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# Landslide Hazard Analysis of Western Washington State, US

## Problem Overview

Landslides are widespread and dangerous geologic hazards that can cause billions of dollars in damage and result in the death and injuries of dozens in the United States every year. These events are generally fast and frequent, making prediction difficult, but, by understanding the basic mechanics of landslides, it is possible to create a hazard assessment, which is a proxy to predicition. These assessments can then be used by city planners and emergency officials to be better prepared for such these disaters. In this analysis, I have chosen four of the most important factors leading to a landslide event: slope, precipitation, seismicity and soil characteristics. Each of these factors was then ranked, weighted then added together to create the final hazard analysis.

## Data Collection

This analysis required a DEM of western Washington State for slope analysis, which was collected from the University of Washington and is a mosaicked 30 meter raster (fig 1a). The precipitation data was a raster of annual precipitation averaged over a ten-year period from 2000 to 2010 collected from the Washington State Department of Transportation (1b). Soil data was collected from NRCS State Soil Geographic (SSTATSGO) Database via the USGS website, which contained soil data for all of the conterminous United States (1c). Finally, a vector file of earthquake data downloaded from the National Atlas contained information for all

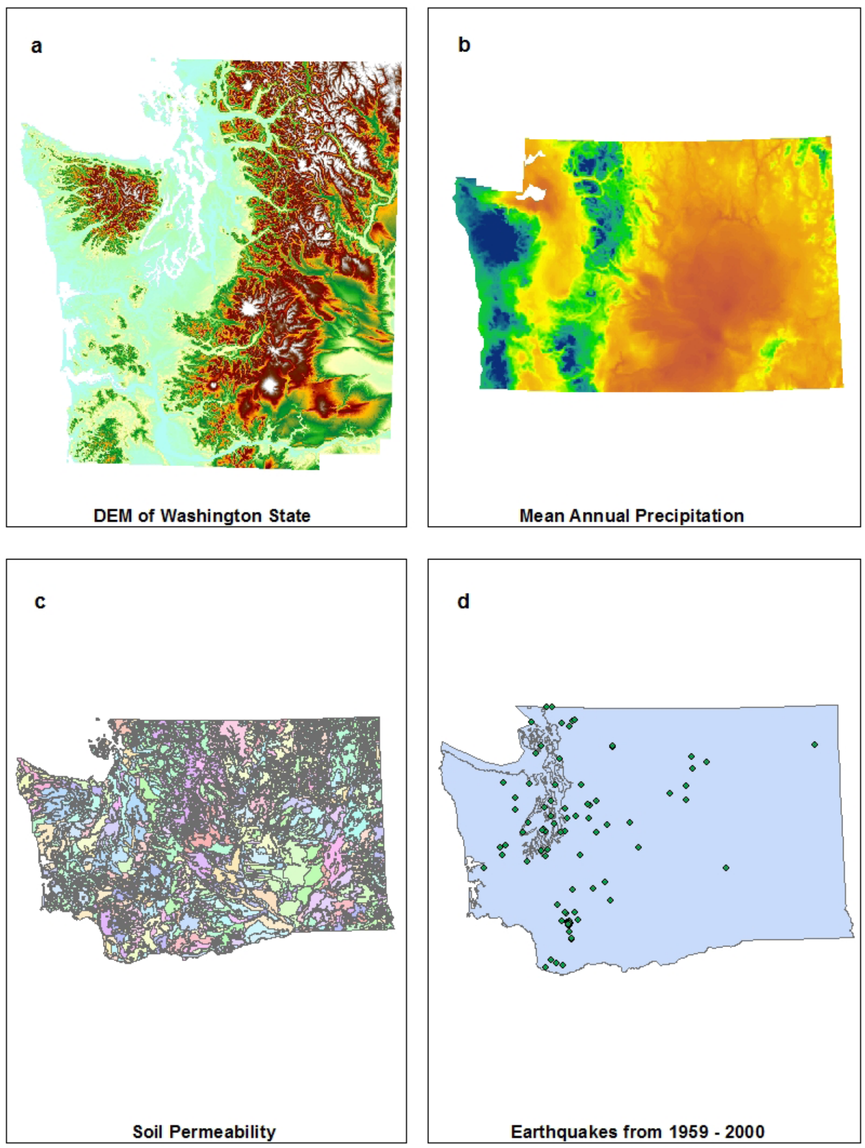



Figure 1 Original data mining results (clipped to study area)

earthquakes in the United States from 1959 to 2000 (1d). Other data, such as the city and river vector files for Washington State were taken from previous labs used in this course.

**Data Processing**

For this project, I chose NAD83 HARN Lambert Conformal Conic as the coordinate system, since my study area would have expanded beyond the two zones of the Washington State Plane Coordinate System as well as in the UTM Coordinate System. The precipitation raster was already in this coordinate system, so all of the files used in the analysis were projected from this data. The 30 meter DEM was thus converted to a 98.43 foot cell size, which I then rounded up to 100. This cell size became the standard by which all my rasters would then be compared. The DEM of Washinton State was then used to calculate a new raster for slope. This was achieved with ease using ArcGIS's Slope function and keeping the cell size at 100.

The soils vector file was downloaded in the e00 format, which had to be converted for use in ArcGIS by using "Import from e00". Once converted, it was then projected to the Lambert Conformal Conic projection then clipped to the area of interest using a shapefile of Washington State (fig 1c). The newly cropped shapefile then had to be converted to a raster using the Polygon to Raster function in ArcGIS, but I had to choose a specific value to convert. Since cohesion and permeability are two important qualities in landslide analysis, I decided to use the attribute "perm" (permeability) as the value for the

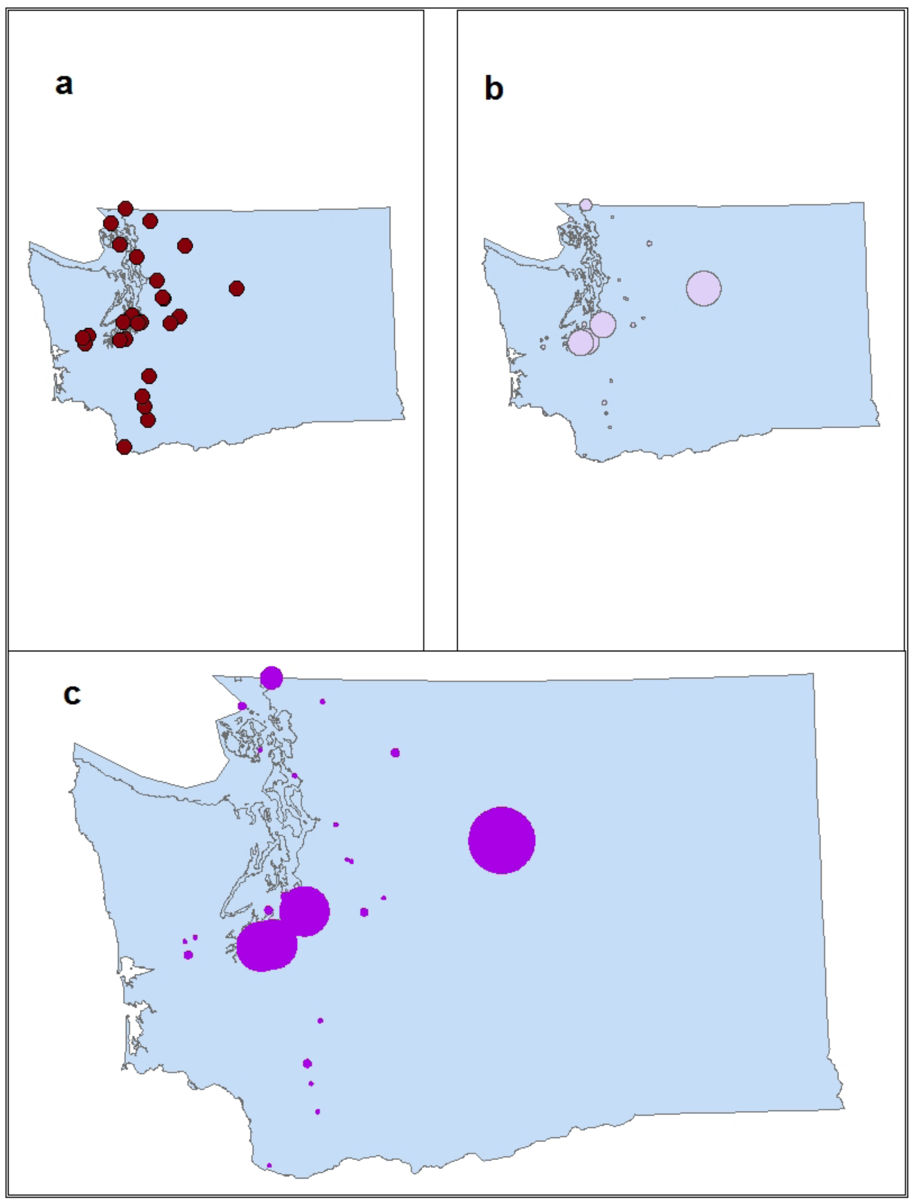


Figure 2 Earthquake data preprocessing

new raster file. Finally, the earthquake data vector file required conversion through a different process (fig. 2). I first identified all earthquakes from 1959 to 2000 in Washington State with magnitude 5 and greater (fig. 2a). I then created a buffer several shapefiles based on the average rupture in 0.5 magnitude step intervals. The result was 5 separate vector files, each with a range of buffers. Using the Merge function under Geoprocessing, I was able to create a single shapefile containing all of the earthquake buffers (fig. 2b). The final step was to convert the file to a raster with a 100 foot cell size (fig. 2c), but the value I choose did not particularly matter, which is explained below.

With these tasks complete, the project was then ready to move into the actual analysis.

## ArcGIS Processing

In order to understand the relationship between the criteria, I compared and renormalized the relative importance of each criterion into Table 1. I proposed that the most important factor in a landslide is slope. Since these events are gravity-driven, it stands to reason, at least to a first-order, that the closer the topography gets to true gravitational acceleration, the more probable a landslide will occur. I then weighted earthquake and precipitation equally, reasoning that since a large magnitude earthquake could trigger a landslide event, but these larger earthquake events are much rarer than precipitation, which is important in making sediment mobile. Soil, specifically permeability, I rated as the least important factor. Once the preliminary relationships were established, I then renormalized the values then took the average of each row (slope, precipitation, earthquakes and soil) to derive the final weight of each factor to be used in the final raster calculation.

| | Slope | Precipitation | EQ | Soil |
|---|---|---|---|---|
| Slope | 1 | 2 | 2 | 4 |
| Precipitation | 0.5 | 1 | 2 | 5 |
| EQ | 0.5 | 0.5 | 1 | 2 |
| Soil | 0.25 | 0.2 | 0.5 | 1 |
| Total | 2.25 | 3.7 | 5.5 | 12 |

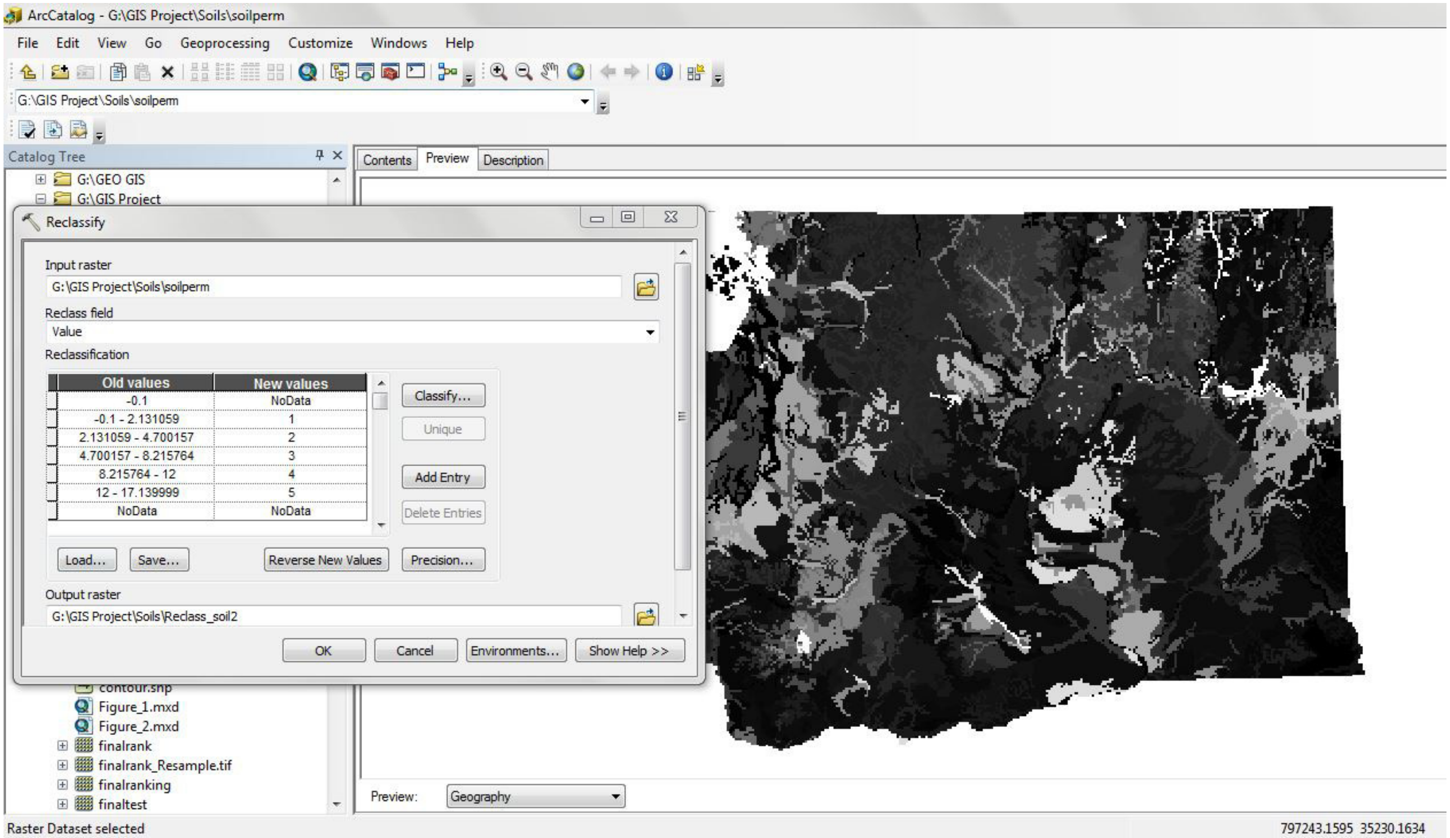
| | Slope | Precipitation | EQ | Soil |
|---|---|---|---|---|
| Slope | 0.444444444 | 0.540540541 | 0.363636364 | 0.333333 |
| Precipitation | 0.222222222 | 0.27027027 | 0.363636364 | 0.416667 |
| EQ | 0.222222222 | 0.135135135 | 0.181818182 | 0.166667 |
| Soil | 0.111111111 | 0.054054054 | 0.090909091 | 0.083333 |
| Total | 1 | 1 | 1 | 1 |

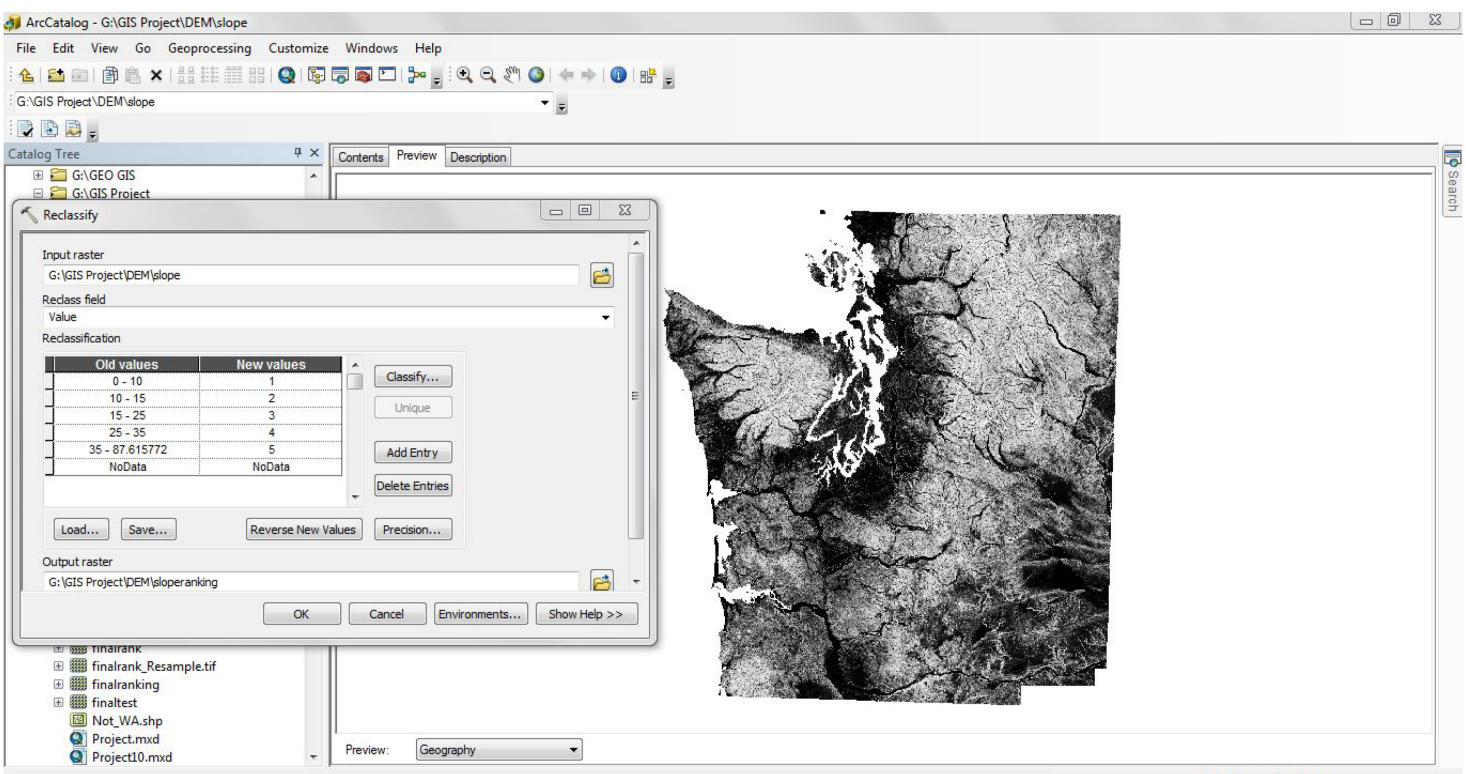
| | Slope | Precipitation | EQ | Soil |
|---|---|---|---|---|
| **Final Weights** | 0.42048867 | 0.318198881 | 0.176460551 | 0.084852 |

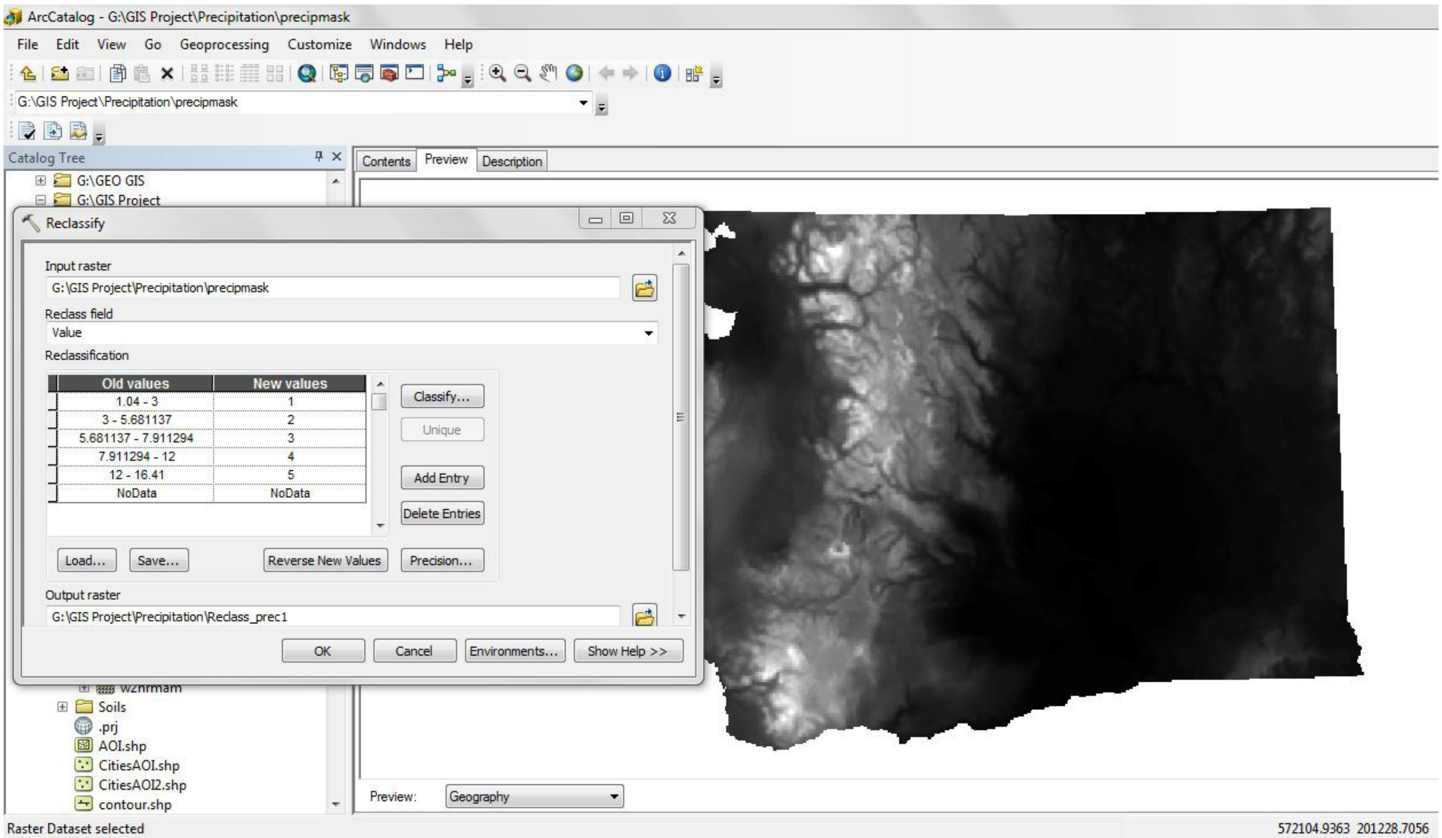
Table 1: Relationship between weights and the selected criteria

The next series of steps was to reclassify all four rasters into integer values (figure 3 shows a screen shot of this process). For the slope raster, very low slopes (0˚ - 10˚) were ranked a 1, low slopes (10˚ - 15˚) a 2, moderate slopes (15˚ - 25˚) a 3, steep slopes (25˚ - 35˚) a 4 and very steep

Figure 3 Reclassification of all four rasters

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5.681137 - 7.911294 3
7.911294 - 12 4
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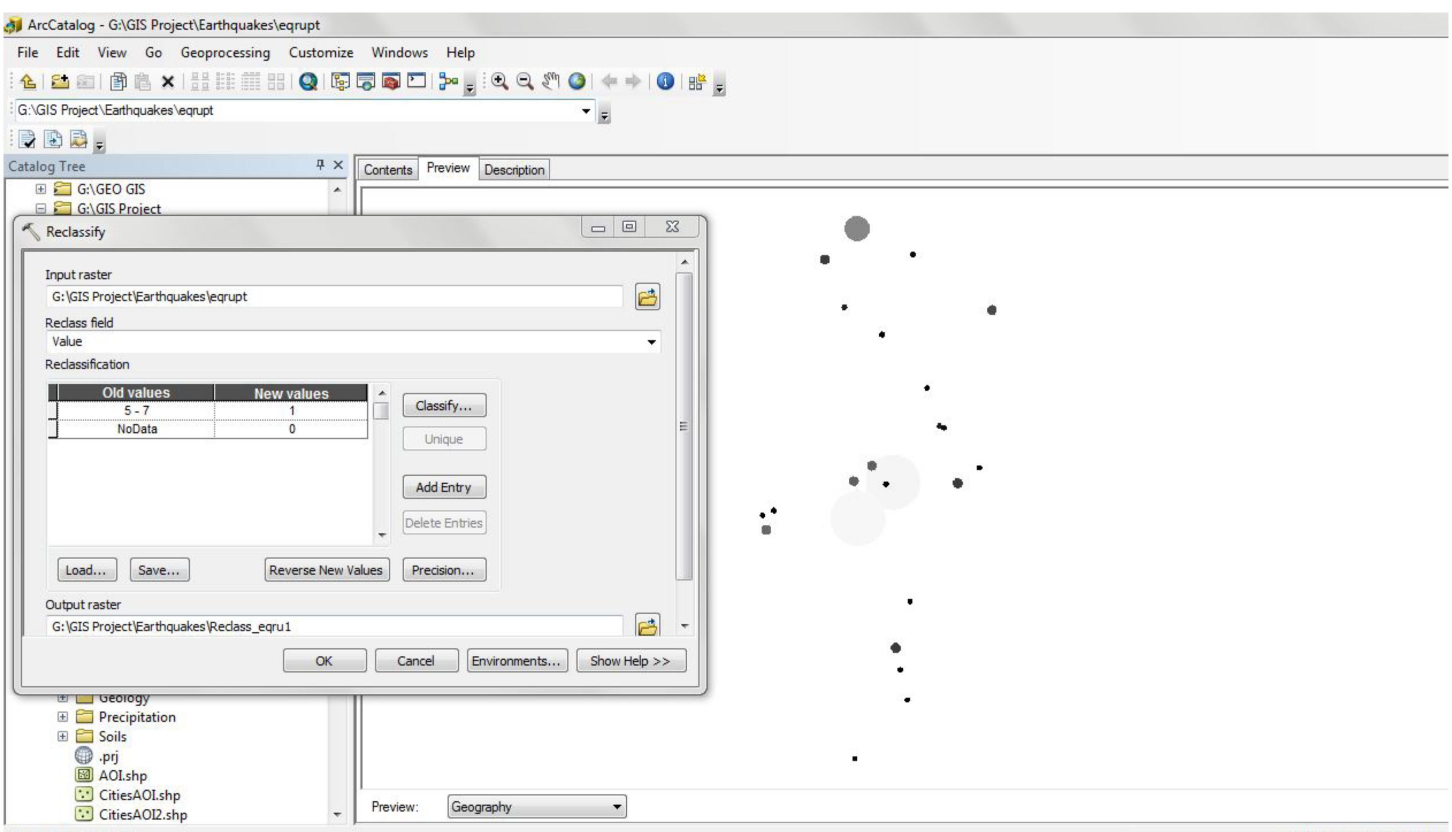
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slopes (>35˚) a 5. The choice of greater than 35˚ was chosen because this is well beyond the angle of repose and a difference in degree has a smaller effect and a more compartmentalized ranking system became unnecessary. Figure 4a is the resulting raster.

The precipitation rank was based off the minimum and maximum values, 1.04 and 16.41 inches respectively. To keep the calculations consistent, a 5 rank system was used: 1 – 3 inches was ranked a 1, 3 – 6 a 2, 6 – 9 a 3, 9 – 12 a 4, and 12 – 16 was ranked a 5 (fig. 4b). Similarly, permeability was reclassified to a 5 rank ordinal system of near equal interval (fig. 4c).

The only raster that was different was the earthquake data. Since I had already created a buffer for the historical earthquakes, I assumed that all areas that fell under the umbrella of the buffer were affected by the earthquake and all areas outside it were not. Therefore, I gave a value of 1 to all earthquake buffers and a value of zero for everything else (fig. 4d). The final step was to multiply each raster by its calculated weight and add them together.

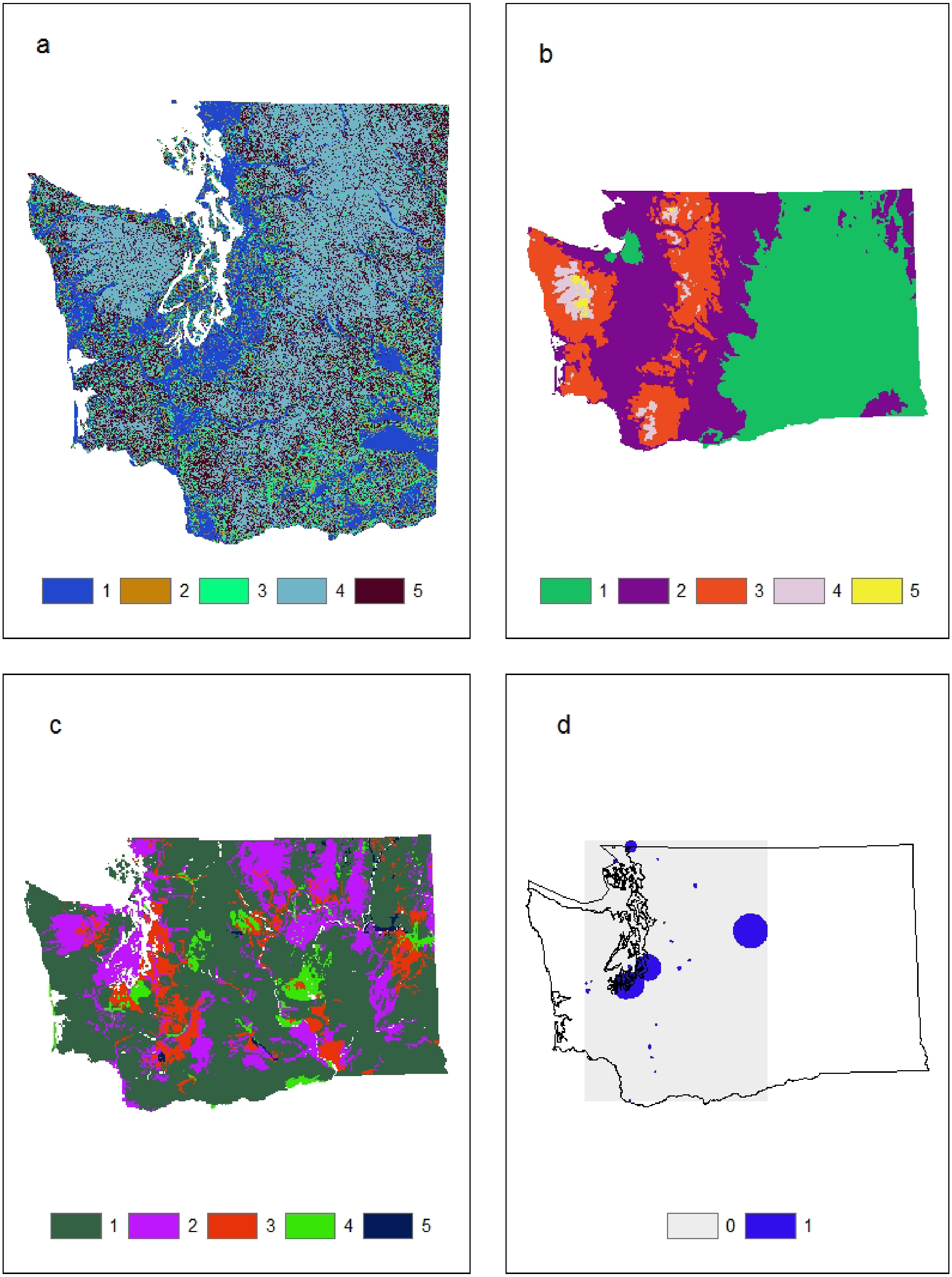



Figure 4 Ranked rasters of each of the four criteria for landslides
a) slope, b) precipitation, c) soil permeability, d) historic earthquake rupture area

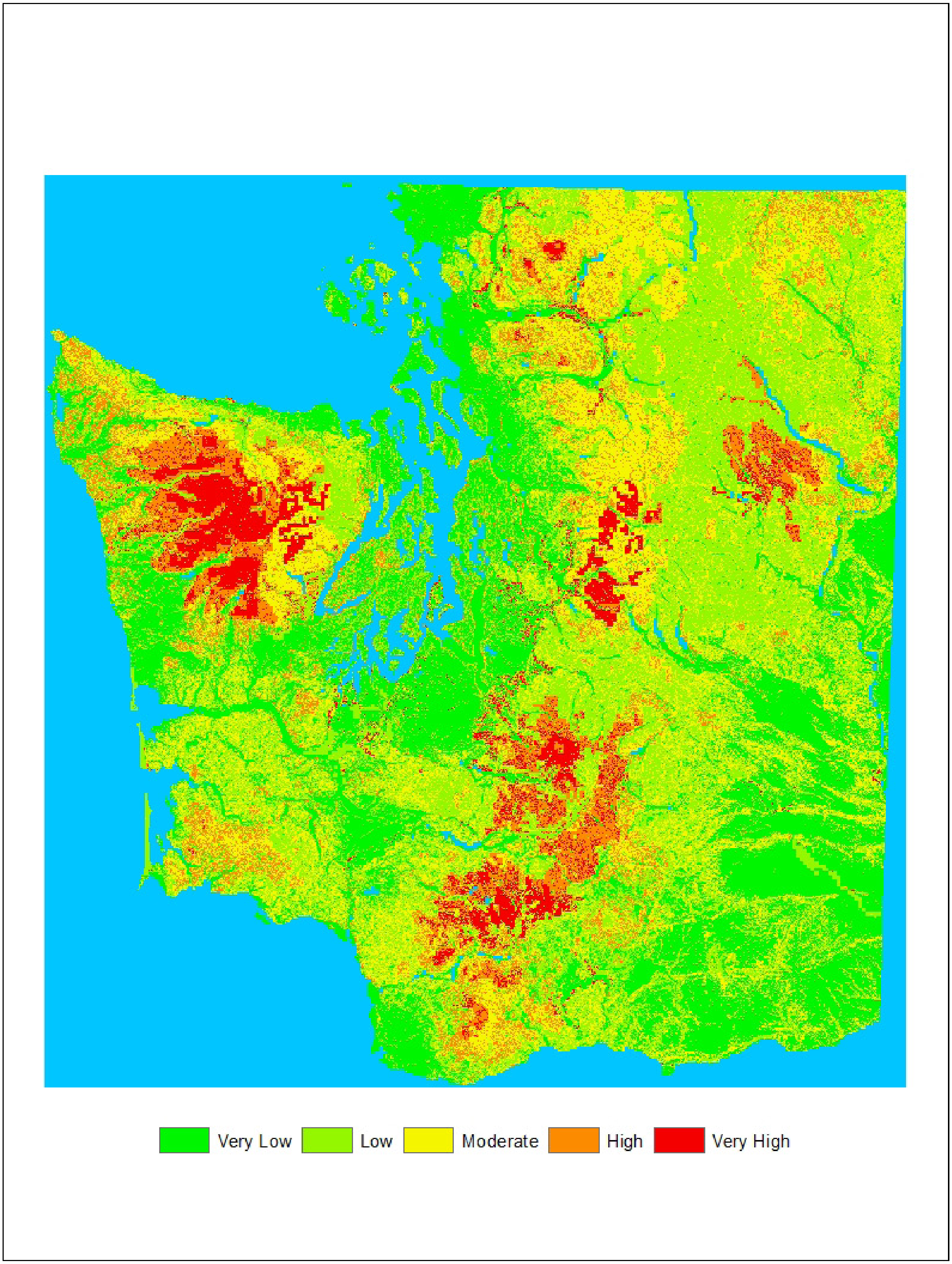



Figure 5 Final ranking of landslide analysis

## Analysis

This hazard assessment (fig 5) is, to a first-order, comparable to actual landslides recorded by the Washington State Department of natural resources. Most of the recorded landslides have historically occurred along the Cascades and west of Puget Sound, as my analysis shows. However, the southwestern portion of the state, where the Columbia River nears the Pacific Ocean has many landslides that my model shows as having a moderate to high occurrence rate, which does not fully explain the swarm of landslides observed in the area. Clearly, there are other factors not taken into account in this assessment that contribute to landslide occurrences.

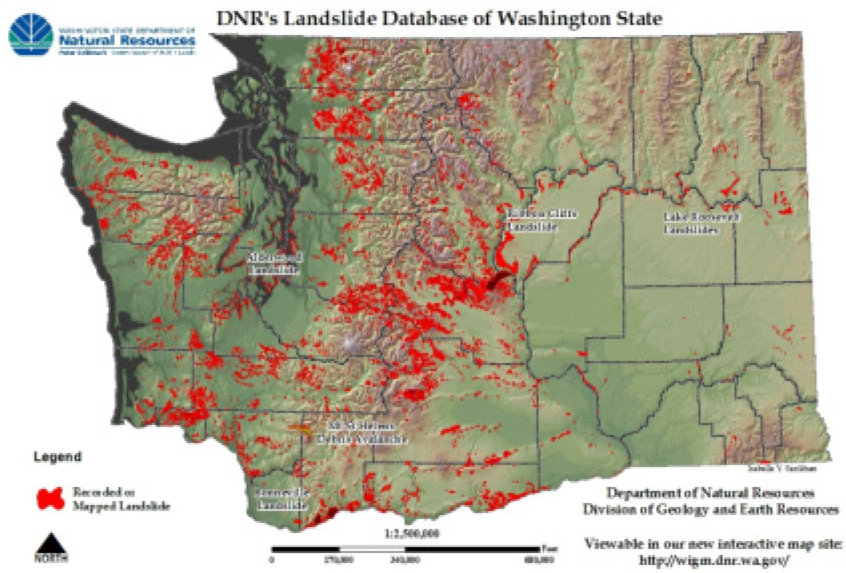


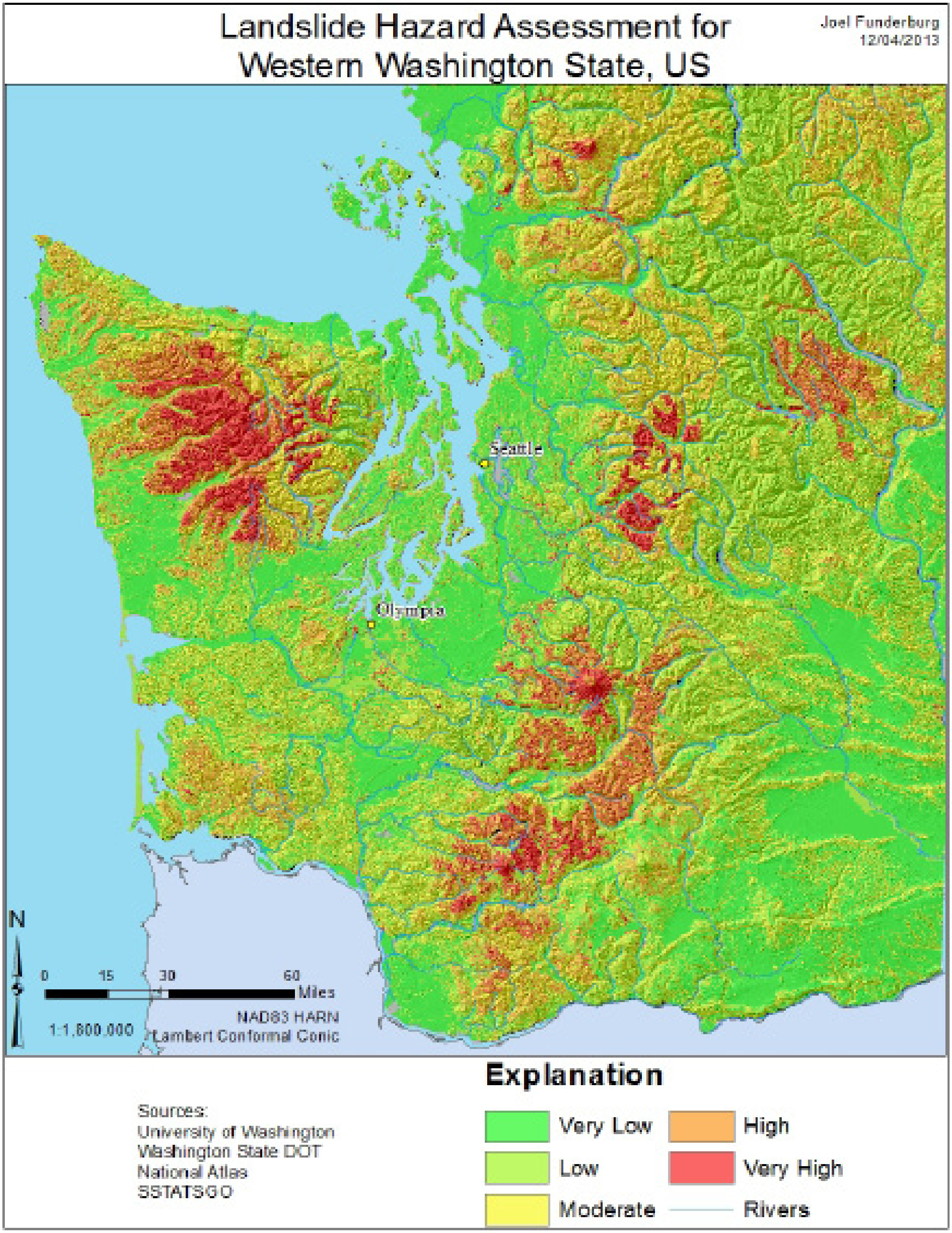

Figure 6: Recorded landslide occurrences (2009)
Source: Washington State Department of Natural Resources

## Conclusion

Hazard assessments are a simple way to understand the complicated dynamics that control observed natural phenomena. What is more, they can guide us to be better prepared for inevitable damage resulting from natural disasters, such as landslides. This assessment shows the major areas at risk for a landslide and is based on four simple criteria. Future assessments could take into account other factors for a more complete analysis, such as known fault zones, soil cohesion, logging/deforestation rates and erosion rates. However, the most essential triggers – slope, precipitation, seismicity and soil permeability – result in most of the landslides that occur in nature.

## Sources

University of Washington Geomorphological Research Group
Washington State Department of Transportation
National Atlas
NRCS State Soil Geographic (SSTATSGO) Database
Washington State Department of Natural Resources


Landslide Hazard Assessment for
Western Washington State, US
Joel Funderburg
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Seattle
Olympia
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NAD83 HARN
Lambert Conformal Conic
Sources:
University of Washington
Washington State DOT
National Atlas
SSTATSGO
Explanation
Very Low
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High
Very High
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