Avalanche Risk in Rocky Mountain National Park

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EOS-104: Geological Applications of GIS

INTRODUCTION

Rocky Mountain National Park is a 415 square mile national park located high in Colorado's Front Range, about an hour and a half drive northwest of Denver. Each winter, the park gets hundreds of thousands of visitors, many of whom come for the winter recreation opportunities such as skiing, snowshoeing, and mountaineering. The park is located in a high-altitude backcountry environment, with much of its land above the tree line. None of the terrain in the park is controlled or monitored, so avalanches are a risk for most of the year. [1]

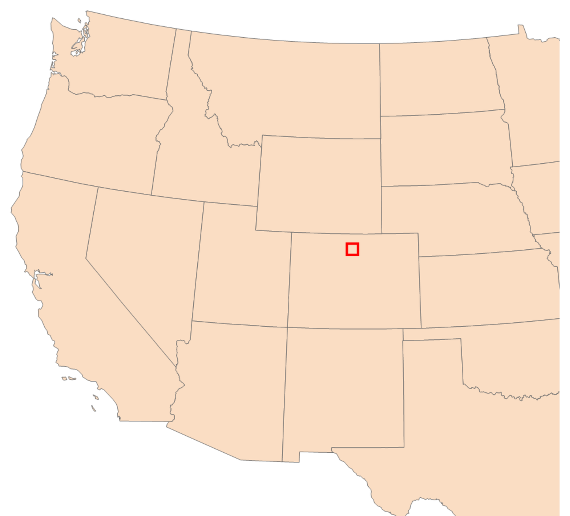


Figure 1: Location of Rocky Mountain National Park

According to the Colorado Avalanche Information Center, five people per year on average die in an avalanche in the state of Colorado, and twice as many people have died in avalanches in Colorado than in any other state in the past 70 years. Avalanches have killed people in Colorado in every month of the year except for September, so this topic is important to park visitors in all seasons, not just the winter months. [2]

The goal of this project was to use GIS methods to provide visitors of Rocky Mountain National Park with a guide for where to expect avalanche risks based on factors easily quantified in a GIS model, such as slope, aspect, and vegetation. The project is not intended to predict avalanches. Many factors that are highly variable and not easily quantified by in a GIS model, such as snow depth, snowpack layering, temperature variations, and human activity play a major role in avalanche risk. The project is intended to be a tool that helps users plan their recreation in the park safely, not a substitute for good preparation, awareness, decision making, and training.

METHODS

I had three goals in my analysis. The first was to produce a map of avalanche risk based just on the features of the terrain – slope, vegetation height, and vegetation density (Figure 2). The next was to produce maps of risk based on the features of the terrain and the prevailing wind direction (Figures 5-12) . The final goal was to produce maps highlighting the avalanche risk on trails and roads in the park (Figures 3-5).

Projection

I chose the NAD 1983 UTM Zone 13N Projection for all of the data for this project because it is a good projection for relatively small areas, and the park lies within Zone 13N. [3]

Surface Analysis

A digital elevation model (DEM) was obtained from the National Map [4], trimmed to the park boundaries, and analyzed using the Spatial Analysis Surface tools in ArcGIS to create three separate rasters:

- Hillshade
- Slope values in degrees
- Aspect values in degrees

Reclassification

I reclassified the slope raster based on avalanche risk levels to the following values with 1 being low risk and 6 being high risk:

Slope (°)	Risk Level	Slope (°)	Risk Level
0-20	1 (low)	40-45	6
20-25	2 (marginal)	45-47	5
25-27	3 (moderate)	47-50	4
27-30	4 (considerable)	50-55	3
30-35	5 (high)	55-60	2
35-40	6 (extreme)	60-90	1

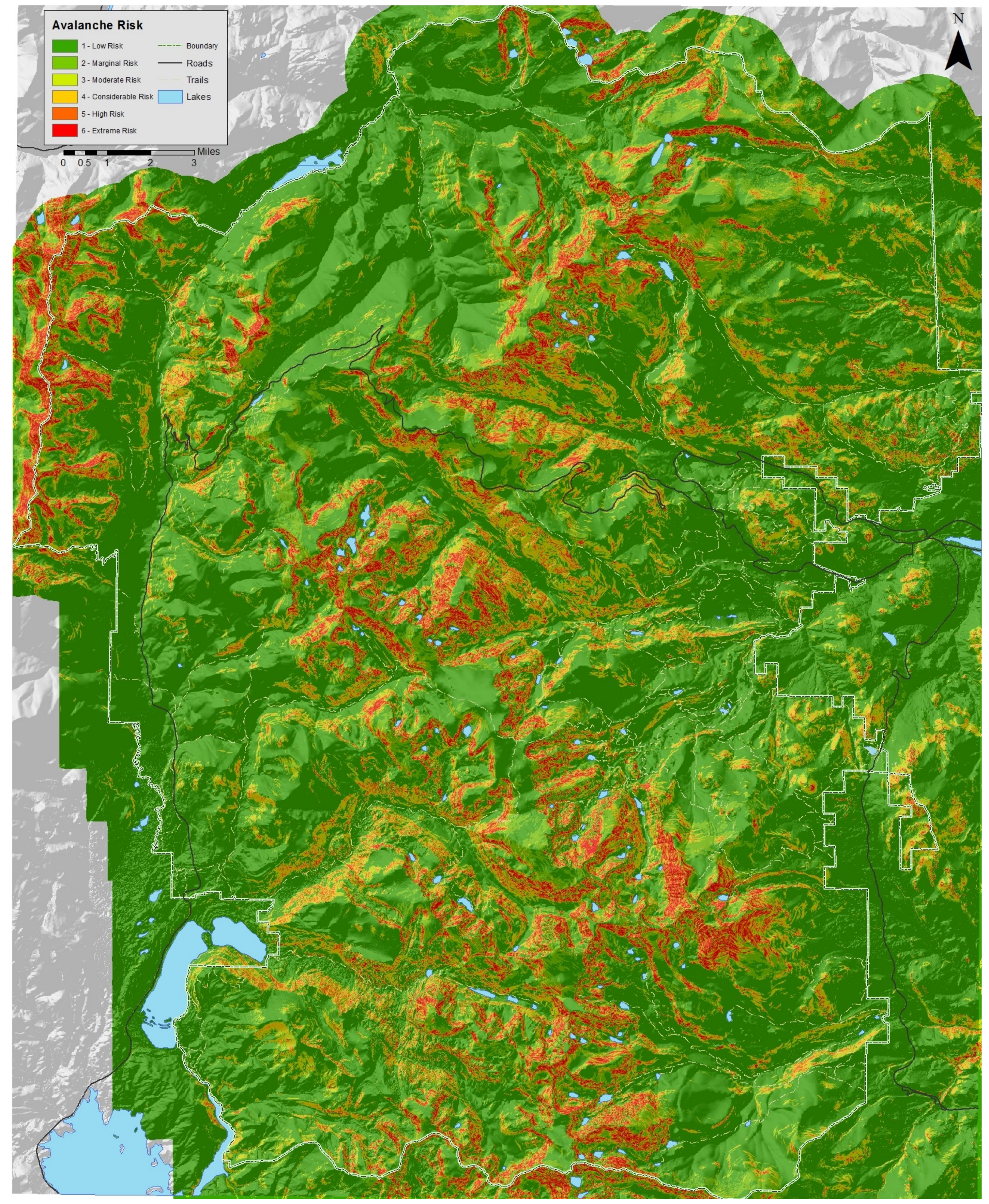


Figure 2: Generalized Avalanche Risk Map

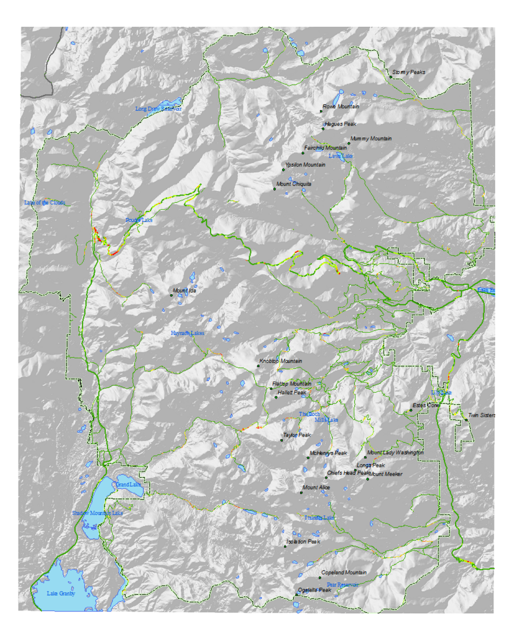


Figure 3: Avalanche Risk for Trails and Roads

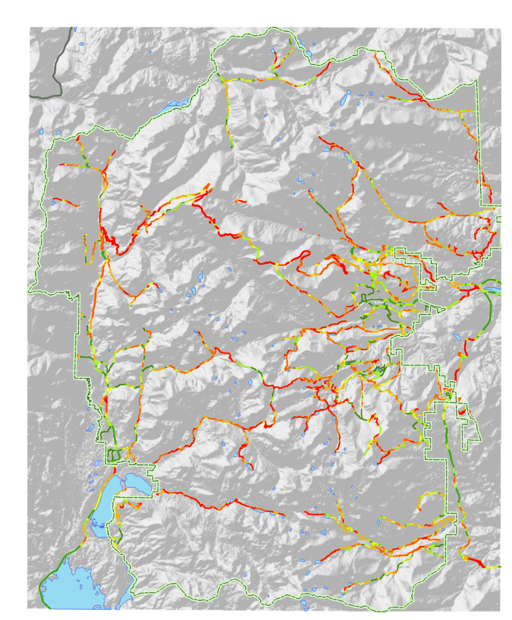


Figure 4: Roads and Trials within 500 feet of Highest Avalanche Risk Zones

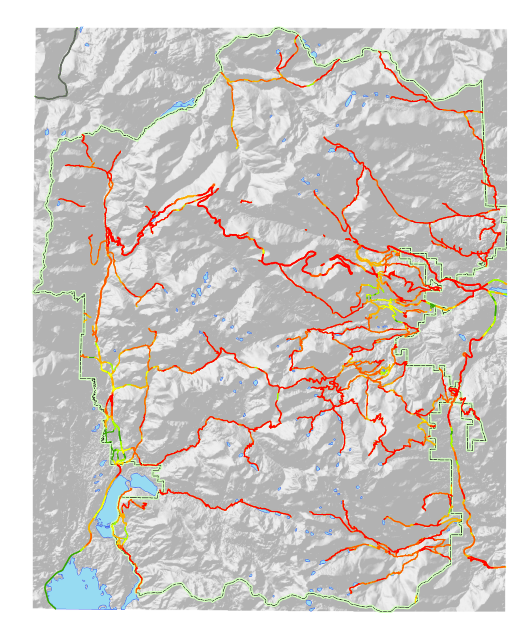
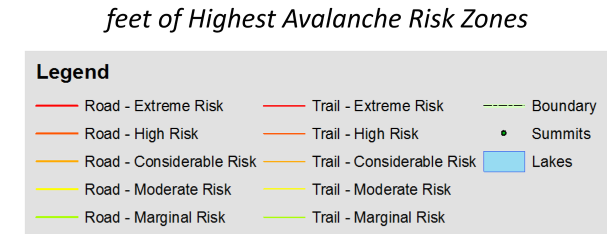


Figure 5: Roads and Trials within ¼-mile of Highest Avalanche Risk Zones



Reclassification (continued)

I converted the vegetation data from the National Park Service [5] into two separate rasters. One raster had vegetation density values, with 6 being the densest and 0 being no vegetation. The other had vegetation height with 5 being the tallest and 0 being no vegetation. These rasters were combined using the Spatial Analyst Map Algebra tool with the equation below to create a raster with a "stopping power" value for the vegetation based on the fact that an avalanche will be unable to gather momentum and volume in areas of taller, denser vegetation.

$$Stopping\ Power = int(\frac{height + density}{3})$$

Weighted Analysis

After the reclassification I subtracted the stopping power raster from the slope raster to yield a general terrain risk raster, which was the basis for all other analysis results. The general terrain risk raster is limited to the extents of the National Park Service Vegetation data.

I classified the aspect raster into eight rasters with values for additional avalanche risk for each prevailing wind direction (N, NE, E, SE, S, SW, W, and NW). The leeward side of a slope (facing opposite the wind direction) was given an additional risk value of 3. Each direction adjacent to leeward direction and the windward side (facing the wind direction) were given additional risk values of 2. Each direction adjacent to the windward side were given additional risk values of 1.

For example, for a prevailing wind blowing north: south would have an additional risk value of 3; southeast, southwest, and north would have additional risk values of 2; and northeast and northwest would have additional risk values of 1.

My risk values are based on the principles of wind loading outlined in "Wind Slab" on avalanche.org [6]. I added the additional wind risk values to the general slope risk for each of the wind directions instead of subtracting because I did not want to assume that wind would decrease the avalanche risk, only that it would add to it slightly for slopes with certain aspects.

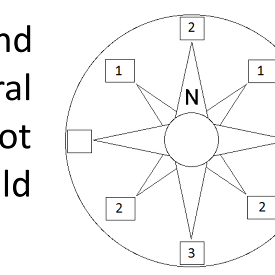


Figure 13: Additional Risk Values assigned to each aspect for a prevailing wind to the North

Raster Expansion

I highlighted trails and roads based on the highest avalanche risk that they intersect, that they come within 500 feet of, and that they come within a quarter mile of. In order to obtain the 500 foot and quarter mile rasters, I reclassified the my risk raster into six individual rasters, each containing only one risk value. Then I used the Spatial Analyst expand tool to expand each raster by a specified number of cells, which I chose based on the cell size and desired expansion distance.

Intersection

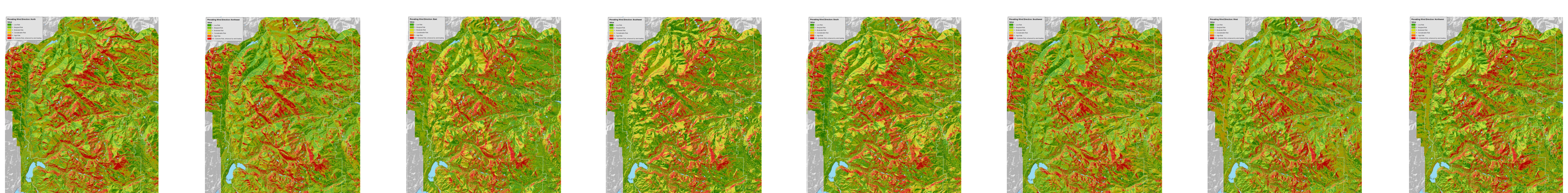
Finally, I intersected the trails and roads with each of the rasters produced in my expansion to yield graphs with trails and roads highlighted based on the highest avalanche risk that they intersect, that they come within 500 feet of, and that they come within a quarter mile of.

CONCLUSIONS

The goal of this project was to use GIS to analyze the terrain in Rocky Mountain National Park and produce maps of general avalanche risk, avalanche risk based on wind direction, and avalanche risk for trails and roads. It is clear that there is plenty of avalanche terrain in the park, especially in the high alpine zones mostly in the middle of the park. The amount of trails and roads that are within 500 feet and a quarter mile of significant avalanche risk zones should be a warning to park visitors to always plan ahead and be aware of their surroundings.

Some future applications of this research include seasonal risk maps using snowpack data and up-to-date risk maps based on wind direction and snow depths.

This project is intended to be a tool to help users plan their recreation in avalanche terrain. The risks posed by slope, wind direction, and vegetation were assigned weight values based on information from reliable sources on avalanches [6,7]. However, users should be aware that avalanches are hard to predict and influenced by a variety of other factors before venturing into avalanche terrain.



Figures 5-12: Avalanche Risk for Prevailing Wind Directions of N, NE, E, SE, S, SW, W, NW respectively

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Sources

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2. "Statistics and Reporting" *CAIC.* http://avalanche.state.co.us/accidents/statistics-and-reporting/
3. "RMNP GIS Analysis of Trails" *CSU.* http://gisedu.colostate.edu/webcontent/nr505/nps07/team4/Index/homepage.html
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7. "Recognizing Avalanche Terrain" *MSR. https://thesummitregister.com/backcountry-basics-recognizing-assessing-avalanche-terrain/*
8. https://images.google.com/