7 December 2017 James Gearon

Assessing Landslide Risk in Glacier National Park, MT

I. Problem:

With the recession of glaciers inside of Glacier National Park, as well as a warming climate and changing weather patterns, landslides pose a serious risk to tourists and wildlife. Is there a computationally simple and time-sensitive method using pre-existing landslide risk factors to create a hazard-map of landslide risk? Furthermore, can this map be used to—generally—predict new areas of landslide risk?

My hypothesis is that a reasonably accurate map (i.e. verifiable with historical landslide data) of landslide risk can be attained for Glacier National Park using publically available rainfall, land-cover, elevation, and geological data. This is not to say any categorization of risk via solely second-hand data is a solution to the challenge that is geo-hazard prediction and evaluation. However, it is a cheap, inexpensive method to analyze possible sites of further—or novel—research.

II. Data Collection:

I acquired 10m DEM elevation data from the National Park Services' Integrated Resource Management Applications Department (IRMA)[3]. I downloaded the Land Cover data for the United States from data.gov, which hosted the data collected by the USGS[6]. Precipitation coverage I acquired from The USDA as well, collated by Mauro Di Luzio at Texas A&M University[2]. Geological data was collected from the National Park Service's Natural Resource Program Center[4]. I also collected data from a project done by D. Butler and L. DeChano-Cook—more about this in **Section III[1].**

III. Data Preprocessing:

The main challenge with preparing the myriad of data I collected was to make sure each dataset was defined with a common Projected Coordinate System. I chose the NAD 1983 NSRS2007 Lambert Conformal Conic Projection due to its tendency to preserve shape over area. Additionally, I clipped datasets where appropriate to only display data within the confines of Glacier National Park. I next had to make sure that all downloaded raster data could be displayed with the same resolution and extent, as combining raster data effectively depends on this—more about raster compatibility in **Section IV**. Additionally, I used the National Park Service's Geologic Resource Evaluation Report on Glacier National Park[5] to assess which geologic units would be most susceptible to landslide events. I then singled out these units (16 total) and created a new shapefile with only the pertinent units. Stable rock formations were characterized with no data.

Finally, I needed historical data. This proved to be harder than expected. The best data I found were a collection of points that represented the frequency and location of landslides in Glacier National Park over the course of the year 1998. This data came from a paper published in the

'Disaster Prevention and Management' Journal[1].

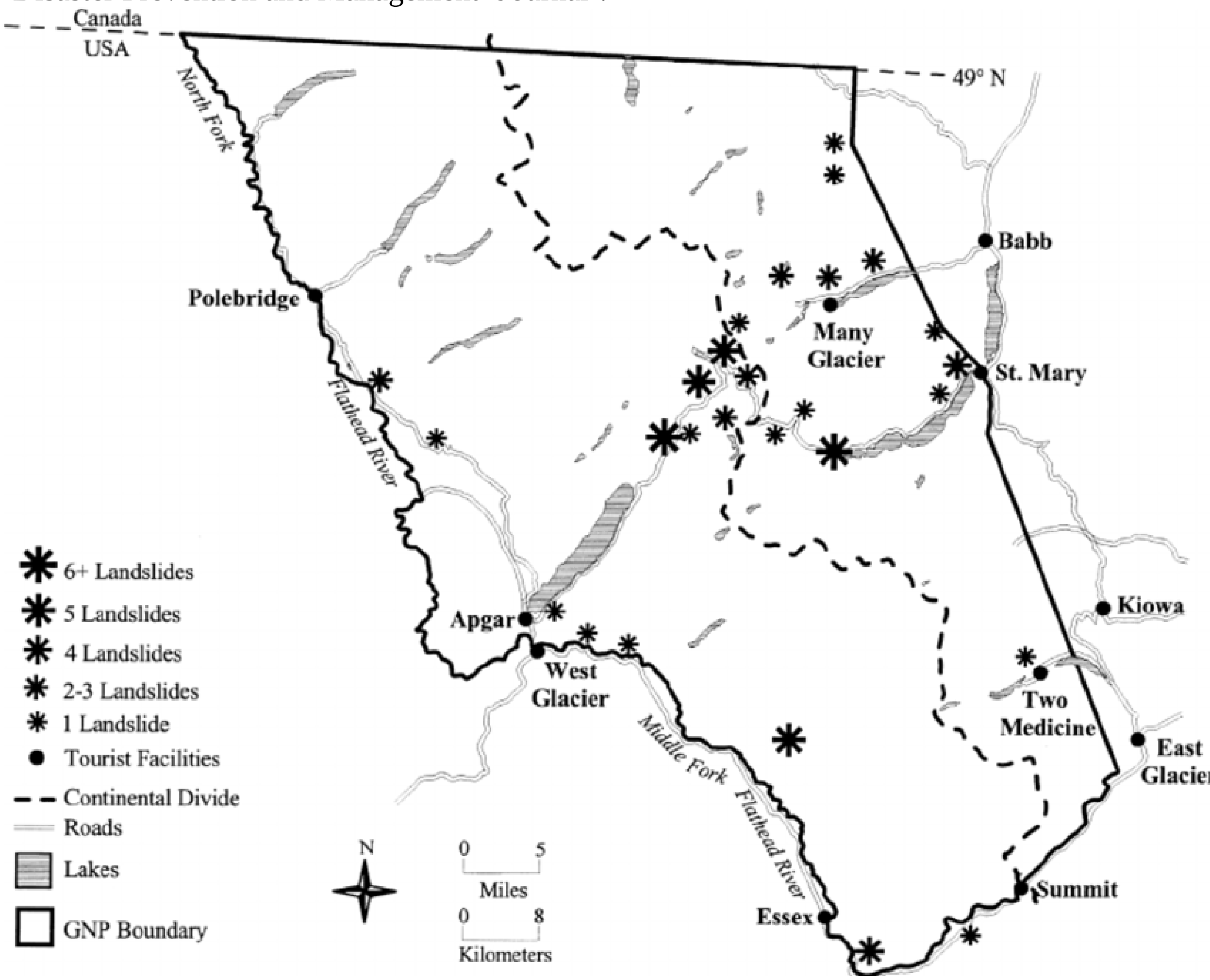


Fig. 1: *Historical Landslide data collected by D. Butler and L. DeChano-Cook for the year 1998*

I digitized this map by hand and added in points with corresponding frequencies. These data were to serve as my checks as I went along.

IV. Data Processing & Analysis—Data Presentation

Processing relevant data and analyzing the results took up the majority of time with this project. After preprocessing of the data was complete--rasterized rainfall, geological, land-cover, and elevation data—I derived a slope raster from the DEM, as this is the major control on landslide events. However, I found that slope data was not as helpful as I had originally planned. While slope does control the formation of landslides, it does not always account for where the landslide will flow. Of course, it is not the formation of a landslide that is hazardous, it is the path which it takes until rest. With this fluid behavior, I found it more pertinent to create a 'drop raster', which is defined as a raster that 'returns the ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells, expressed in percentages'. This type of raster assigns values based on *changes* in elevation/slope. I found this to be an important insight. When using slope data, many of the historical landslide regions were directly adjacent to high 'risk' values, but not concentrated there.

After checking past landslide locations with the drop raster, it seemed evident that this was the more accurate representation of a landslides' destructive path. There are, of course, other factors that contribute to the formation and magnitude of landslides. Once all the data were of the same projection, cell size, and extent it took some digging to find out the best way to combine them. Eventually I settled on Map Algebra. However, in order to combine the data in any meaningful way I had to normalize all four rasters on the same scale. I chose a scale from 1-5 due to the limiting number of land-cover categories that influenced landslide activity (Barren Land, Scrub, Perennial Snow, Herbaceous, and Developed: Open Space)[6]. ArcGIS quickly broke the continuous data into 5 classes, but classifying the geology on this scale took some research into the regional geology of Glacier National Park.

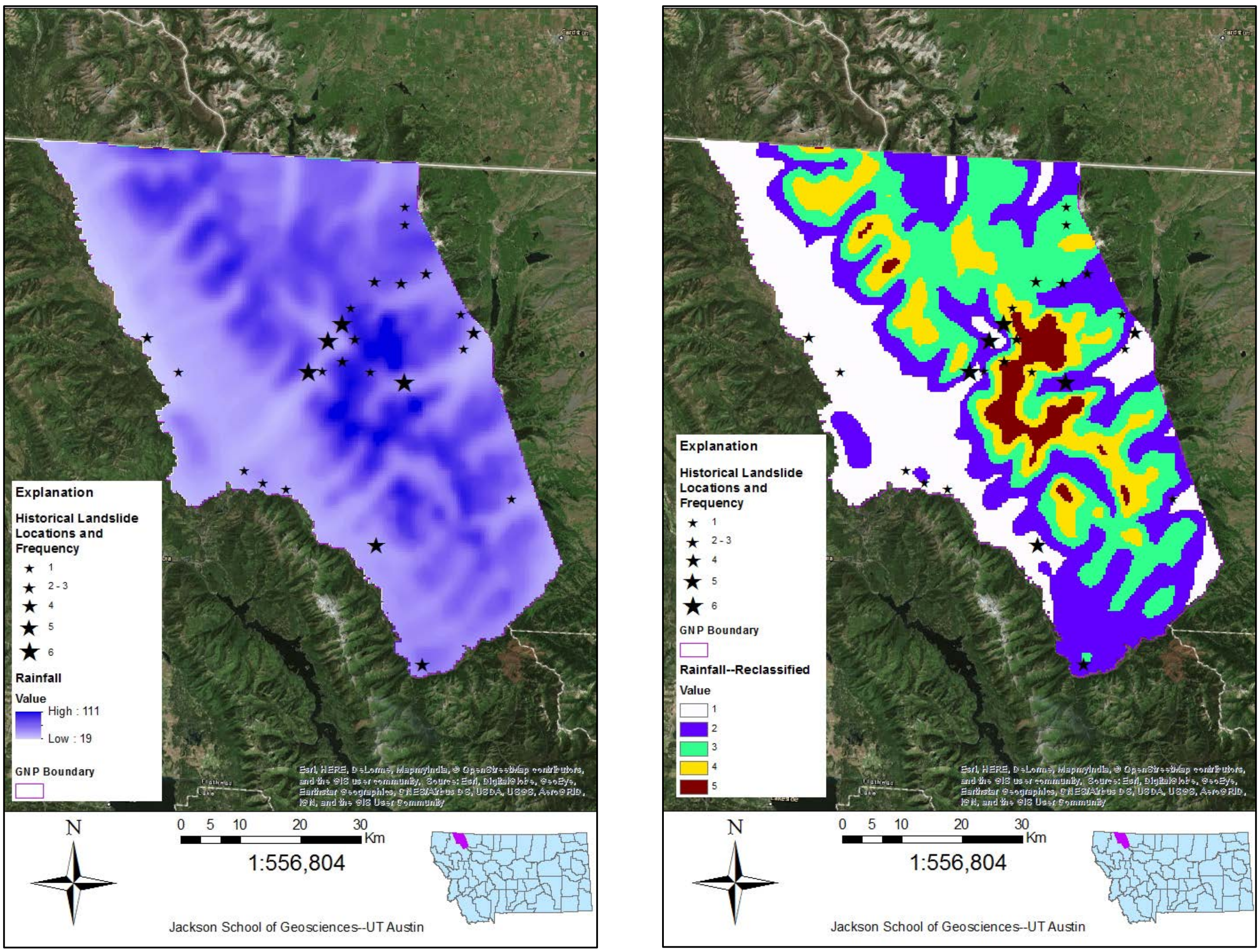


Fig. 2: *All data was rasterized, then reclassified. In this case, the rainfall raster was reclassified from values ranging between 19 and 111 inches of annual precipitation to a normalized scale of 1-5. Cell size was conserved as well as extent.*

The Geologic Resource Evaluation Report again came in handy, as the units were categorized in terms of erosion resistance on a scale from ‘Very Low’ to ‘Very High’[5]. The units that I deemed susceptible in the pre-processing phase ranged from ‘Very Low’ for Quaternary Deposits, to ‘Moderate to High’ for the jointed bluffs of limestone that categorize many of the cliff faces in Glacier National Park (Fig 6). Once all of the data were reclassified, it came down to choosing weights for each raster to plug into the Raster Calculator. I again turned to the literature. A paper in ‘Natural Hazards and Earth System Sciences by Costanzo et. al (2012) did a similar study in which they weighted landslide factors according to their findings on landslide formation in Spain[7]. I used their values as a guide, but not a rubric. After a few iterations, I settled on weights for the raster as follows.

(B) Translational slides

FACTOR	*R*	G-K	ARPA	SHIFT
USE	0.54	−0.72	−0.243	0.61
TWI	0.44	−0.63	0.172	0.08
SLOPE	0.44	−0.62	0.028	−0.18
DIST	0.43	0.55	0.112	0.08
ILL	0.42	0.54	0.291	−0.07
GEOM	0.31	0.48	−0.047	0.40
ROUGH	0.31	0.47	0.083	0.09
LITH	0.40	0.45	0.137	0.20
ASPECT	0.39	0.44	0.170	0.18
SPI	0.25	0.33	0.012	0.02
ELEV	0.54	−0.32	−0.064	0.50
EDAF	0.38	0.09	0.037	0.33
TPI	0.29	−0.03	0.191	0.05
PROF	0.29	−0.03	0.149	0.04
PLAN	0.30	−0.01	0.193	0.03

Fig. 3: *Weights used by Costanza et. Al to classify ‘Traditional’ Landslides*[7]

Drop %	Land Cover	Rainfall	Geology
.5	.3	.1	.1

Fig. 4: *In my calculation, drop % (or change in elevation) was weighed more heavily than in Costanza et. al. This is because of the large amount of sub-vertical bluffs that are susceptible to rock-fall, whereas Costanza et. al studied a river basin where slopes are not as extreme*[7].

Formation Properties Table

Age: West	Age: East	Unit Name (Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards
QUATERNARY		Glacial and Alluvial Sediments (Qal, Qc, Qls, Qg, Qtr, Qor, Qac, Qrg, Qta, Qso, Qtr, Qt2, Qtg, Qes, Qt3, Qat, Qtdi)	Unconsolidated surface deposits 0 - 50 m (0- 164 ft) thick; includes alluvium, alluvial fill, colluvium, landslide deposits, terrace gravel, glacial till and outwash deposits; till is jumbled assortment of subrounded to subangular bouldery rubble combined with sand, silt and clay; landslides are large slumps, block slides and earth flows; colluvium is comprised of unsorted, angular gravel- size clasts in a sand- silt- clay rich matrix with small pockets of till, talus, rock-avalanche and debris flow deposits; alluvium consists of sand and gravel deposits as well as channel and overbank deposits of silt and sand	Very low	Unconsolidated material underlies most valleys of the park where buildings already exist and may heave with frost or extreme moisture	Slump and slide potential high
TERTIARY		Kishenehn Formation (Tku, Tkp, Tkcc)	Unit is more than 610 m (2000 ft) thick; contains layered gravel, sand, mud, volcanic ash, limestone, and coal; appears pale gray and tan in outcrop, with poor cementation; interlayered sandstone, mudstone and conglomerate; most pebbles are from Belt Supergroup rocks, some up to 2.5 m (8.2 ft) in diameter; oil shale, coal, marlstone, litharenite, lignite and tuff beds are locally present	Low	Altered volcanic clays and poorly cemented rock layers render this unit unstable for development, especially for roads and structure foundations	Slump, slide and rockfall potential high if slope is present
MP	MID PROTEROZOIC (MP)	McNamara Formation (Ym)	Exposed locally at GLAC, unit is 61 m (200 ft) thick near Mt. Shields; contains grayish- green siltstone and argillite with fining upward sequences common; some local beds of calcareous siltstone and arenite	Moderate	Locally exposed in park; suitable for all development unless highly fractured	Rockfall potential in steeper terrain
MP		Bonner Quartzite (Ybo)	Exposed locally at GLAC, unit is 244 m (800 ft) thick near Mt. Shields; consists of pinkish- gray to pale red, very fine- to medium- grained feldspathic arenite, some channel deposit sand some siltstone and argillite in fining upward sequences; ripple marks are common	High	Locally exposed in park; suitable for all development unless highly fractured	Rockfall potential in steeper terrain
MP	MP	Mt. Shields Formation (Yms)	Unit 777 m (2550 ft) thick in GLAC; maroon to pale purple argillite, siltstone and some greenish- gray siltstone and arenite, some unique cream colored limestone beds present locally (contain stromatolites), and black argillite at the top of the unit; fining upward sequences are common, as well as wavy and parallel bedding and salt casts.	Moderate	Good for most uses unless thin bedding is present, providing planes of weakness in the rock column. Mostly exposed at higher elevations	Rockfall potential in steeper terrain

Fig. 6: *Table compiled as part of the Geologic Resource Evaluation Report*[5]

The combined raster:

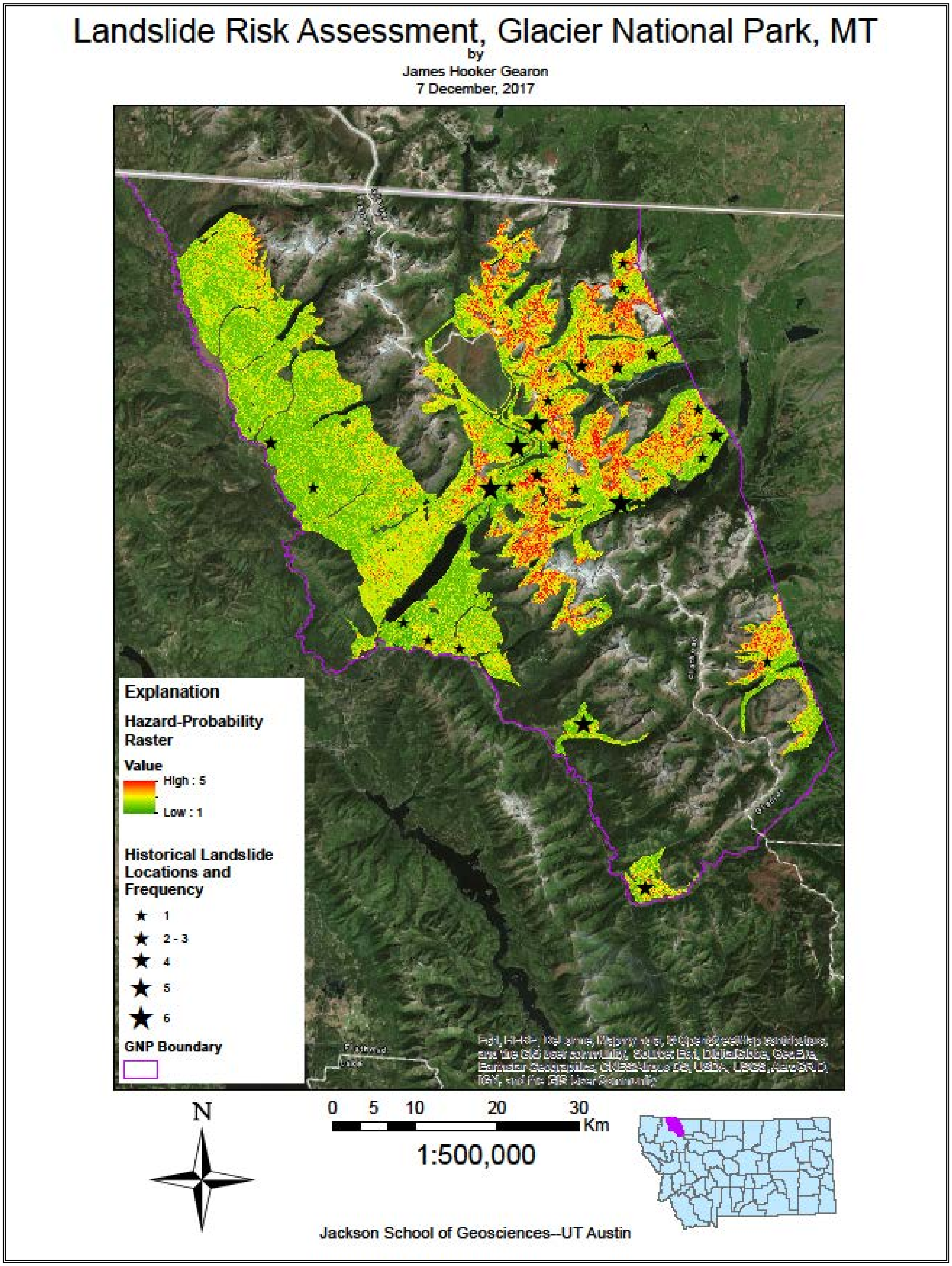


Fig. 7: *Combined, scaled, and weighted raster of landslide hazard.*

I then attempted to do some ground-truthing for this data. Due to the inherent error in digitizing a map, as well as the unknown error of the historical landslide data, I decided to add a 1000m radius buffer around each point. The rationale behind this was that there was no indication in the journal article of whether the team mapped landslide origin, landslide destination, or just path. Additionally, the resolution of the historical data was not accurate enough to get a distinct point via digitization. Inspecting the points and buffers yielded interesting observations:

Fig. 8: *FID #0*

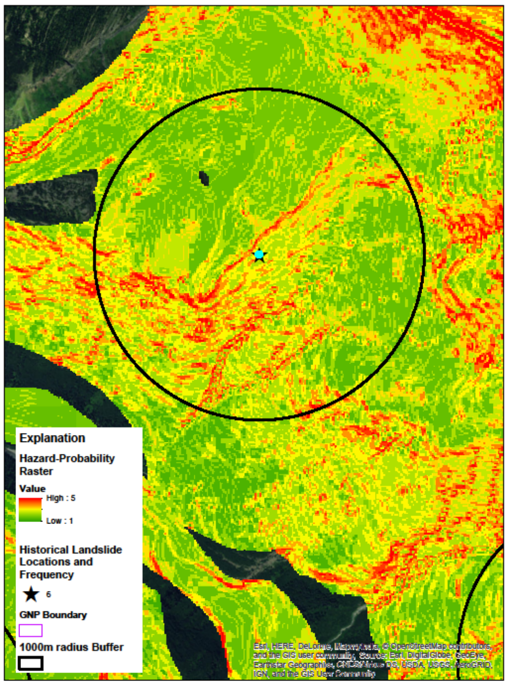


Fig.9: *FID #3*

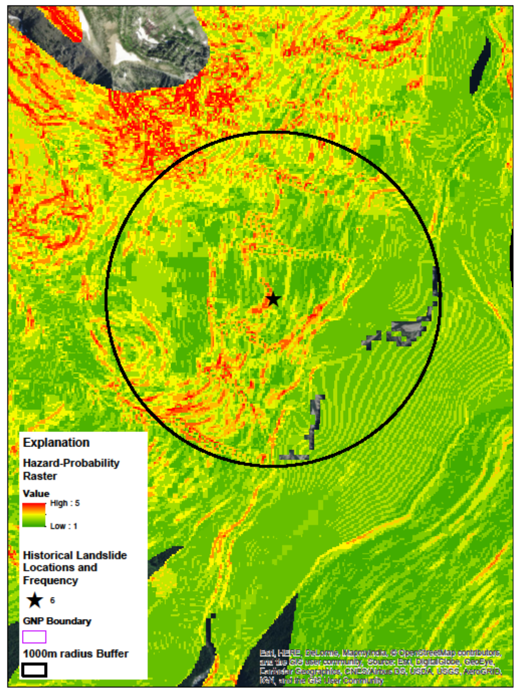


Fig. 10: *FID #15*

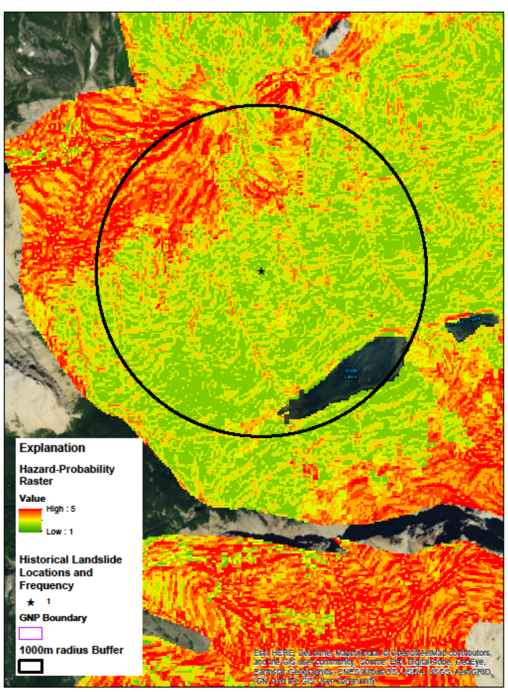
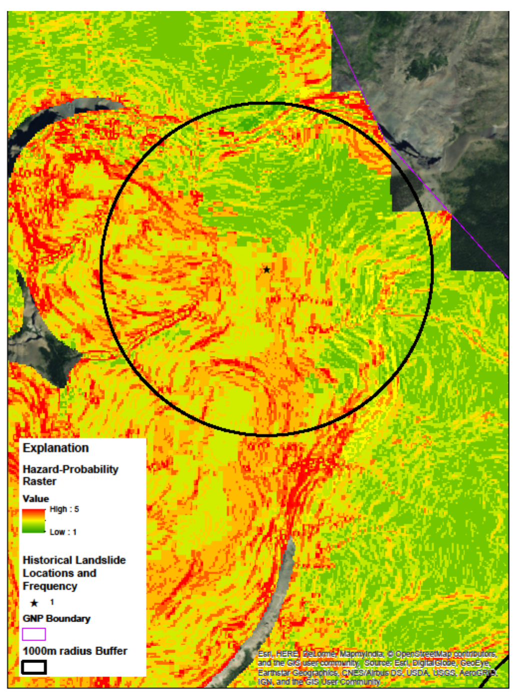
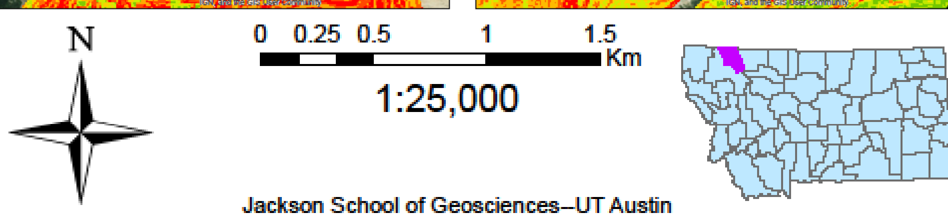


Fig. 11: *FID #14*





For the vast majority of point-locations (22/25) the 1000m buffer encapsulated both red and green regions. In other words, the buffers usually captured a marked transition between high and low values. This is most likely because of the error as described above. I then inspected the aerial photography to gain more insight:

Fig. 12:
FID #0

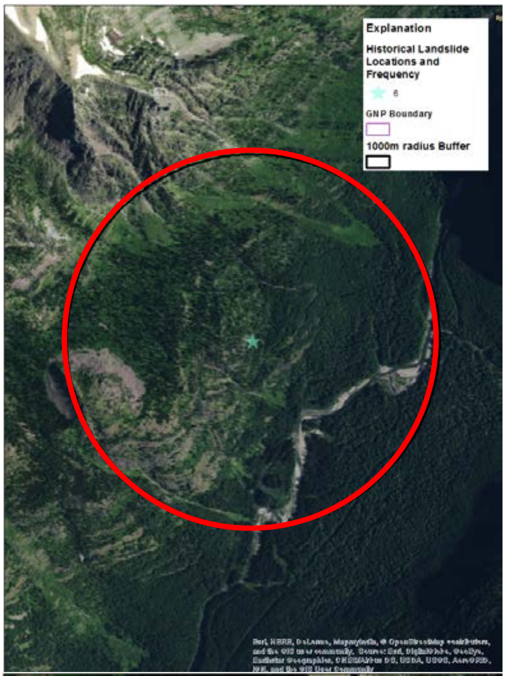
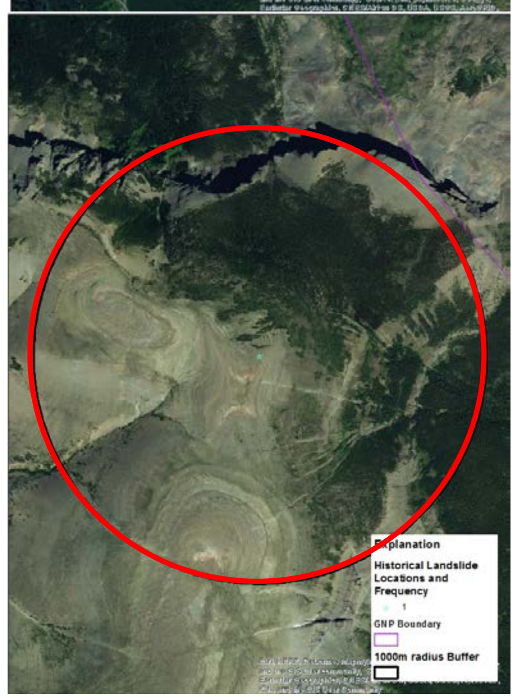
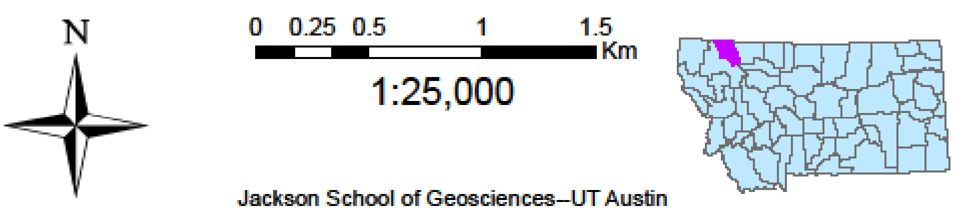


Fig. 13:
FID #3

Fig. 14:
FID #15

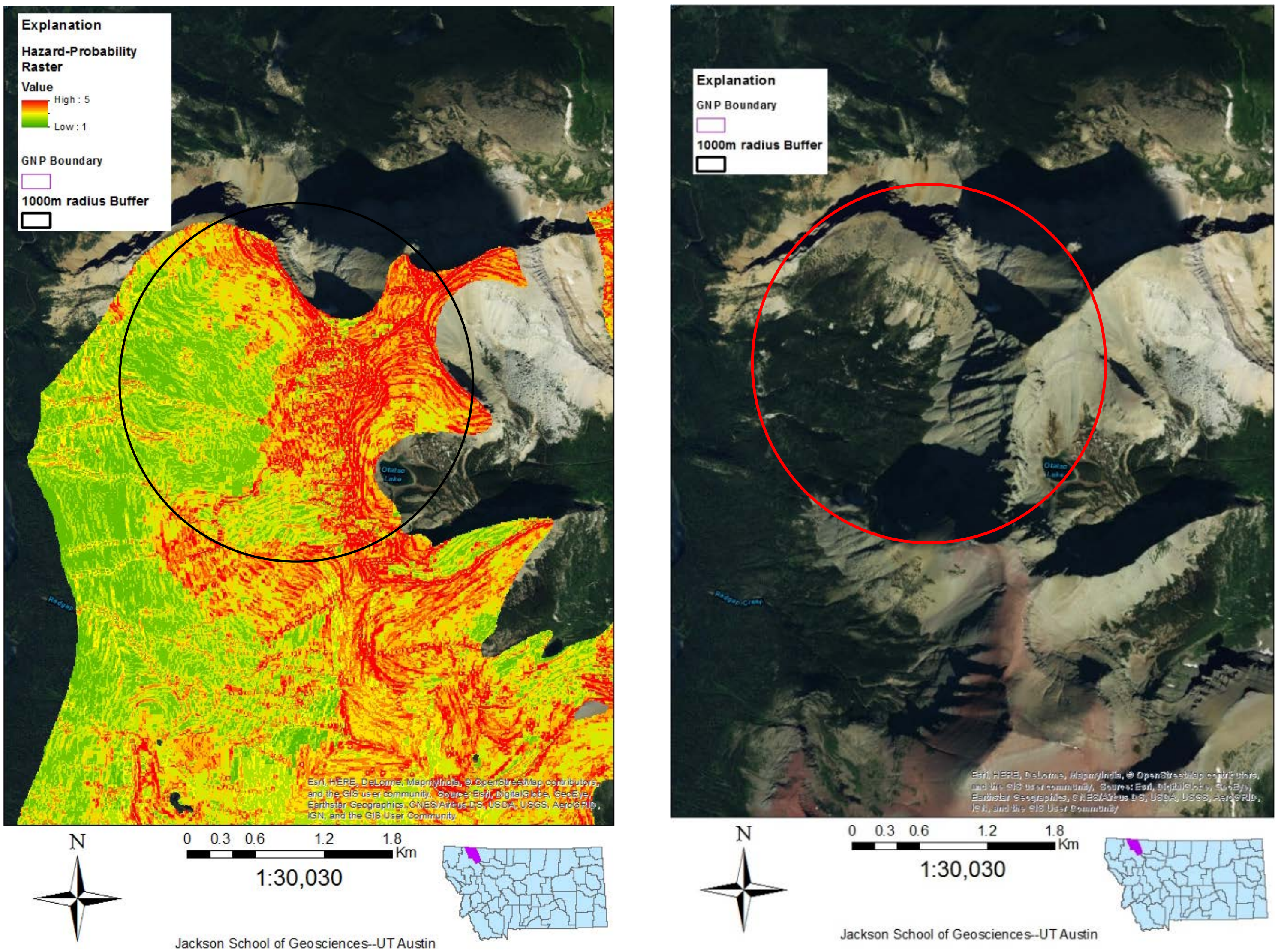
Fig. 15:
FID #14





Inspecting the aerial photography of the identified regions showed transitions between barren, steeper slopes to vegetated areas of lower relief. This aligns with the notion that D. Butler and L. DeChano-Cook mapped areas of total landslide movement as opposed to just nucleation sites. As an exercise, I looked for similar regions of transition in the created hazard raster that had no recorded activity of landslides (in 1998) and compared them with aerial photography[1]. An example:

Fig. 16: *A handpicked area not within the historical data that exhibits characteristics of landslide potential. Some photographic evidence of past sliding activity.*



There seems to be some evidence of landslide activity in the form of lobate deposits at the base of the mountain. While this method is relatively ‘quick and dirty’ I believe it has the potential to inform researchers in the future about possible landslide hazards. Changing climate and weather patterns put humanity at the mercy of nature more than ever before. I believe this method for landslide hazard analysis could help in the preparation for these events.

Works Cited

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3. Menicke, Richard K. “Title Glacier National Park, 10-Meter Digital Elevation Model.” 18 July 2001.

4. O'Meara, Stephanie. “glac_geology.” National Resource Program Center, 24 June 2013.

5. Thornberry-Ehrlich, Trista. *Glacier National Park Geologic Resource Evaluation Report*. Department of the Interior, 2004, *Glacier National Park Geologic Resource Evaluation Report*.

6. USGS. “National Land Cover Database (NLCD) Land Cover Collection.” 1 Jan. 2015.

7. Costanzo, D. “Factors Selection in Landslide Susceptibility Modelling on Large Scale Following the Gis Matrix Method: Application to the River Beiro Basin (Spain).” Natural Hazards and Earth System Sciences, 13 Feb. 2012.

Landslide Risk Assessment, Glacier National Park, MT

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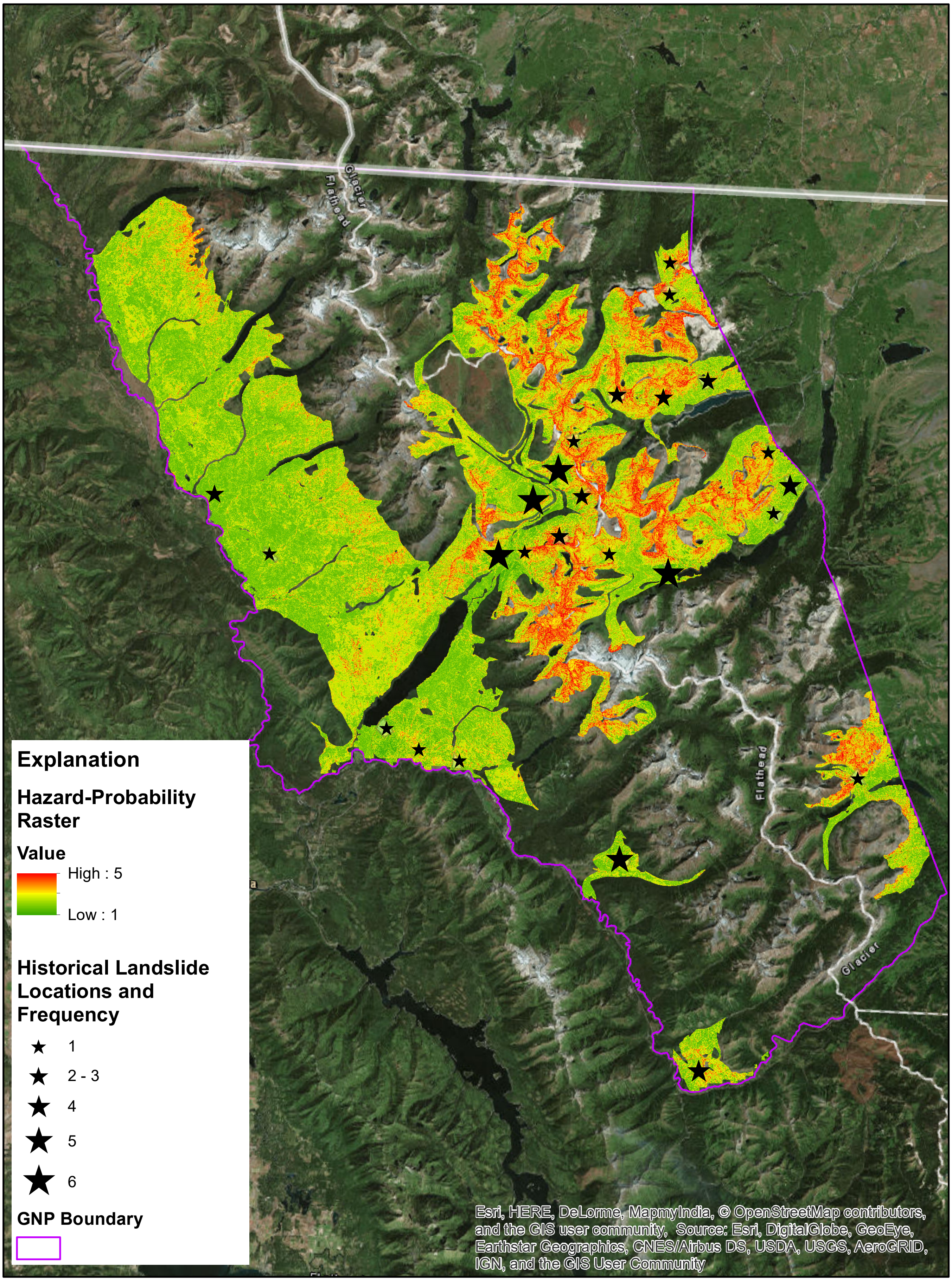

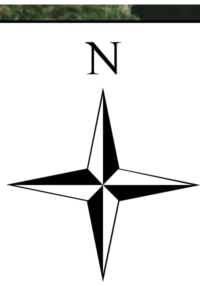

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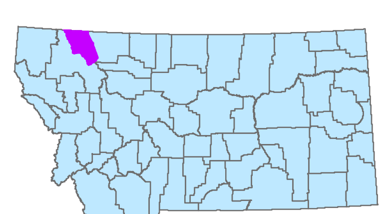

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