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# Debris flows in the North Pacolet River valley, Polk County, North Carolina, USA - case studies and emergency response

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**Abstract**

The North Pacolet River valley is incised into the Blue Ridge Escarpment (BRE) near Tryon in southwestern North Carolina. The BRE is a mountain front that marks the change from the mountainous Blue Ridge physiographic province to the lower, rolling topography of the foothills zone of the Piedmont provinces. This escarpment is often comprised of steep slopes with exposed bedrock cliffs and shallow colluvial soils. The down slope sides of the escarpment have evidence of past slope movements in the form of large scale deposits, debris fans, talus slopes, and dormant debris slides. Debris flows have been documented along the BRE in multiple past storm events including those in 1916, 1940, 1996, and 2004. On May 18, 2018, debris flows again initiated near the top of the BRE slopes and travelled down to the North Pacolet River valley floor during heavy rains on soils with high antecedent moisture contents. At least 27 debris flows were initiated, travelling up to ~966 meters (~3,170 feet) down drainages below. At least 6 homes were damaged or destroyed and one fatality occurred due to these debris flows. Main highways, interstates, and multiple private roads were covered by the debris. Appalachian Landslide Consultants, PLLC (ALC) and the North Carolina Geological Survey (NCGS) responded to this emergency situation in order to provide Polk County Emergency Management information about the stability of the slopes before the arrival of Tropical Depression Alberto just 9 days after the May 18 rains. During this reconnaissance, ALC and the NCGS identified areas of potential instability in the coming rains. County Emergency Management used this information when deciding to issue a voluntary evacuation recommendation to the people of the North Pacolet River valley. This paper discusses the findings of the reconnaissance mapping, as well as a general overview of the integration of geological information into emergency response and preparation.

*Keywords:* debris flow; North Carolina; Blue Ridge Escarpment, landslide, natural hazards identification, management policy

## 1. Introduction

On May 18, 2018, the North Pacolet River valley (Pacolet Valley), on the Blue Ridge Escarpment near Tryon, in Polk County, North Carolina, received as much as 20 cm (8 inches) of rain in just a few hours (NCEI, 2018b). These heavy rains triggered numerous small and large slope movements, particularly impacting communities near U.S. Highway 176 and Warrior Drive. “One 59-year-old woman died when her garage collapsed as she was trying to flee her home. Her husband was swept into Highway 176 but survived with mostly minor injuries” (NCEI, 2018b). These landslide events impacted all who lived in the Pacolet Valley, as the Highway was closed for several days while mud from the debris flows was removed. Some people in the community whose homes were damaged were not able to return for several months. Other homes were completely destroyed and dismantled by the owners. These events occurred nine days before Subtropical Depression Alberto was forecast to hit the same area.

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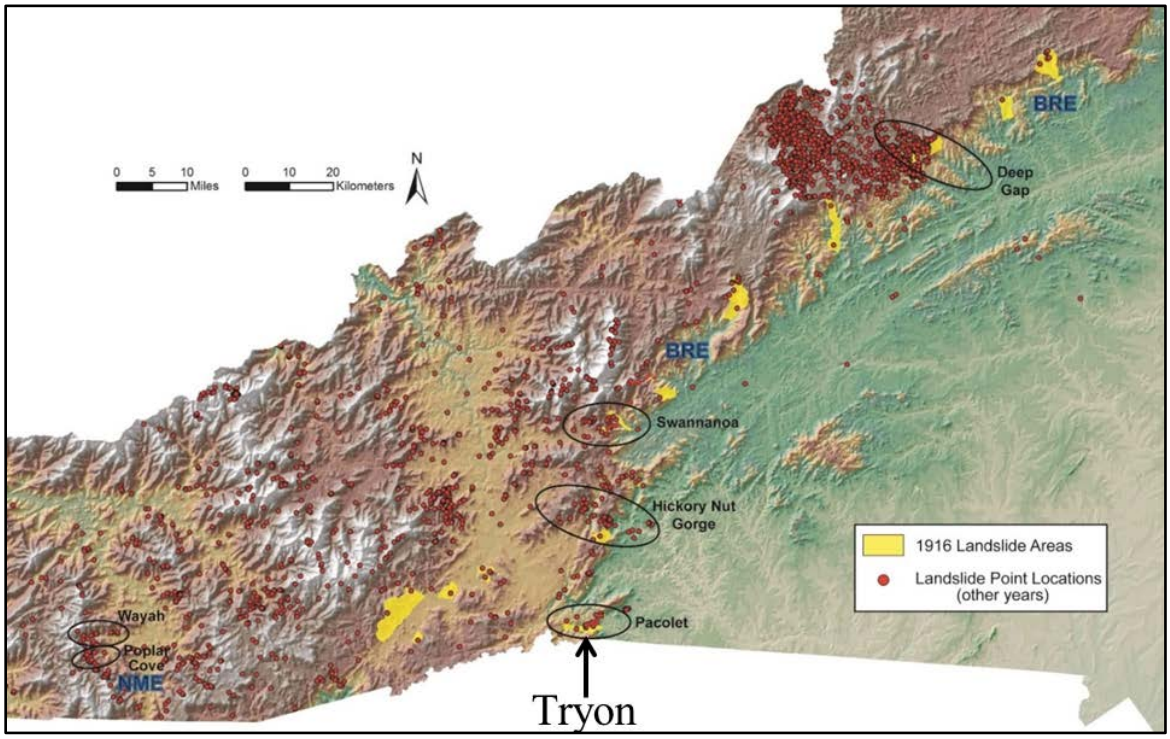


Fig. 1. Hillshade map of Western North Carolina. Ellipsoids define erosional reentrants into high relief areas. Blue Ridge Escarpment extends from the southern to northern border of North Carolina, separating the mountains from the piedmont. Landslide locations from the NC Geological Survey geodatabase are indicated as yellow polygons for 1916 landslide areas, and red points for all other mapped landslide locations.

While these damaging debris flows took residents by surprise, there is evidence that debris flows have been taking place in this valley and similar topographic regions in North Carolina for quite some time. During reconnaissance mapping of the 2018 debris flows, previous slope movement deposits were identified, but dates were not determined. Many homes had been built on debris deposits or close to streams draining the steep slopes above. Landslide susceptibility maps are not available for Polk County, and people in the valley were not aware of these hazards.

### *1.1. Geomorphic Location*

The North Pacolet River valley is a reentrant incised into the regional landform known as the Blue Ridge Escarpment (BRE) (Fig. 1). The BRE is a high relief, erosional feature that extends from northeast Georgia to northwest Virginia, which generally corresponds with the Eastern Continental Divide, and marks the boundary between the Blue Ridge Mountains and the rolling foothills of the Piedmont physiographic province to the east (Wooten et al, 2016). Landslides, particularly rapid to extremely rapid-moving debris flows and slides, have been recorded along the Blue Ridge Escarpment in multiple storms in historic times. "Heavy rainfall, when combined with the high-relief areas of certain landforms and erosional reentrants into them, are more prone to debris flow activity," (Wooten et al, 2016) (circled areas in Fig 1). This is especially the case with high antecedent soil moisture conditions. In the past 102 years, there have been four scenarios where back-to-back, major storms within 6-20 days of each other triggered debris flows in WNC (July 15-16 1916; August 1940; September 2004, May-June, 2018). The May-June, 2018 storms triggered landslides along the Blue Ridge Escarpment and other areas in surrounding counties.

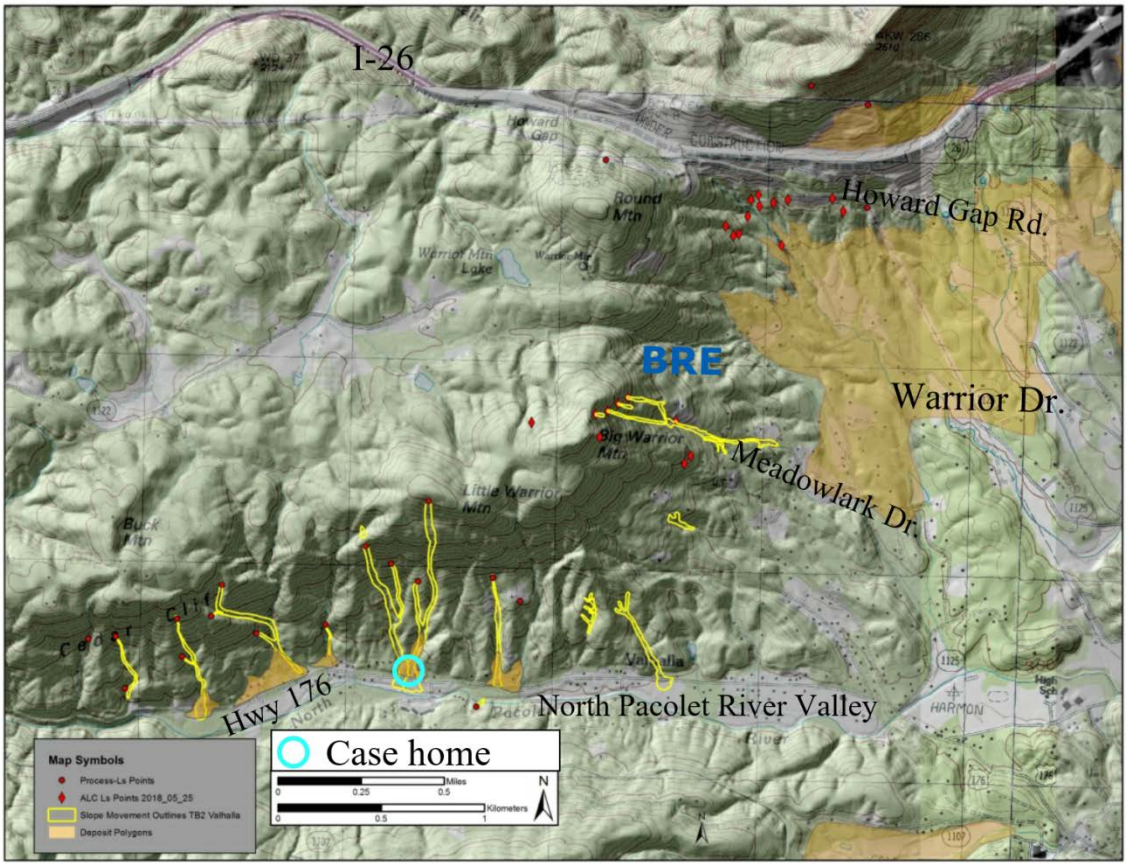


Fig. 2. 2004 hillshade draped with Saluda 1:24,000 quadrangle topographic map. Debris flow outlines are yellow polygons, red points are slope movement initiation zone locations; tan polygons are slope movement deposits. Data from NCGS and ALC geodatabases, 11/01/2018. Home location of Mr. and Mrs. Case is highlighted.

### *1.2. Summary of events of May, 2018*

On the evening of May 18, 2018, heavy rains inundated the Pacolet Valley and surrounding area, triggering debris flows, other types of slope movements, and flooding in the area. The home of Mr. and Mrs. Case was initially hit by a debris flow from the eastern drainage above their home (Fig 2, Fig 3). The Cases tried to get out of their home at that time, but Mrs. Case was not able to due to health complications. Mr. Case assisted Mrs. Case into a detached garage next to the home. He then left, wading through the mud trying to get help, when a second debris flow from the western drainage behind the home hit the garage (Fig 3). Mr. Case tried to get back to the house to get to his wife, but was unable to do so. Early the morning of May 19, Polk County Emergency Management (EM) requested assistance from North Carolina Geological Survey (NCGS) to determine if slopes above the home were stable enough for crews to get to Mrs. Case. Sadly, she was not alive when crews were able to access the garage.

During the following days, NCGS geologists surveyed the damage throughout the valley, assisted by volunteers from Appalachian Landslide Consultants, PLLC (ALC) and former members of the NCGS landslide mapping team. ALC and NCGS geologists spoke to individual members of the community whose homes, property, and/or roads had been damaged by debris flows, and investigated the potential debris-flow source areas upslope of some of the affected properties. The NCGS and ALC participated in Emergency Management meetings, passing on information gathered in the field. The NC Forest Service provided a helicopter flight so geologists could view the extent of the damage and potential remaining source areas from the air.


Fig. 3. (a) Georegistered 2018 UAV Image from the NC Geodetic Survey. Original location of Case home and detached garage outlined in black. (b) Georegistered 2018 Aerial Image from the NC Forest Service. Two debris flows that merged at the base of Little Warrior Mountain at the Case home location along Highway 176.

The week following the debris-flow events, Subtropical Depression Alberto was forecast to bring significant rains to the same region along the Blue Ridge Escarpment. EM requested that the NCGS and ALC provide locations that remained unstable, which they provided in GIS format. Meteorologists from the National Weather Service in Greenville-Spartanburg, SC came up to survey the damage with the NCGS and to participate in EM meetings to assist in preparations for additional rain. Based on information from the geologists and meteorologists, EM decided to issue a voluntary evacuation for the entire Pacolet Valley and Warrior Drive area during Subtropical Depression Alberto. Bobby Arledge, Polk County Emergency Management Director issued a statement saying "The county has been surveyed by professional geologists and these storms will further destabilize areas that have experienced above average rainfall and potentially cause further landslides. A heightened level of concern exists for residents in and around areas that have already experienced land movement" (Tryon Daily Bulletin, 2018).

Rainfall from Subtropical Depression Alberto spanning from May 26-31, 2018 totaled over 18 cm in the Tryon, NC area (7 inches), contributing to continued sliding of unstable areas and erosion (NWS, 2018a). Two news media personnel were killed during these rains when a tree fell on their vehicle on Hwy 176.

## 2. Data Collection

### *2.1. Data collection*

In the days after the May 18 debris-flow events, data collection was initially targeted to capture GPS locations of debris deposits that had damaged or destroyed homes or roadways. To assist a client, ALC, along with a local grading contractor, hiked to the source area of a coalescing debris flow that impacted homes and roads along

Meadowlark Drive. Most of the other data collection was along Hwy 176 in the Pacolet Valley, or along Howard Gap Road. At the request of a landowner trying to decide if she should evacuate her horses from her farm, ALC and NCGS geologists noted impacts along a trail above her home below the heavily-damaged Howard Gap Road and Warrior Drive.

Several times within the weeks after the May 18 and Alberto events, NCGS geologists went back to the Pacolet Valley to gather more detailed information about debris-flow tracks and characteristics and debris deposits. ALC geologists evaluated another site off of Meadowlark Drive for a client concerned about their driveway. Data was collected in an ArcGIS geodatabase of points, lines, and polygons (Fig 2). Point locations were taken for slope movement initiation locations and for field data collection locations. Lines were used to indicate extents of ground rupture (i.e. tension cracks and scarps). Data for slope movement outlines, delineating the extents of the debris flows or debris slides, were collected as polygon features. These features were mapped either from field observations, aerial photographs (see below), or a combination of the two. Polygons were also used to delineate extents of debris deposits, either from field observation, or remote sensing of a 2004 lidar-derived digital elevation model (6 meter horizontal pixel resolution).

### *2.2. Aerial photographs*

Many types of aerial photographs were taken of the valley and the debris flow features. Multiple photos were taken from a digital camera and smartphone cameras from the North Carolina Forest Service (NCFS) helicopter. Video was also taken with a GoPro™ camera. The Broad River Fire Department and the North Carolina Geodetic Survey captured photos of some of the debris flow locations with an unmanned aerial vehicle (UAV). Unfortunately, orthophotos were not taken immediately after the debris-flow events; however, orthophotos taken during the following leaf-off season greatly aided mapping efforts. Select UAV and NCFS photographs were georeferenced and used for drawing slope movement outlines or areas of impact.

## 3. Findings

### *3.1. Debris-flow characteristics*

Twenty seven debris flows were cataloged in the geodatabase, although several others remain uncatalogued because they were difficult to delineate through the tree cover. Nineteen debris flow initiation zones were explored in more detail either by foot or via aerial photographs. The dominant initiation zone scenario was one where shallow colluvial soil less than 1.5 meters (5 feet) thick slid, and then flowed off of competent bedrock (stained-state to fresh on the Unified Rock Classification System scale), where groundwater was flowing at the interface of the two. However, there were also examples of debris flows initiating within boulder- and cobble-filled colluvial soil, and residual soil. The common finding was groundwater flow at or near the failure surfaces.

Many of the debris flows on these steep slopes started upslope of the prominent rock cliff, marking the upper edge of the BRE. Most started in concave hollows where water was converging, and most flowed down drainages. Springs were noted just upslope of the cliffs within the debris-flow tracks that were walked. The lengths of the debris flows catalogued range from 966 meters (3170 feet) to 40 meters (130 feet). The depths of these debris flows exceeded 3.6 meters (12 feet) in some areas, based on mudlines and nick marks on standing trees, see Fig 4. The approximate average width of the debris-flow tracks themselves is around 17 meters (56 feet), ranging from 7.6 meters (25 feet) to 30 meters (100 feet). The volumes of material that flowed down the slope have not been calculated to date.

One debris flow that initiated on a convex slope was observed to flow through the trees, rather than uprooting them. This debris flow did not travel far, and spread its deposit out across the convex slope. Another debris flow upslope of Interstate 26 flowed through the trees, and onto the interstate, blocking traffic and creating a traffic control issue for Emergency Management, while they were experiencing the torrential rains, flooding, and landslides.

Fig. 4. Downstream view of debris flow in the Meadowlark Drive area. Tree nick marks can be observed twice as high as the height of the worker by the tree, approximately 3.6 meters high (12 feet).

### *3.2. Debris deposit characteristics*

Many of the debris flows deposited material in areas where prior slope movement deposit material was observed or mapped using a lidar-based digital elevation model. In some locations, pre-existing deposits were incised during the May 2018 event (Fig 2). Many of the homes that were damaged were constructed on these past debris flow deposits.

Debris deposits consisted of silt, sand, gravel, cobbles and boulders. 2018 debris also included woody debris, and in some cases, debris from structures. In the main Pacolet Valley, debris flows tended to stay within the drainages all the way down to the valley bottom. On Meadowlark Drive, several roads and culverts had been placed to access homes on the middle part of the mountain. The debris flows took out these roads in some cases, and blocked culverts in others. Where culverts were blocked, debris was diverted across and down the paved road, and off the embankment side. One home in particular received up to 3.6 meters (12 feet) of mud in the lower driveway. Another home was somewhat protected by a large van parked between the house and the slope that the debris flowed down. The van diverted the mud around the home along the ditch and driveway on both sides, instead of into it.

### *3.3. Other landslides*

There were many (perhaps dozens) of other types of slope movements observed during the aerial reconnaissance flight and while driving the roads. Many of the road cut failures were debris slides or rock/weathered rock slides. Most of these road cut or fill slope landslides have not yet been documented, and therefore are not discussed in detail here.

### *3.4. Unstable locations and communication*

After the initial May 18 landslide events, EM asked NCGS and ALC geologists to provide them with locations of unstable soil that could mobilize during rainfall from Subtropical Depression Alberto. Geologists identified several locations, many of which included fill slopes that had been damaged or destroyed. The sides of the fill along the drainages had been over-steepened by the scour of the debris flows, and loose, unstable slide blocks remained. Because of the remaining dense tree vegetation, and the narrowness of the debris-flow tracks in many areas, it was

difficult to identify all of the potential log jams or blocks of loose soil from the helicopter reconnaissance flight. Two impoundments for ponds or sediment retention structures were identified as potentially unstable locations to monitor. Geologists recommended that anyone living downslope of the areas that were identified, as well as any areas that had experienced previous debris flow activity, evacuate during Alberto. In addition, they recommended that anyone who lived in the valley that was impacted evacuate, due to the potential for additional road damage preventing emergency rescue.

After hearing these recommendations from geologists and other members of the emergency response team, and the predicted rain amounts from the NWS meteorologists, the County Emergency Manager issued a voluntary evacuation recommendation for several of the communities in Polk County.

## 4. Conclusions

### *4.1. Debris flows*

The May 18 landslide event is the latest in a long history of slope movements in the Pacolet Valley and along the Blue Ridge Escarpment. The exposed bedrock near the top of the ridge is likely evidence of past initiation zones, too steep for vegetation to regrow. Slope movement deposits at the base of the slope indicate past movement events, and now have an additional layer of debris on them, where it has not yet been removed. There were numerous landslides reported along the Saluda Railroad grade on the south side of the Pacolet River valley during the 1916 storm (Southern Railway Company, 1917). The Atlanta Journal Constitution, July 18, 1916 reported 'landslides from the mountains buried the road for long distances' on the Saluda-Tryon Road (current-day Howard Gap Road). Additionally, the NC Department of Transportation had landslide problems during construction of I-26 on the Saluda grade in 1968 (NCGS geodatabase, 2018).

Debris flows from the May 18 event are evidence that although their source areas can be relatively narrow and shallow, they can, nonetheless, cause significant damage and even fatalities because of long run out distances and proximity of residences to the drainages. Intense rainfall was the trigger for these debris flows, where surface or groundwater contributed to destabilizing the relatively shallow colluvial and organic soil on top of the bedrock. Debris flows that started on concave slopes and travelled down drainages had the longest run out distances, compared to debris flows on convex slopes.

### *4.2. Communication*

This event is an example of two communication scenarios: 1) post-May 18 emergency management and pre-Alberto planning and 2) pre-May 18 awareness and preparedness. In scenario one, there was open communication among a vast number of interdisciplinary professionals. Emergency Managers were relying on the geologists and others on the ground for updates on slope stability. Geologists were relying on emergency responders, the NC Forest Service, and others for assistance with evaluation. Landowners were providing access to geologists, the Red Cross, and others assessing damage. Many partners played a role in helping evaluate the current situation, responding to it appropriately, and providing recommendations to best prepare for the predicted upcoming additional heavy rains. However, it became obvious that having tools, such as debris flow susceptibility maps indicating potential source areas and potential debris flow pathways would have assisted in making evacuation decisions.

In the second scenario, pre-May 18 awareness and preparedness, it is clear that the communication in this scenario was not sufficient. Many of the people living in the Pacolet Valley and at the base of the BRE were not aware that they were in the path of debris flows. They did not know that the small stream behind their home could become a raging torrent of mud, rocks, and trees that could destroy their homes. Slope movement deposits that are obvious to a trained geologist's eye looked like nice relatively flat home sites with pretty boulders to the untrained eye. Local citizens did not have this information because the valley had not been evaluated, mapped and modeled. Without this prior work, potential hazards could not have been communicated thoroughly and effectively and therefore, no evacuations were called-for.

### *4.3. Future work*

Recognizing the importance of landslide mapping information to residents of mountainous areas, the North Carolina legislature reallocated funding to the NCGS to re-start a landslide mapping program that was de-funded in 2011. The intention of the funding is to provide maps for the mountainous areas that do not currently have landslide maps (Macon, Watauga, Buncombe, and Henderson Counties were mapped previously by the NCGS, a portion of Haywood County, and all of Jackson County were mapped by ALC). Communication about landslide hazards will be an important component to the landslide mapping program. As the May 18 event in the Pacolet Valley exemplifies, mapping + communication and awareness can save lives.

## Acknowledgements

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