The mountainous regions in Western North Carolina are areas of high vulnerability for landslide occurrence. By using arcGIS to map different variables associated with landslides, we can get a better idea of which locations are at the highest risk.

Landslides in Buncombe County

Brandi Martin

Introduction

Landslides are geologic hazards that pose a great threat to infrastructure and human safety. A landslide, according to the North Carolina Geological Survey, is a downward motion of soil and rock that can be attributed to many factors and is usually triggered by heavy precipitation (“Geologic Hazards in North Carolina—Landslides”). The United States Geological Survey lists the main areas of concern as the following: areas on existing old landslides, on or at the base of slopes, and at the base or top of steep cut slopes. Other factors that increase vulnerability of landslide occurrence include: the presence of tension cracks, or faults within the earth which suggest unstable land, and vegetation coverage which lowers the risk of erosion (“Landslide Preparedness”). When assessing areas of high vulnerability, it is important to understand these contributing factors and areas that are generally prone to landslides to be able to predict areas of future concern.

The original goal of this project was to use GIS to create spatial representations of these contributing factors and find relationships with past landslides to create a hazard map that showed areas of greatest concern. After the necessary data was collected and analyzed, it became clear that not all of these factors had a strong correlation with past landslides, despite being cited in the literature as strong contributors of landslides. This only meant that some factors with a weak correlation with past landslides would not be beneficial for making a hazard map. Therefore, the project had to be tweaked slightly. In the end, the factors with strongest relationship were used and joined to create a hazard map showing areas of greatest concern for the future.

Location

Buncombe County is situated in Western North Carolina in the Appalachian Mountains, an area with numerous landslides occurring per year and varying in levels of destruction. Buncombe County is an area of concern in Western North Carolina and a great deal of research has been done to assess past landslides.

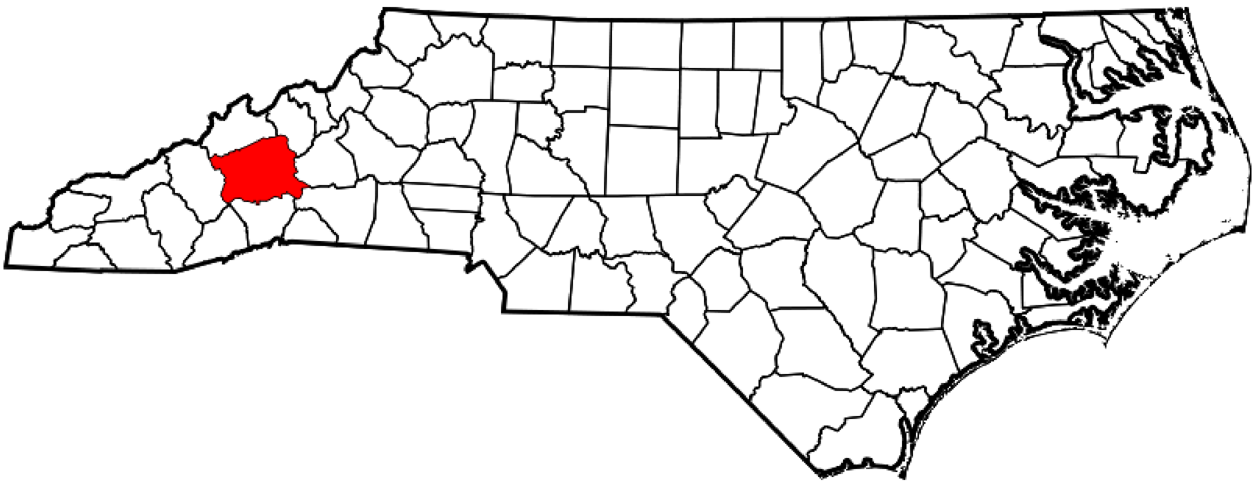


Figure 1. Location of Buncombe County in relation to North Carolina

Methods ,Maps, Analysis

Nearly all of the data came from Rick Wooten, Senior Geologist for the North Carolina Geological Survey. Wooten worked on compiling data of past landslides from 1970-2014 with corresponding attributes such as vegetation and land type (unmodified or land with road construction). This information was sent through email in the format of a large attribute table. Wooten also sent a shapefile of tension cracks recorded in Buncombe County. Thus, by analyzing areas of past landslides with their corresponding attributes, maps could be made that would hopefully show relationships between the landslides and their corresponding recorded attributes.

In Wooten's data, landslides are plotted according to their process points, or the origin of the landslide, and appear as follows:

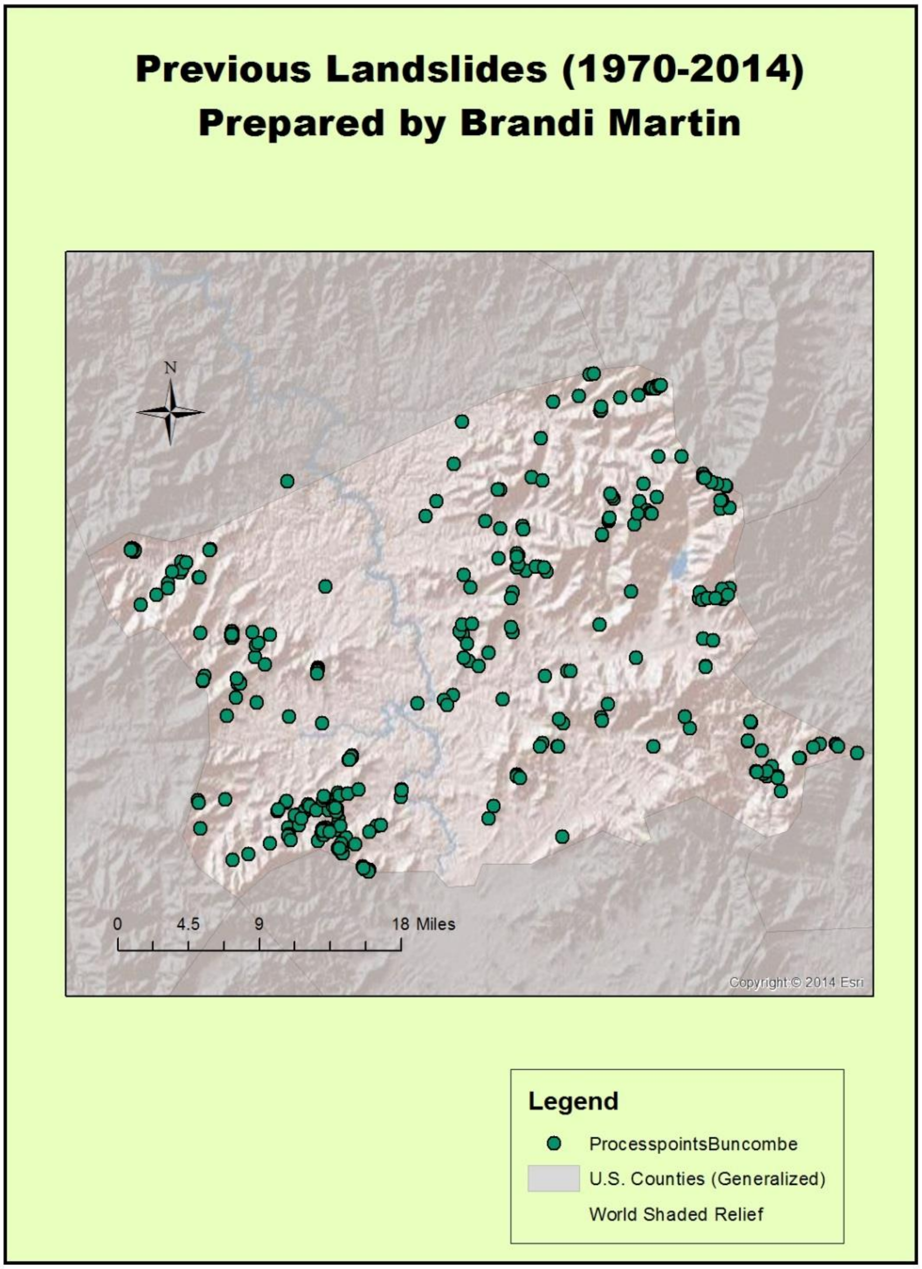


Figure 2. Landslides that have occurred in Buncombe County from 1970-2014 as recorded by Rick Wooten.

The next step was to start mapping known contributing factors to landslides and determining relationships. Wooten's shapefile of tension cracks was mapped first in relation to past landslides to determine what relationship they had, if any. The map is as follows:

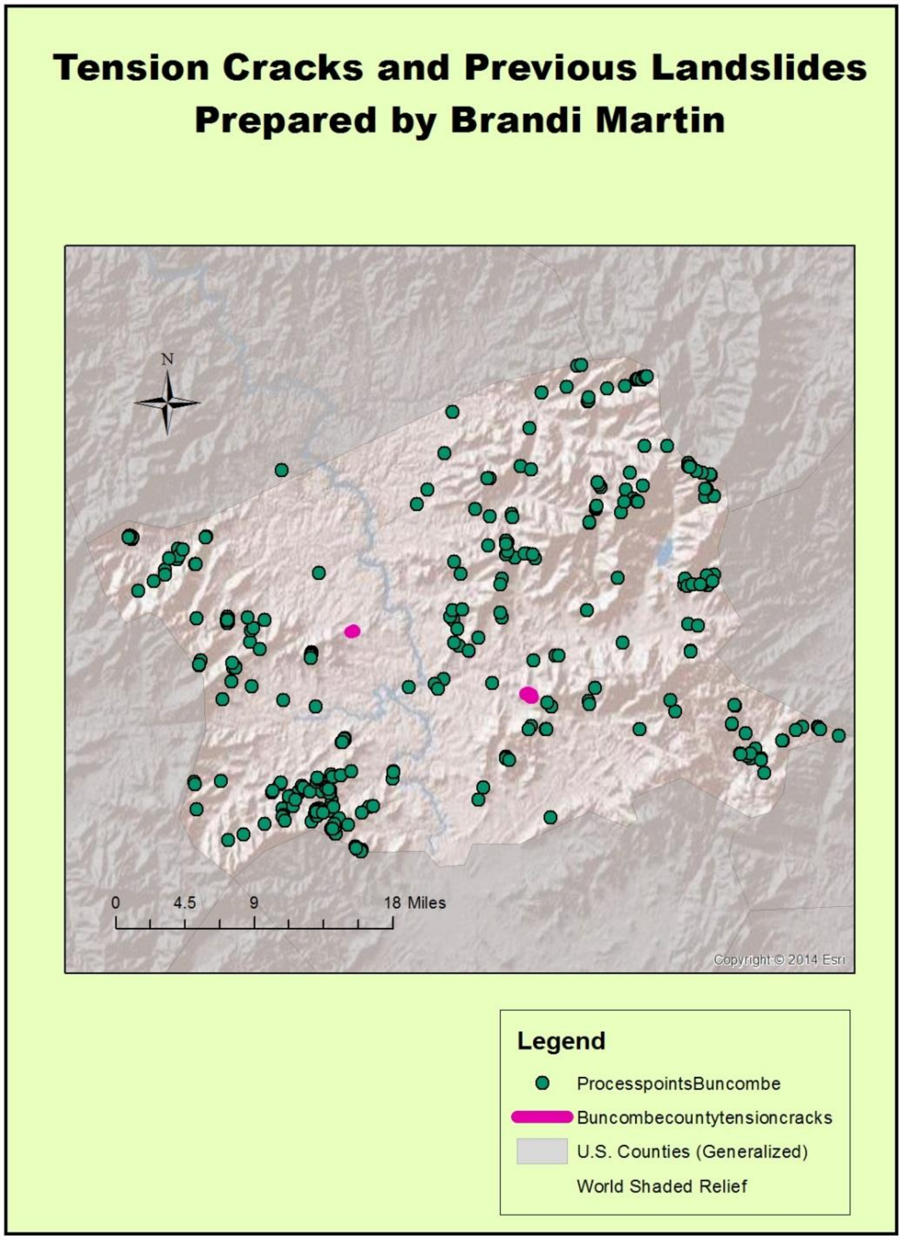


Figure 3. The weak relationship between known tension cracks in Buncombe County and past landslides.

Although tension cracks suggest unstable land and increase the chance for landslides, this map does not show a strong correlation between the two, mainly because not many tension cracks exists, or have been recorded. Therefore, it did not seem beneficial to use this variable as one for predicting future landslides even though they significantly increase the vulnerability.

Wooten had recorded the type of vegetation that corresponded to past landslides, so it was worth extracting this data from his attribute table and creating a graph of the frequency of landslides that occurred on each vegetation type. It would seem intuitive that the highest frequency of landslides would occur on areas with little or no vegetation because this would increase the risk of erosion, but this did not turn out to be the case after having analyzed the data.

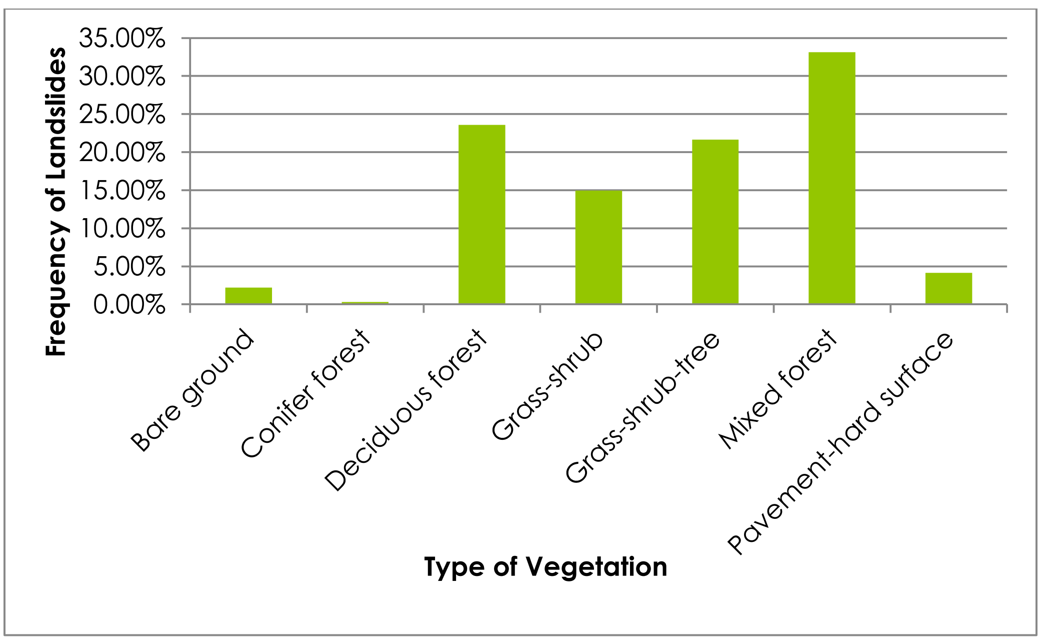


Figure 4. This graph shows the frequency of past landslides as recorded by Wooten with the corresponding vegetation cover attributed to each process point.

As one can see from **Figure 4,** there was actually a very low frequency of landslides that occurred on land with no vegetation (bare ground). In fact, the highest frequency of landslides occurred in mixed forests. This could very well be that only a small fraction of Buncombe County is not covered in vegetation. Without a further analysis of the vegetation in each square foot of Buncombe County, this data is inconclusive and not beneficial in going forward with the hazard map-making process.

With further research into the landslides specific to Buncombe County, it was clear that the greatest contributor to landslides in Western North Carolina was slope. The North Carolina Geological Survey states that "landslides are most common in the mountain region of North Carolina because of slope" ("Geologic Hazards"). Therefore, the slope of Buncombe County was calculated using a 30-meter DEM from the North Carolina Department of Transportation and the "slope" function in arcmap. The slope (in degrees) of Buncombe County is as follows:

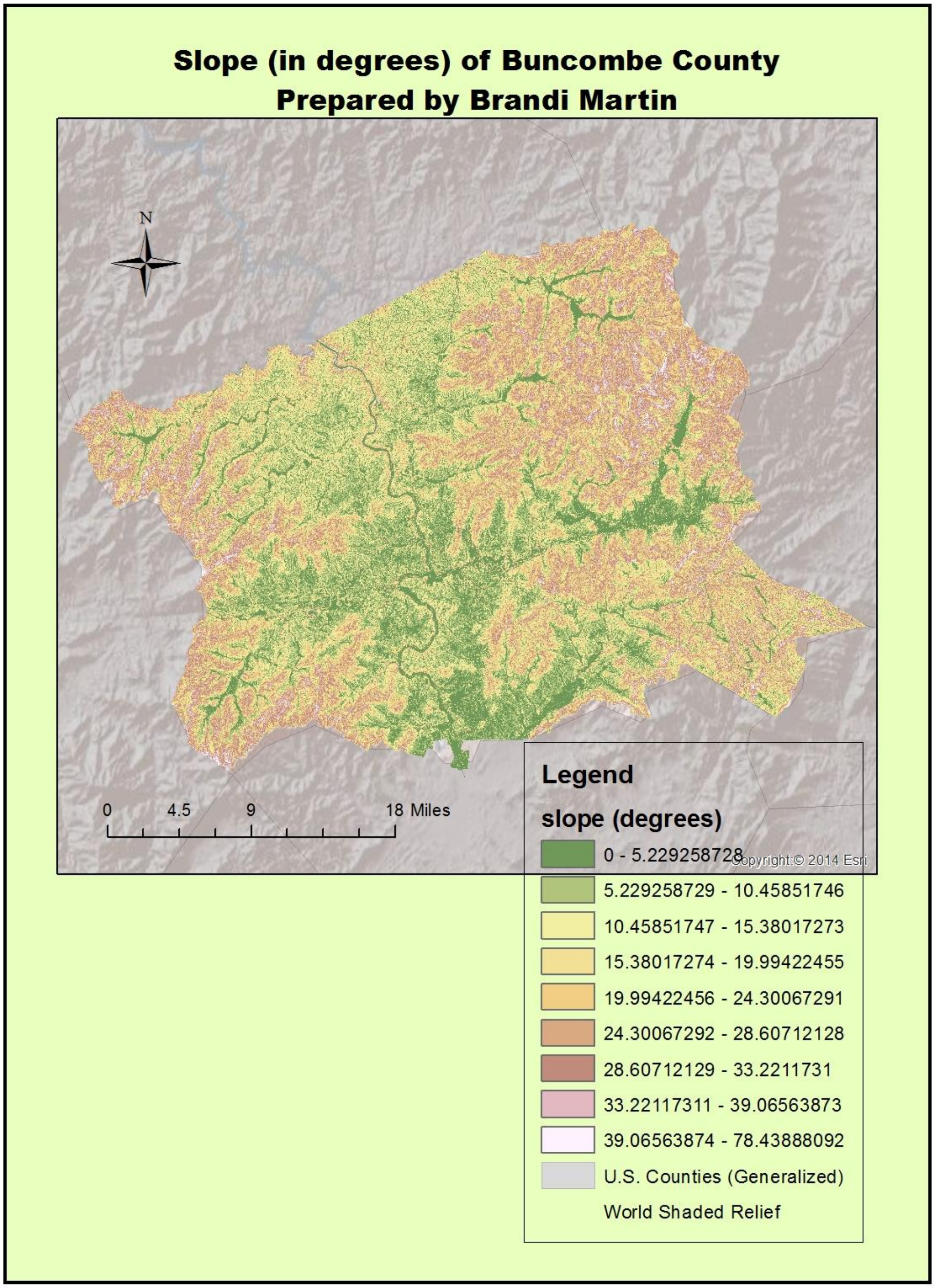


Figure 5. Slope (in degrees) of Buncombe County as calculated from a 30-meter DEM.

As one can see, the steepest slopes lie in the far western areas of the county as well as much of the eastern part of the county. From here, the previous landslides were plotted on the map of the slope to see if the correlation was strong. The map is as follows:

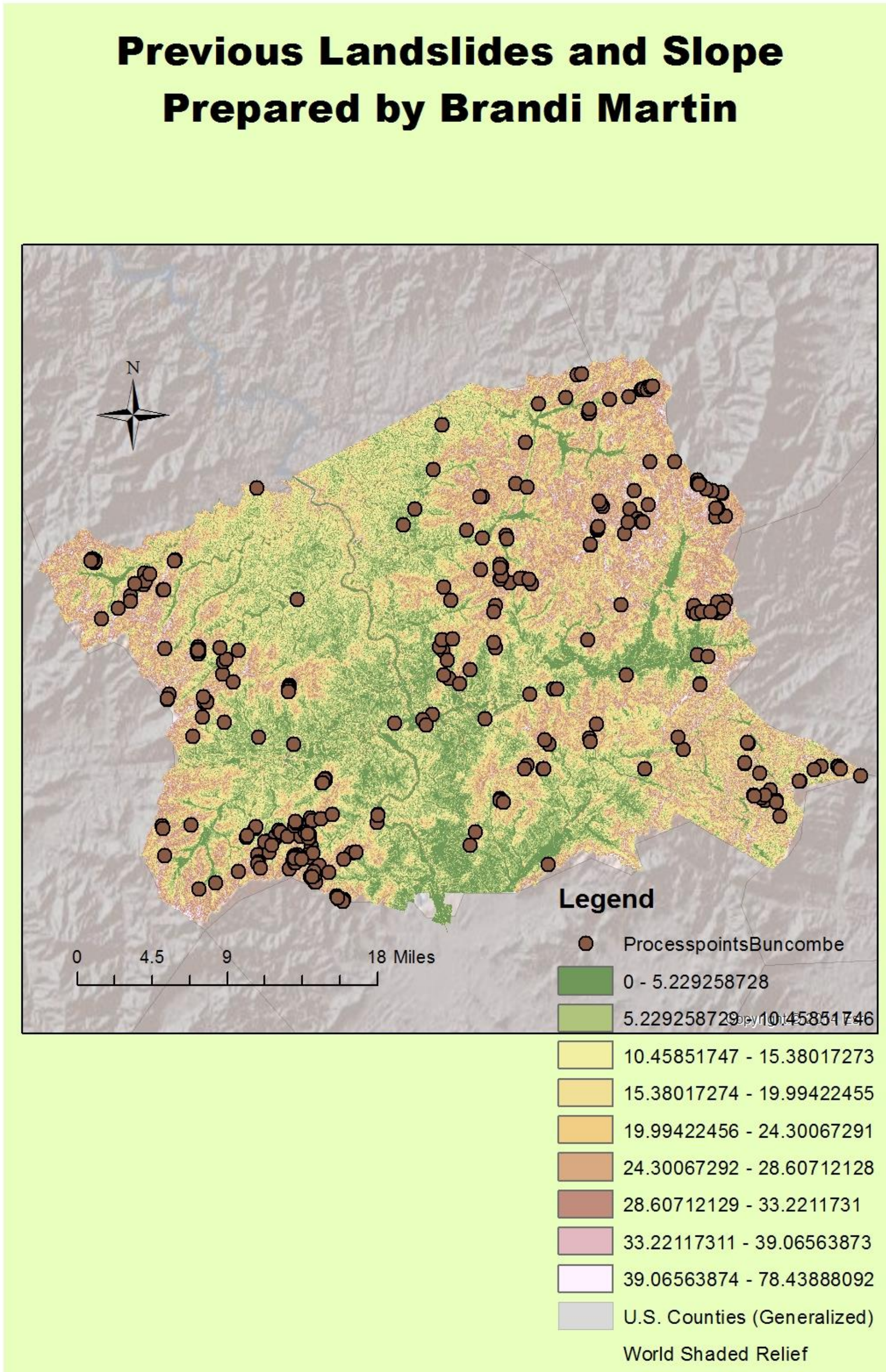


Figure 6. The strong correlation between high slope value and previous landslides that have occurred.

As one can see, the spatial representation of previous landslides and slope shows a strong correlation between slope value and occurrence of landslides. The great majority of landslides occurred in regions with high slope values, as indicated by the pink color on the map. So far, areas of past landslides and slope values are useful in creating a hazard map.

Landslides are also caused by anthropogenic effects such as road construction. Oftentimes, in order to make roads, a cut in the mountain side or an embankment on low land must be made first to level the elevation for a future road. A road cut is made when the land is originally higher than necessary and a cut is made in the land for the road, while and embankment is just the opposite, in that the land was originally lower than necessary and an embankment had to be made in order to reach the desired elevation. Although road cuts and embankments are basically opposite in definition, they both contribute to steep slopes in mountainous regions, therefore increasing landslide vulnerability. The type of land that is corresponded to past landslides was extracted from the attribute table, placed in excel, organized and displayed as a frequency of past landslides in relation to the type of land on which they occurred. The graph is as follows:

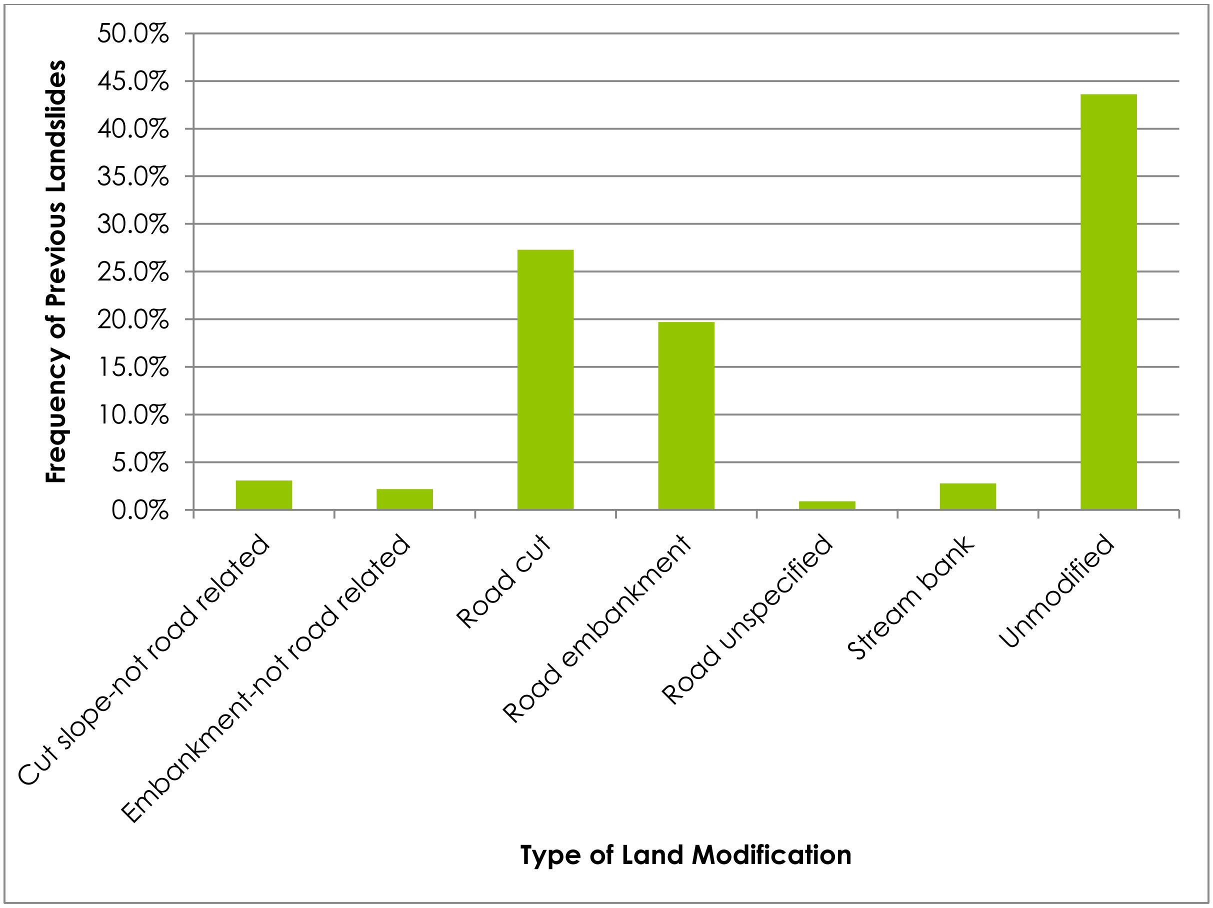


Figure 7. Representation of the type of land modification and the frequency of landslides that have occurred on this type of land.

For the land that *has* been modified by humans, it is clear that road cuts and road embankments correspond to the highest frequency of previous landslides, which means that areas with road cuts and embankments are areas of concern when predicting future landslides. The large assumption made here, though, is that both road cuts *and* embankments increase the vulnerability of a future landslide an equal amount because they are plotted together with no distinction between the two. Furthermore, these road cuts and embankments corresponded with previous landslides, and based on Wooten's notes, these roads were destroyed and never rebuilt, damaged but reconstructed, or not severely damaged. Another assumption was made going forward. It is possible that the man-made slopes caused by the road cuts and embankments were not as steep due to the landslide that occurred. Therefore, the assumption is that even if the road was destroyed and never rebuilt, the slope of the land remained the same, for the purpose of simplicity, since the new slope was not recorded. Thus, the corresponding latitude and longitude values for the landslides that had occurred on *either* a road cut or an embankment were extracted and plotted using the "display x,y" function in arcmap. The map of previous landslides that occurred on areas with either a road cut or an embankment is as follows:

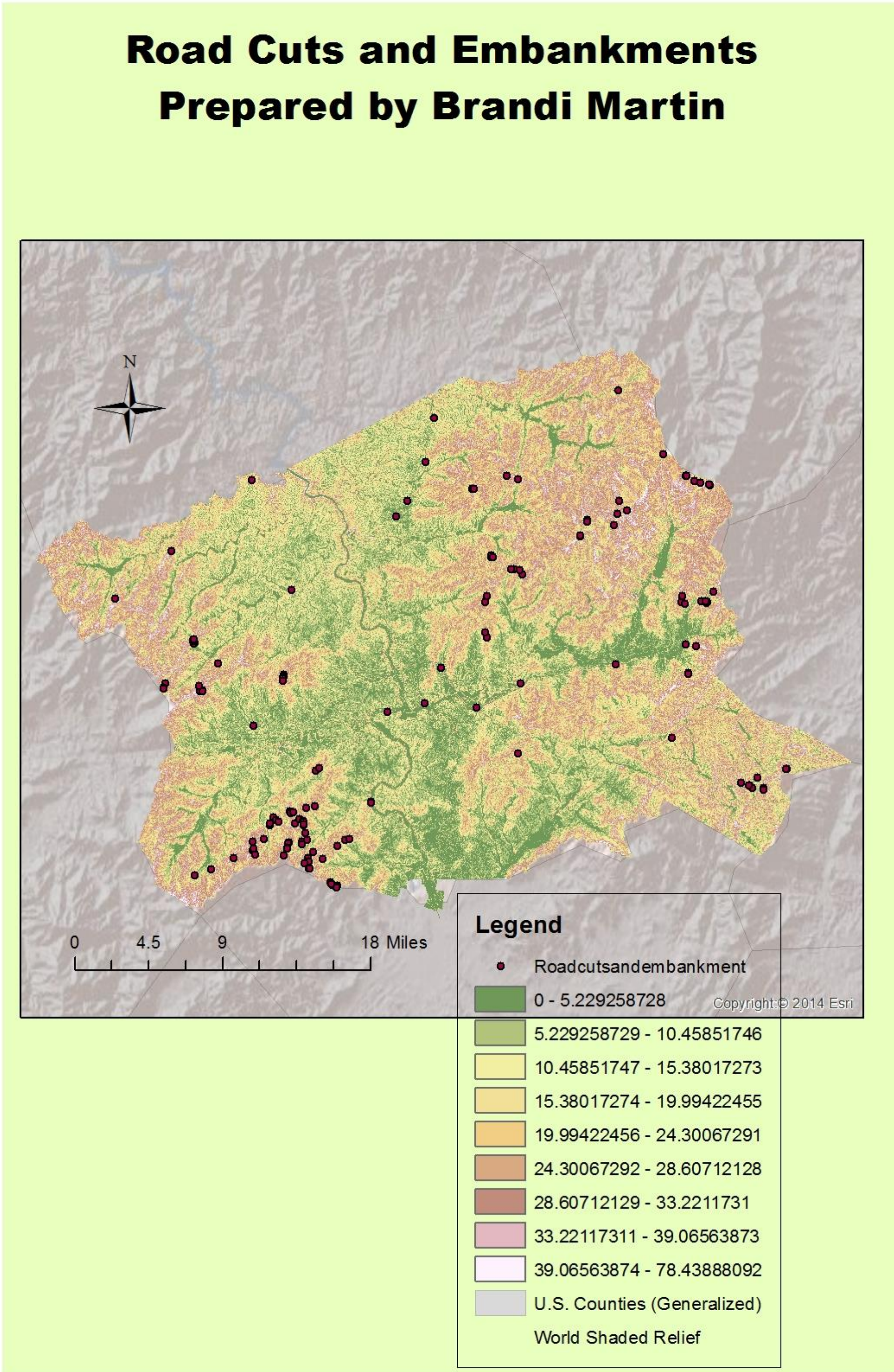
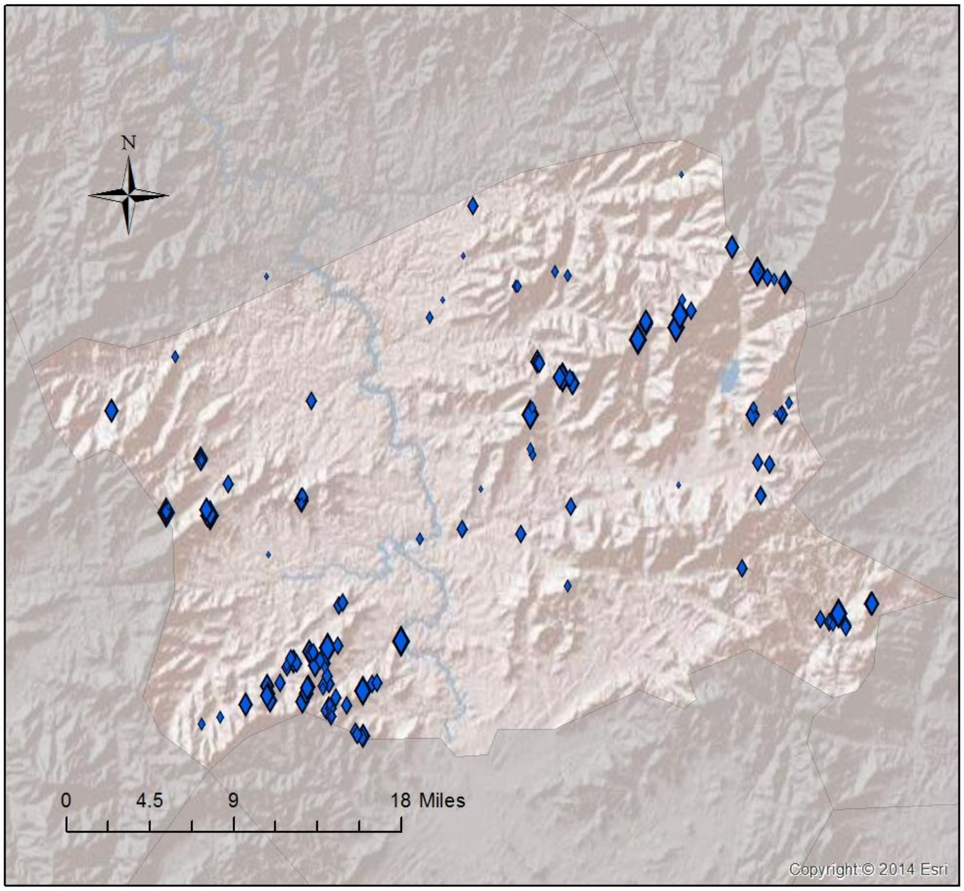


Figure 8. Locations of previous landslides that occurred on areas with either a road cut or an embankment.

After having analyzed Wooten's data and created a map of the slope of Buncombe County, a hazard map was made by relating three variables: points of previous landslides, road cuts and embankments, and slope. By plotting the points of previous landslides that occurred on either a road cut or an embankment and then using the "raster value to point" function to relate these points to their corresponding slope value, a hazard map was created to show the varying vulnerability of future landslides. The hazard map is as follows:

Road Cuts and Embankments in Relation to Slope Value

Prepared by Brandi Martin



Legend

road cuts and embankment (slope)

- 0.506415 - 12.699304
- 12.699305 - 27.382292
- 27.382293 - 36.049000
- 36.049001 - 45.022366
- 45.022367 - 61.459202
- U.S. Counties (Generalized)
- World Shaded Relief

Figure 9. This map represents the locations of previous landslides that have occurred on either road cuts or embankments. The varying sizes of diamonds correspond to the slope value associated with each location. The larger diamond sizes indicated a steeper slope, and therefore, the highest vulnerability of a future landslide occurrence, based on this method.

Results

Based on this particular analysis, one in which individual variables were chosen to determine correlation between the variables and past landslides, it seems fitting that the areas of most concern and highest vulnerability for landslides are locations of past landslides where the roads were either cut or an embankment was made and where the slope is steep. Although the literature about landslides incorporates other variables that do, indeed, contribute to landslides, for this particular project of making a hazard map it was more beneficial to incorporate the variables that showed the strongest correlation to past landslides, as it is almost impossible to show true causation through this map-making process. Thus, the variables with the strongest correlations were chosen as the variables that contribute to vulnerability and were used in creating the hazard map in Figure 9. Figure 9 shows that the areas of most concern are in the four corners of the county and the areas extending from the middle of the county eastward. It would be beneficial for city planners to locate these points and build away from the locations, as well as away from the corresponding locations down slope from these points.

Conclusion

This project soon became quite daunting when it was clear that not all of the plausible variables that would cause landslides showed a clear correlation with past landslides, and therefore would not be beneficial in creating a hazard map. Thus, there are downfalls to this particular method. However, based on the North Carolina Geological Survey, almost all of the landslides that occur in western North Carolina are because of slope steepness. Even though not all of the variables showed a strong correlation during the map-making process, the steepness of slope definitely did. And, it made sense to incorporate anthropogenic effects of road cutting and embanking which also contribute to steep slopes. With the “raster value to point” function, these variables could be related and shown in a hazard map such as Figure 9. This method is only one of many methods possible for creating a hazard map, and based on the modeling used, it is very possible to get different results. Assumptions were made in this method such as assuming that road cuts and embankments cause the same level of vulnerability. Both road cuts and embankments corresponded to the same frequency of landslides within 10 percent as shown in Figure 4. However, in other hazardous landslide areas, this may not be the case. For simplicity sake, though, the assumption was made. In summary, predicting future hazards is tricky business due to the complexity of nature, itself. Oftentimes, variables that increase vulnerability of landslides must be in conjunction with one another for landslides to occur. Other times, there is a clear trigger such as unusually heavy precipitation. Unfortunately, some of these variables are not represented, such as tension cracks, for example, because there was not a strong enough correlation to past landslides, even though the literature describes tension cracks as a variable that increases vulnerability.

Works Cited

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http://commons.wikimedia.org/wiki/File:Map_of_North_Carolina_highlighting_Buncombe_County.svg

Rick Wooten, Senior Geologist for the North Carolina Geologic Survey