GEO327G: GIS & GPS Applications in Earth Sciences

Classification of Erosion Susceptibility

Denali National Park, Alaska

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1 Abstract

This study will classify the susceptibility of erosion in Denali National Park, Alaska, USA using ArcGIS methods based on 4 factors that affect erosion. Looking at precipitation, geology, topography, and land cover, we attempt to rate the erosion susceptibility on a scale of 4 to 16. The higher the score, the most susceptible the area is to erosion. Accordingly, I will try to answer this question:

Which areas are the most susceptible to runoff and erosion in Denali National Park, Alaska?

2 Introduction

Erosion is an important surface process in geology. Though it creates a dynamic system of mass transport, one should seek to understand its causes and hazards. This is especially important in National Parks where education and preservation of cultural and natural resources is the mission. Thus I chose to focus on Denali National Park in Alaska to question its areas most susceptible to runoff and erosion.

To solve this problem, I have created a map of Denali National Park showing rankings (from 4 to 16) of susceptibility levels to erosion and runoff. This is done by using ArcGIS raster analysis and manipulation of various parameters detailed below.

2.1 Universal Soil Loss Equation

When discussing soil loss due to erosion, the Universal Soil Loss Equation, or USLE, is a good starting point. This equation, developed in the 1930's, is a mathematical model developed in the US in the 1930's by the Department of Agriculture Soil Conservation Service.

$$A = R \times K \times LS \times C \times P$$

Where:

A: potential soil loss due to erosion

R: rainfall factor

K: soil erodibility factor – geologic factor

LS: topographic factor

C: land cover factor

P: conservation practices (not applicable in area of interest)

Figure 1, USLE explained

2.2 Simplifying the USLE

In this study, the USLE is used as a starting point. There is, unfortunately, not enough data for the full mathematical analysis. For example, R – rainfall factor requires calculations requiring both annual precipitation data as well as maximum 30 minute intensity information. This is impractical due to the lack of data available online. As a result, this study will start by looking at the 4 factors that affect erosion as given by the equation. An arbitrary ranking system instead has been developed, shown below.

Rank	R – precipitation	K – geology (soil erodibility)	LS – slope (topography)	C – land cover
1	<20 inches	See Section 4.2	<10°	Forests
2	20-40 inches		10-20°	Shrubs
3	40-60 inches		20-30°	Sparse Vegetation
4	60-80 inches		>30°	Bare Ground, Burned Land

Figure 2, chosen ranking scale for the 4 criteria factoring into susceptibility to erosion

Finally, each raster cell will sum up all of its 4 rankings to produce a score between 4 and 16, from lowest susceptibility to highest. This new calculated raster can tell us more about the potential runoff and erosion problems.

3 Data Collection and Preprocessing

Basic Park features such as roads, railroads, park boundaries and buildings were downloaded from Denali National Park website under tourist information. (http://www.nps.gov/dena/planyourvisit/gis_gps_data.htm) They provided GIS and GPs data in .kml/.kmz format intended to be used in programs such as Google Earth. Thus the first step is conversion from kml/kmz format into workable layer files using the *KML to Layer* tool shown in figure 3.

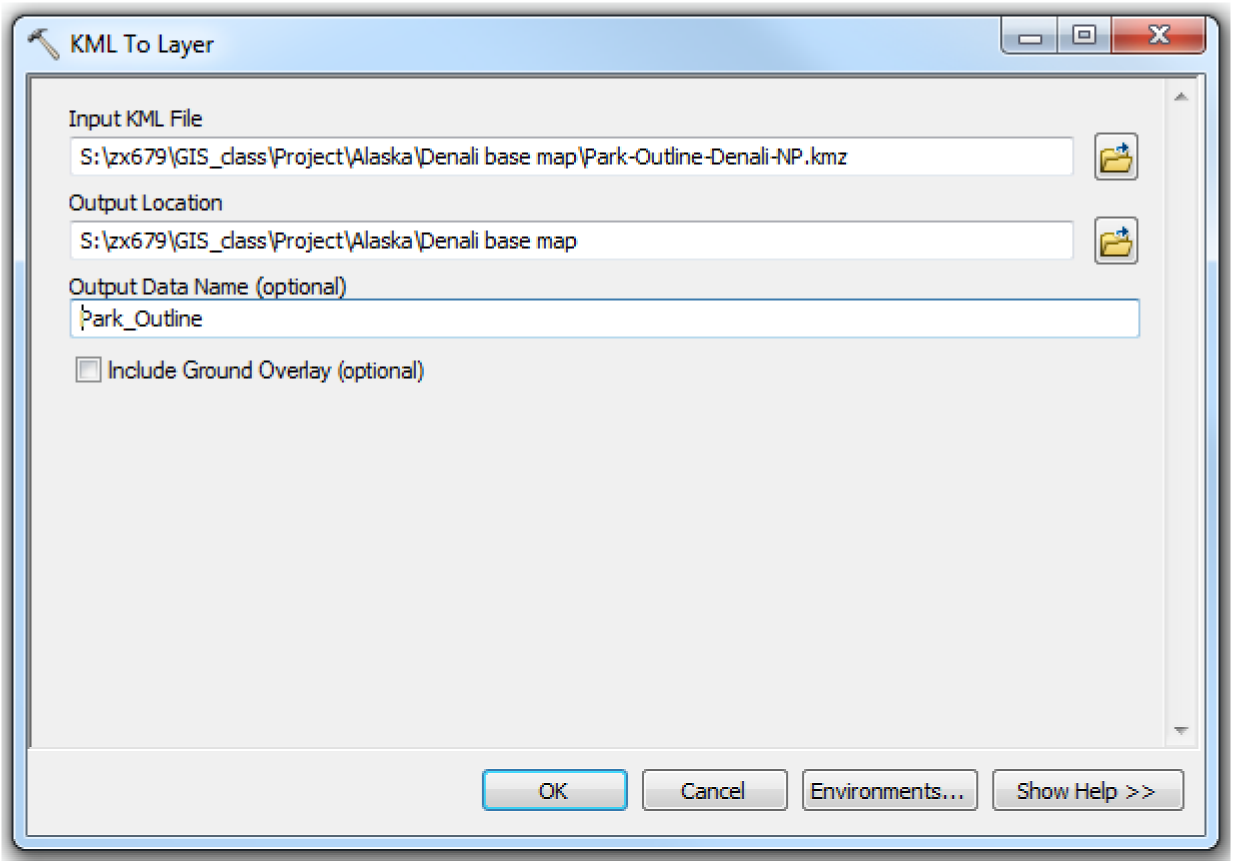

Figure 3, KML to Layer tool

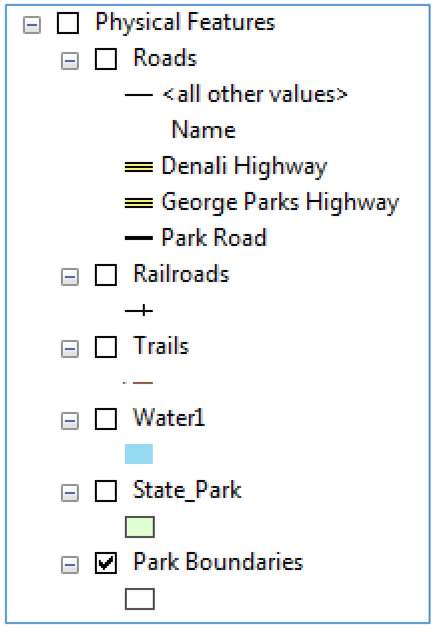

Figure 4, Layers converted with this method, grouped under physical features

Most of the data collected were from National Park Services' Integrated Resource Management Applications website. (https://irma.nps.gov/App/Portal/Topics/Geospatial) I used their Data Search and searched for *Geospatial Data and Denali in Title.* Figure 5 displays the results. Fortunately, there is abundant data available on national parks. The collection and processing will be discussed in detail below. I obtained 3 out of the 4 needed data sets including geology, topography and land cover.

Results Download

Reference Code	Type	Display Citation	Title	File Count
2214154	Geospatial Dataset	2004. DENA Denali Park Road AutoCAD. Geospatial Dataset-2214154.	DENA Denali Park Road AutoCAD	1
2214518	Geospatial Dataset	2005. Denali Climbing Routes. Geospatial Dataset-2214518.	Denali Climbing Routes	1
2171686	Geospatial Dataset	AK I&M Inventory Program. 2000. Denali National Park and Preserve image m...	Denali National Park and Preserve image mosaic - true c...	2
2171684	Geospatial Dataset	AK I&M Inventory Program. 2001. Denali National Park and Preserve landcove...	Denali National Park and Preserve landcover	2
2221655	Geospatial Dataset	Denali National Park and Preserve. 2015. 1974 Sheep Survey Units, Denali Na...	1974 Sheep Survey Units, Denali National Park and Pres...	2
2171957	Geospatial Dataset	National Park Service- SRI. 2004. Denali National Park and Preserve NRCS D...	Denali National Park and Preserve NRCS Detailed Soils	2
2209603	Geospatial Dataset	NPS - Land Resources Division. 2014. Denali National Park and Preserve Tra...	Denali National Park and Preserve Tract and Boundary D...	1
2164801	Geospatial Dataset	NPS Geologic Resources Inventory Program. 2010. Digital Geologic Map of D...	Digital Geologic Map of Denali National Park and Preserv...	2
1016869	Geospatial Dataset	2001. Denali National Park & Preserve Small-Scale Base GIS Data. Geospatial...	Denali National Park & Preserve Small-Scale Base GIS Data	1
1041715	Geospatial Dataset	Fire Management Program National Park Service, Alaska Regional Office. 200...	Denali National Park and Preserve Fuels Data, 2001	1
1040373	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2000. BW Photo Mo...	BW Photo Mosaic - Lower Caribou Creek- Denali National...	1
1040374	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2000. BW Photo Mo...	BW Photo Mosaic - Upper Caribou Creek- Denali National...	1
1040385	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2001. BW Photo Mo...	BW Photo Mosaic - Kantishna Hills - Denali National Park ...	1
1040397	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2001. Color Photo M...	Color Photo Mosaic - Lower Caribou Creek- Denali Nation...	1
1041274	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2002. 60 Meter Hills...	60 Meter Hillshade of the NED for Denali National Park an...	1
1040375	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2002. Compressed ...	Compressed Denali National Park and Preserve Satellite I...	1
1041384	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2003. Compressed ...	Compressed Denali National Park and Preserve Satellite ...	1
1041387	Geospatial Dataset	GIS Team National Park Service, Alaska Regional Office. 2006. Satellite Image	Satellite Image Map of Denali National Park and Preserve	1

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Figure 5, List of data available for Denali NP with relevant data highlighted

Finally, Precipitation was obtained from USGS website on Alaskan Geospatial Data Committee section. This precipitation map was prepared in 1994 as part of a flood frequency study of the streams and rivers of Alaska and was digitized into a GIS format.
http://agdc.usgs.gov/data/usgs/water/statewide.html

	Collection	**Preprocessing**	**Needed Data**
3.1 R – Rain fall	1994 study on flood frequency of the streams and rivers of Alaska (Appendix 1)	Convert to raster, reclassify	Precipitation
3.2 K – Soil Erodibility	Digitized Geologic map downloaded from Integrated Resource Management Applications (IRMA) provided by National Park Service (NPS)	Convert to raster, reclassify	Geology
3.3 LS – Topography	Digital Elevation Model downloaded from IRMA provided by NPS	Calculate slope, reclassify	Slope
3.4 C – Land Cover	Land Cover map downloaded from IRMA, NPS	Reclassify	Land Cover

Figure 6, summary of data collection and preprocessing

NAD83 horizontal datum with Albers conic projection is the preferred coordinate system for accurate representation of Alaska. This minimizes areal distortion due to the northward location of Alaska.

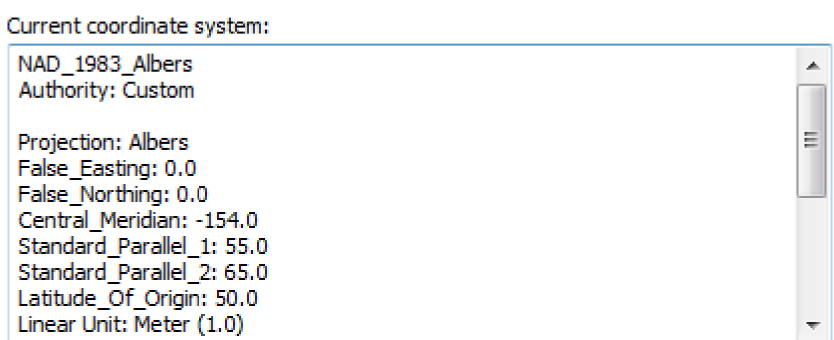


Figure 7, coordinate system options showing the details of Albers Conic Projection we are using

4 ArcGIS Processing

4.1 R Factor – Rainfall Factor

The R value is the most important factor that influence erosion susceptibility. In the USLE model, R is the measure of the erosive forces of rainfall and runoff. Mathematically it is calculated with kinetic energy of rain multiplied by the greatest amount of rain in 30 minutes. Due to the lack of data, I will only be considering the amount of annual rainfall in inches and reclassifying them into ratings from 1 to 4.

Appendix 1 shows the mapped original dataset downloaded from USGS website. This data was used in a previous study to determine flooding risks in the state of Alaska in 1993. The format of this data was in shapefiles categorized by amount of annual precipitation in inches. Steps needed to process this include conversion to raster, clipping raster to park boundaries, and reclassifying new raster based on 20 inch intervals of annual precipitation.

To rank this data, I first used the tool *Feature to Raster* which converts vector classes into rasters. In this case, I decided that the raster field would be precipitation in Inches.

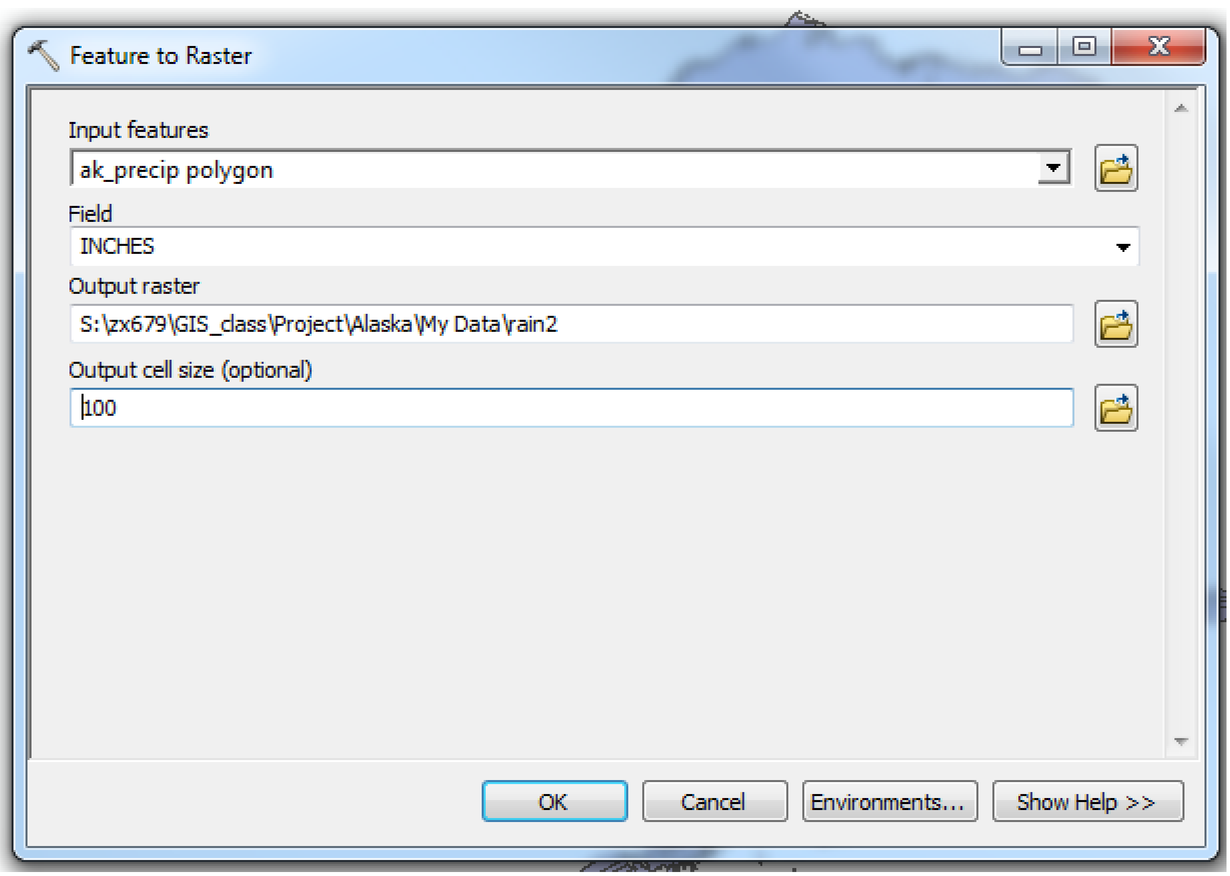


Figure 8, Feature to Raster tool in ArcMap used to convert vector feature into raster

After clipping the newly converted raster, I reclassified it based on 20 inches increments starting from 0. This creates 4 ranks of erosion susceptibility due to rain, starting at a rank of 1 being receiving less than 20 inches of precipitation a year, up to a rank of 4 with 60-80 inches of precipitation a year.

Figure 9 shows the completed map with a scale from 1 – low to 4 – high susceptibility.

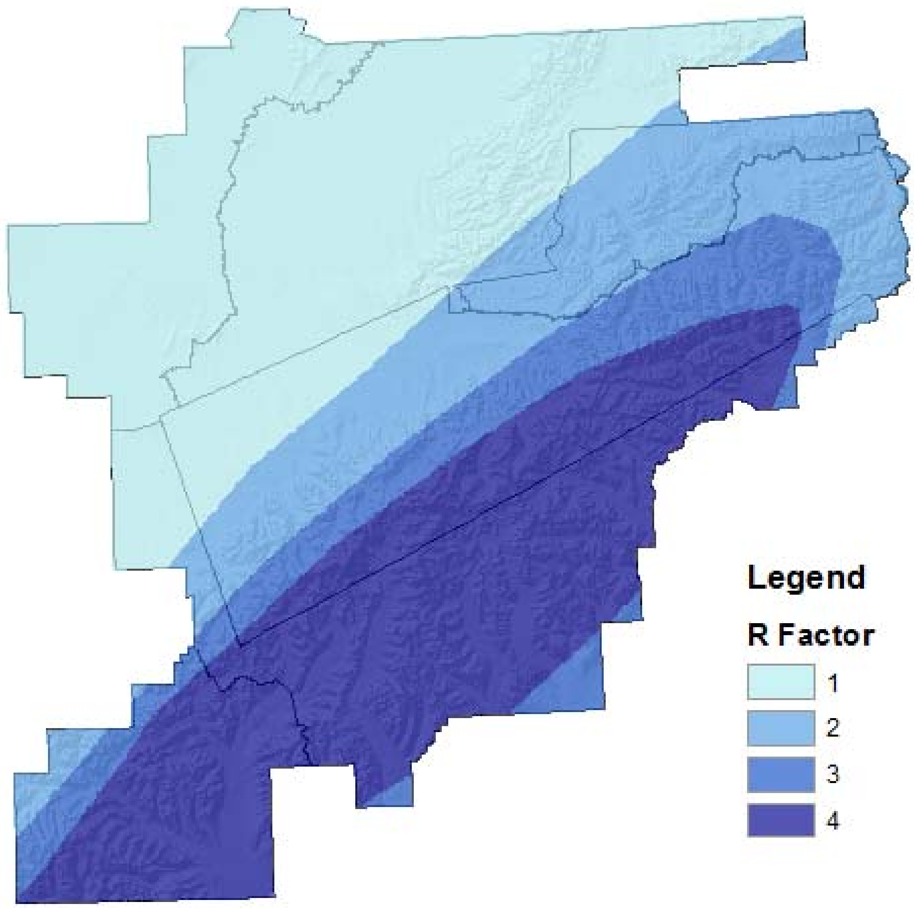


Figure 9, map of erosion susceptibility due to precipitation in Denali NP

4.2 K Factor – Soil Erodibility Factor

In the USLE equation, the K factor is the soil erodibility factor which reflects the susceptibility of a soil type to erosion. In this study, geology of the underlying rocks is used exclusively to analyze this factor.

As mentioned above, this data was acquired from National Park Services website on Denali NP as a part of a digitized Geologic map. The data was packed in to a personal geodatabase with layers such as glacial features, geologic line features and most importantly, geologic units.

Using the geologic units vector file I produced a raster of all the different units using the unit abbreviation as the variable. Since there is less than 255 different unit abbreviations in the vector, the produced raster has a list of coded values corresponding to different lithologies.

Next is clipping and reclassifying the new raster. After clipping the lithology raster to the outline of the park, I reclassified the vector based on erosion resistance. To determine the erosion resistance of each rock unit, I used a report named *Geologic Recourses Inventory Report, Denali National Park and Preserve* published alongside with the geologic map by National Park Services. This report included a table of all the geologic units present in Denali and their features/description, hazards, paleontological resources and erosion resistance. (https://www.nature.nps.gov/geology/inventory/publications/reports/dena_gri_rpt_view.pdf)

Map Unit Properties Table: Denali National Park and Preserve (Large Scale [1:63,360] Map Units)

Age	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Infrastructure	Hazards	Paleontological Resources	Cultural Resources	Mineral Occurrence	Karst Issues	Habitat	Recreation	Geologic Significance
QUATERNARY	Peat (**Qp**) Artificial Fill and Excavation Sites (**Qh**) Undifferentiated Stream Alluvium (**Qa**) Stream Gravel (**Qsg**) Alluvial Fan Deposits (**Qaf**) Outwash Gravel (**Qo**) Floodplain Alluvium (**Qfp**)	**Qp** contains dense, dark organic material, often found in boggy areas. **Qh** is composed of pebbles, cobbles, gravels, sand, and silt beneath roads and former gravel pits. Unit is well- to poorly sorted. **Qa** includes stream gravel, pebbles, cobbles, sand, and silt, with some boulders in well-stratified and moderately sorted channels, floodplains, and low terraces. Stream gravel (**Qsg**) is present in active streambeds. **Qaf** contains fan-shaped, heterogeneous strata of gravels, sands, silts, and boulders. Some debris flow deposits present locally. **Qo** contains gravel in layers fluvially deposited and well sorted. **Qfp** consists of elongate deposits of fluvial sand, gravel, and silt with scattered boulders. Unit is well- to moderately sorted, well-stratified, often mantled by thin silt-clay layers. Some terrace deposits locally.	Low to very low.	Hummocky topography and scarps make **Qfp** unstable if water saturated.	Units are prone to rapid erosion during flood events, slope failure if undercut, and slope creep, especially when water saturated.	Modern remains possible; pollen, plant macrofossils, insects.	May contain campsites, settlements, and other artifacts. Historic mining?	Gravel, sand, silt, and clay. Placer deposits? Congeliturbate deposited along Alaska Railroad between Lagoon and Carlo.	None.	**Qa** supports extensive willow-alder thickets and other riparian habitats. **Qfp** supports bog environments and riparian zones.	Units are suitable for most recreation. Avoid development of use-areas on riparian zones and undercut floodplain areas.	Units record most recent geologic activity in the area.
	Undifferentiated Colluvium (**Qc**) Landslide Deposits (**Qcl**) Talus and Rubble Deposits (**Qct**) Rock Glacier Deposits (**Qrg**)	Units contain irregular masses, aprons, tongues, and fans of angular rock fragments, sand, and gravel. May include drift and outwash. Surface expression often mirrors underlying rock structure. Medium to thickly bedded layers of lobed and terraced deposits. Rubble includes blocks up to 15 m in diameter. **Qct** contains mostly large blocks, with little- to no matrix material such as silt and sand. **Qrg** includes mixtures of blocks, ice, gravel, sand, and silt in tongue- and fan-shaped masses with very irregular surfaces.	Low.	Units are often found at the base of unstable slopes. Surfaces are usually steep and irregular with large spaces between blocks; unsuitable for most forms of infrastructure.	Units are associated with mass movement processes, including sliding, rolling frost creep, gelifluction, and flowing. Open work rubble surfaces are dangerous. Extensive ground cracks present locally.	Modern remains possible; pollen, plant macrofossils, insects.	None documented.	Sand, gravel, and boulders.	None.	Lichen communities help determine relative ages of deposits. Units may support large trees if old enough.	Avoid for recreational use; dangerous surfaces associated with units.	Units record recent slope processes in the area; vegetation patterns can date slide activity.
	Swamp Deposits (**Qs**) Outwash Alluvium (**Qao**) Colluvial-Alluvial Valley Fill, Fan, and Apron Deposits (**Qcf**) Terrace Gravel (**Qtg**) Abandoned Channel Deposits (**Qac**) Terrace Alluvium (**Qat**)	**Qs** includes water/ice-saturated layered peat, and organic silt and sand of variable thickness. **Qao** and **Qcf** contain elongate, apron, tongue- and fan-shaped heterogeneous mixtures of boulder, pebbles, and cobbles with matrices composed of sand and silt in thick beds. Terrace and channel gravels (**Qtg**, **Qac**, **Qat**) are typically more rounded than angular cobbles, and are well sorted with local crossbeds and smooth surfaces.	Low.	Slopes and scarps associated with **Qao** and **Qtg** may be too unstable for heavy infrastructure. High permeability of these units are probably not suitable for waste-water treatment facilities.	**Qcf** is associated with debris flow mechanisms, and may include avalanche deposits.	Peat, plant fragments.	May contain campsites, settlements and other artifacts. Historic mining?	Sand, silt, and gravel. Placer deposits?	None.	Units contain bogs, wetlands, and riparian environments.	Fine for most light recreation. Avoid development of use-areas on riparian zones and undercut floodplain areas.	Units record Quaternary fluvial activity in the area.

Figure 10, sample table of units and explanations; erosion resistance highlighted

Using this table, I was able to reclassify all 120 geologic units into erosion resistance on a scale of *high*, *moderately high*, *moderate*, and *low* corresponding to the scale from 1 to 4. This means the higher the rating is, the less resistant to erosion, or the more susceptible to erosion.

Tweaking the symbology of the raster, I produced Figure 11.

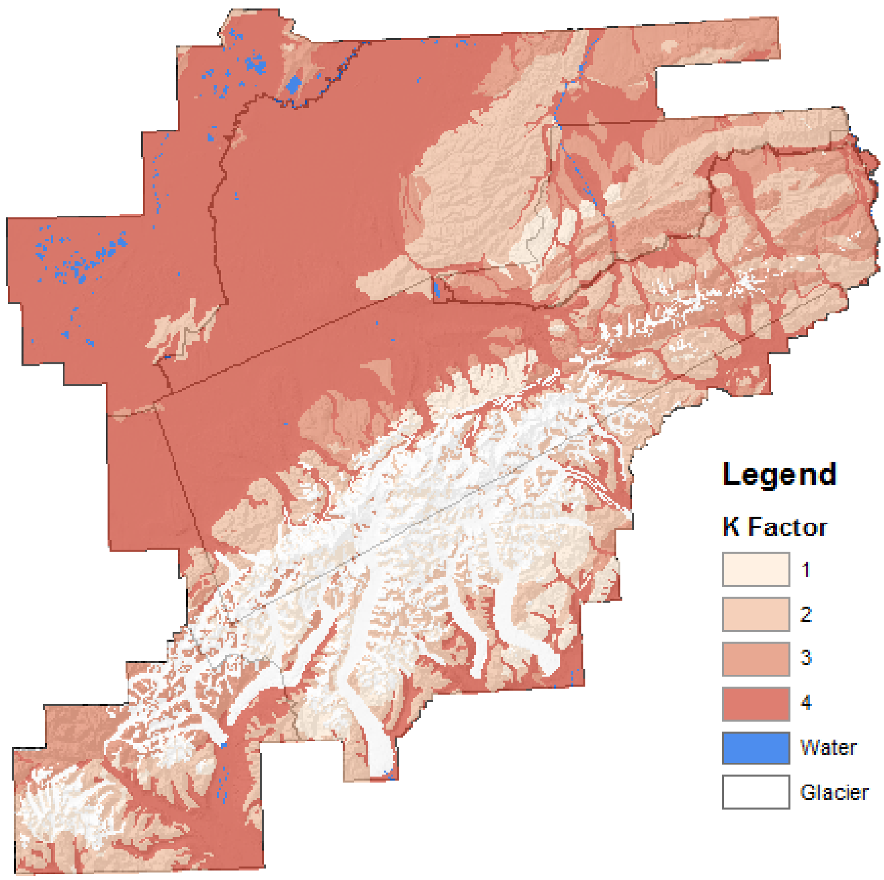


Figure 11, map of erosion susceptibility due to geology in Denali NP

4.3 LS Factor – Topographic Factor

In the USLE equation, the LS factor stands for length and slope factor summarized as the topography factor. In the complete USLE calculation, L and S are ratios of actual soil loss and slope compared to a standard of 22.6 meters and 9% of slope. In this study, only the slope will be considered.

Similar to the geologic data above, this data was acquired from National Park Services website on Denali NP as a Digital Elevation Model. Processing needed include calculating slope, clipping the raster, and reclassifying into a rating of soil erosion susceptibility due to slope.

Using the *calculate slope* tool Figure 12, I was able to produce a new raster showing the slope throughout the region.

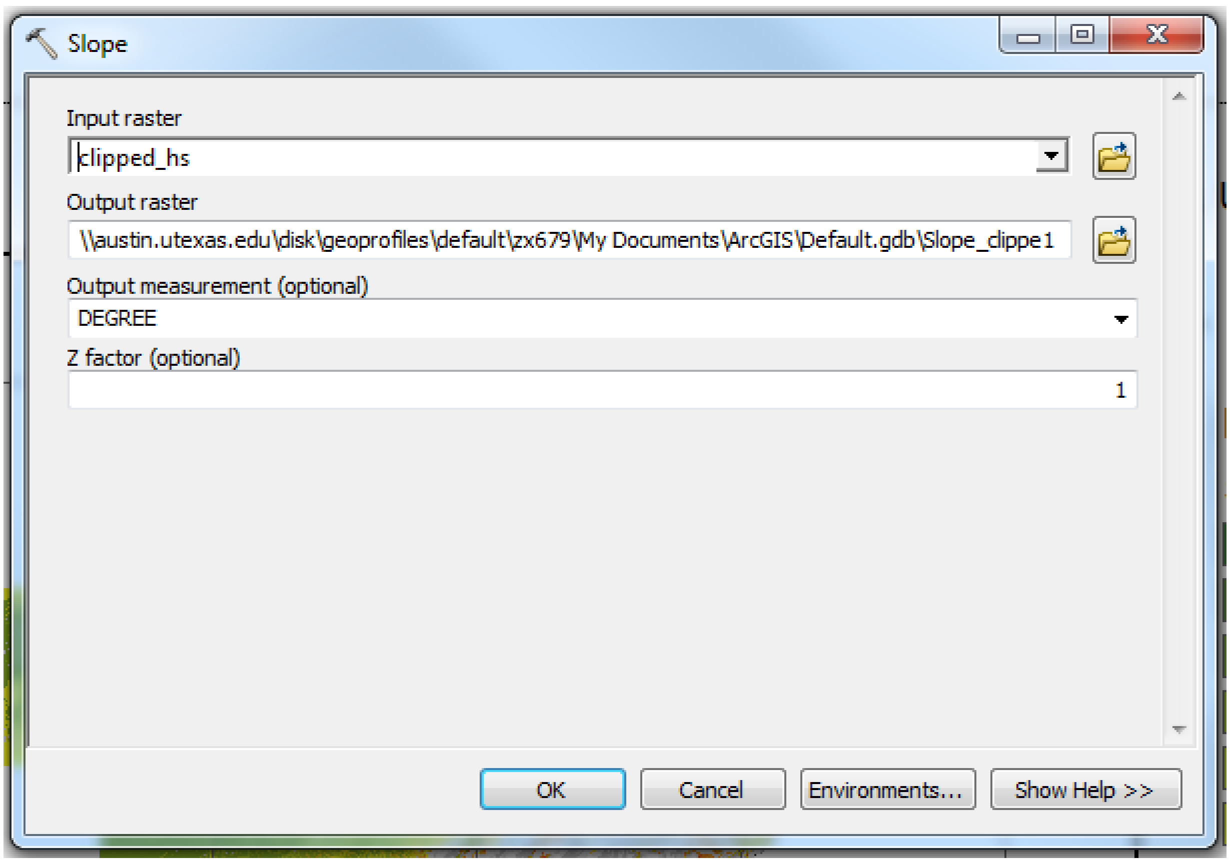


Figure 12, Slope tool in ArcMap used to calculate a slope raster from elevation

After clipping the new slope raster, I was able to reclassify based on the slope. Slopes <10°, 10-20°, 20-30° and >30° are classified as ratings from 1 to 4, the higher value indicating a higher susceptibility.

Also using the elevation model, I created a hillshade clipped to the park boundaries using the *Hillshade* tool. This layer is included in all produced maps to show the landform better and to produce a neater map.

Figure 13 shows the completed slope factor map of Denali.

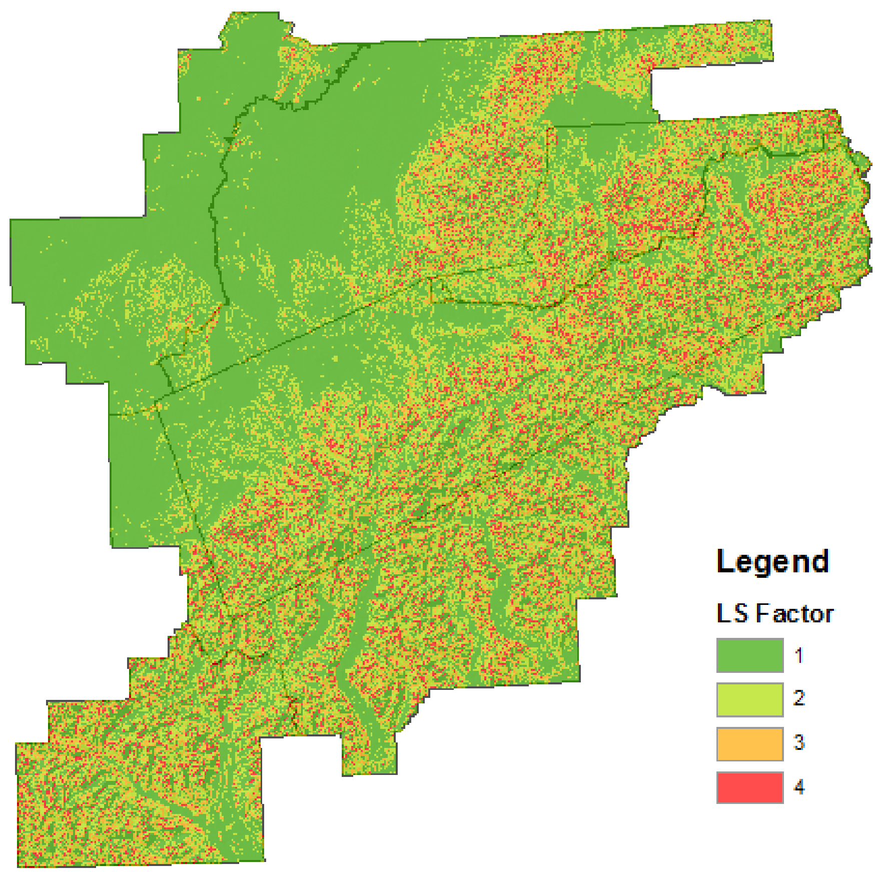


Figure 13, map of erosion susceptibility due to slope in Denali NP

4.4 C Factor – Land Cover Factor

Lastly, C factor was originally the crop management factor, a function of land cover. In the mathematical model, C is a ratio of actual soil loss to a standard field of crop. Land cover such as crops or forest and shrubbery in case of this study. I will not be using the mathematical ratio for calculations in this study. Instead, a rating scale from 1 to 4 with 4 being the highest susceptibility will be used.

Similar to the geologic and elevation data above, this data was acquired from National Park Services website on Denali NP as a raster file. The downloaded raster consisted of coded values for different land covers in the park. Processing needed include clipping the raster, and reclassifying into a rating of soil erosion susceptibility due to land cover.

After *clipping,* I reclassified the raster by land cover. Forests of spruce, broad leaf, willow etc are classified as 1 – low susceptibility; shrubs and herbaceous land covers are classified as 2 – moderate susceptibility; sparse vegetation is classified as 3 – moderately high; bare ground and burned regions are rated as 4 – high susceptibility. Glaciers and water bodies are not rated.

Figure 14 shows the completed raster for erosion susceptibility due to land cover.

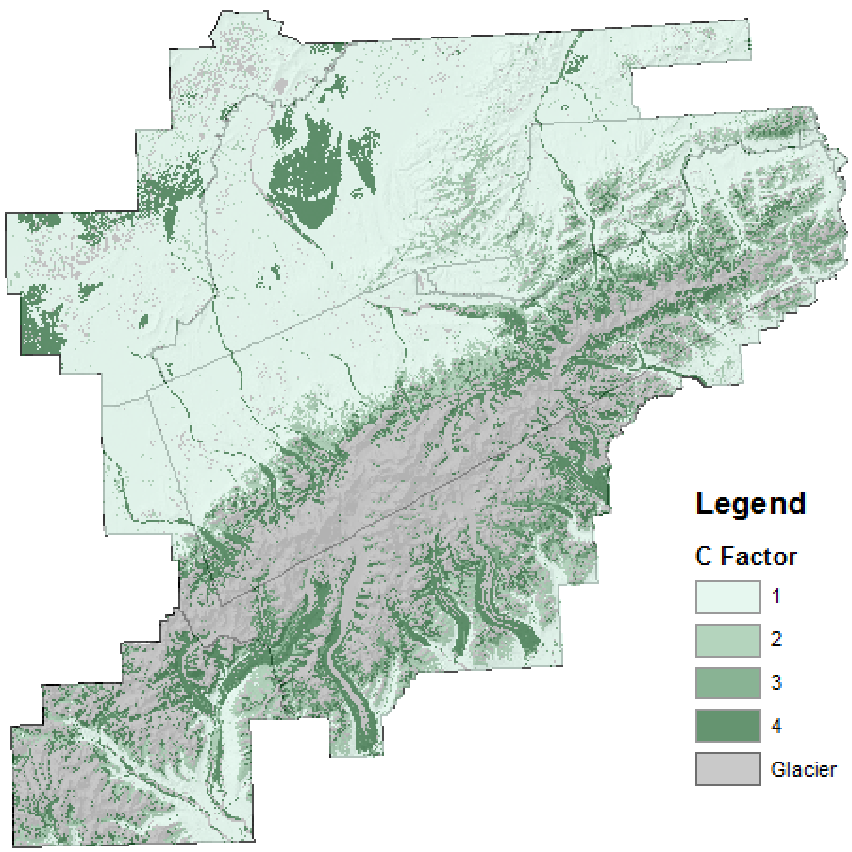


Figure 14, map of erosion susceptibility due to land cover in Denali NP

4.5 Raster Calculation

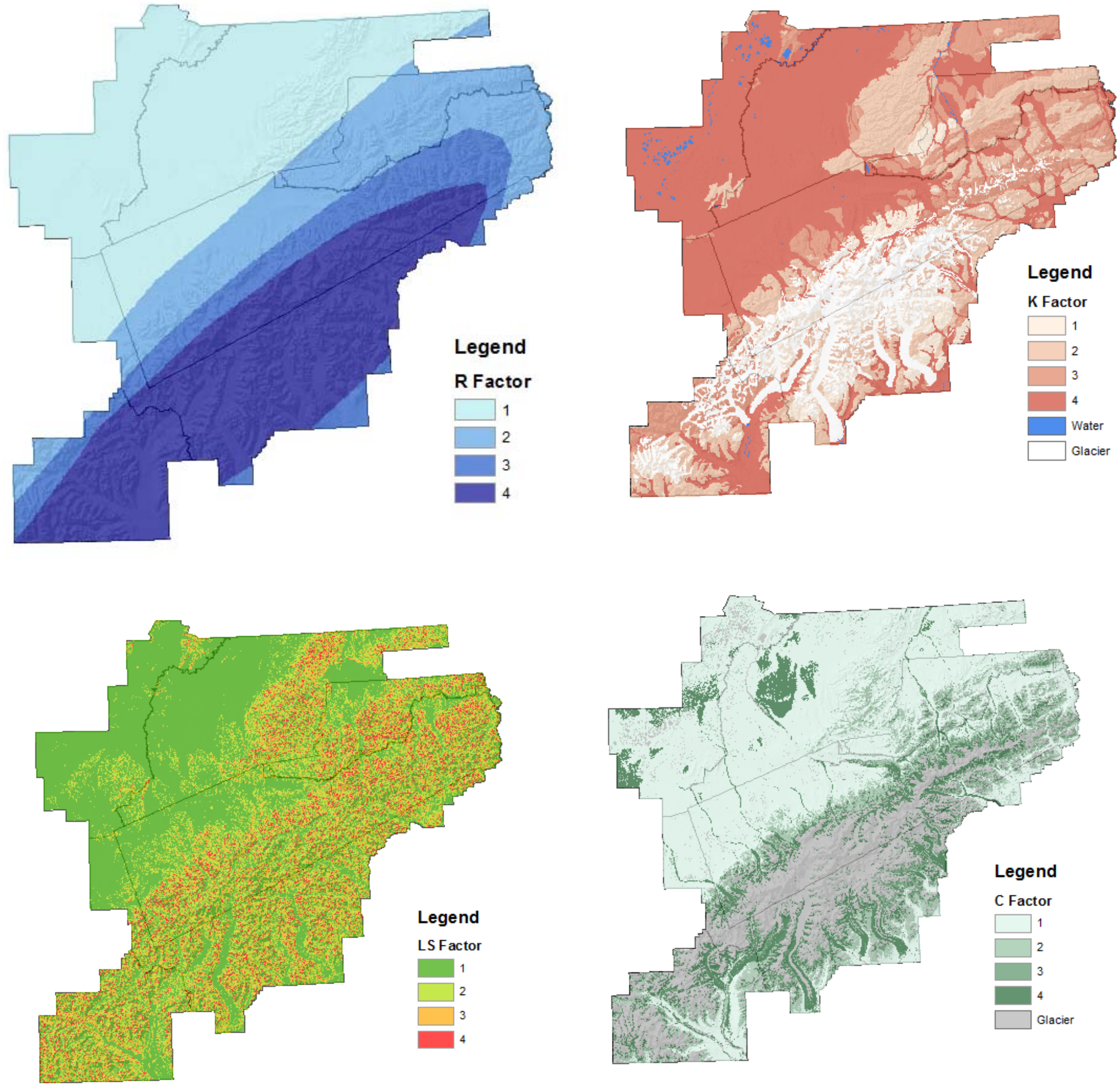


Figure 15, completed rasters of the 4 different factors affecting erosion resistance/susceptibility;

After processing the 4 layers of factors of erosion, raster calculations is needed to assemble them into a complete map.

Using the *Raster Calculator* tool, I added the 4 rasters from *figure 15* together. Since all 4 are measured using the same rating scale from 1 to 4, each factor is weighted equally. The resulting raster is *Figure 17*.

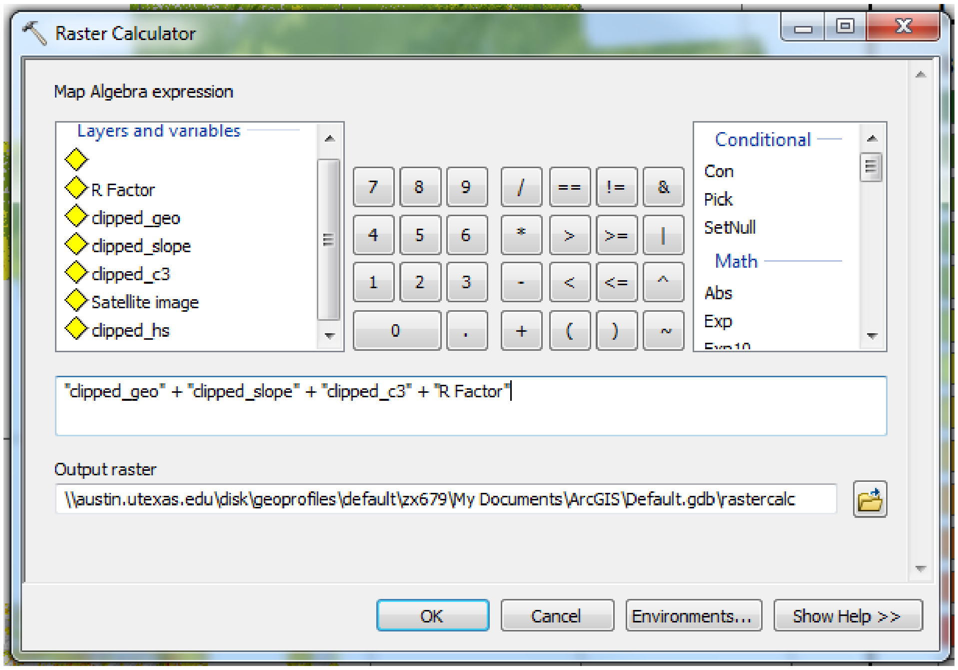


Figure 16, Raster Calculator tool in ArcMap used to add the 4 rasters together

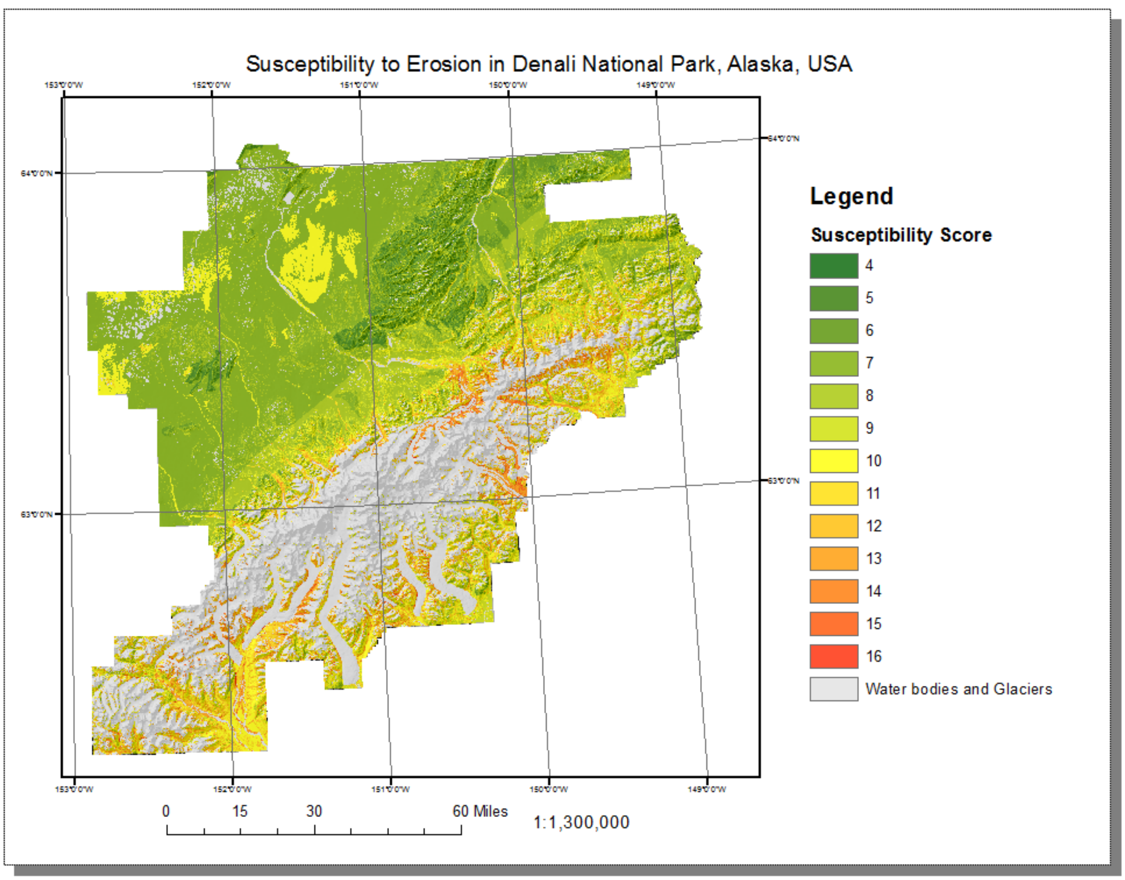


Figure 17, combined susceptibility map of Denali NP; refer to appendix 2 for full map

5 RESULTS

Figure 17 illustrates the susceptibility to erosion in Denali National Park. With this data

There are a total of 2,434,530 100m*100m cells in this raster. I produced a histogram of the different ratings.

VALUE	COUNT
4	33
5	34809
6	92135
7	666641
8	278170
9	172460
10	218855
11	127455
12	83579
13	52199
14	24315
15	6460
16	1040

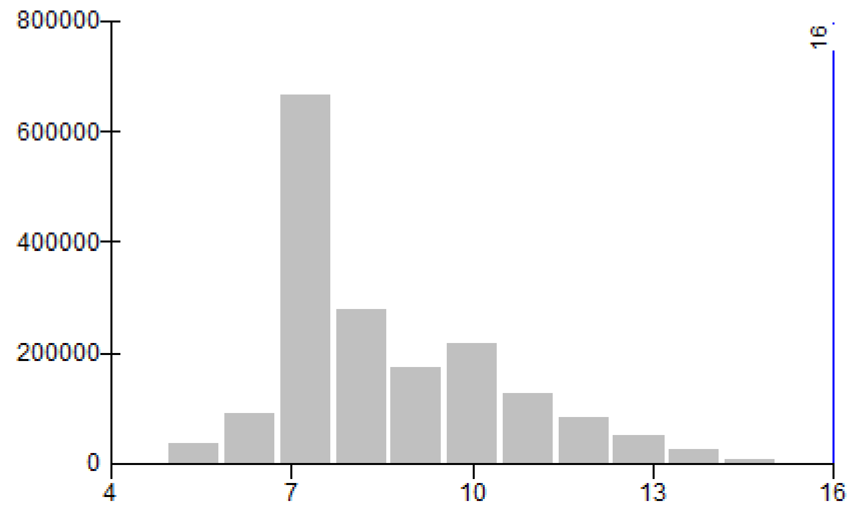


Figure 18, table and histogram of ratings with number of cells vs rating

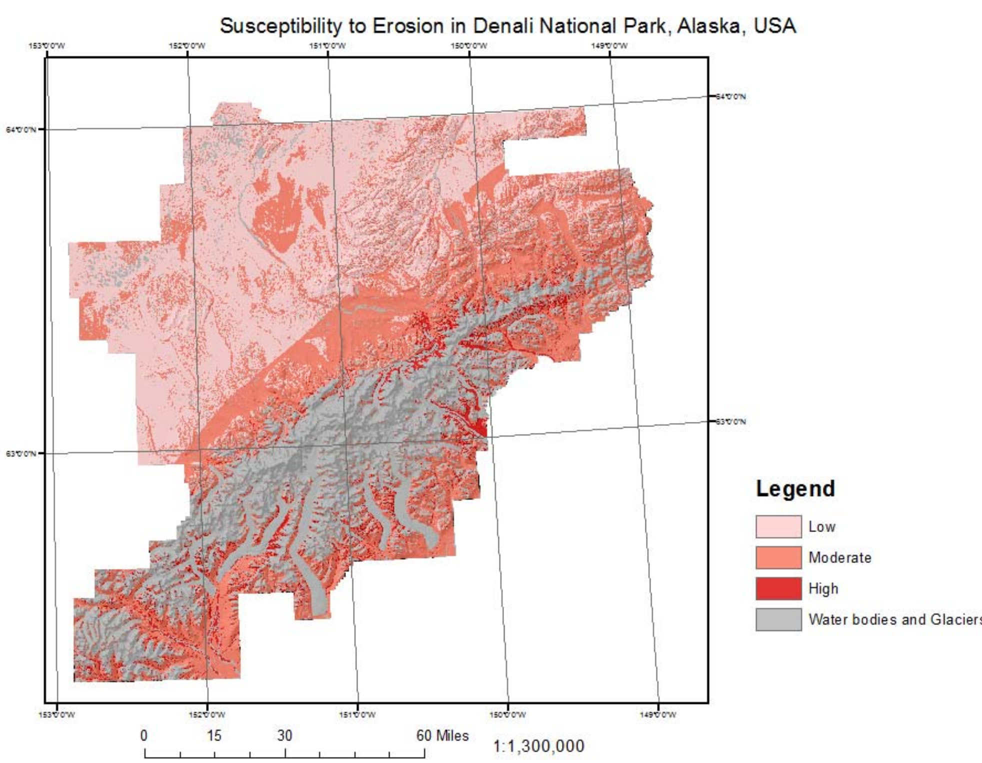


Figure 19, categorized total susceptibility map

I further categorized the score into low, moderate and high susceptibility regions using a score of 4,5,6,7 – low, 8,9,10,11,12 – moderate, and 13,14,15,16 – high. The resulting raster looks like Figure 19. Figure 20 is a table summarizing the percentage of area that is categorized as low, moderate and high susceptibility.

Low	33%
Moderate	36%
High	3%
Glacier and water	28%
Total	100%

Figure 20, percentage summary table for areas in each rating category

6 CONCLUSION

The vast majority of areas in Denali Nation Park, AK has low to moderate susceptibility to erosion. This number is at 69%. Only 3% of the park area is prone to soil loss. The rest 28% of the land area is either water bodies or glacier. Glaciers are subjected to a different type of erosion that cannot be accounted through this study using precipitation and land cover due to lack of data and resources. (*Figure 20)*

These results can be contributed by a few different factors. Figure 15 can tell us a lot of information.

- First, there is little precipitation on the northern side of the park; the only high precipitation regions are the mountains. This means there is little rain to erode material away.
- Geologically, Denali mountain range is made of Mesozoic and Paleozoic igneous rocks, moderately to highly resistant to erosion. However, the flat lands north of the mountain range is mostly Cenozoic sedimentary rocks which have low resistances to erosion.
- Third, the mountainous region is a small part of Denali NP, with the majority of the areas being relatively flat with slopes <10%. This means low erosion susceptibility.
- And lastly, the land cover of Denali is very well vegetated with forests and shrubbery. These natural resources

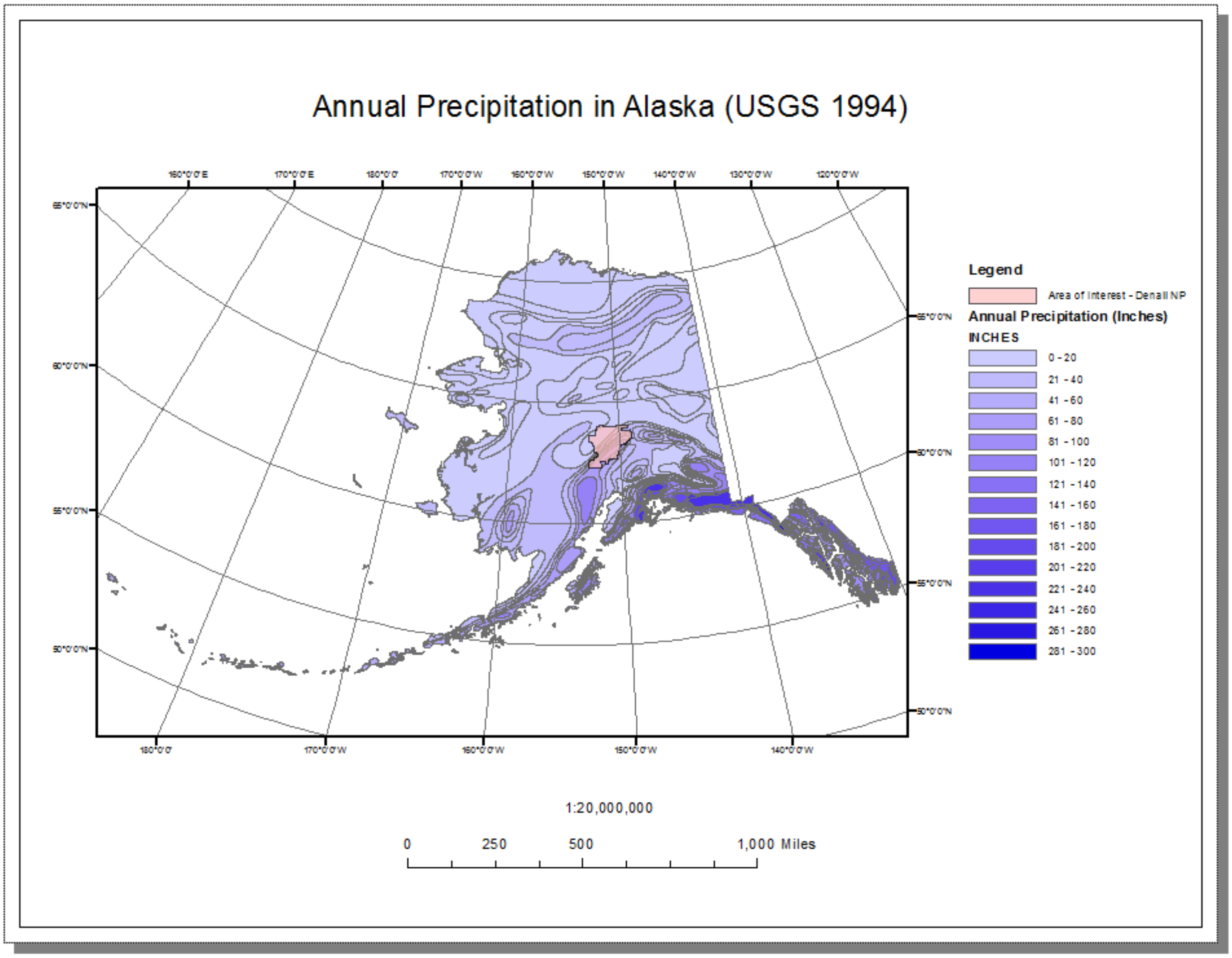
These 4 factors combined resulted in the erosion susceptibility pattern seen on Figure 17.

Using ArcGIS raster analysis methods, the question of "*Which areas are the most susceptible to runoff and erosion in Denali National Park, Alaska?"* has been answered. This study has provided a rough look at the erosion susceptibility that may be important to the education and preservation of the natural and cultural resources of Denali National Park.

Although this study provided an introductory look at the erosion hazards of Denali NP, it is not a complete study including all factors. It oversimplifies the USLE into a partially qualitative scale. Future improvements include acquiring complete mathematical data on the four factors of soil erosion to conduct a thorough analysis. Moreover, I would like to include the study of the glacial erosion in an additional study since glacial erosion processes like abrasion, plucking and ice thrusting are a major part of Denali NP and surrounding regions.

7 APPENDIX

APPENDIX 1, ANNUAL PRECIPITATION IN ALASKA



The precipitation map was prepared in 1994 as part of a flood frequency study of the streams and rivers of Alaska and was digitized into a GIS format.

Projection: Albers Conical Equal Area

Zehao Xue, 12/02/2015

Data source: http://agdc.usgs.gov/data/usgs/water/statewide.html

APPENDIX 2, FULL MAP OF SUSCEPTIBILITY TO EROSION IN DENALI NATIONAL PARK, ALASKA, USA