Modelling Volcanic Hazards from Fuego Volcano in Guatemala

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Geo 327: GIS and GPS Applications

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Question:

On June 3rd 2018, Volcan Fuego erupted killing 165 people and affecting 3.7 million more (Reid). In this report I would like to create a hazard map of the Fuego volcano to examine the possible extents of a volcanic eruption by analyzing ash radius and lahar flows of previous eruptions, and see if I can model the flow paths based on elevation data to examine which urban areas are most at risk.

Data Sources and Works Cited:

DEM Files 30m Resolution of Southern Guatemala: *USGS/NASA Earthdata Aster Files, 2019*

- https://e4ftl01.cr.usgs.gov/ASTT/ASTGTM.003/2000.03.01/ASTGTMV003_N14W091.zip
- https://e4ftl01.cr.usgs.gov/ASTT/ASTGTM.003/2000.03.01/ASTGTMV003_N14W090.zip

These are simply 30m resolution elevation data for Guatemala, which together span:

- Northern Limit: 15N
- Southern Limit: 14N
- Western Limit: 92W
- Eastern Limit: 90W

Guatemala Shapefiles and Point Data: Princeton University, Feb 7th 2019

- https://gisportal.princeton.edu/arcgis/rest/services/Hosted/Guatemala_Boundaries/FeatureServer

Guatemala Population Data by City: *Census of Guatemala, 2018*

- https://www.censopoblacion.gt/explo/TabA5.xlsx

Guatemala Rivers and Road Shapefiles: *World Bank*

- https://datacatalog.worldbank.org/dataset/roads-guatemala
  - July 27, 2017
- https://datacatalog.worldbank.org/dataset/rivers-guatemala
  - July 21, 2017

Tephra Sizes and Hazards:

- https://pubs.usgs.gov/of/2001/0431/pdf/of2001-0431.pdf

Volcano Hazard Data:

"Global Volcanism Program - Fuego ." *Global Volcanism Program | Volcanoes of the World (VOTW) - Fuego (342090) Citation*, The Smithsonian Institute, https://volcano.si.edu/gvp_votw.cfm?vn=342090.

Michigan Tech University,

- http://www.geo.mtu.edu/volcanoes/fuego/hazards2.html

National Oceanic and Atmospheric Administration, National Centers for Environmental Information

- https://www.ngdc.noaa.gov/nndc/servlet/ShowDatasets?dataset=102557&search_look=50&display_look=50

Reid, Kathryn. "2018 Guatemala Volcano Eruption: Facts, FAQs, and How to Help." World Vision, World Vision Inc., 10 July 2019, www.worldvision.org/disaster-relief-news-stories/2018-guatemala-volcano-eruption-facts.

Data Preprocessing:

After loading in the shape files, the volcano point data, and the 30m resolution elevation data files into ArcMAP, I created an area of interest, selected arbitrarily. Then I created a mosaic (Fig. 2) of the two together into a new file and clipped the elevation data into my area of interest (Fig. 3), scrapping the rest. Additionally to make loading the program go by faster I would select a handful of departments (states) and their municipalities to keep. All data was in the GCS_WGS_1984 coordinate system. I also symbolized the state boundaries to be a little heavier than the city boundaries for contrast (Fig 4).
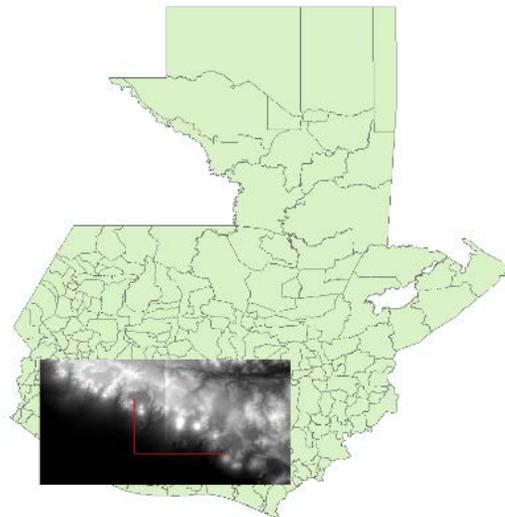

*Figure 1 Guatemala Shapefile with Area of Interest and ASTER data
file overlain*
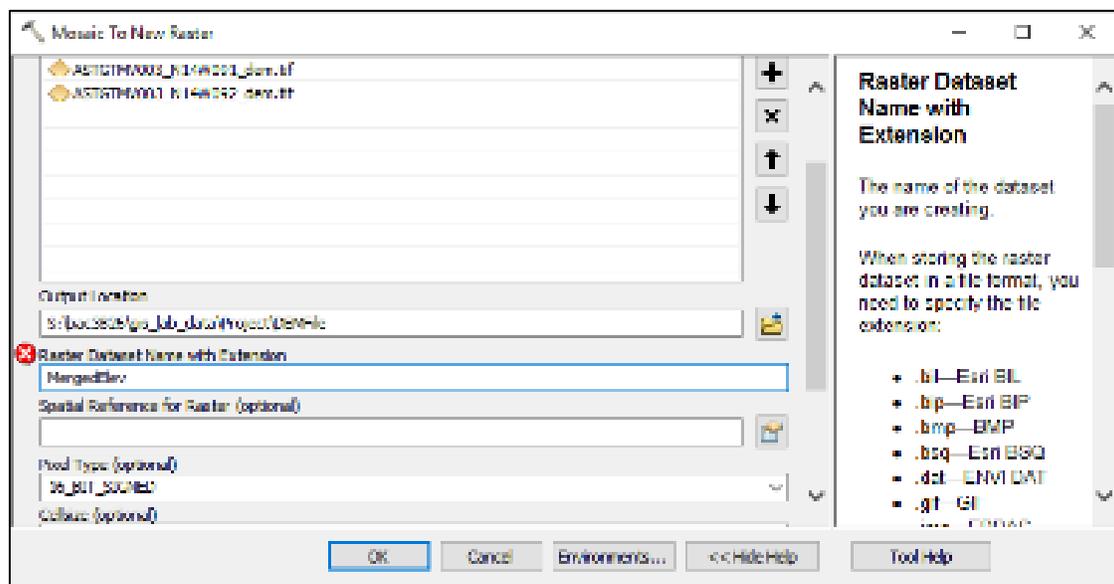
Figure 2 Mosaic of ASTER grids to a new File
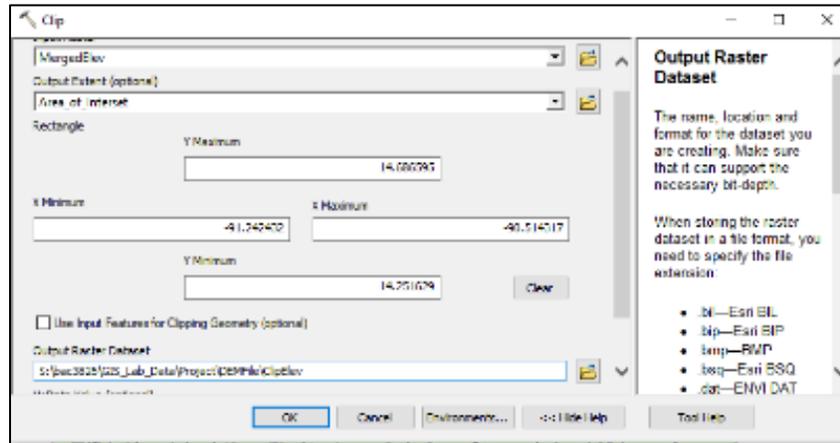
*Figure 3 Clip of the new Mosaic File to the Area of Interest*
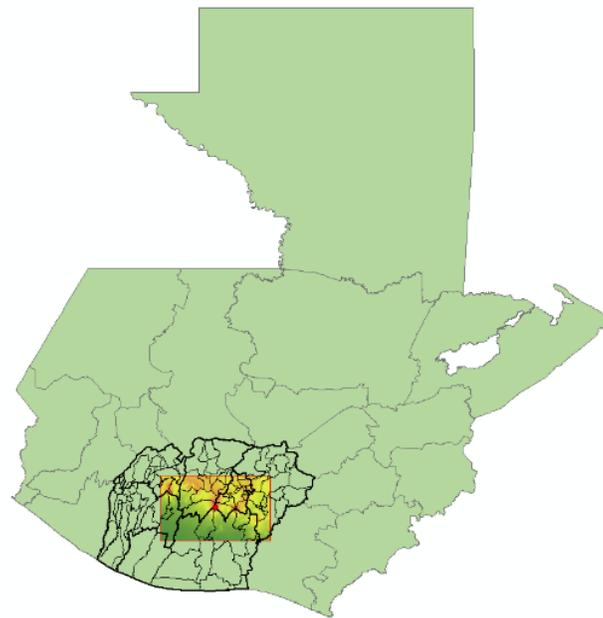
Figure 4 Shape of Guatemala with Cropped Municipality Lines. Elevation Data has been colored and cropped into Area of Interest. Municipality lines are preserved within Department (state) lines.

To assess the amount of people at risk, I downloaded population data from the Guatemalan Census website and used a table joins in ArcMap after importing the City Point Data and Population data sets. With the population data set, I first had to convert from an XML file to a CSV. After the table join between the City Point Data my values for population were string values.

City Points were already in the appropriate coordinate system as they were derived from the shapefile of the municipality lines. To convert string values to long integers I used the code in Figure 5 with the Field Calculator in VB Script and plotted the points on the map, labeling the cities. Additionally, I would project both the Roads and the Rivers layers with the define

projection tool, clipping them to the area of interest as well, symbolizing the paved and unpaved roads differently (Fig. 7).
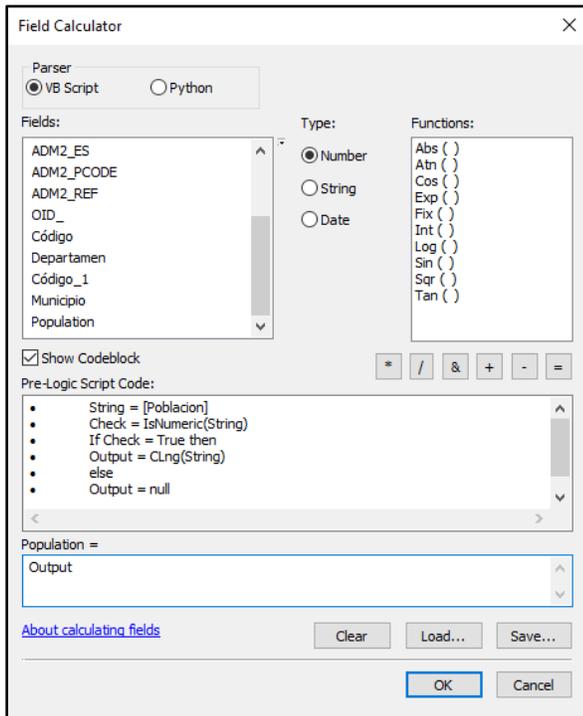
Figure 5. Field Calculator in the Calculate on a new column "Population" to take all string values from the column "Poblacion" and return them into the new column as integers.
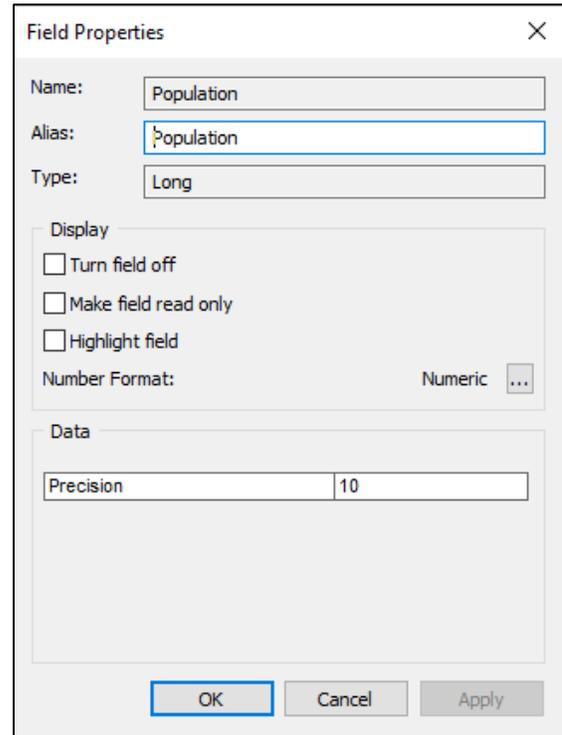
*Figure 6. Field Properties of the Population Column to show Long Integer*
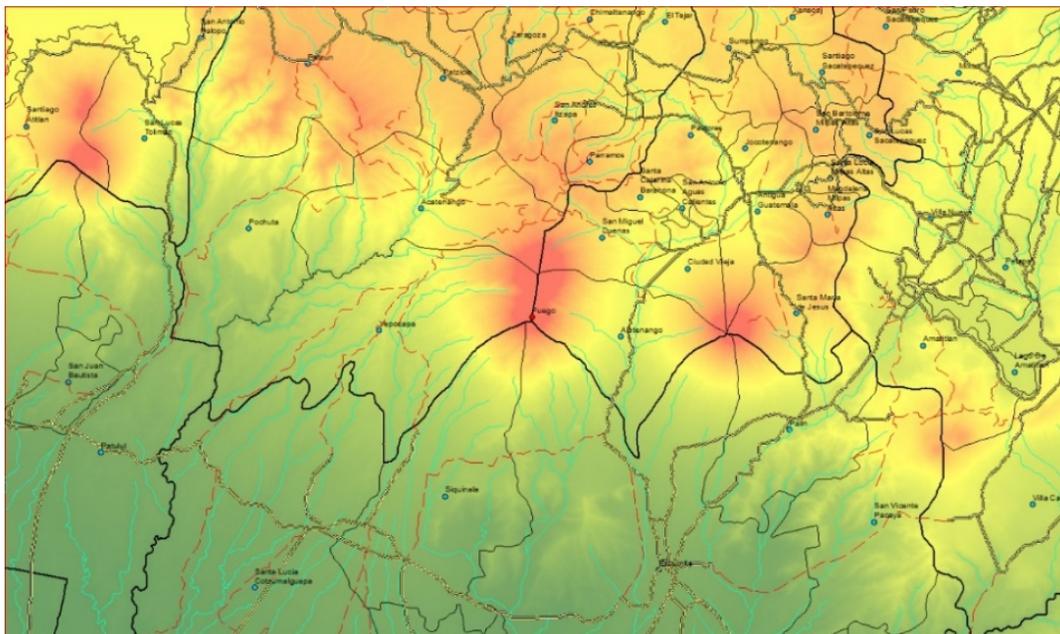
Figure 7. Map of Area of Interest (Fuego Volcano) with Rivers and Roads clipped in and City Point data distributed.

Processing:

To get a better sense of slope and topography on the map I decided to create a Hillshade of the elevation map and create contour intervals as well. For the Hillshade, I ran the Elevation Data layer through the Hillshade (Spatial Analyst Tool) using a Z-factor of .00000934 since I am around a longitude close to 15N (Fig. 8 & 9).
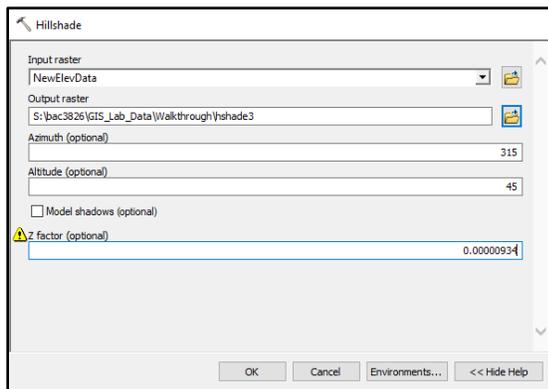
Figure 8. Conversion of Elevation Data into a Hillshade to Demonstrate Data on a Map.
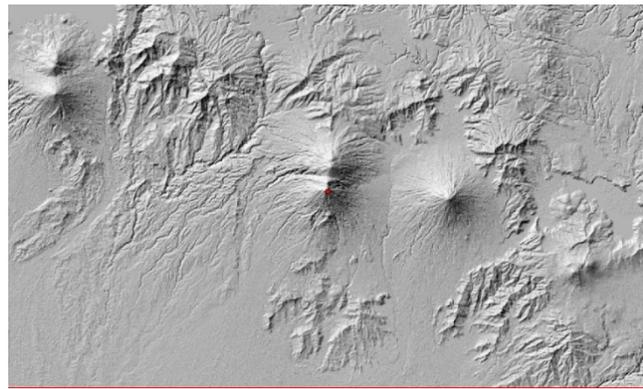
Figure 9. Hillshade of Elevation Data
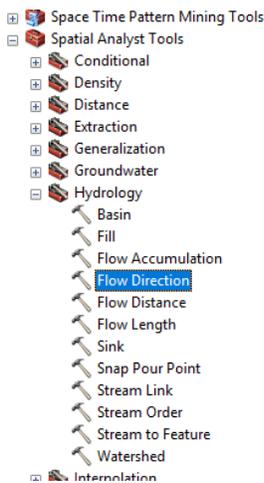
Figure 10. Contents of Hydrology Toolbox
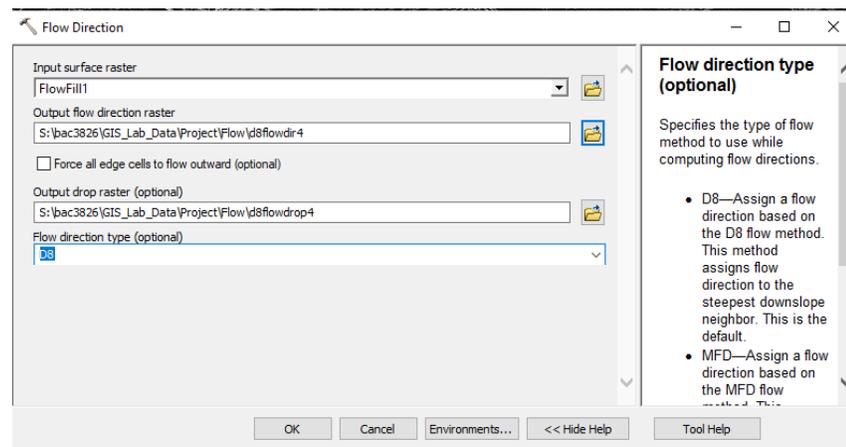
Figure 11. Turning the smooth elevation file into an flow direction profile.

To generate Lahars I used the Hydrology (Spatial Analyst) toolbox (Fig. 10) which has a variety of tools that work in sequence with one another. Since the tools analyze differences in elevations to create flow patterns, small imperfections in the data where drainage direction may not be assigned (sinks) need to be smoothed over which is done by using the Fill tool. After this I used the Flow Direction tool to rasterize flow direction (Fig. 11) using the D8 method which models flow direction from each cell to its steepest downslope neighbor, also creating an output drop raster which 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 (Fig. 12).
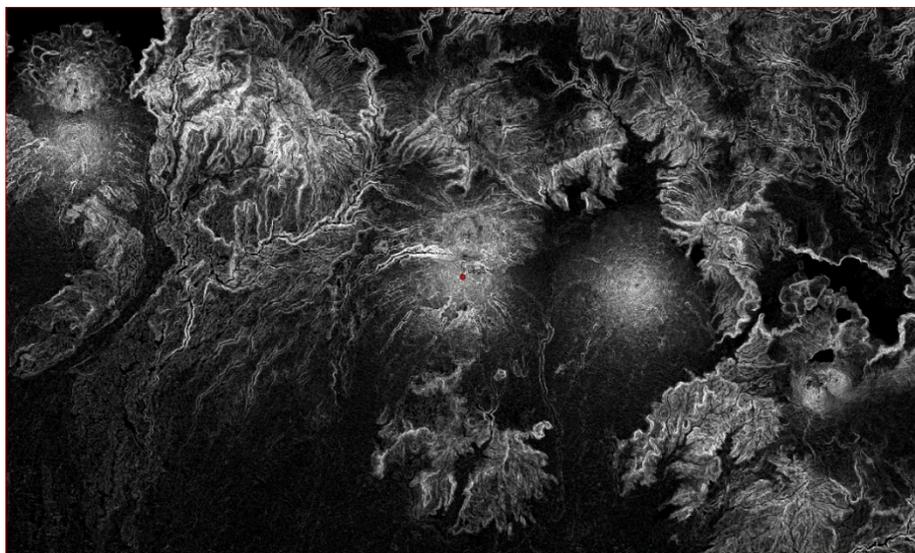
Figure 12. Drop raster of the elevation in the Area of Interest. Produces a profile very similar to a Slope file, but differs slightly in that it is a ranks these elevation changes.

Finally, I used the flow accumulation tool to assign accumulated flow into each cell with my direction raster using my drop raster as a weight and created some flow channels. Then I resclassified and symbolized the data to get more of the possible channels to appear (Fig. 13). Overlaying the river shapefile on top of the flow paths (Fig. 14), we may get a sense for the accuracy this method of creating flow patterns may create in helping us potentially model lahar flows for the future, if not simply rivers and streams themselves.

Figure 13. Flow Accumulation. A ranking of how powerful flow is based on how many streams discharge into a single stream. The brighter the line or area, the greater the flow. The symbolization has been enhanced for visual ease.
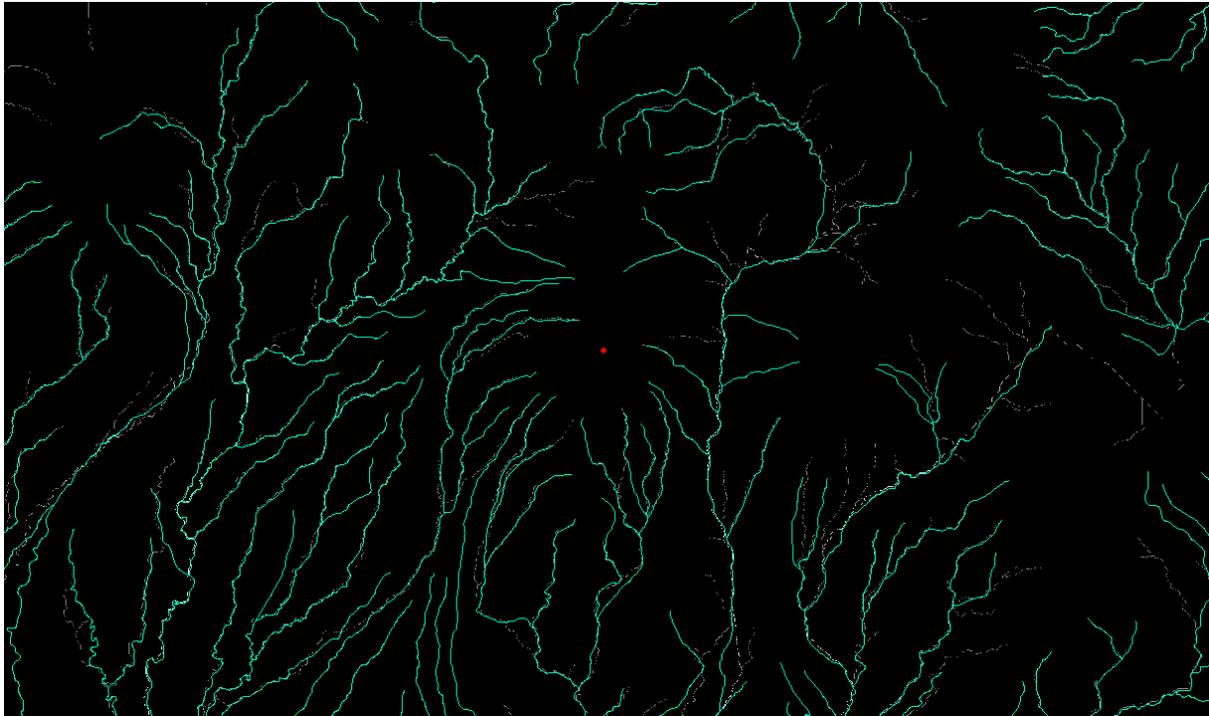
Figure 14. River shapefile, previously loaded in, overlain on Flow Accumulation raster to demonstrate accuracy of flow generation.

To get our new raster into polyline form for manipulation, we must run a raster calculation on our new accumulated flow layer essentially reranking it to a binary raster (Fig 15&16) and then run the raster to polyline tool on the resulting layer (Fig. 18). We must do this twice to get a set of flow paths for both the lahars and rivers (Fig. 17&19).
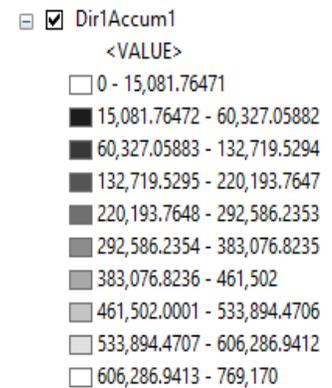
Figure 16. Ranking and classification of different line weights. The first class was changed to have no fill color so pathways could be overlain on a map.
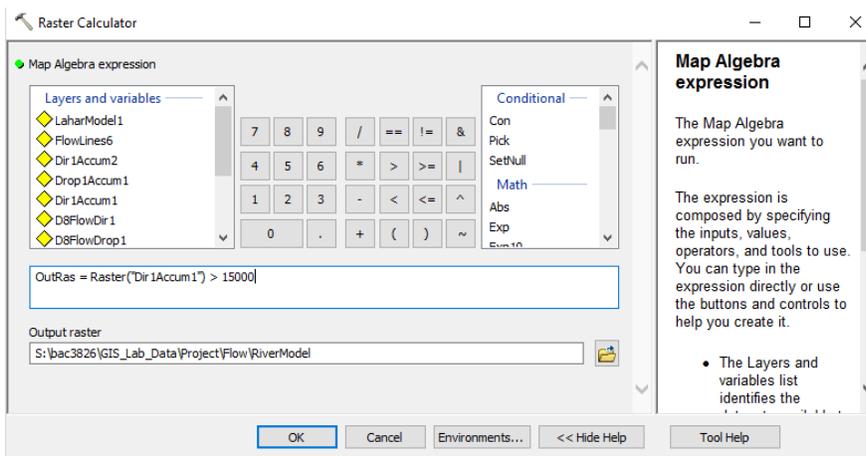
Figure 15. Raster calculator to form new binary rasters. Values over 15000 will generate a flow path of all rivers. Values over 60000 will represent a stronger accumulation of flow which are more likely to serve as Lahar flow pathways
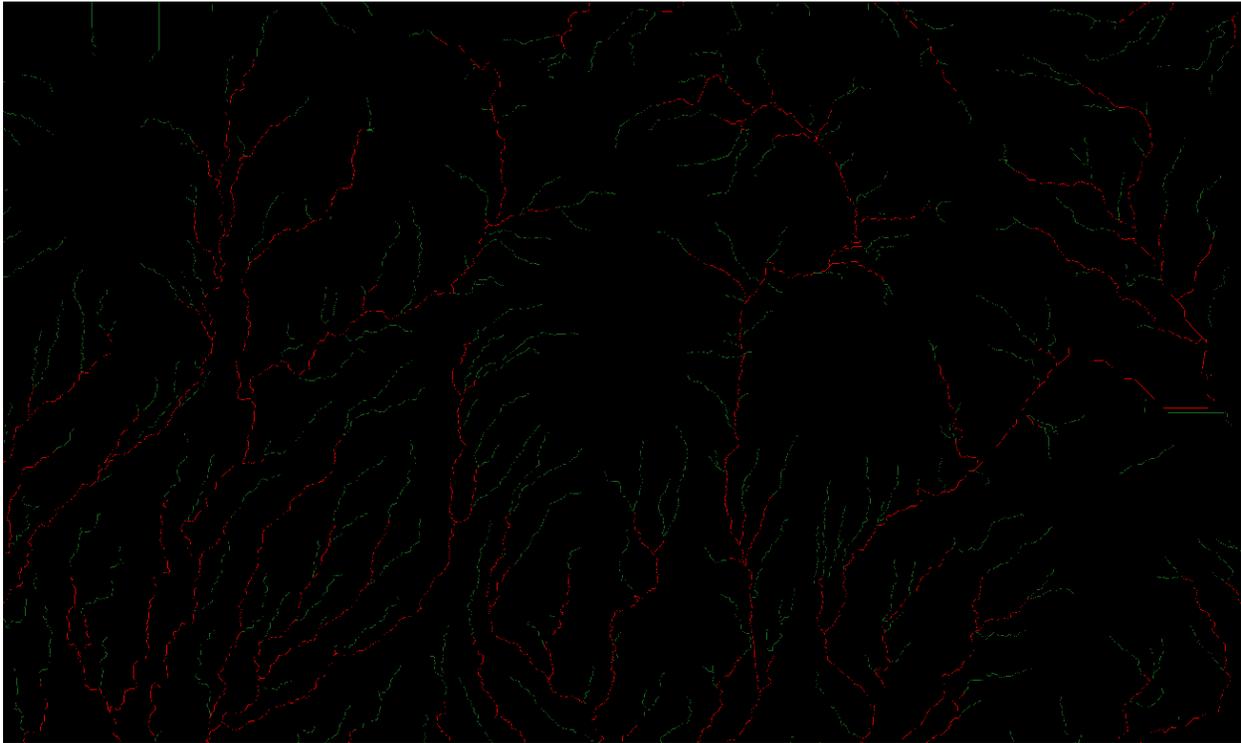
Figure 17. Representation of newly generated rasters. Green lines represent paths of rivers. Red Lines represent possible lahar flow lines.
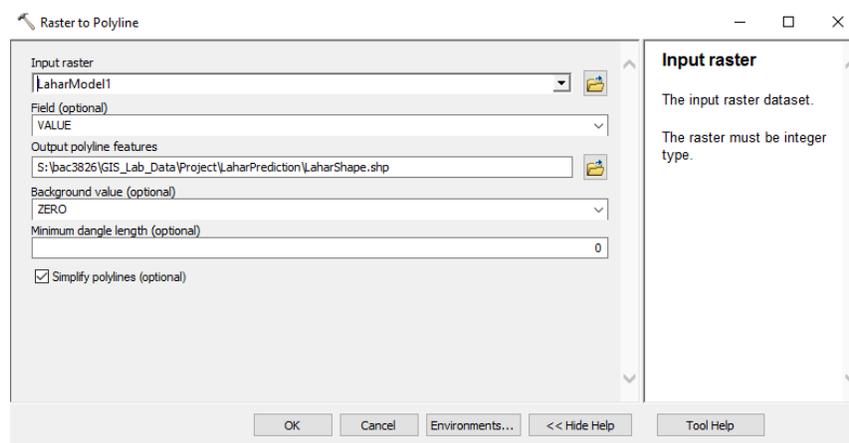
Figure 18. Converting Lahar Raster File into a Line Shapefile. The same is done for the rivers raster.
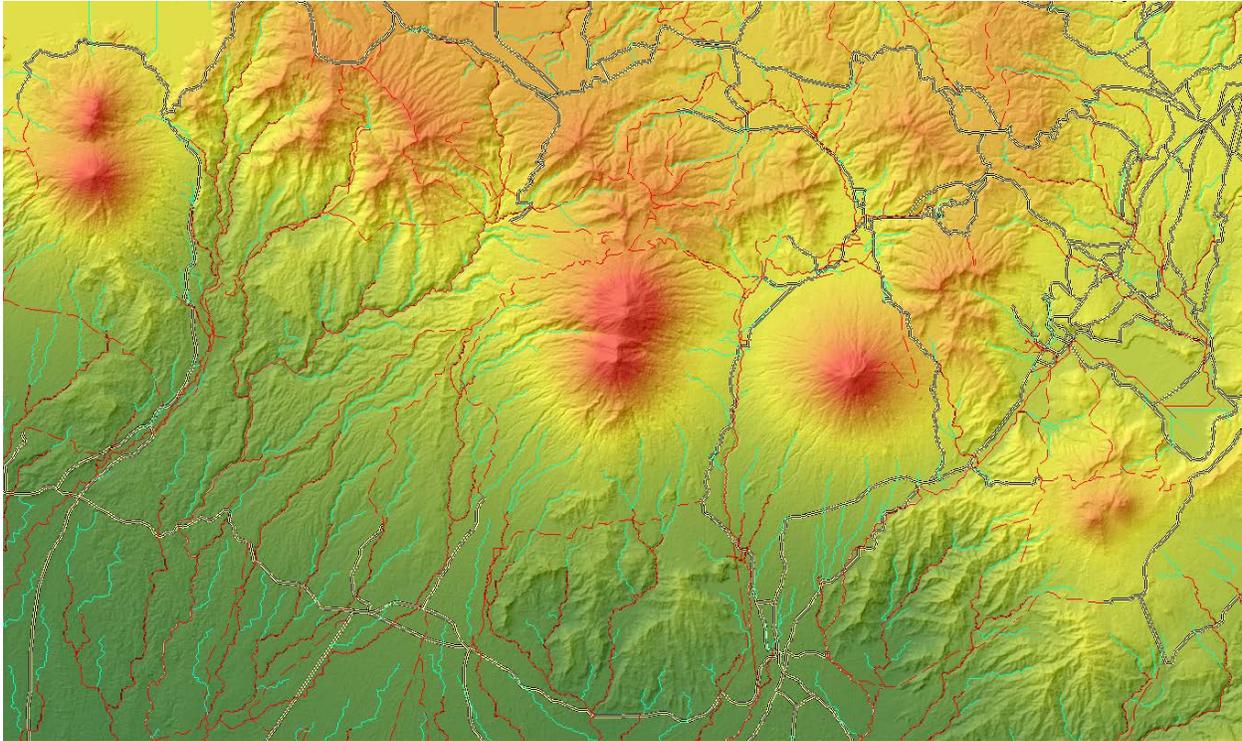
Figure 19. Map with Newly Created Lahar and River Flows as Shape Files that can be manipulated.

Unfortunately, since lahars rely on a variety of factors and mechanisms, our flow model for lahars (in red) will not accurately reflect those in reality to their fullest extent although it will do a great deal to identify pathways further downslope. The catch is that with this model, additional work needs to be done to identify the starting points of lahar flows, and so lahars will need to be buffered in manually utilizing the river flow patterns as they all flow into the lahar paths eventually.

Acknowledging the fact that Lahars have historically come down the southern flank of the volcano, I created a new layer by selecting rivers that stem from the southern hemisphere of the Fuego Volcano and travel southward. From there, I buffered a series of lahar extents from there on the river flow model to show areas potentially at risk for being impacted by small, medium, and large lahars (Map 1). Lahars paths that are typical and which occurred during the 2018 eruption may be compared with in Figure 20.
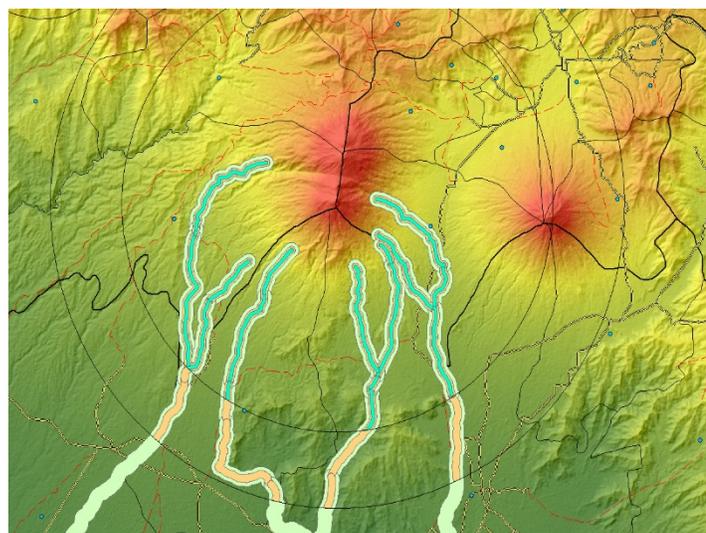
Figure 20. Lahar Path buffer of small, medium, and large lahar analogous to other hazard maps.

A map for aerial hazards was created by buffering areas around Fuego volcano for Ash and Tephra Cloud radii which were compiled from various sources seen in Map 2 (Smithsonian, Reid, Michigan Tech University).

Discussion:

In this project there are many errors and limitations to these models in discussing what may be pulled from them. Though this map may have some uses qualitatively, there is not much to pull from it quantitatively. The first mistake was using WGS 1984, a system which uses degrees and not meters. This means my shapefiles do not have lengths of meters associated with them, and area calculation is disabled in geometric calculation for the shape files. This has broad implications on being able to quantifiably assess the hazards in terms of area or volume.

Initially, I wanted to use population data to assess how much damage would be done by these volcanos due to lahar flows and pyroclastic flows, however associating them with points located at the geographic centers of the shapefiles is not an accurate means of showing population distribution. Simply dividing the area into the population to get a generic density as a means of attaining a "maximum" number of people who may be affected is also inaccurate. A more detailed analysis of population distribution throughout the region would be necessary to assess the true destructive potential of these lahar flows and projectile hazards, which goes beyond the scope of this project.

If I were using another coordinate system that used a linear unit of measurement, I would be able to use an intersection selection tool on roads and lahar flows to see how many square meters of road would be impacted. I could also use an inclusion selection tool to do the same with aerial hazards.

To generate better lahar flow patterns, mechanisms and triggers need to be identified to acquire more data, although the river models generated are pretty close to those imported into the project from World Bank. Another option would have been to use to the Laharz_py toolbox made available by the USGS which helps to create more accurate lahar flow patterns, however this requires that data is in meters to function properly. Elevation on a 10m scale would also be incredibly beneficial for creating more accurate flow maps for rivers so the subtle nuance of streams building up over distances may be more accurately portrayed. Most importantly, the generation of a proximal lahar zone is necessary to understand how flow occurs at Fuego, as my flow models would only be considered distal – away from the area affected by slope failure, avalanches, etc.

For the projectile or aerial hazards in my project, a larger area of interest is needed. Finding a way to correlate ash cloud height above the mouth of the volcano with the distance it travels would be incredibly useful alongside wind direction and speed to create models on possible ash coverage of neighboring areas. Following a similar process with tephra size and height would also be useful in generating a more accurate hazard map.

Lahar Flow Hazards of Fuego Volcano in Guatemala

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09 December 2019

N

Point Data
- Fuego
- Municipality Centers

Projected Flows
- Lahar Flows
- Rivers

Lahar Path Projections
- Small Lahar
- Medium Lahar
- Large Lahar

Roads
- Asphalt
- Unpaved

Department Borders
- Department Borders
- Municipality Lines
- Area of Interest

Elevation (m)
- High : 3977
- Low : 43

GCS WGS 1984

Aerial Hazards of Fuego Volcano in Guatemala

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09 December 2019

N

91°0'0"W 90°50'0"W 90°40'0"W 90°30'0"W

14°40'0"N

14°30'0"N

14°20'0"N

91°10'0"W 91°0'0"W 90°50'0"W 90°40'0"W 90°30'0"W

San Antonio Palopo
Patzun
Patzicia
Zaragoza
Chimaltenango
El Tejar
Sumpango
Santo Domingo Xenacoj
San Pedro Sacatepequez
Lucas nan
San Andres Itzapa
Pastores
Jocotenango
Santiago Sacatepequez
San Bartolome Milpas Altas
Mixco
Parramos
Santa Catarina Barahona
San Antonio Aguas Calientes
Santa Lucia Milpas Altas
San Lucas Sacatepequez
Acatenango
Pochuta
San Miguel Duenas
Antigua Guatemala
Magdalena Milpas Altas
Villa Nueva
Ciudad Vieja
Petapa
Fuego
Yepocapa
Alotenango
Santa Maria de Jesus
Amatitlan
San Juan Bautista
Lago De Amatitlan
Palin
Patulul
Siquinala
San Vicente Pacaya
Villa Canales
Escuintla
Santa Lucia Cotzumalguapa

Point Data
- 🔴 Fuego
- 🔵 Municipality Centers

Projected Flows
- —— Lahar Flows
- —— Rivers

Aerial Hazards
- 20cm Tephra
- 10cm Tephra
- 8km Ash Radius
- 12km Ash Radius
- 19km Ash Radius

Roads
- Asphalt
- —— Unpaved

Department Borders
- Department Borders
- Municipality Lines
- Area of Interest

Elevation (m)
High : 3977
Low : 43

GCS WGS 1984

Volcanic Hazards of Fuego Volcano in Guatemala

Brandon Cooper
09 December 2019

N

GCS WGS 1984

Point Data
- 🔴 Fuego
- 🔵 Municipality Centers

Projected Flows
- Lahar Flows
- Rivers

Lahar Path Projections
- Small Lahar
- Medium Lahar
- Large Lahar

Aerial Hazards
- 20cm Tephra
- 10cm Tephra
- 8km Ash Radius
- 12km Ash Radius
- 19km Ash Radius

Roads
- Asphalt
- Unpaved

Department Borders
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Elevation (m)
- High : 3977
- Low : 43