Landslide & Debris Flow Hazard Assessment for Los Alamos County Following the Cerro Grande Fire, May 2000

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Introduction

The Cerro Grande Fire started on May 4th, 2000 as a controlled burn in Bandelier National Monument, in northwest New Mexico. Due to high winds and extremely dry fuel loads, the fire burned through its control lines on May 5th, advancing eastward toward the community of Los Alamos and the Los Alamos National Laboratory property. The fire ultimately burned approximately 48,000 arces, 34,000 within Los Alamos County (Plate 1), reaching its maximum extent by May 21st. 235 dwellings in Los Alamos were destroyed, leaving over 400 families homeless. Burn severity was moderate to high over 42% of the burn area (Plate 2), resulting total to near-total vegetation loss over much of the burn area. Subsequent to the Cerro Grande Fire, large areas of Los Alamos County were under threat of landslides and debris flows, due to slopes destabilized by vegetation loss, increased runoff, and newly exposed bedrock.

This project will use raster analysis techniques to show how GIS tools can help identify areas of high landslide and debris flow risk following a wildfire, using the Cerro Grande Fire as an example.

Inputs into this analysis include (1) burn area and burn severity within the burn area, (2) slope steepness, (3) buffers surrounding streams and roads, (4) geology, (5) slope aspect, and (6) a progressive buffer surrounding the burn area. Rasters were generated from available GIS data, ranked according to strength of effect, and combined using map algebra to result in a cumulative hazard assessment for Los Alamos County following the Cerro Grande Fire.

Data Collection

The Los Alamos National Laboratory's (LANL) Cerro Grande Rehabilitation Project (CGRP) website (http://cgrp-gis.lanl.gov) contains a repository with GIS data pertaining to conditions during and after the fire, and detailing rehabilitation efforts. From this website polygon shapefiles for the maximum extent of the fire, and the burn severity within that extent were acquired. A polyline shapefile of perennial streams and rivers in the region of the burn area and Los Alamos County was also obtained from the CGRP website.

Roads and political boundaries for Los Alamos County were downloaded from the GeoCommunity website (http://www.geocomm.com). The 2000 U.S. Census TIGER "all lines" polyline shapefile was used.

Elevation data, in the form of a 1/3 arc-second digital elevation model (DEM) enclosing Los Alamos County, were downloaded from the U.S. Geological Survey's (USGS) National Map Seamless Server.

GIS data on the geology of Los Alamos County were obtained from the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), which oversees the STATEMAP program, a statewide geologic mapping effort. Geology polygons used in the generation of geologic maps for the Valle Toledo, Bland, Guaje Mountain, and Frijoles quadrangles were acquired from NMBGMR, to give near-total coverage of Los Alamos County and the Cerro Grande burn area.

Data Pre-processing and Initial Raster Creation

The TIGER 2000 polyline file had a defined geographic coordinate system, NAD83, but not a projected coordinate system. The preferred coordinate system for the analysis was Universal Transverse Mercator (UTM), so the TIGER data were re-projected into the NAD83 UTM Zone 13N projected coordinate system. The lines of interest for this study were the roads and county boundary, which were selected and exported to separate polyline shapefiles using the "select by attribute" tool. The county boundary was converted from a polyline to polygon shapefile.

Metadata from the CGRP indicated that the burn area, burn severity, and streams shapefiles were projected in the New Mexico State Plane Central Zone coordinate system, but a coordinate system was not defined in the downloaded files. The projected coordinate system for the CGRP data was therefore defined as New Mexico State Plane, then reprojected into NAD83 UTM Zone 13N. The burn area shapefile was a polyline file, and as with the county boundary, needed to be converted to a polygon file for use as a analysis mask. The burn area extended beyond the ultimate analysis extent, which was the Los Alamos county boundary, so the burn area and burn severity polygons were clipped to the Los Alamos county boundary polygon. The burn severity polygon included three classes of fire damage in its attribute table, which in ascending order of severity were “underburn”, “mosaic burn”, and “stand replacement”. This shapefile was converted into a three-value raster for later reclassification.

Because it is unrealistic to assume the landslide and debris flow hazard ends at the boundary of the area burned in the Cerro Grande Fire, buffers at 100, 500, and 1000 meters were created around the burn area polygon. The purpose of these buffers was to simulate the decreasing but still extant danger of landslide and debris flow hazards outside the burn area. Thus, the study area was defined at its maximum by the 1000km burn area buffer polygon clipped by the Los Alamos county polygon. These buffers, along with the burn area polygon, were used to generate four rasters, each with a single value field, which would later be reclassified in order to represent a general high landslide risk within the burn area and progressive decrease in hazard risk away from its margin.

As with the TIGER data, the USGS DEM data were projected into the UTM projected coordinate system from NAD83 geographic coordinates. From the base DEM, raster files representing slope steepness in percent and slope aspect were generated using the Spatial Analyst tool in ArcMap, with both the burn area and 1000m burn area buffers used as analysis masks in order to cover the entire study area.

Both the perennial streams and roads polyline shapefiles were buffered at 100m to simulate (1) the increased hazard near watercourses after a wildfire due to increased runoff and channelizing of mud/debris flows, and (2) the fact that most manmade structures are within 100m of roads, and any debris flow or landslide that impinges on a populated area is inherently more destructive and “hazardous” than one that occurs in an unpopulated wilderness. These buffers were clipped to the study area extent and converted into single-value rasters.

The geology polygon files needed to be reprojected from NAD27 UTM coordinates to NAD83, and clipped to the maximum extent of the study area. Each of the four clipped quadrangle fragments were then converted to raster using the spatial analyst tool, and merged at their edges into one raster using the “merge(raster1, raster2,…)” map algebra command.

Raster Classification

The assignment of relative importance to the analysis inputs in this study is necessarily somewhat arbitrary. However, the advantage of creating a raster analysis GIS is that the inputs can easily be adjusted if the initial importance or weighting of the inputs is later deemed to be incorrect. Thus, the classifications arrived at here should be treated as a best-guess, qualitative treatment that could be subsequently altered.

The raster converted from the burn severity polygon was ranked 2, 3, and 4 for underburn, mosaic burn, and stand replacement fields, respectively (Plate 2). In addition to the burn severity modifier the burn area polygon overall was given a rank of four. The high values reflect the assumption that the burn area and degree of fire damage are the primary controls on hazard risk. The 100m, 500m and 1000m buffer rasters around the burn area were ranked 3, 2, and 1, reflecting the decreasing but non-trivial landslide and debris flow risk beyond the margins of the burned area.

The slope percent raster was reclassified into four classes corresponding to slopes of 0-25%, 25-50%, 50-75%, and >75% and given values of 1-4, respectively (Plate 3). The steepest slopes in the study area (up to 200-400%) correspond generally to near-vertical resistant rock cliffs of Bandelier Tuff, and hence may not in and of themselves represent high landslide hazard. However, these represent a small area within the >75% slope category that is deemed at highest risk for slope failure.

The slope aspect raster was reclassified into northwest, northeast, southwest, and southeast and assigned values of 1-4, respectively (Plate 4). The rationale for this ranking scheme follows from the observations that (1) south-facing slopes are generally drier and less vegetated than north-facing slopes, so any vegetation that survived the fire will likely be more robust on north-facing slopes, (2) the direction of propagation of the Cerro

Grande Fire was SW-NE, so it is reasonable to suspect that fire damage was more severe on the windward slopes facing the fire's origin, and indeed this supposition holds true if one visits the burn area, and (3) the general slope of the study area is down to the east, toward the community of Los Alamos.

The geology raster was reclassified based on the assumed relative susceptibility to erosion (Plate 5). Quaternary sediments (alluvium, colluviums, landslides, stream terraces, etc.) were given a value of 4, unless they were listed as intercalated with tuffs or rhyolites, in which case the value was set at 3. The Pleistocene Bandelier Tuff was given a value of 2, as it can range from poorly to strongly welded, and form either cliffs or slopes. The Pliocene Puye fanglomerates were given a value of 3. Pliocene Tschicoma Formation andesites, dacites, rhyodacites and anything else that was described as welded was give a value of 1, and tuffs were given a value of 2.

The roads and streams buffer rasters were each given a ranking of two, which was intended to show the heightened risk to community and LANL structures, and additionally to multiply the calculated hazard where streams cross roads in non-urban parts of the study area (Plate 6). Unfortunately, shapefiles showing the locations of laboratory facilities appear not to be available to the public, so like the community of Los Alamos, LANL structures are assumed to lie near the roads in the TIGER line file, even though this is not necessarily always the case. Both of these buffer rasters were merged over a "background" raster with a cell value of zero and an extent equal to the study area, in preparation for addition to the other rasters.

Raster Addition

Once all of the rasters were properly classified, the actual creation of the final hazard raster was simply a matter of adding all the rasters together using map algebra (e.g. [raster1] + [raster2] + [raster3]…). The final hazard assessment raster (Plate 7) has a range of values from 4 to 24, reflecting the six input rasters (fire boundary plus buffers, fire severity, slope, aspect, roads, and streams), two of which, roads and streams, having zero values over much of the study area.

Discussion and Conclusions

The highest predicted hazards using this model occur in steep-walled canyons with perennial streams and roads in valley bottoms. From south to north, the highest-risk canyons are Water, Twomile, Los Alamos, Pueblo, Rendija, Guaje, and Garcia. The model seems to predict hazards well for certain areas of Los Alamos County. For example, it highlights the hazard in Los Alamos Canyon, the site of the Los Alamos reservoir at the up-canyon end of the canyon-bottom road, and the Omega Research Reactor at Tech Area 2 down-canyon. The hazards are highlighted where Pueblo Canyon flows into the townsite, and in Rendija Canyon as it parallels Arizona Street and crosses the Guaje Pines development. Also well modeled is the risk posed by steep, burned-out canyons such as Water and Twomile to LANL facilities southwest of the Los Alamos townsite. Though the Guaje Canyon and Garcia Canyon hotspots do not affect the Los Alamos townsite, there are resources that could be affected by hazards in those localities, including a pumice mine and ancestral Native American ruins.

Possible improvements to this model could include:

- Addition of land ownership parcels within the Los Alamos townsite, so that proximity to roads need not be used as a proxy for habitation, lowering the signal in rural areas with roads.
- Shapefiles of LANL structures. These are naturally hard to come by, given that some of the facilities have high-level security. However, geologic hazards that put LANL facilities at risk are possibly more “hazardous” than those that threaten civilian communities, given the presence of radioactive and toxic waste and experimental materials in LANL facilities.
- A quantitative ranking scheme for the input variables. This perhaps could be gleaned from a careful overview of the geomorphology literature, however will likely always have some element of subjectivity.

Map Plates for:

Landslide & Debris Flow Hazard Assessment for Los Alamos County Following the Cerro Grande Fire, May 2000

Plate 1: Extent of Cerro Grande Fire within Los Alamos County, NM

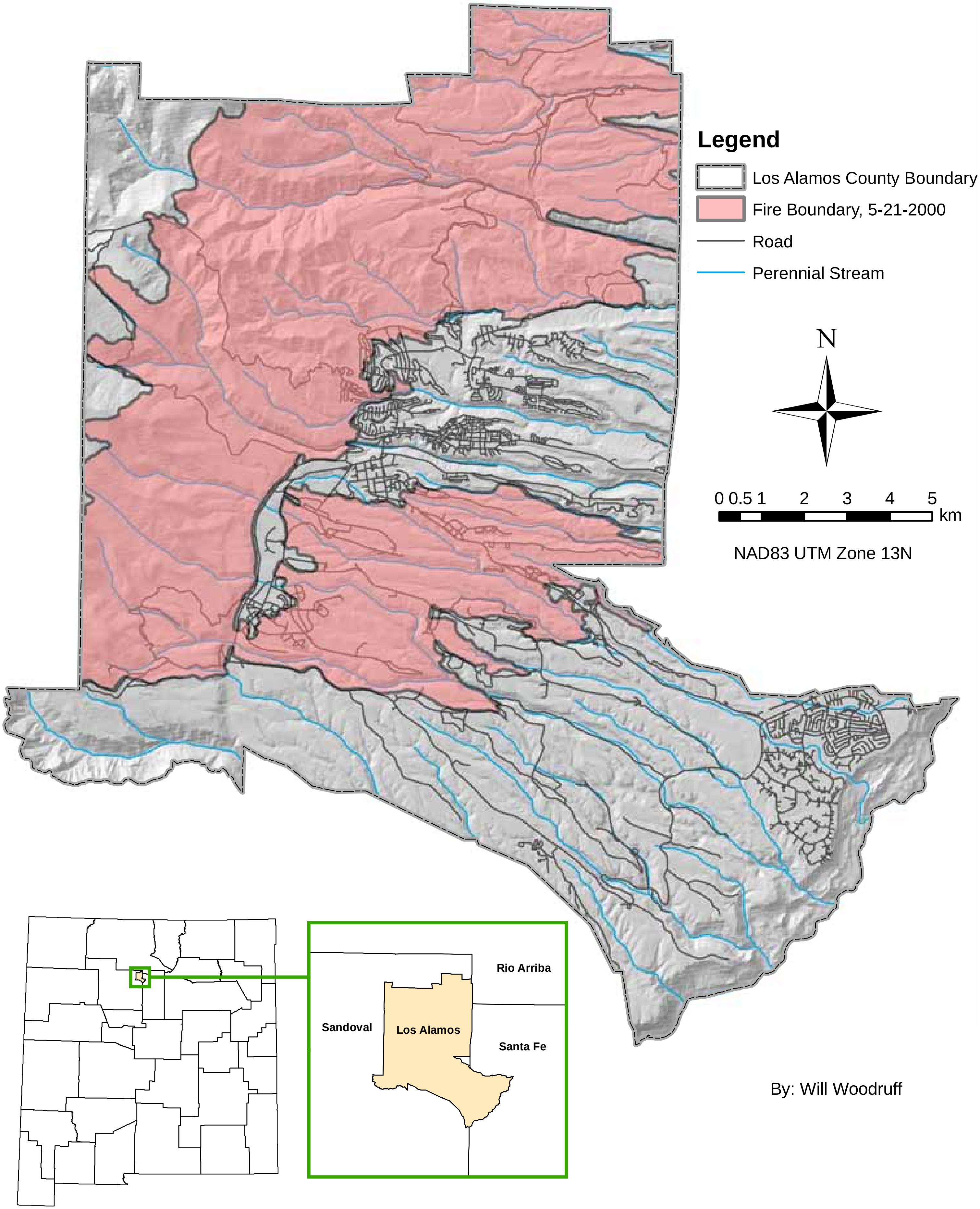

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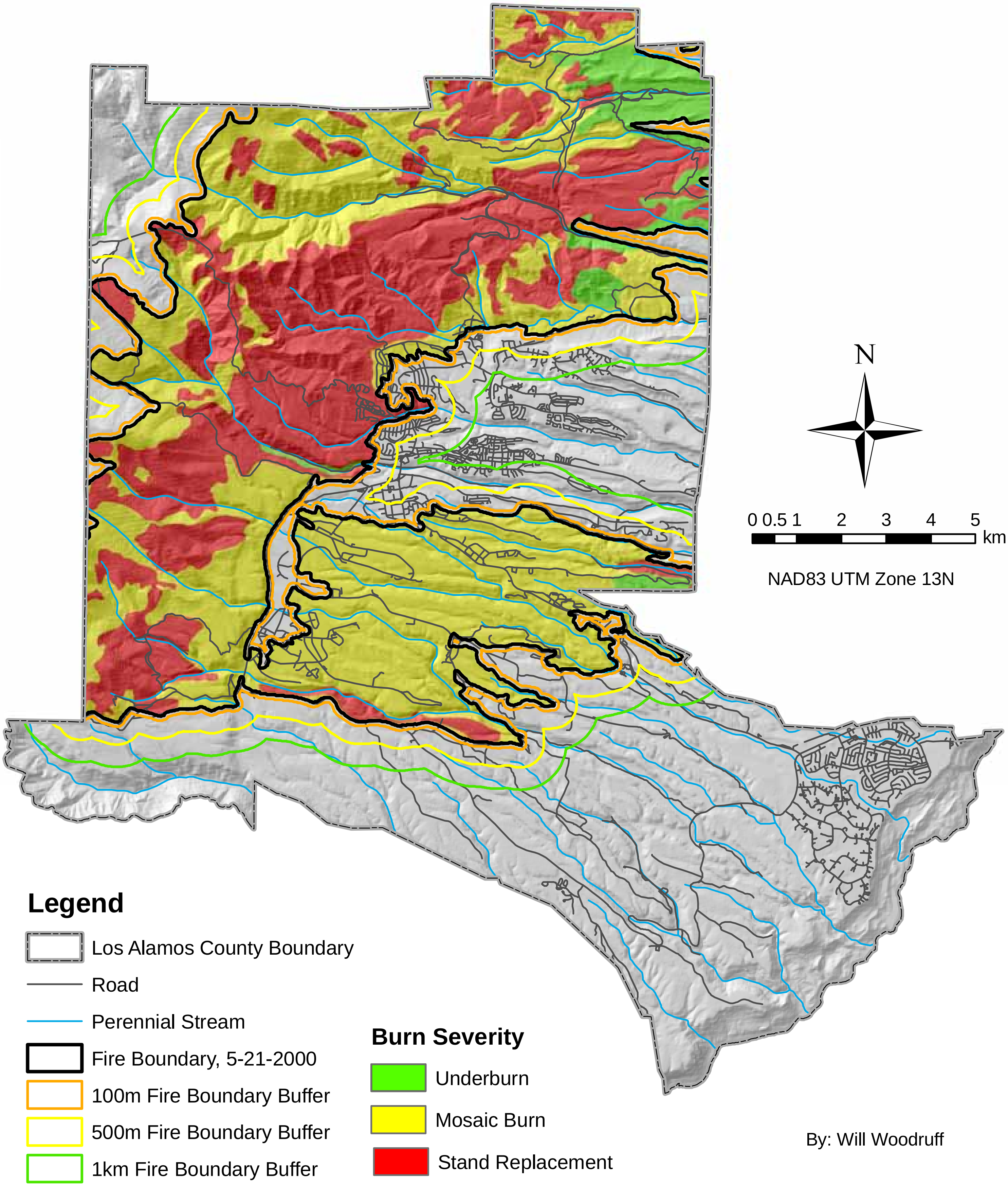
Plate 2: Burn Severity and Fire Boundary Buffers
Los Alamos County, NM



By: Will Woodruff

Plate 3: Reclassified Slope Percent within Study Area
Los Alamos County, NM

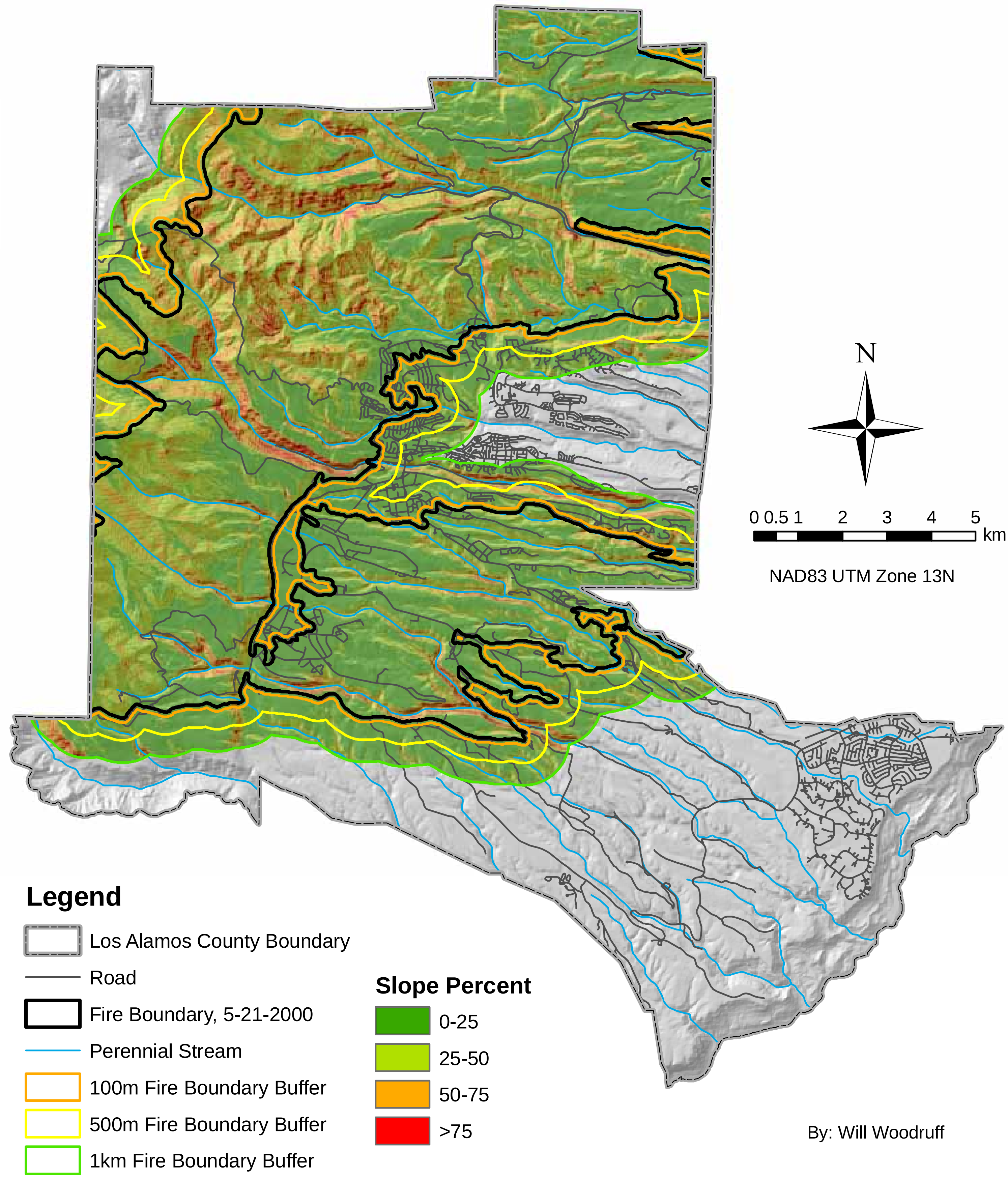


Plate 4: Reclassified Slope Aspect within Study Area
Los Alamos County, NM

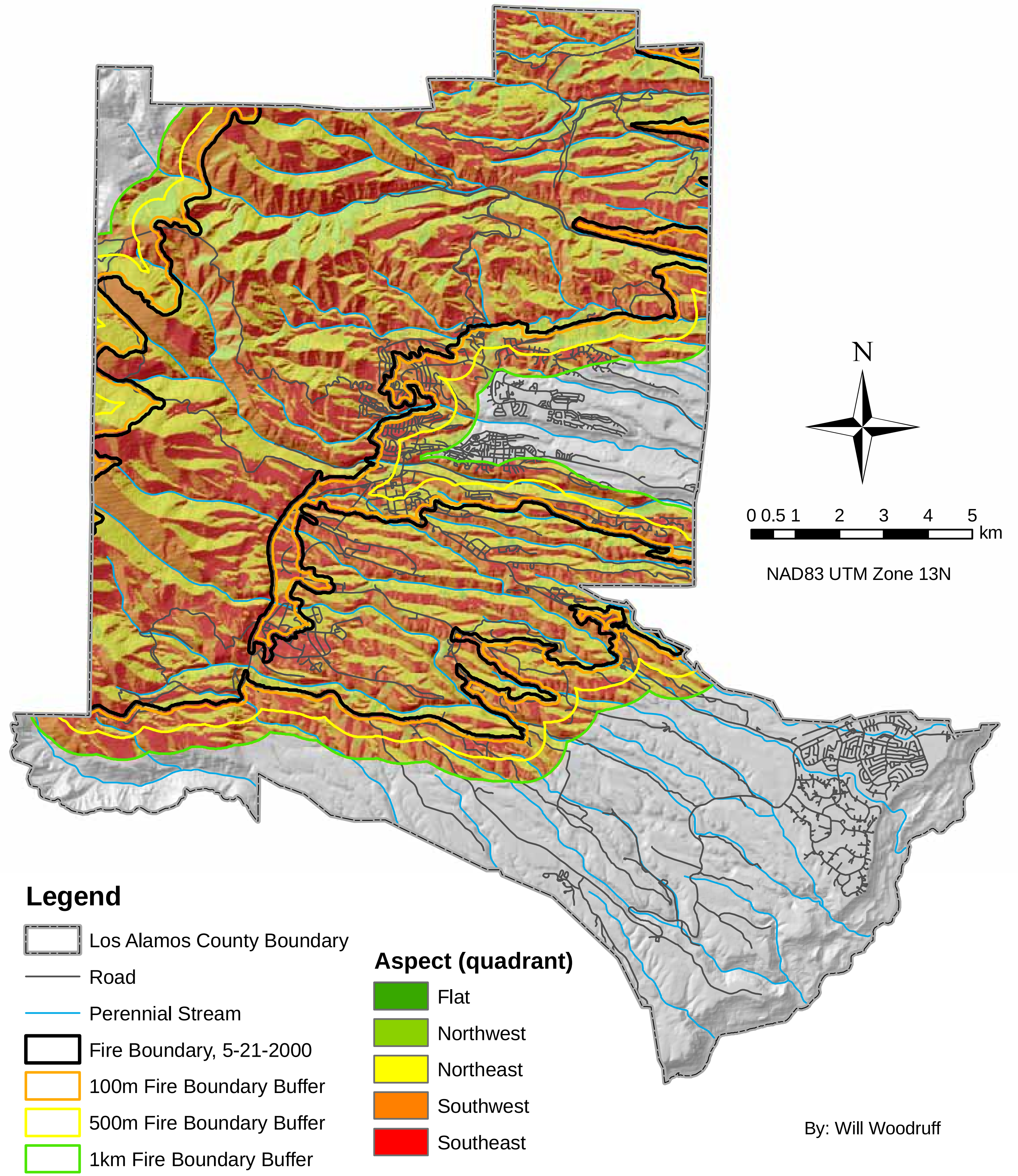
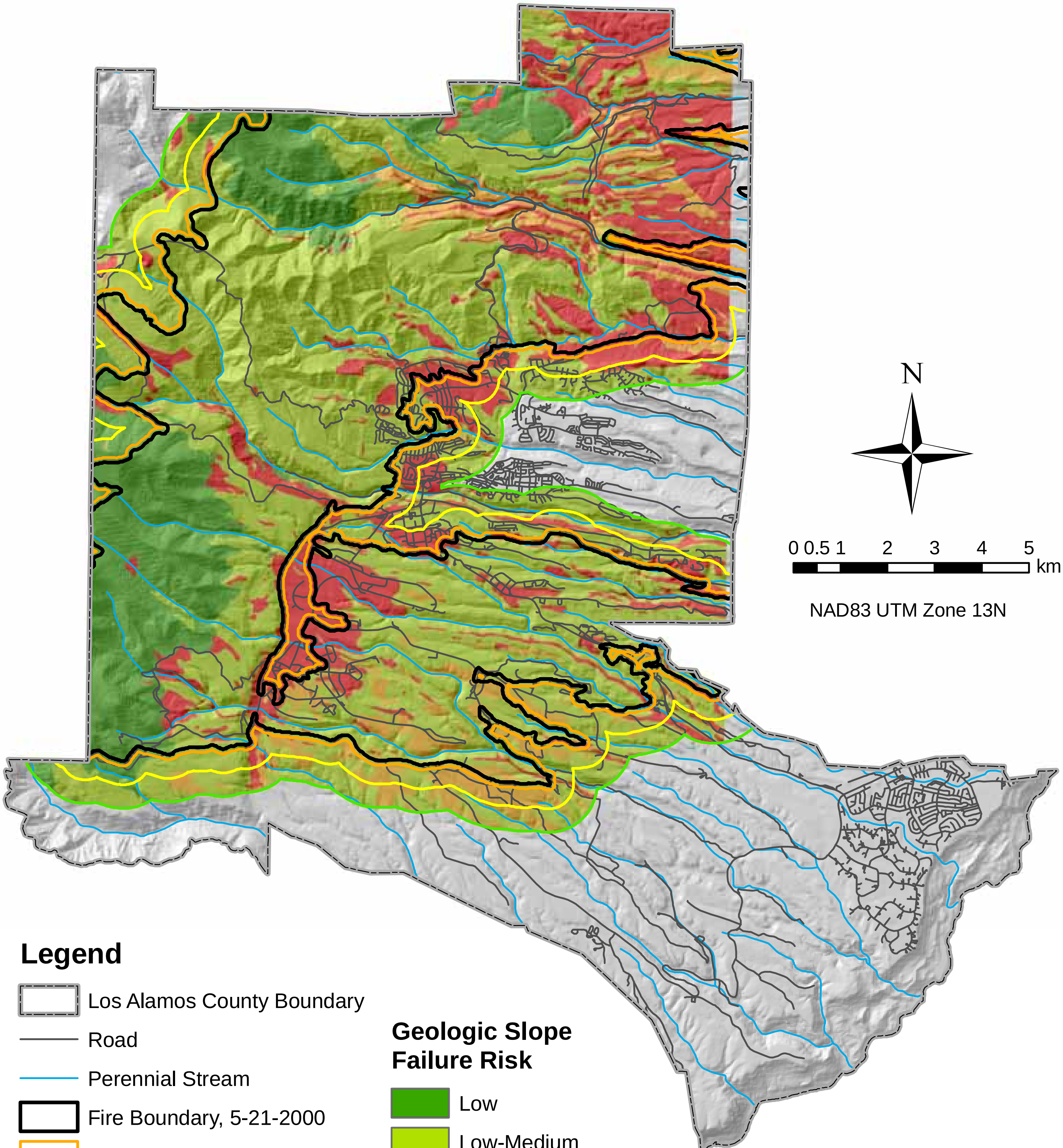


Plate 5: Reclassified Geology within Study Area
Los Alamos County, NM



Legend

- Los Alamos County Boundary
- Road
- Perennial Stream
- Fire Boundary, 5-21-2000
- 100m Fire Boundary Buffer
- 500m Fire Boundary Buffer
- 1km Fire Boundary Buffer

Geologic Slope Failure Risk

- Low
- Low-Medium
- Medium-High
- High

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Plate 6: Buffered Roads and Streams within Study Area
Los Alamos County, NM

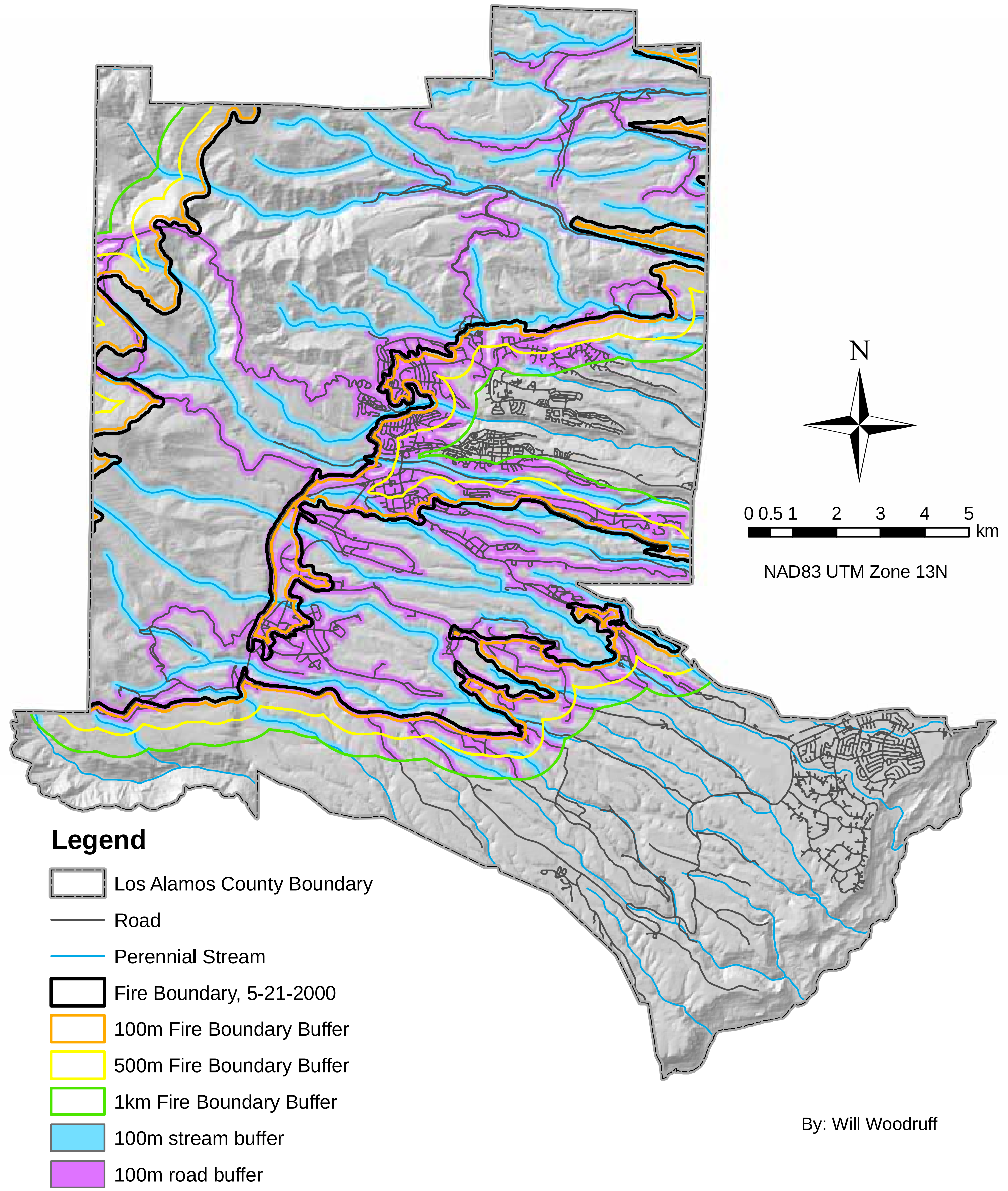
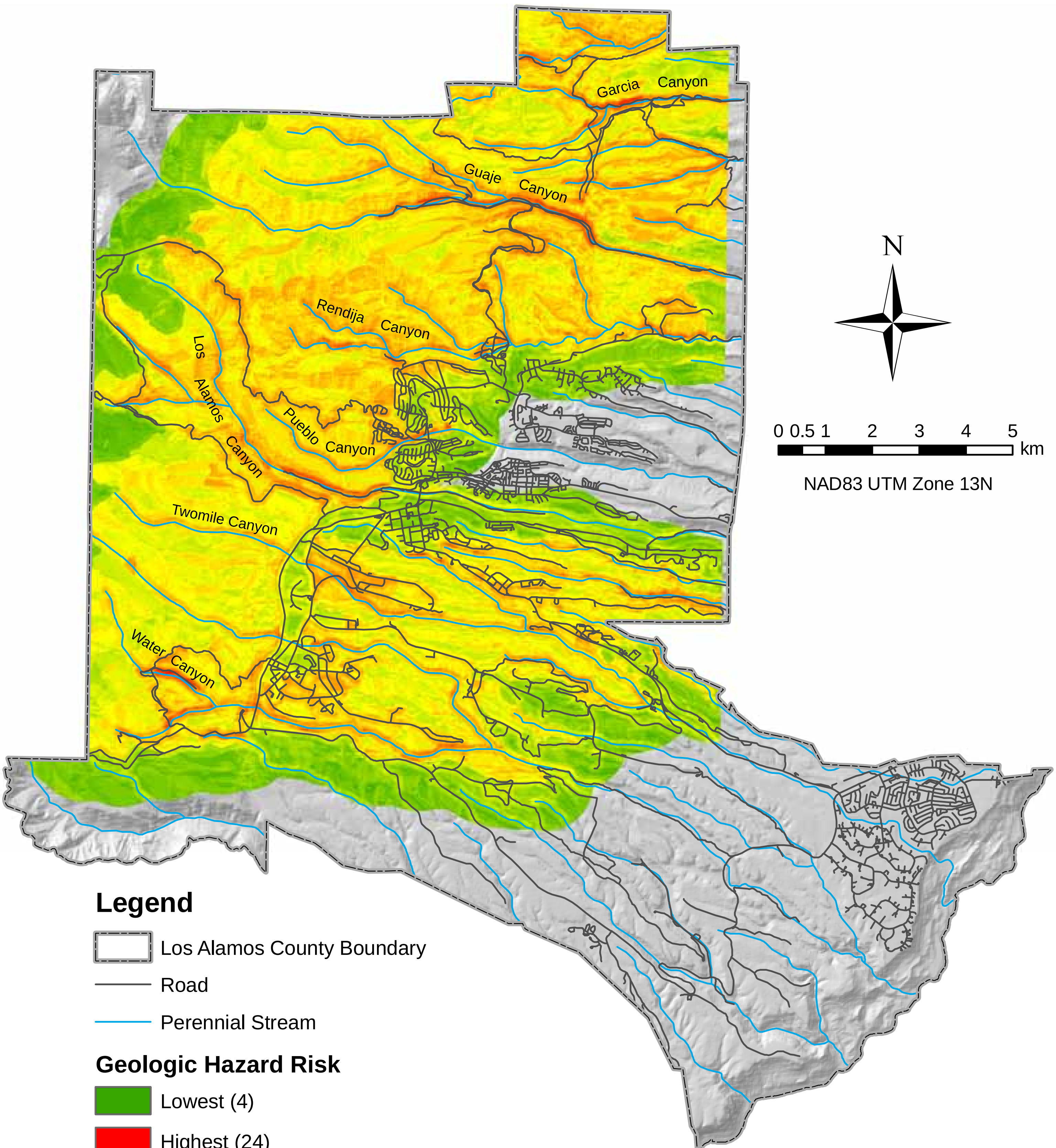


Plate 7: Landslide and Debris Flow Hazards Subsequent to the Cerro Grande Fire. Los Alamos County, NM



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