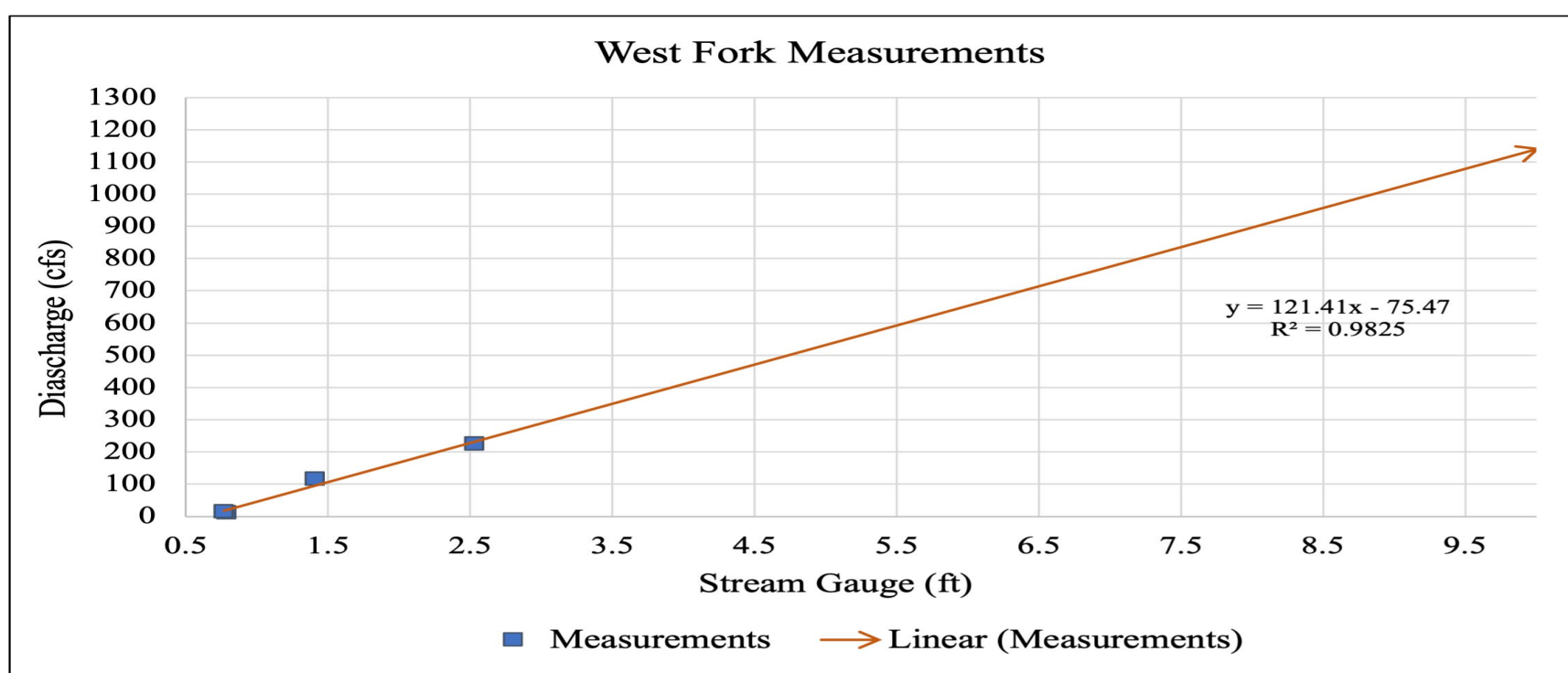


Figure 1 Above: Stage-discharge rating curves of West Fork, East Fork and Cummins Bridge stations.



Figure 2 Above: Stitched panorama of Blackburn Fork section upstream looking downstream to Cummins Bridge.

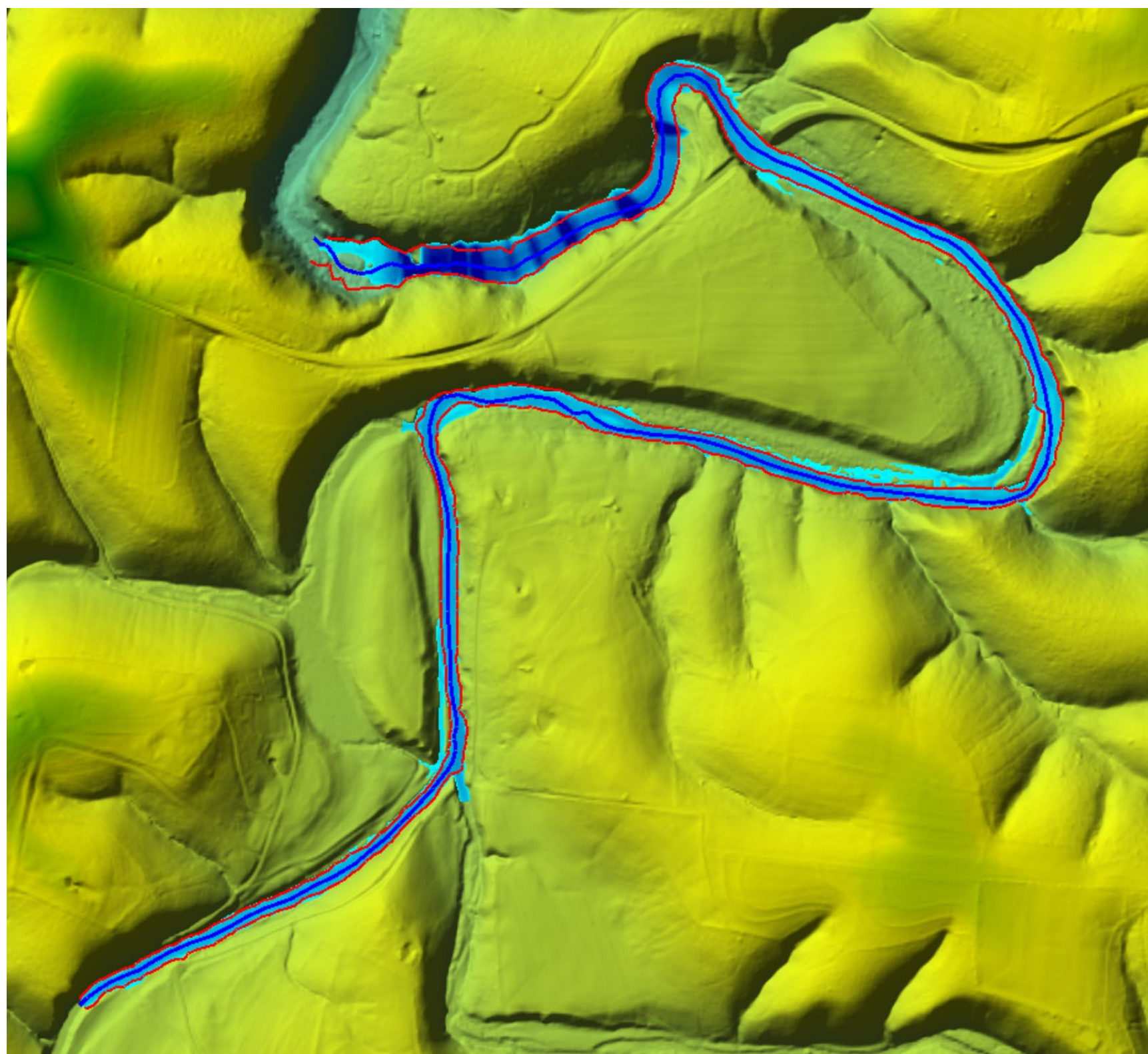


Figure 4 Above: Stream section from HEC-RAS showing channel (blue), bank lines (red.). Shaded blue area indicates the water levels during a simulation run.

## Results:

From the stream set up in ArcGIS and HEC-RAS, the stream length of the West Fork from headwater to confluence with the East Fork is ~45,767 ft or 8.67 miles with an elevation change of ~236 ft yielding an average slope of 0.005. The East Fork stream length from headwaters near Jere Whitson school is ~41,770 ft or 7.91 miles in length and an elevation change of ~264 ft yielding an average slope of 0.006. The portion of the Blackburn in this study is 9874' in length or 1.87 miles with a slope of 0.12 including Cummins Falls.

Four discharge measurements were performed near the West Fork stream gauge to develop a rating curve. Three were using a Flo-mate electronic meter and wading rod, one was made using a float method. Two of the measurements were done at normal base flow and both indicate a typical discharge of ~13 ft<sup>3</sup>/sec. The other measurement with the wading rod indicated a mid-level flow of ~115 ft<sup>3</sup>/sec per sec and the float method yielded an estimate of ~224 ft<sup>3</sup>/sec. The linear trend between stage and discharge yielded a linear equation of  $y=121.41x-75.47$ , which equation was then used to estimate discharge for any level of stage. Two discharge measurements were made at the Knight Church stream gauge using the wading rod method. Flows at ~2ft<sup>3</sup>/sec and ~8ft<sup>3</sup>/sec yielded a linear equation of  $y=22.596x+2.541$ . At the East Fork gauge station, two wading rod measurements yielded discharge measurements of ~5ft<sup>3</sup>/sec and ~20ft<sup>3</sup>/sec and a linear equation of  $y=29.302x-11.053$ . The East Fork flow is approximately half the volume of water carried by the West Fork, which is expected based on drainage area. At the Cummins Bridge gauge station, two wading rod discharge measurements were completed at a location approximately 200 meters downstream of the bridge. This location was selected due to difficulty in access and unfavorable geometry at the bottom of the bridge. These flow measurements were ~21ft<sup>3</sup>/sec and ~202ft<sup>3</sup>/sec, with a linear equation of  $y=277.69x-184.03$ . (Figure 1 Left)

Three days were selected to analyze the timing between rainfall and peak discharge using the gauge station records. (Figure 3 Bottom Left) 01/25/2021

Over a period of 7 hours, rainfall averaged 1.49 at all stations. The Cummins Bridge stream gauge increased from 0.97' to peak at 3.36' at 1/26 00:40. Earlier in the evening, rainfalls ranging 0.1 – 0.17" in 5 mins caused notable stream level rises in 45 – 65 mins. A larger peak of rainfall amounting to 0.33" in 5 mins caused stream rise 15 mins later at the West Fork East Fork gauges and at Cummins Bridge 15 mins later. The increases at both East Fork and West Fork took about 15 mins to appear at Cummins Bridge. The rainfall measured by the West Fork rain gauge took ~30 mins to affect the stream level at Cummins Bridge.

2/28/2021

The rainfall amount recorded over the watershed averaged 1.79" over 8 hrs. Cummins Bridge gauge increased from 1.42' to a peak at 6.22' at 01:10 on 3/1/21. The highest rainfall rate recorded on 2/28/2021 was 0.19" in 5 mins, which is less than the peak rate on 1/25/2021, but there were more peaks over more of the watershed. At the Knight Church gauge, rainfall began at 20:25 while the Knight Church stream gauge began to rise at 20:45, a 20-min lag time. Rainfall measuring ~0.19" at Echo Valley, TTU Farm, and Dodson Branch gauges at 20:35 may have caused all three stream gauges at West Fork, East Fork, and Cummins Bridge to begin rising ~80 mins later. The Cummins Bridge gauge rose only ~5 min after the West Fork gauge. However, the Cummins Bridge gauge rose ~65 min after the rise on the Knight Church gauge.

3/17/2021

The total rainfall of the period averaged 1.06" per station. The Cummins Bridge gauge readings ranged from 0.94 ft to peak at 4.09 ft. The West Fork ranged from 1.15 ft to 5.49 ft. Peaks in rainfall, ranging from 0.08 in to 0.14 in at Cummins Bridge, created a marked rise in stream levels ~60 mins later at West Fork to ~80 mins.

### HEC-RAS Modeling

HEC-RAS model results based on a simulation run of a flash flood storm in July 2019, indicated a travel time of approximately 45 mins from the West Fork gauge station to the Cummins Bridge station. These predicted model results are similar data observed. One model simulation was completed producing a hydrograph of expected stage which ran ~1' below the stage observed at the stream gauge. This may be due to the difference in DEM surface of the water to the actual stream bed.

## Conclusions:

The results of this study indicate that most rainfall events occurring upstream from the Cummins Falls will cause appreciable increases in water levels at Cummins Falls within 2 hours. Typically, storms that cause significant increases in stream level at Cummins Bridge, are those that produce at least 0.2 in of rain within 5-min intervals. Hydrograph peaks at the Cummins Bridge station generally occur 30-40 min after flood peaks at the West Fork and East Fork stations, and sometimes less depending on where the rainfall occurs. This would give rangers 40-50 min before the increased water levels are coming over the falls. Ten min of 0.3" or more sustained rain can cause a 1' rise in stream levels, which may make traversing the gorge at the bottom of the falls dangerous. In summary, results from monitoring provide valuable time to move people to safety, and with continued study, the system can be fine-tuned for efficiency and accuracy.

### Acknowledgements & References:

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### References:

Arcement, George J. Jr., and Verne R. Schneider. 1989. *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*. Denver, CO: USGS - US Government Printing Office.  
USGS. 2020. "USGS StreamStats." *USGS*. 03 10. Accessed 03 10, 2020. <https://streamstats.usgs.gov/ss/>.

### Cummins Watershed Map with Rain Gauge Polygons

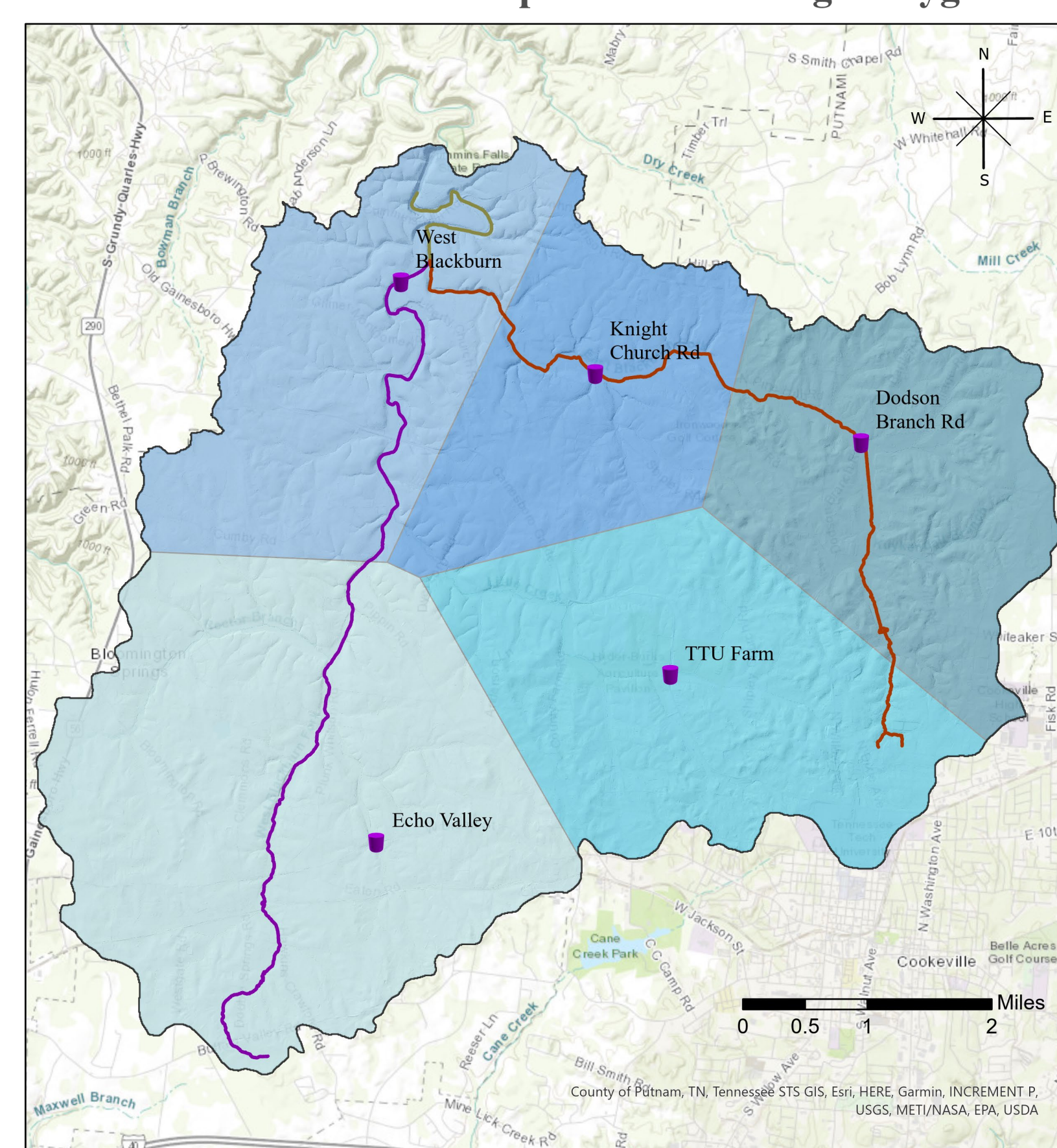


Figure 5 Above: Map of Cummins Falls watershed with Theissen polygons for each rain gauge. The stream channels are also labeled. Watershed background is the DEM with hillshading.

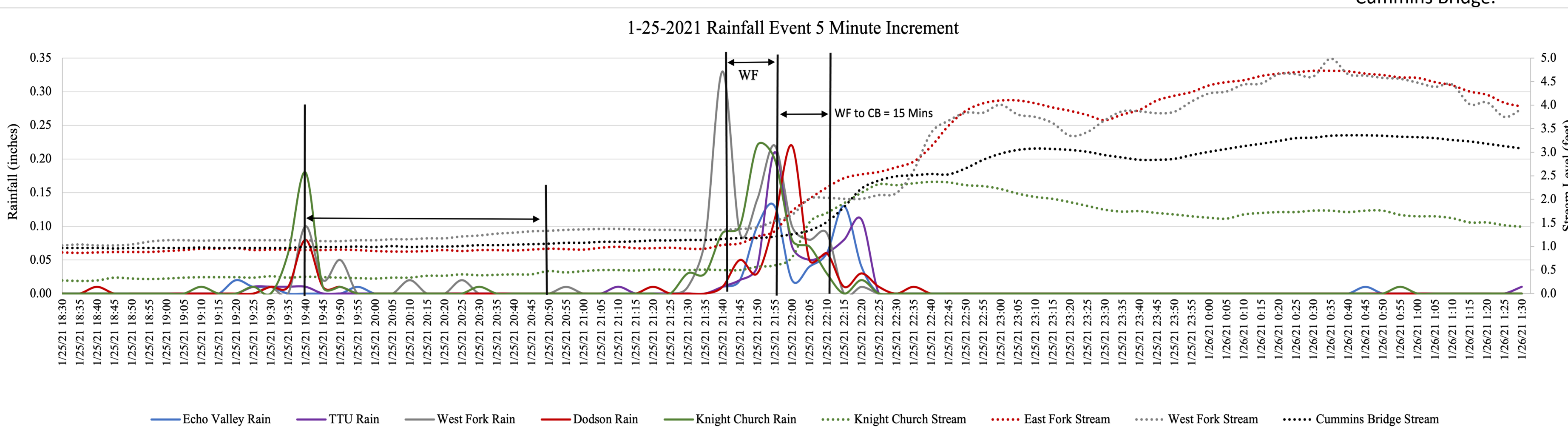


Figure 3 Left & Below: Graphs of the 3 rainfall events which show the rainfall compared to stream levels.

