

Hazard Map Executive Summary

Open-File Report 620B

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This hazard map displays the distribution of the level of risk associated with the potential for having an erosion (loss of sediment) or deposition (accumulation of sediment or “sedimentation”) event in the Cañon Largo watershed on the southern Jicarilla Apache Nation. The risk values displayed on this map range from 0 (low risk) to 1 (high risk for erosion) and -1 (high risk for deposition). These are categorized metrics as they are hindered by a lack of classical risk analysis and heavily depend on expert opinions. This leads to impreciseness and necessitates the categorization of risks (e.g., "low risk", "moderate risk", and "high risk") as opposed to quantification. The map represents a combination of many relationships related to an erosion or deposition event. The erosion and deposition risks presented result from the quantitative analysis of the risk factors summarized in Table 1. The map is not meant as an exact prediction of the location of such an event but as a probability map for where an event might likely occur. No timescale is given for when an event may occur. The hazards represented on this map have been split into erosion and deposition, and each was estimated from the mathematical formulas used to categorize and classify a watershed. The risks were estimated using fuzzy set theory, wherein multiple risk factors (e.g., slope, relative relief, drainage density, et al.) were quantified with methods outlined below and presented in Table 1. These two models have then been combined into a single hazard map.

Table 1— Formulas to create rasters of the parameters that have a relationship to the hazard.

Hazard	Formula	3D Area formulations notes	Variables	Source
Hypsometric Integral	$HI = (H_{mean} - H_{min}) / (H_{max} - H_{min})$	Use Focal Statistics in the Neighborhood toolbox to calculate and iterate over every cell value in an elevation raster. Then use raster calculator to solve equation for the rasters generated from focal statistics. To determine the analysis area one should build a semivariogram of the raster to determine the rate of change over the area to find the inflection point where the rate of change is no longer increasing rapidly as the area of analysis increases.	Hmax=Max Elevation, Hmin=Minimum Evaluation, Hmean=Average Elevation	Pike and Wilson 1971
Relative Relief	$Rr = H_{max} - H_{min}$	Use Focal Statistics in the Neighborhood toolbox to calculate and iterate over every cell value in an elevation raster.	Hmax=Max Elevation, Hmin=Minimum Evaluation	Strahler 1952
Dissection Index	$DI = Rr / H_{max}$	Use Focal Statistics in the Neighborhood toolbox to calculate and iterate over every cell value in an elevation raster. Then use raster calculator to solve equation for the two rasters (Rr.tif/Hmax.tif)	Rr=Relative Relief, Hmax=Maximum Elevation	Nir 1957
Slope	1st derivative of elevation surface	Slope tool in Spatial Analysis/Surface toolbox		
Curvature	2nd derivative of elevations surface	Surface Parameters tool in Spatial Analysis/Surface toolbox		
Drainage Density	$Dd = Lu / Wa$	In GIS this is completed by generating a raster. This is done by determining the Stream Order (Strahler or Sheve) per unit study area again by using the semivariogram of the elevation area. Make a grid, then count the stream order for each grid. Convert the grid to a point dataset with the grid code being the count of the stream order. Then interpolate the stream order per unit area.	Lu=Length of all the streams in the basin, Wa=Area of basin	Horton 1945
Stream Frequency	$Sf = Nu / Wa$	In GIS this is completed by generating a raster. This is done by determining the streams per unit study area again by using the semivariogram of the elevation area. Make a grid, then count the streams for each grid. Convert the grid to a point dataset with the grid code being the count of the streams. Then interpolate the stream count per unit area.	Nu=Total Number of Streams, Wa=Area of basin	Horton 1945
Stream Power Index	$SPI = \ln(As * \tan(\theta))$	Raster Calculator Formula $SPI = \ln(" AccumulationRaster.tif" * (\tan(" SlopeRaster.tif" * (\pi / 180))))$	As=Specific Catchment area, θ =Slope in Radians, AccumulationRaster.tif=Accumulation derived from Spatial Analysis/Hydrology/Accumulation, Slope.tif=Slope derived from Spatial Analysis/Surface/Slope	Moore et al. 1991

Locations for each risk are not surveyed but plotted from calculations of the LIDAR data; therefore, the accuracy of risk depends on the values used to calculate the risk and some interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the mapping detail and may result in erroneous interpretations. Site-specific conditions should be verified by detailed field investigation and larger scale analysis and surface mapping or subsurface exploration. Topographic and cultural changes may not be shown due to recent development that was not captured when the LIDAR data was captured. Areas on the map with small holes in the data have been noticed (Figure 1). These holes are where the risk calculated is off the normal scale due to the calculation method. While holes represent the highest risks, they may also be present due to existing infrastructure already in place to manage the risks, such as existing culverts or tanks. Further investigation of the data holes is required to establish the true nature of the sight-specific risk at these locations.

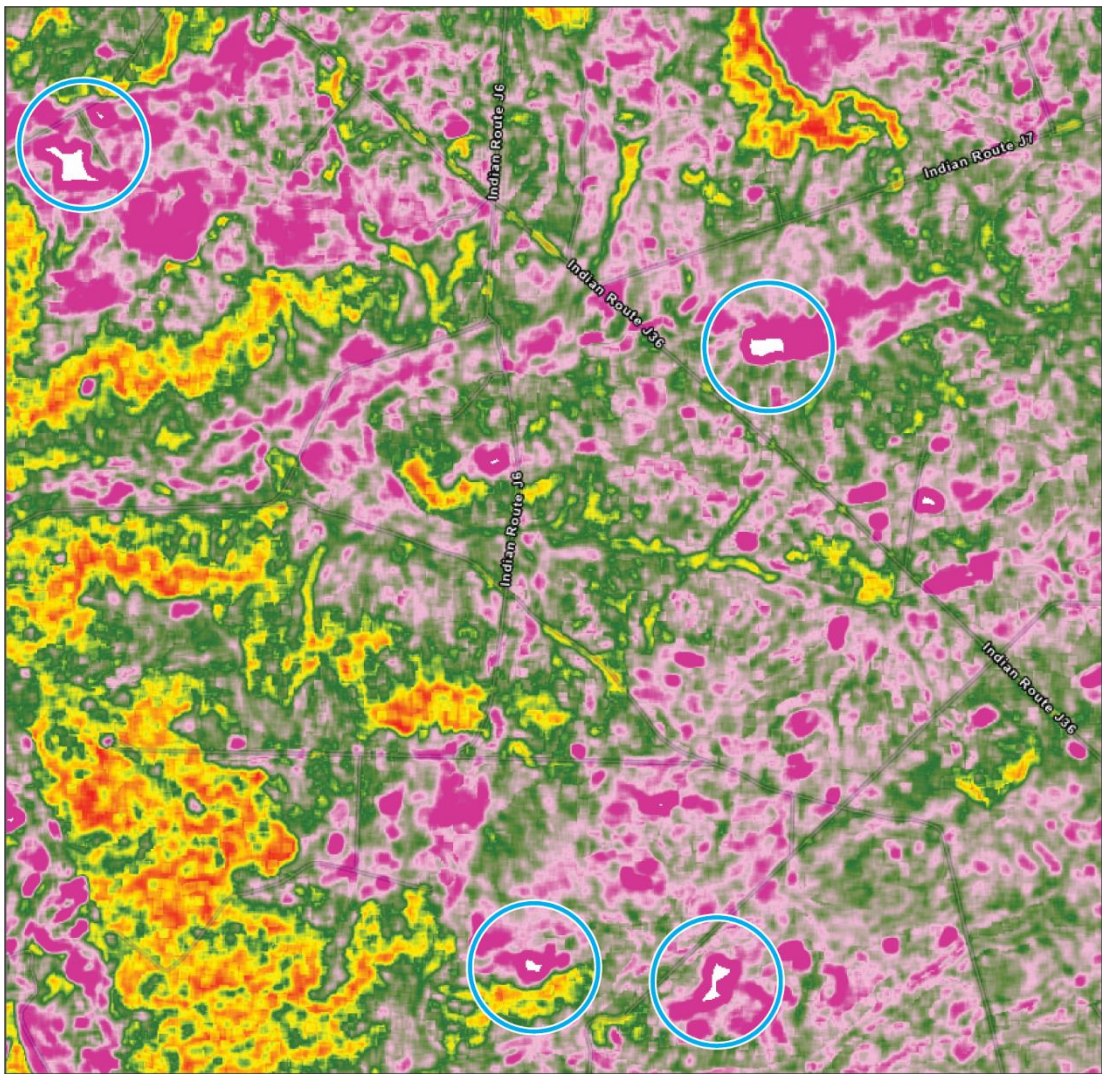


Figure 1—Blue circles surround white hot spots. The hot spots are “holes” in the data due to the geostatistical clipping of outlying data.

Much of the analysis conducted to create the Cañon Largo Hazard map was completed via long-established formulas that categorize the level of watershed development. However, some of these formulas have to be modified for the modern GIS environment as the formulas were not developed for detailed 3D evaluation and were more for two dimensions. The parameters in Table 1 are the main factors related to deposition and erosion. Creating rasters of these parameters is the first step to completing the hazard analysis. Rasters are needed for both the erosional hazard and for the depositional hazard. This analysis can be conducted for both end members using the same hazard parameters because there is a relationship of watershed development that encompasses both erosion and deposition.

After creating the hazard parameter rasters, a fundamental issue with the watershed hazard parameters is that the range of values and range of units for them are different, making a quantitative analysis difficult. To manage this issue, it is best to normalize the data to be able to use the Overlay tools in ArcGIS and make Fuzzy membership rasters. The normalizing for the range of values for every parameters is done using the Fuzzy Membership tool. This will reset the rasters to values ranging from 0 to 1, with 0 being not influential for the model and 1 being very influential for the model. For example, slope is measured in degrees of angle, and range from 0–90°, while the Hypsometric Integral is a unitless measure and will be dependent entirely on the area being studied.

Before using the Fuzzy Member tool it must be determined the important range of values that are significant for each end member of the hazard analysis; deposition and erosion values. Processing the data to manage for the various values by normalizing these data can be specific to the watershed, but to use slope again as an example, it was determined in Love 1980 that in the Chaco Canyon region (close to the Cañon Largo study area) that deposition occurs at angles of less than 0.30°. Erosion angle is a much more complex topic but generically speaking, erosion becomes likely at angles >45° but is relative to the rock or sedimentary material being studied.

For example, for the Fuzzy Membership of Slope in relation to deposition, angles that are near 0.30° are determined as being a high-risk hazard for deposition. Therefore values near 0.3° were given a normalized value of 1. Then values away from 0.30° were given a normalized value of 0 for the low-risk relationship for depositional as at higher angles sediment is more easily transported. Oppositional to the erosion risk, angles greater than 45° were given a normalized value of 1 for the relationship to a high risk for erosion, and angles less than 45° were given a normalized value of 0 for the relationship to a low risk for erosion. Table 2 shows the values associated with the normalized values established for the Fuzzy Members of the risk.

Table 2—Values used to establish the normalization for the Fuzzy Memberships

EROSION				
Member	Member Type	lowest value (normalize to 0)	Mid	Highest Value (Normalize to 1)
SPI	Large	0	10.5452	21.0904
DI	Large	0.002602876	0.022204	0.0418059
HI	Large	0.5	0.75	1
Rr	Large	50	69.3432	88.6864
Slope	Large	45	67.5	90
Mean Curve	large	0	7.9115	15.823
Dd	Large	24.33041856	31.77471	39.219
SF	Large	0.000951194	0.015476	0.03
DEPOSITION				
Member	Member Type	lowest value	Mid	Highest Value
SPI	Small	-10.7443	-5.37215	0
DI	Small	0	0.001301	0.002602876
HI	Small	0	0.25	0.5
Rr	Small	0	25	50
Slope	Near	NA	0.3	NA
Mean Curve	Small	-9.77834	-4.88917	0
Dd	Small	5.640158653	14.98529	24.33041856
SF	Small	-0.001694705	-0.00037	0.000951194

Next, a Fuzzy Overlay will need to be made, one for each erosion and deposition. A Fuzzy Overlay is the combination of each of the normalized members of hazard parameter values; SPI, DI, HI, Rr, Slope, Mean Curve, Dd, Sf. These are combined in a geostatistical manner to represent the combined risks for both Depositional and Erosional Hazards.

Finally, to visualize the two hazards in the same raster, the raster calculator is used to combine the Erosion and the Deposition Fuzzy Overlay Hazard rasters. Because both are normalized to 0 to 1, we need to make one of the values negative and then sum the two together. This will also weight the overlapping risks to show which is more probable for areas where the overlaps are mid-range values. Which is made negative is not significant, at least to this author. For this study, the deposition was made negative. Resulting in a formula for the final raster which represents both Erosion and Deposition hazards as:

$$\text{Composite Hazard Map} = (\text{Erosion Hazard}) + ((-1) * (\text{Deposition Hazard}))$$

More sight-specific studies should be conducted at locations identified from this analysis, and through a series of repeated drone flights at different times, each drone flight's elevation data could be used to conduct the same analysis presented on the map but in greater detail because of the larger scale and smaller area to be analyzed. More time could also be used to develop a better analysis method so that the holes in the data are included in the preliminary steps. This requires much more time in testing the values from the Table 1 formulas and the fuzzy set theory methods to calculate the fuzzy member's weight. While the method conducted in this analysis is more appropriate from a geostatistical method, it does eliminate the outliers before the final analysis instead of letting the analyst evaluate the outliers beforehand.