Landslide Susceptibility along Denali National Park Road

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G578 Capstone Project

Research Question (Capstone Statement)

Denali National Park is an Alaskan National Park whose main park road has recently fallen victim to a landslide, cutting the west portion of the park off from the bus system in the park for the first time in the park's history. This project would look at other areas along the park road susceptible to landslides by creating an "optimal site" layer of slope, vegetation or land cover, soil type, permafrost conditions, geologic faults along the roadway, and current landslides along the roadway.

Figure 1: Image of Denali National Park

Introduction and Background

In 2021, the Pretty Rocks Landslide, which had been an ongoing landslide at Mile 43 of the Denali National Park road in Alaska, sped up to a rate of slippage of 0.65 inches per hour, causing the park to close the roadway to visitors, and cutting off the west portion of the roadway for the first time in the park's history (NPS.gov). Four years later, the west portion of the road is still not open for public travel.

It is generally accepted that climate change is speeding up landslide rates across the world, but this has especially impacted Alaska, where melting permafrost creates unstable soil layers full of moisture (two variables of landslide susceptibility according to DGGS). Ketchikan, a city on an island in the southeastern portion of Alaska, has been affected by two landslides in less than a year's time (Seattle Times). The Denali National Park road is a mostly gravel roadway following the landforms of the park, making it especially susceptible to the conditions of those landforms surrounding it.

This project looked at conditions outlined by the Alaska Division of Geological and Geophysical Surveys (DGGS) as landslide potential factors: slope angle, rock and soil type, vegetation, water and soil saturation. It also included areas prone to landslides in the form of areas along the roadway where ongoing landslides have been recorded by the National Park Service (NPS). Using these variables, it created a layer identifying areas along the roadway where all of these conditions come together to create potential landslide sites.

Literature Review and Methodology

Literature Review

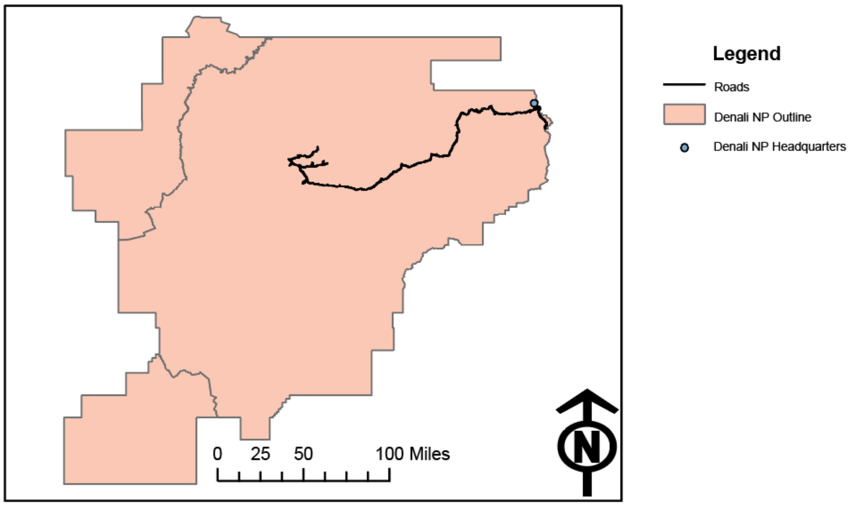
As stated in the introduction, the main source for this project is the Alaska Division of Geological and Geophysical (DGGS)'s Landslide Hazard circular. This circular outlines succinctly what causes landslides and where they are most likely to occur.

Soil and Water

Soil saturation is the number one cause of landslides. If soil is extremely saturated, landslides can occur on even the most moderate of slopes. According to DGGS, "Heavy rain, prolonged periods of damp weather, and intense, short bursts of rain may increase landslide risk." The park does measure weather and precipitation at the park headquarters in cooperation with the National Weather Service, and according to the park website, Denali National Park contains two climate zones, north and south of the Alaska Range. The southern regions of the park, due to influence from the Gulf of Alaska, experience more precipitation than the northern regions (NPS.gov).

The Denali Park Road is completely contained within the northern region, along with the park headquarters. As there are no other weather stations with available recordings along the park road, there is no way to model precipitation variation along the roadway. For this reason, despite precipitation being a large, definitive cause of landslides, it is not present in this project.

Figure 2: Denali NP map with park headquarters



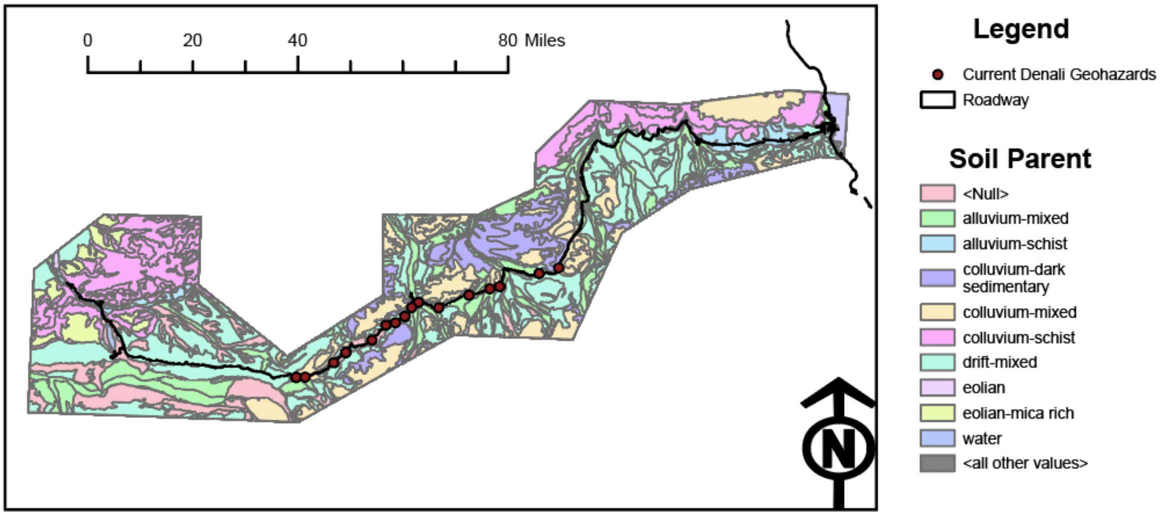
Other landslide causes according to the DGGS include “changing climate conditions (like increased rainfall, permafrost degradation, rapid snow melt, and glacial retreat).” For this reason, even though there is not a lot of research on permafrost’s effect on landslide susceptibility, it was included as a separate factor in this project. Melting permafrost contributes to soil saturation, and discontinuous areas of permafrost are more likely to experience melt due to having more surface area exposed to the warming soil.

The Alaska Range that splits the park into the northern and southern climate zones contains a lot of glaciers, so glacial retreat is a factor. However, measuring the effects of glacial retreat on the limited area around the park road would be a project in itself (see the Future Research section), so glacial retreat was not included as a variable in this project.

Specific soil characteristics make a soil type more likely to contribute to landslides than others. This project looked specifically at soil parent materials: alluvium, colluvium, eolian, and drift materials. These terms describe their depositional environment, which affects their composition and density.

Colluvium soils were deposited by gravity and are most likely to be a mix of large and small particles loosely compacted together, so they are at the highest risk of landslide. Alluvium were deposited by water and are more likely to have particles somewhat closer in size as larger particles will sink in moving water. They are at moderate landslide risk. Drift soils were deposited by glaciers and are at moderate to low risk of landslides. Eolian soils are at the least risk of landslide because they were deposited by wind and are therefore very fine-grained material more closely compacted.

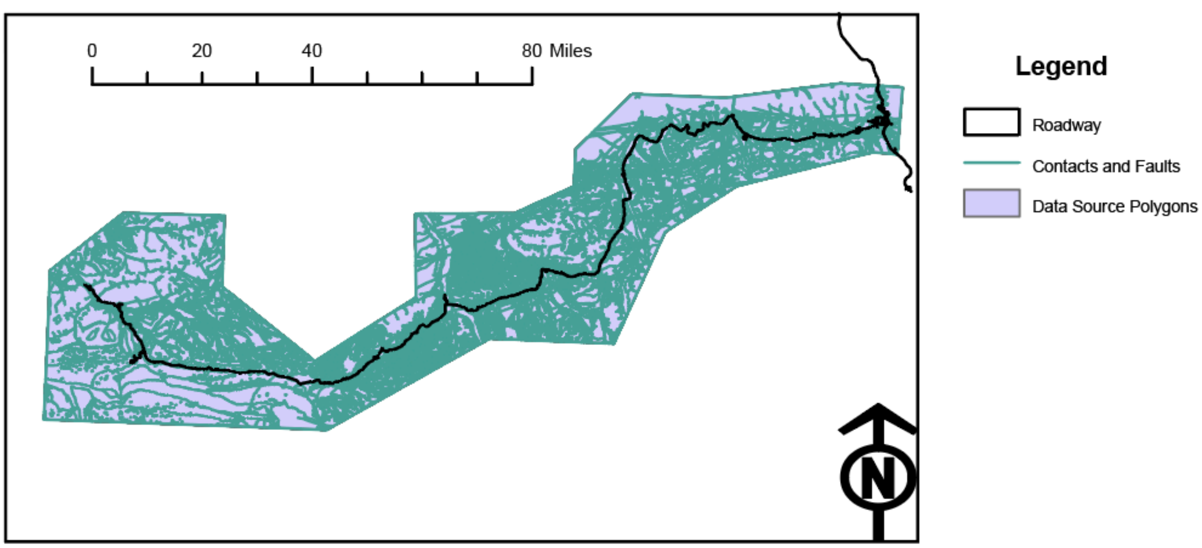
Figure 3: Soil Map



Geology and Geophysics

“Earthquakes and ground shaking may trigger landslides” (DGGS). Moving away from water and soil saturation, another cause of landslides is earthquakes. According to the park website, Denali National park experiences an average of 3,000 earthquakes within the park each year. “Most events occur within the Kantishna seismic cluster” (NPS.gov), north of the Alaska Range in the foothills where the Denali Park Road lies. A lot of research has been done on geologic activity in Denali National Park, so thankfully this project does have a shapefile of fault lines specific to the extent of the Denali Park Road. The group of shapefiles that contain the layer of fault lines also contributed the spatial extent of the project because it limited its research area to a buffer around the road.

Figure 4: Fault Lines and Spatial Extent

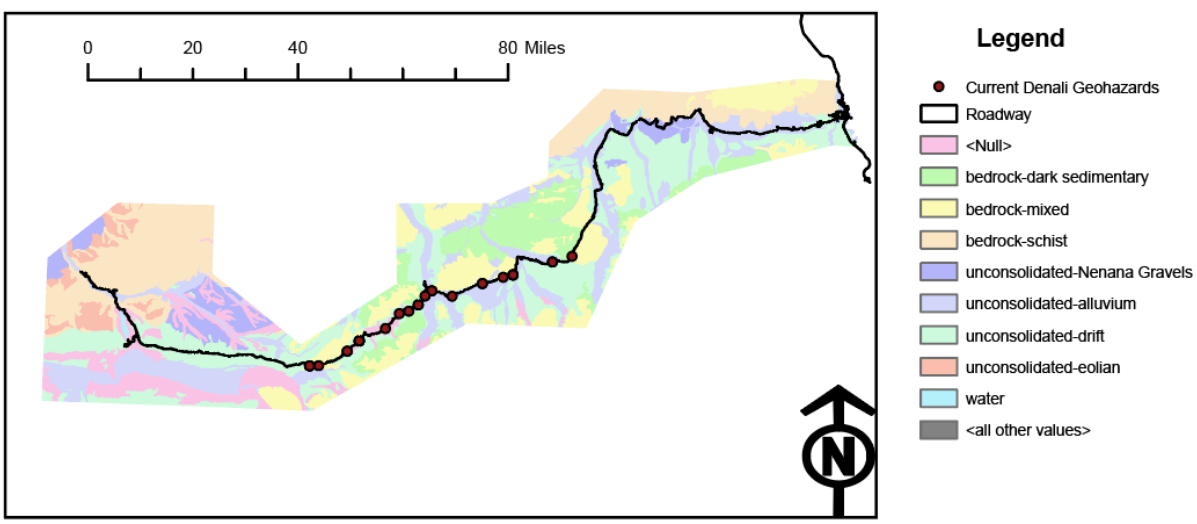


There has been so much research on the geology of Denali National Park because it is very close to the epicenter of the largest earthquake ever recorded in Interior Alaska: the 2002 Denali Earthquake. It had a magnitude of 7.9, according to the park website.

Areas where landslides have occurred in the past are areas more likely to experience landslides in the future, according to DGGS. The National Park Service has past and current landslide events saved in a dataset from a 2019 “Geohazard Analysis” study (NPS.gov). They do not contain any spatial data aside from mile marker information. Please see Methodology for the process of spatially locating the mile markers in GIS.

The United States Forest Service (USFS) found in a study on landslides in the Rocky Mountains of Idaho that geologic border zones and sediments experienced the most landslides. For the lithographic layer in Denali National Park, the United States Geological Survey (USGS) has labeled the layers as bedrock or unconsolidated. “Unconsolidated” means loose sediments that have not undergone lithification. In Denali, these primarily consist of gravel, alluvium, and colluvium. These are clearly not as stable as lithified bedrock, and for that reason, they were considered more likely to cause landslides for this project, with unconsolidated gravels being the most likely.

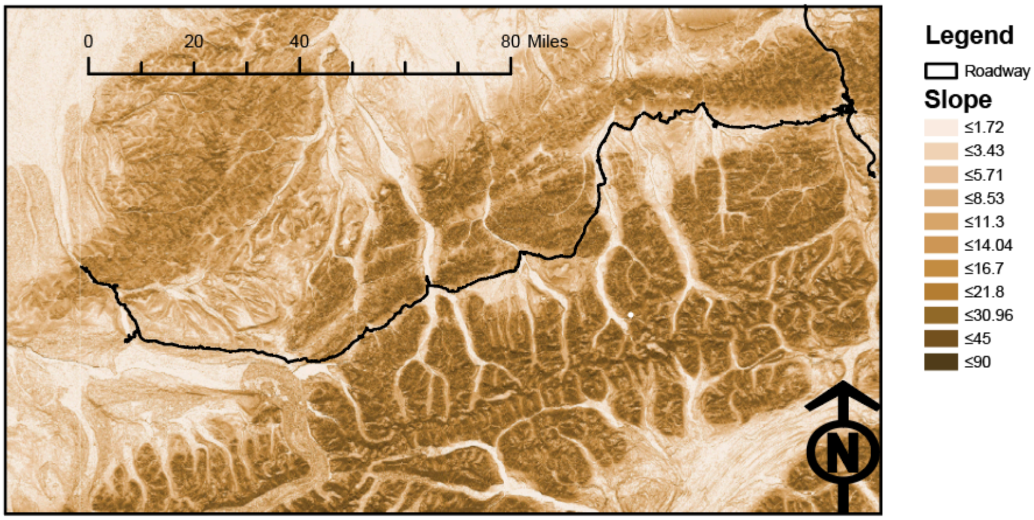
Figure 5: Geology Map



Slope and Vegetation

Slope is probably the most commonly thought-of landslide risk factor. Anyone driving in the mountains faced with a steep scree slope can imagine one misplaced shake bringing the whole thing down. Slope can make normally stable soil and lithology unstable due to the simple fact of gravity.

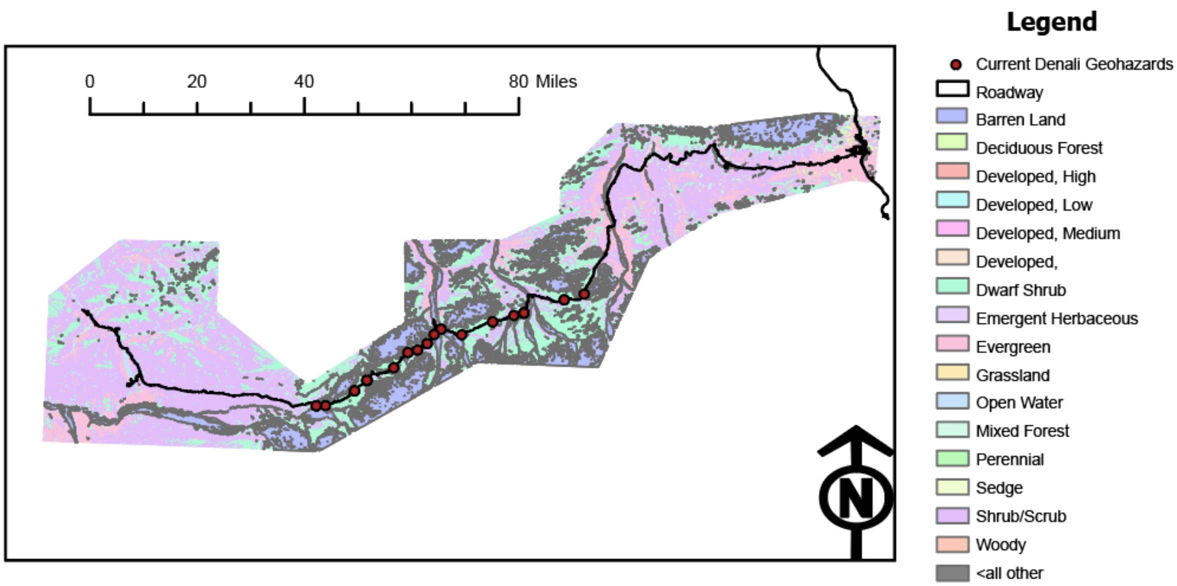
Figure 6: Slope Map



One of the only factors that can alter slope's effect on an area is vegetation. Certain categories of vegetation can stabilize unstable slopes by providing a deep root framework to hold the slope together. This is probably the least thought-of factor in landslide susceptibility, and yet, it is why after large forest fires, affected areas are significantly more prone to landslides. Denali National Park is subject to wildfires just like any other natural area, however, it has not been largely affected like other areas of the country.

Vegetation with deep roots, such as tree and brush species, were identified as the least likely to experience landslides, whereas barren, developed, and perennial ice fields were identified as the most likely.

Figure 7: Vegetation Map

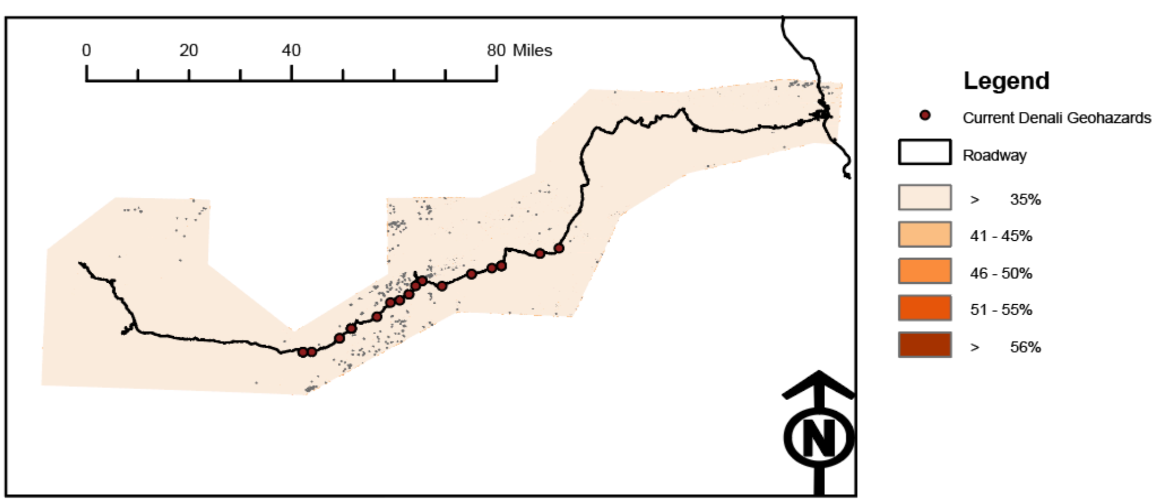


Methodology

The data for the most part came in forms prepared to be input into this project with few exceptions noted below. It was originally envisioned to do this project in raster with a weighted overlay. However, several important layers only came in vector format, and the road is a polygon, so it was subsequently determined to move forward in vector.

Two layers needed to be transformed from raster to vector. Land cover (vegetation) came as a .tif for the state as a whole and then needed to be transformed into vector before being clipped to the extent of the park road. Methodology for slope derivation was described in the Slope and Vegetation section above. As also stated, the road extent came from the geology shapefiles.

Figure 8: Reclassified Slope Map



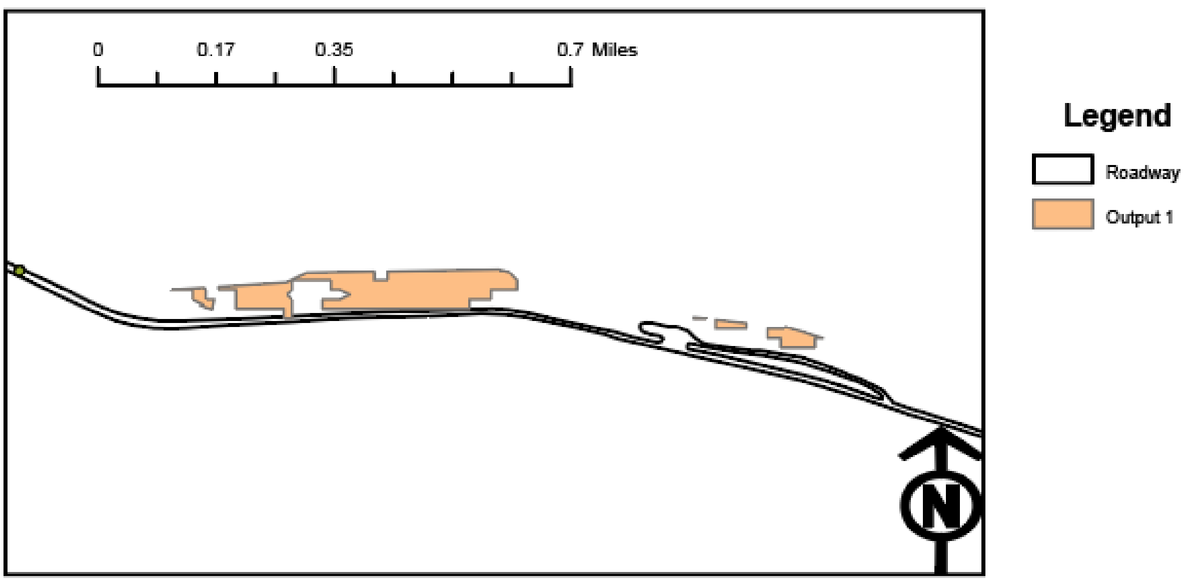
Mile Markers and Geohazards
Denali National Park has an Excel spreadsheet of active geohazards in the park that needed to be georeferenced. The only location information they contained was nearest mile marker. In order to create the mile marker layer, a centerline for the road was needed. This was created using the centerline tool in ArcGIS.

Extra areas of the centerline (the areas of the road that go north and south before entering the park) were deleted. Then, points were generated on the line at one-mile intervals. These points served as mile markers. The Excel spreadsheet from the NPS was then joined to this point layer.

Results, Analysis, Discussion

Results
A lot of research for this project was done to find scoring for variables for landslide susceptibility. This turned out to be erroneous. When all of the variable values with high susceptibility in the research were selected and intersected, only a few tiny polygons were the result, as seen in Figure 9.

Figure 9: Initial Output



As a result, analysis was done on the existing geohazards along the Denali Park Road. Buffers were put around each geohazard point, and the polygons for the variables that intersect the buffers were spatially selected. The values found in the buffers are in Figure 10.

Figure 10: Variables Near Current Geohazards (Tables)

Slope	**Frequency**
> 35%	261
41 - 45%	1824
46 - 50%	213
51 - 55%	34
> 56%	2

Soil	**Frequency**
Alluvium - Mixed	567
Colluvium - Dark Sedimentary	114
Colluvium - Mixed	356
Drift - Mixed	550

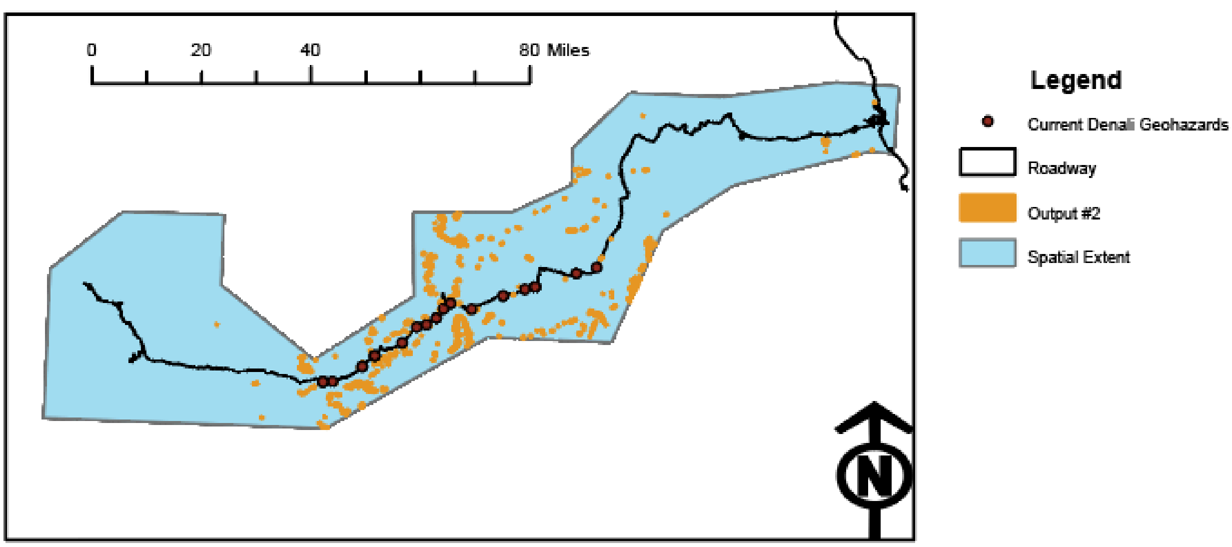
Permafrost	**Frequency**
Discontinuous	597
Sporadic	765
Not Rated	25

Lithology	**Frequency**
Bedrock - Dark Sedimentary	114
Bedrock - Mixed	356
Unconsolidated - Alluvium	567
Unconsolidated - Drift	534
Unconsolidated - Nenana Gravels	16

Land Cover	Frequency
Barren	395
Developed, Low Intensity	154
Dwarf Shrub	479
Emergent Herbaceous Wetlands	6
Evergreen Forest	40
Mixed Forest	4
Open Water	191
Sedge/Herbaceous	53
Shrub/Scrub	381
Woody Wetlands	4

Methodology was then changed to identify areas similar to those already experiencing geohazards, based on the variables in Figure 9 in combination with the literature review done before. Slopes between 41-45% were extracted. Mixed soil parents were extracted. Sporadic and discontinuous permafrost areas were already extracted. Unconsolidated alluvium and drift lithologies were already extracted. Barren land was already extracted. Dwarf shrub and shrub/scrub were then extracted. The results are in Figure 11.

Figure 11: Areas Similar to Current Geohazard Environments



Analysis
The entire area of the second output is 0.431308 square miles. The symbology is misleading. The area of the polygon used as spatial extent is 19,762.817305 square miles, and the road is 92 miles long, so this doesn't represent a large area.

However, as seen in the 2021 Pretty Rocks Landslide, even these small areas can have overwhelmingly large impacts. Denali National Park only has one road in and out of it, and when areas are cut off by landslides, as happened in 2021, it affects tourism, emergency management, and resource management.

Because these high risk areas represent such small overall areas along the road, it would be easy to implement mitigation strategies to stabilize them and prevent further issues down the line. However, being a national park whose mission is "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (National Park Organic Act of 1916), Denali National Park is unlikely to put in place rock netting or retention walls that would impact the scenery. They are also unlikely to plant trees on unstable slopes to provide some stability, as it would impact the natural ecosystems.

In this case, the most that can and will be done is to monitor these areas for any change and remove any landslide debris that does make its way onto the road, which is something the park is already actively doing. Due to being the site of many earthquakes, the park has several stations that monitor minute GPS movements in the Denali faultline and other conditions known to cause landslides. As previously mentioned, Denali is a hotspot for geological research in Alaska.

Conclusions and Future Research
The DGGS is currently working on a landslide inventory of Alaska and a model to find areas susceptible to landslides throughout the state. That project will be extremely helpful in studying permafrost's relationship with landslides in Alaska as well as other variables more specific to Alaska. It will also help identify areas mitigation strategies can be easily implemented to prevent future disasters or minimize their impact.

Future Research
Ideas for future research spawned from this project are as follows:

1. Measurements for precipitation, including snowfall, should be made along the extent of the roadway and beyond at other places in the park. This would create a better model for precipitation and snowmelt variability in the park.
2. The effects of glacial retreat in the park should be measured. Based on the current extent of glaciers in the Alaska Range, optimal routes for glacial meltwater could be found to study areas most affected by increased glacial retreat.
3. With the changing climate, wildfire susceptibility should be studied in the park. Most of the park's infrastructure lies within the forest zone, and due to the type of trees and the type of ground cover around the trees, it is likely a fire could spread very quickly.

4. Viewershed analysis should be done for the Denali Park Road. Not for any scientific inquiry, although it would be interesting to see how it changes with climate. Denali National Park has very few designated trails, meaning most of its adventures occur in the backcountry. Backcountry camping rules state that campers must be 1-mile from the road and not viewable from the roadway, so this map would be helpful in establishing those areas clearly for planning purposes.

References

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