Volcanic Hazard Assessment for Volcán de Fuego de Colima

Daniel Ortega-Arroyo

Objective:
Identify the main hazards associated with Volcán de Fuego de Colima, as well as, the affected communities.

Background:
Volcán de Fuego de Colima located at the boundary of Jalisco and Colima in the western section of the Trans-Mexican Volcanic Belt is the most historically active volcano in Mexico. The magmatism, as well as, tectonics of the region have been associated to the subduction of the Rivera and Cocos plates beneath the North American plate. The composite volcano is part of the Colima Volcanic Complex (CVC) overlapping the older extinct cone of Nevado de Colima. The andesitic composition and water content of Volcán de Fuego de Colima, similar to other volcanoes in the CVC, has favored numerous vulcanian to plinian eruptions as well as many sector collapses throughout its history. Therefore the proximity of the volcano to many rural communities and cities poses many health and economic risks to the population.

Population: Data Collection and Data pre-processing

Vector files for the rivers, water bodies, roads, ranches, villages, towns, cities, state and municipality boundaries were obtained from the Mexican National Institute of Statistics and Geography (INEGI) via the links listed below

- http://www.inegi.org.mx/geo/contenidos/recnat/default.aspx
- http://www.inegi.org.mx/geo/contenidos/urbana/default.aspx
- http://www.inegi.org.mx/geo/contenidos/geoestadistica/M_Geoestadistico.aspx

A 15m-resolution digital elevation model (DEM) for the area surrounding the volcano was also obtained from INEGI through the link listed below.

- http://www.inegi.org.mx/geo/contenidos/datosrelieve/continental/Descarga.aspx

The number of inhabitants per municipality was obtained from the 2010 national population census also available from INEGI. Unfortunately there was no data available for the population of each community; therefore the number of inhabitants per municipality was used instead.

All files were publicly available from INEGI and downloaded as zip files. Since the files only had Geographic Coordinates, once extracted, Batch Project tool was used to project them to the same preferred spatial reference for this analysis (Universal Transverse Mercator (UTM) zone 13 with a NAD 1983 Datum).

Because the vector files spanned all of Mexico, they were further clipped to the states of Jalisco and Colima, the main regions affected by the volcano. This was done by first selecting the Jalisco and Colima state boundaries from the attribute table and creating a new layer from the selection.

The other files were further clipped using the Clip tool found under Analysis in ArcToolbox using the Jalisco and Colima state boundaries as the clip surface.
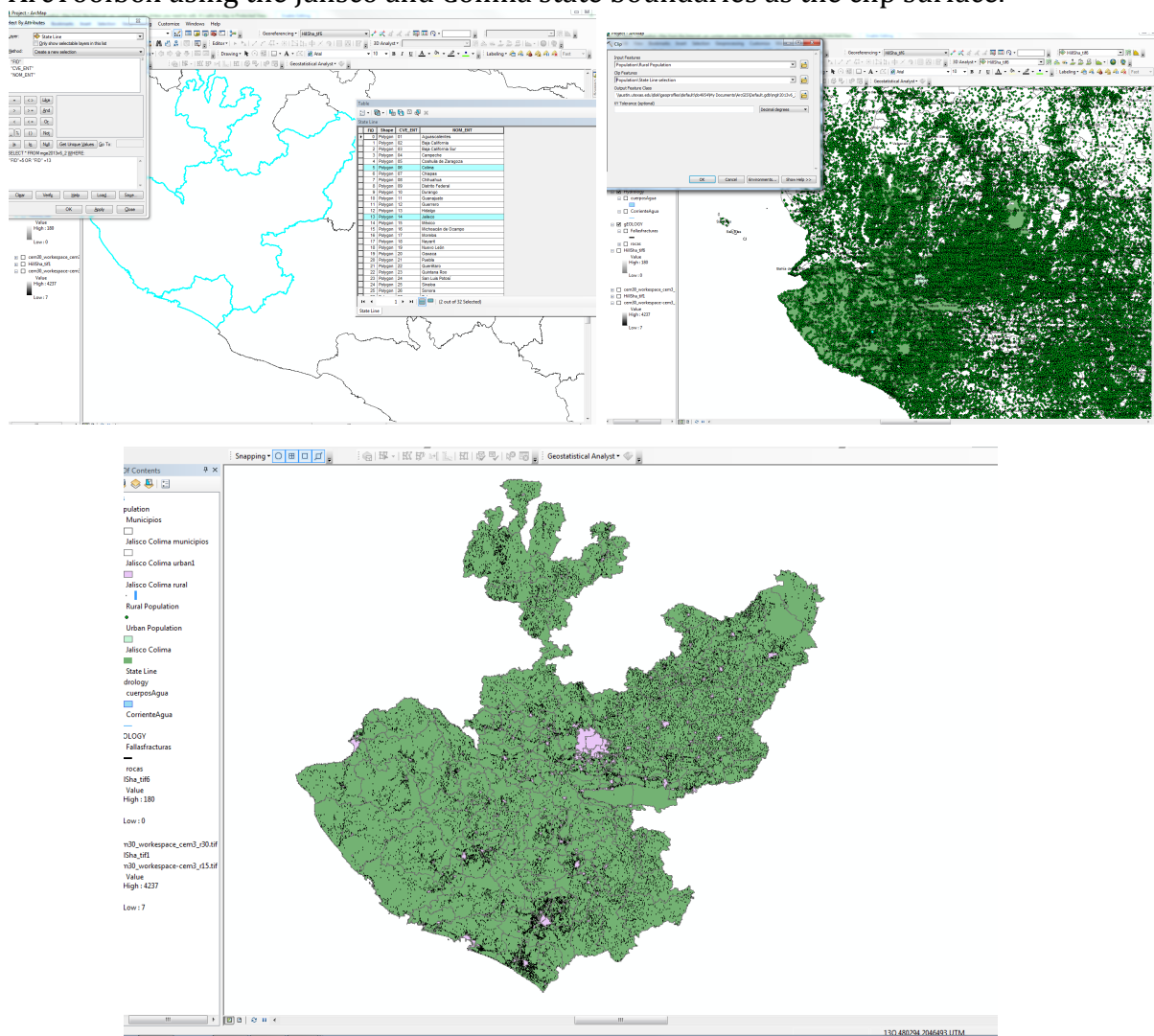

Figure1. The process of clipping the files to the state boundaries. A) Selection of the states of Jalisco and Colima. B) All shape files overlaid on top of the state boundaries before using Clip tool. C) Clipped files.

The number of inhabitants per municipality was later added to the municipality shape file by joining the Excel worksheet containing the data. The Excel worksheet containing the data was saved as a .csv file and later added to the ArcMap project. Once added, the .csv file was opened and formatted so that it matched the

municipality attribute table format. Then, the municipality file is selected with the right click to choose the Join option. The "Join attributes from a table" option is chosen and the field containing the name of the municipality is selected to base the join from the table.

The municipalities were further color coded by population density using the "Graduated colors" option under the Symbology tab in the Layer properties window. The range of inhabitants per municipality was determined by manually classifying representative break values.
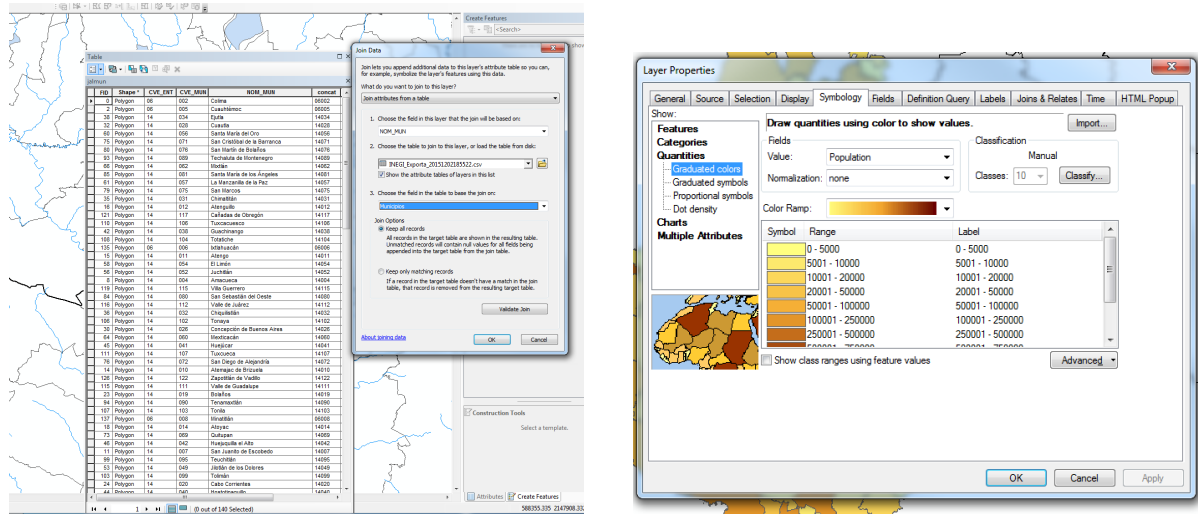

Figure 2. A) Joining table and layer attributes. B) Color-coding municipalities by population density in the Symbology tab.

A hillshade of the area surrounding the volcano was created after the DEM raster file was projected to UTM coordinate system using the Hillshade tool from ArcToolbox.
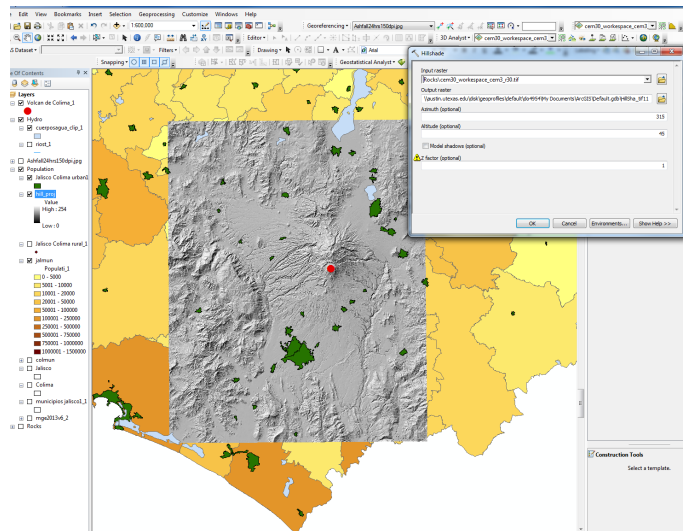
Figure 3. Result of creating hillshade for Volcan de Colima DEM

Hazard Assessment: Data Collection and Processing

The ash dispersion data was obtained from the latest numerical simulations done on Fall3D by Dr. Rosanna Bonasia and Dr. Lucia Capra from CGEO-UNAM, using data from the Mexican Meteorological Service and CENAPRED and assuming a column height of 2km. The ash dispersion data was publicly available as an animated GIF in the website listed below.

- http://www.geociencias.unam.mx/mexican_volcanoes/volcanoes/colima/fall_3D/fall_3D.php?req=show_movies_sp&&fall3d_simu=20151105&&month=11&&year=2015

For this project, the data from the simulation after 24Hrs from the eruption was chosen so as to have a better coverage of the affected areas. This was done by selecting the slide of the animation corresponding to the 24 Hrs mark in Adobe Illustrator and then exporting it into JPG format with a higher resolution. Once the image was exported and opened in ArcMap it was georeferenced to the area of interest by adding control points in the coastline and distinct water bodies using the georeferencing tool.
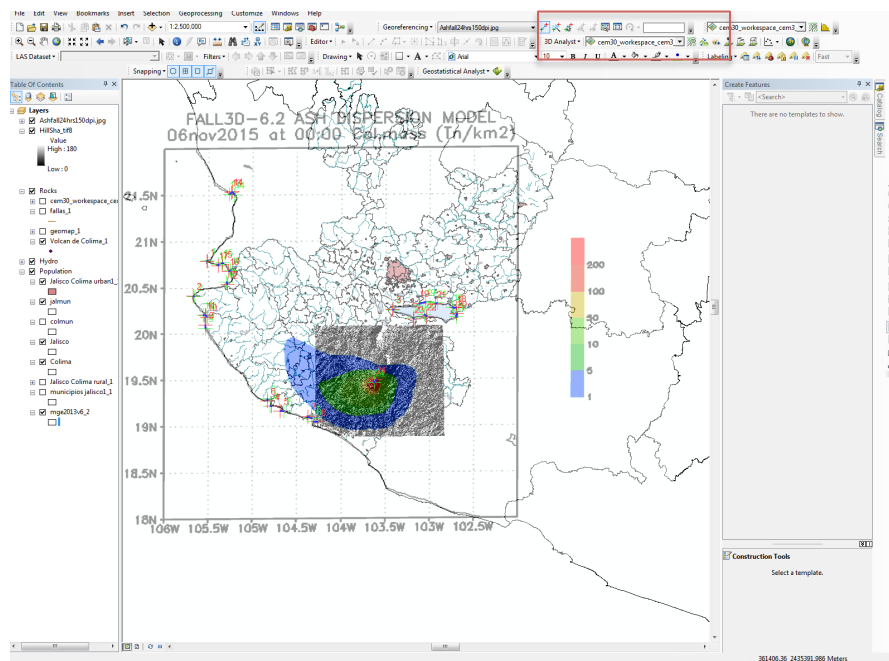

Figure 4. Georeferencing the ash dispersion simulation. Georeferencing tool is highlighted by the red rectangle

A detailed geologic map of the CVC volcanic deposits used to assess areas prone to debris avalanches and lahar and lava flows was taken from (Cortés et al., 2005) in addition to the general geologic map vector files available from INEGI.

The geologic map from (Cortés et al. ,2005) was georeferenced similarly to the ash dispersion data above, using the peak of Volcán de Fuego de Colima as one of the control points and various distinct bends of the rivers.

A personal geodatabase was created in ArcCatalog adding domains for the different ash dispersion zones (short integer data), type of volcanic deposits (text data), volcanic deposits abbreviations (text data), and other volcanic hazards (text data). Inside the geodatabase, polygon feature classes for the ash dispersion zones, volcanic deposits and volcanic hazards were created adding the respective fields to each class. A point class was also created to identify the summit of the volcano.
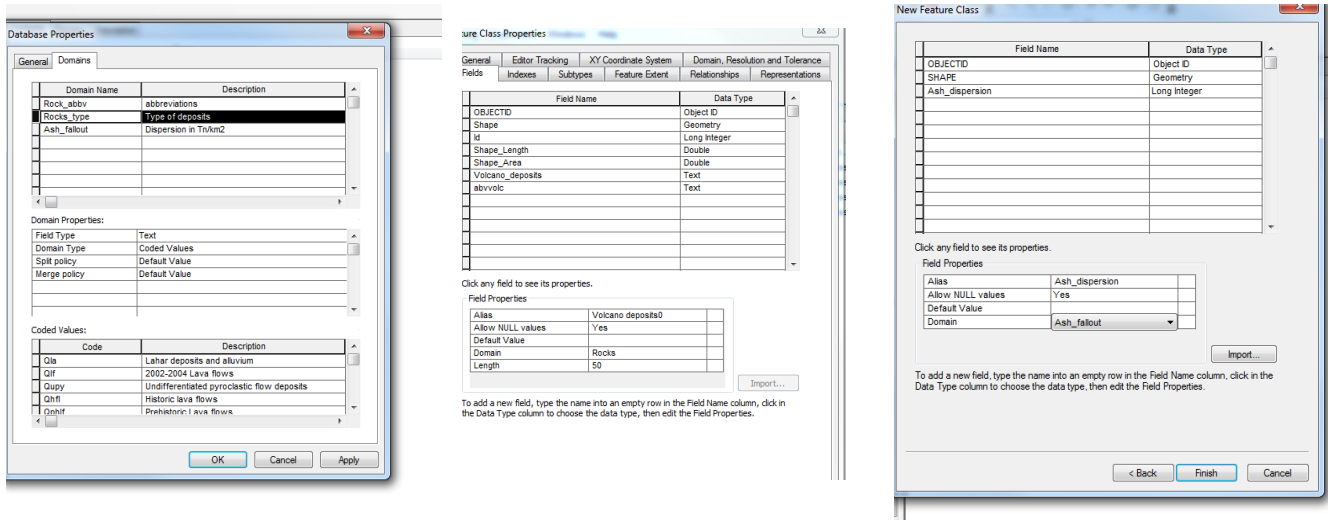

Figure 5. A) Defining domains in the geodatabase. B) Defining the Fields for the Geologic map feature classes and the domains for each field. C) Defining fields for the Ash dispersion feature.
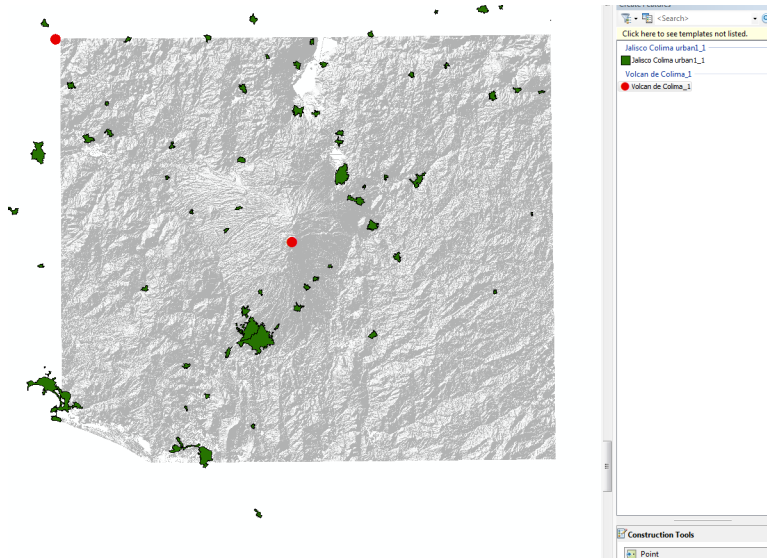

Figure 6. Creating Volcan de Colima summit point feature.

The ash dispersion simulation and geologic map were further digitized to their respective layers by contouring the contact of the different features by creating a new line feature class. The Feature to Polygon tool was then used to create the different polygons. Their attributes were then modified through the attribute option in the editor bar.
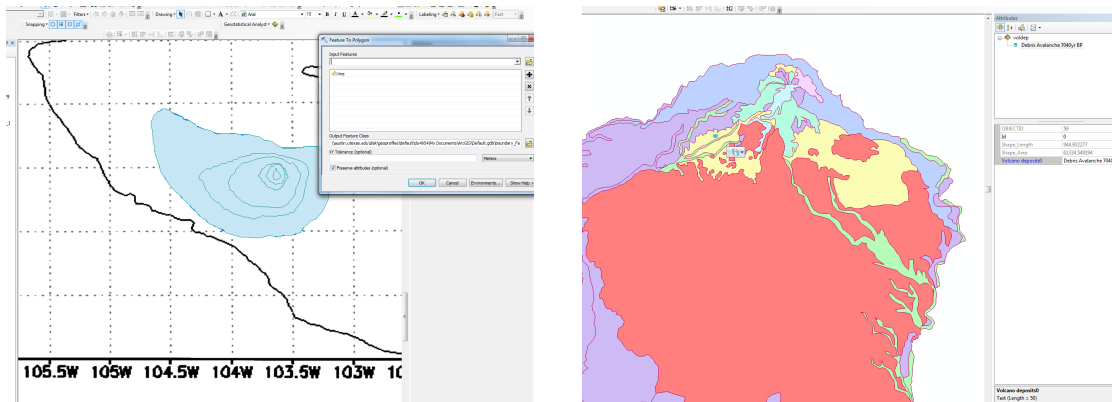

Figure 7. A) Polygon feature for the ash dispersion layer after using Feature to Polygon tool. B) Defining type of volcanic deposits in the geologic map.

For the tephra hazard map, the hazard zone for projectiles bigger than 10cm was calculated using previous studies (Blong, 1983), in which lapilli and bomb sized projectiles from similar volcanoes around the world were found up to 12km from crater. This was achieved using the Buffer tool with a 12km radius.
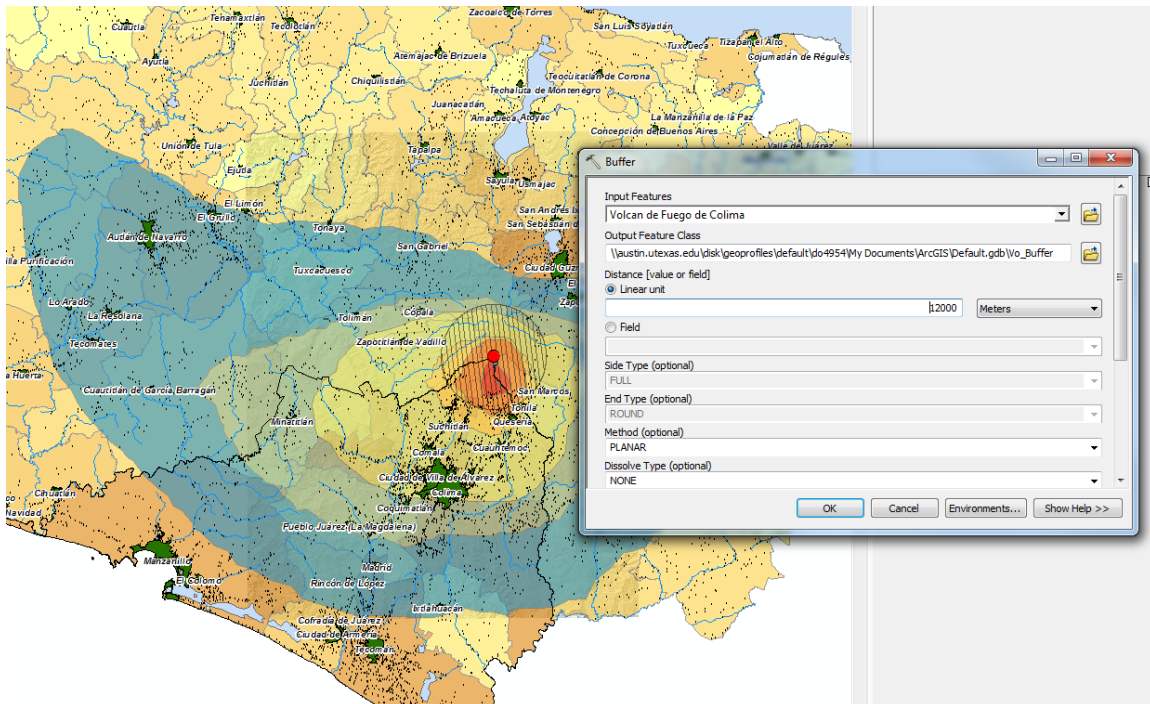

Figure 8. Generating the zone where block and lapilli sized projectiles are likely to hit.

The total population affected ash fallout was then calculated using the selection by location tool. The selection query included any municipality that intersected the affected areas. The same was done for cities, town, villages, and ranches. Once selected, the total population affected by tephra was calculated through the statistic option found by right clicking the population field on the municipality layer, whereas the number of affected communities was calculated by looking at the number of selected feature in their respective attribute tables.
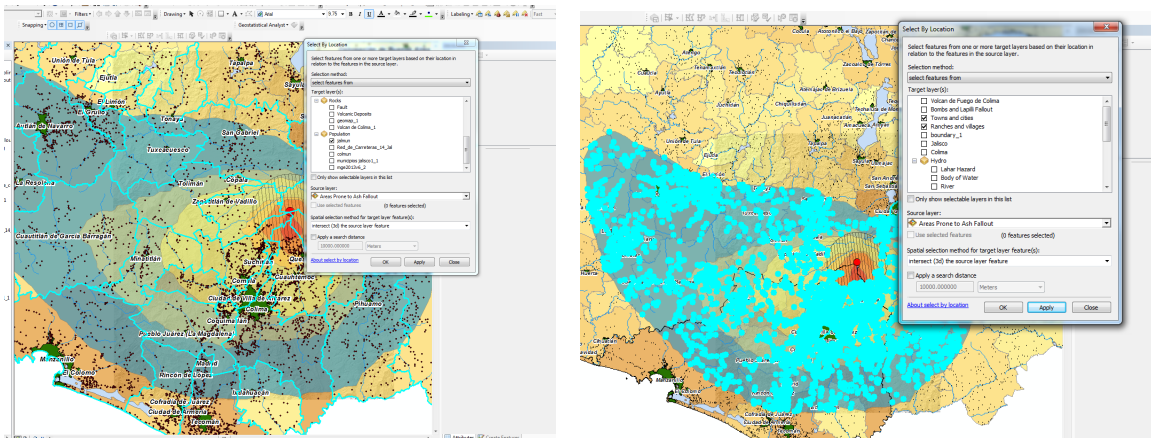

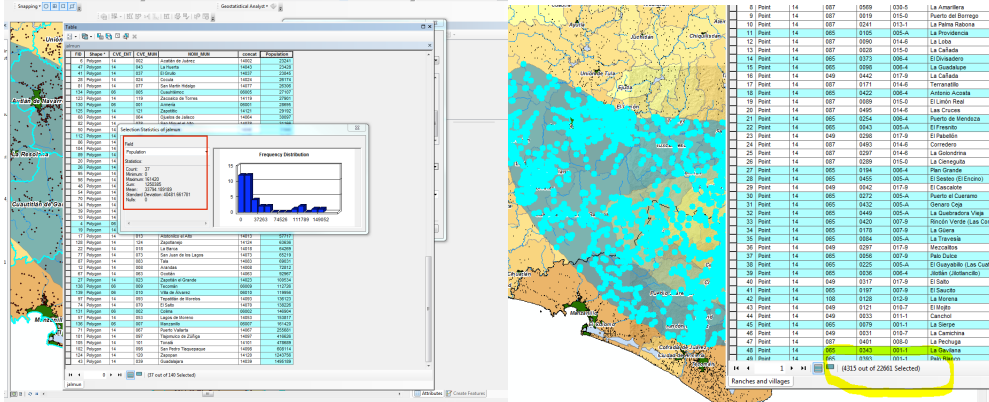**Figure 9.** A) Selecting affected municipalities B) Selecting affected communities.

Figure 10. A) Measuring the number of affected inhabitants. B) Measuring the number of affected ranches, villages, towns and cities.

A more regional map was made for the lava flow, debris avalanches and lahar hazards, given that the phenomena are less dispersed than tephra fallout.

In order to assess their hazards, the type of previous volcanic deposits found in the region and their relation to topography was taken into account, as seen in the geologic map modified from (Cortés et al., 2005), whereas only volcanic deposits from the Volcán de Fuego de Colima are shown.
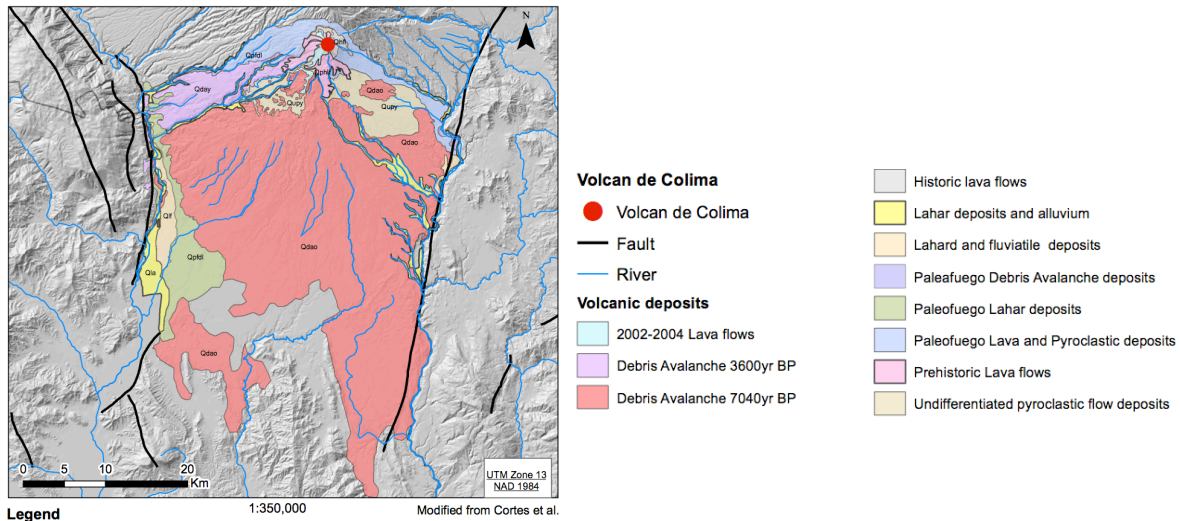
Figure 11. Modified geologic map from (Cortés et al., 2005) showing only the different type of volcanic deposits from Volcán de Fuego de Colima.

It is observed that the lahar deposits are restricted to ravines and rivers that start on the slopes of the volcano and could therefore be areas prone to subsequent lahar flows. In addition to, normal faults, which define the Colima graben, appear to influence the extent to which lahars and debris avalanches are deposited.

ArcScene was later use to help in the assessment of the areas prone to lahar, as it showed clearly which rivers are on the slope of the volcano. The DEM, the volcano summit point, and the river file were loaded on a blank page on ArcScene. In their properties, under the "Base and Height" tab, the option "floating on a custom surface" was selected to render them in 3D.

The lahar prone areas were then calculated with the Buffer tool using the selected rivers as the input features and radius of 200m as most of the rivers are constricted to steep ravines.
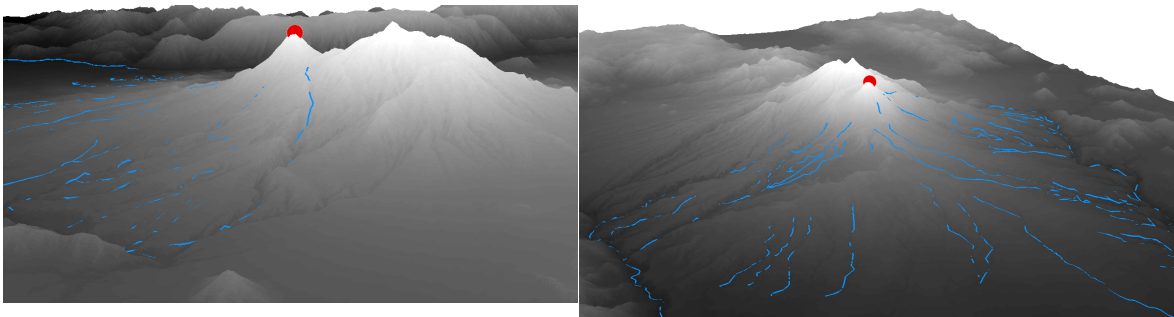.

Figure 12. ArcScene view of the DEM A) E view of the volcano. B) SW view of the volcano
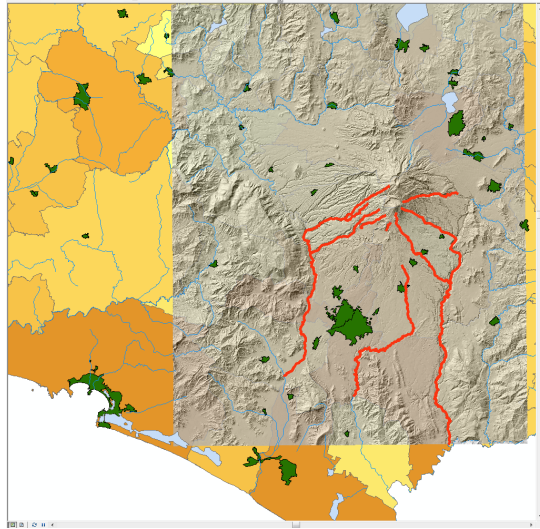
Figure 13. Preliminary selection of lahar prone areas.

The debris avalanche hazard zone was estimated from the extent of previous events, as well as, using the Colima Graben faults and the extinct Nevado de Colima as boundaries. Similarly, the lava flow hazard zone was estimated using past flows and assuming a vulcanian-type eruption. For both hazard zones, a new polygon feature was drawn on top of past deposits found on the geologic map.
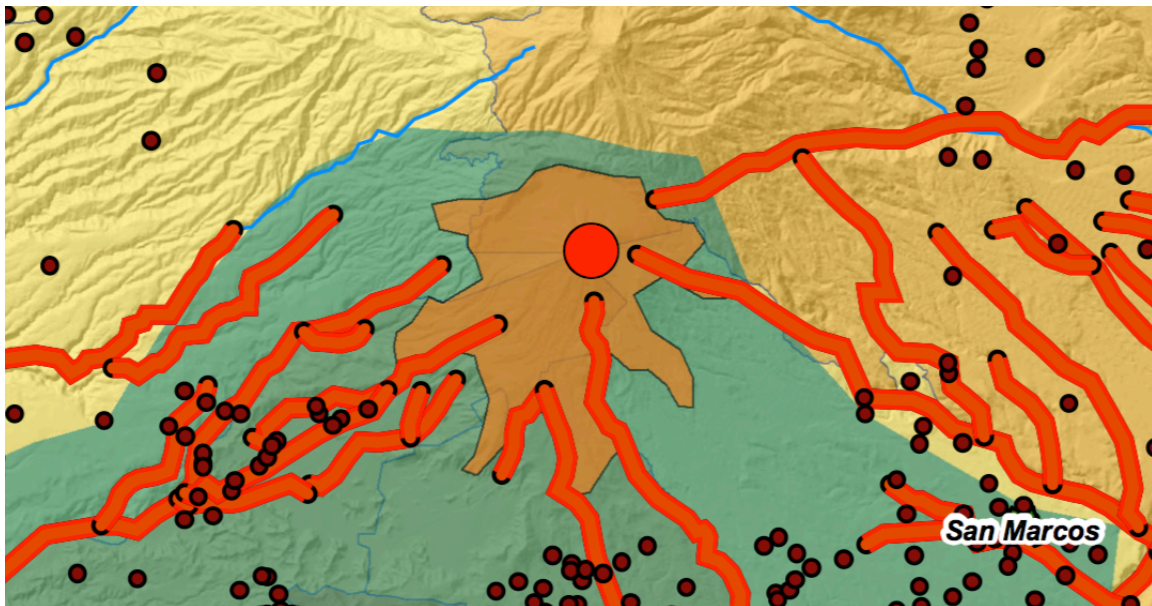

Figure 14. Shows region prone to lava flows, debris avalanches and lahar hazards.

Labels for each of the towns and cities in the region were later added through the label tab under the layer properties.

To calculate the affected population and communities for each of the disasters, the same steps described for the tephra hazards were used.

Results and Conclusions:

My analysis showed that up to 4353 communities and a total population of 1,250,385 could be affected if an eruption were to occur in the Volcán de Fuego de Colima. Interestingly, my results show that about half of the affected population is on the path of the more destructive phenomena, debris avalanches and lahar flows. While a debris avalanche might not be a likely disaster during our lifetime due to the apparent cyclicity observed in the rock record, it was taken into account due to the volcano's numerous sector collapses throughout its history.

Table 1. Affected Population

Hazard	Affected population	Affected towns and cities	Affected ranches and villages
Ash	1,250,385	38	4315
Bombs and lapilli	253,098	0	94
Lahar	431,087	4	77
Lava flow	117,832	0	0
Debris Avalanches	404,077	9	1299

It is likely that this analysis overestimates the total affected population because it counts the total number of inhabitants per affected municipality instead of each community inside the hazard prone areas. Therefore, for future studies it is imperative to collect data for each of the communities to have more accurate results.

Caution should be taken when using this assessment, as it does not take into account the considerable variability of the phenomena, e.g., only one of the possible paths for the dispersion of tephra due to wind strength and direction was considered in this study. For a better and more thorough assessment other important variables should be taken into consideration, eruption type, seismicity, slope gradient, vegetation (forest fires generated due to incandescent material), amount of rainfall, width of ravines, etcetera.
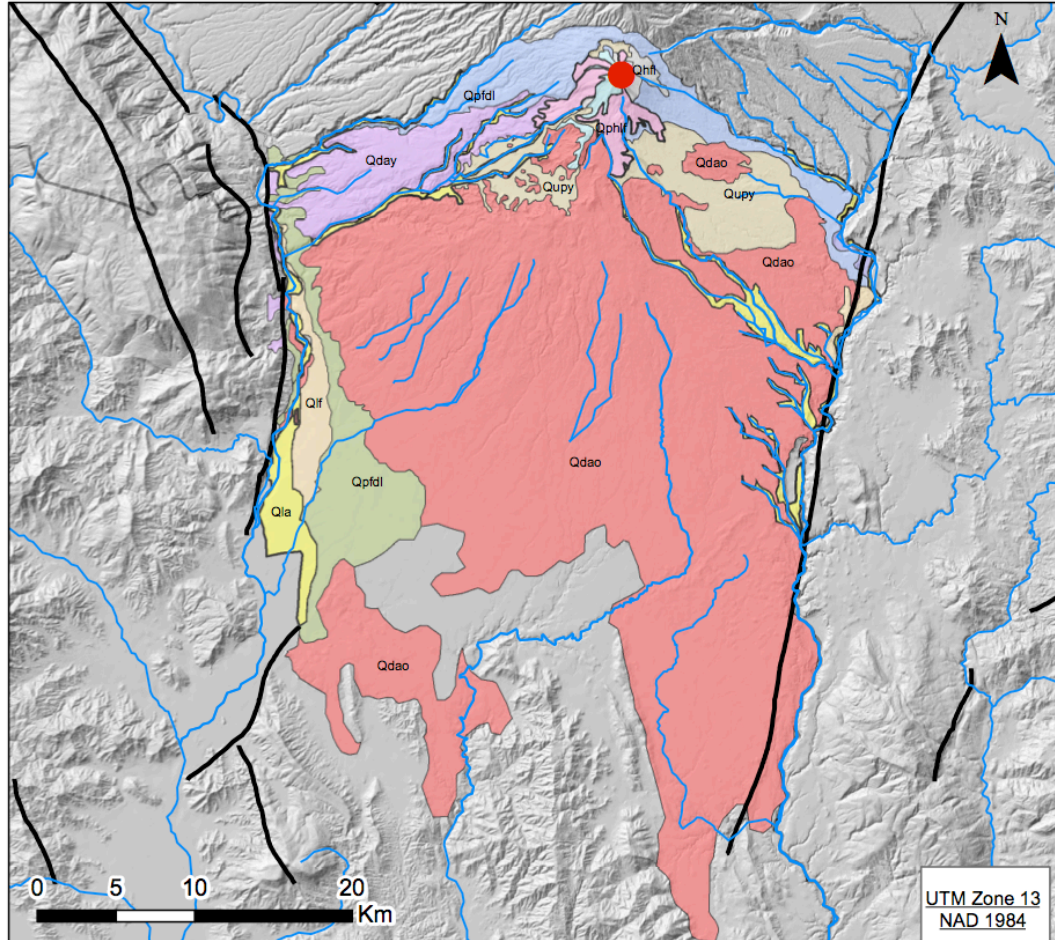
References:

Blong, R. (1984). Volcanic hazards: A sourcebook on the effects of eruptions (1st ed.). Orlando, Florida: Academic Press.

Colima @nline: Fall3D-Simulaciones para la dispercion de ceniza volcanica (Colima @nline: Fall3D-Simulaciones para la dispercion de ceniza volcanica) http://www.geociencias.unam.mx/mexican_volcanoes/volcanoes/colima/fall_3D/fall_3D.php?req=show_movies_sp&&fall3d_simu=20151105&&month=11&&year=2015

Macías, J. (2007). Geology and eruptive history of some active volcanoes of México. In *Special Paper 422: Geology of México: Celebrating the Centenary of the Geological Society of México* (Vol. 422, pp. 183–232). Geological Society of America. http://doi.org/10.1130/2007.2422(06)

Komorowski, J.C.; Navarro, C.; Cortes, A.; Siebe, C. , 1994. The repetitive collapsing nature of Colima volcanoes (Mexico) , Proceeding of Colima Volcano International Meeting, pages 12-18.

Geologic Map of Volcan de Colima deposits

Qhfl
Qpfdl
Qday
Qpfl
Qupy
Qdao
Qupy
Qdao
Qlf
Qpfdl
Qla
Qdao
Qdao

N

0   5   10   20
Km

1:350,000

UTM Zone 13
NAD 1984

Modified from Cortes et al 2005

Legend

Volcan de Colima

🔴 Volcan de Colima

— Fault

— River

Volcanic deposits

2002-2004 Lava flows

Debris Avalanche 3600yr BP

Debris Avalanche 7040yr BP

Historic lava flows

Lahar deposits and alluvium

Lahard and fluviatile deposits

Paleafuego Debris Avalanche deposits

Paleofuego Lahar deposits

Paleofuego Lava and Pyroclastic deposits

Prehistoric Lava flows

Undifferentiated pyroclastic flow deposits

Volcan de Fuego de Colima Tephra Hazard Map
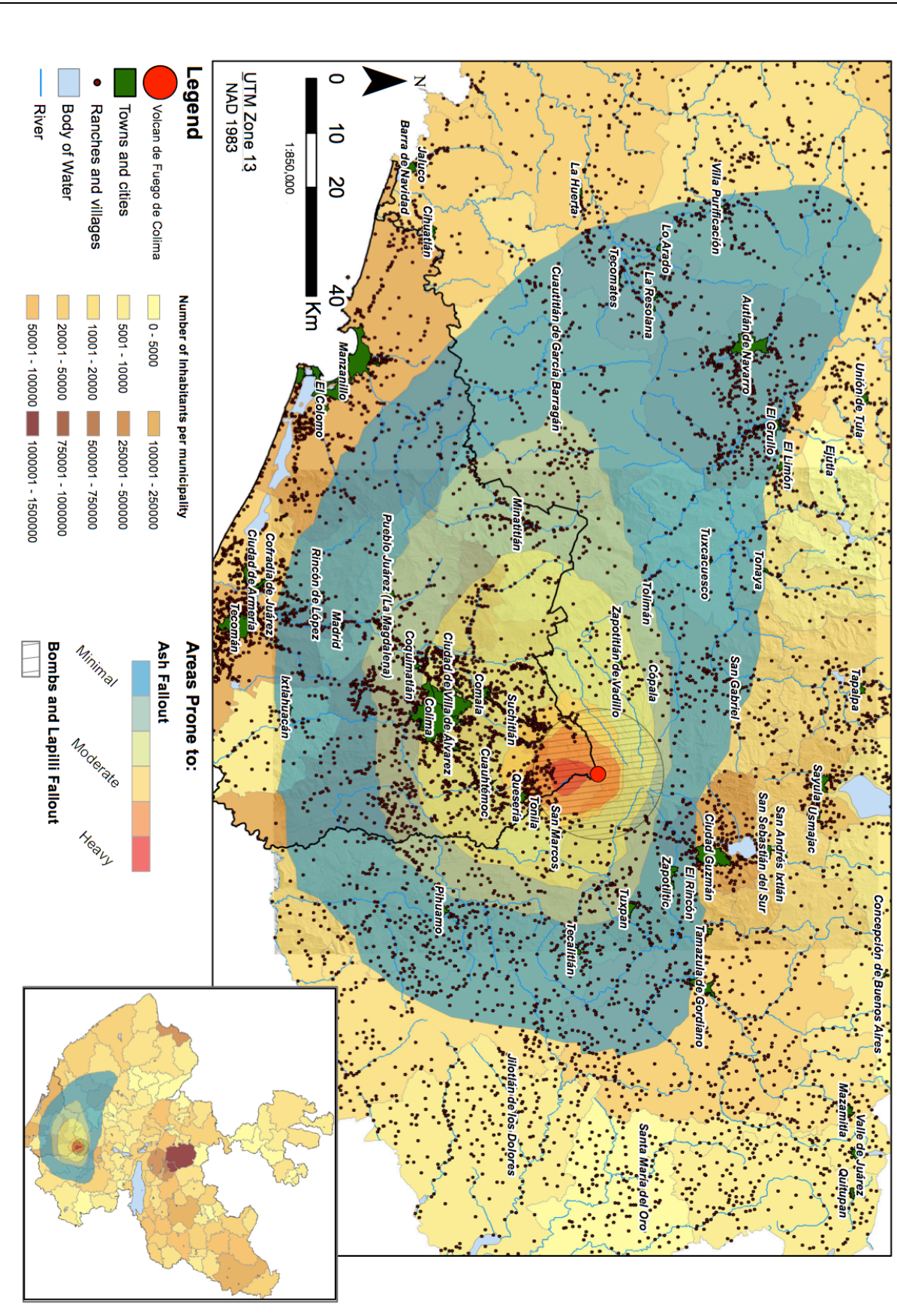
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12/01/2015

Legend

Volcan de Fuego de Colima

Towns and cities

Ranches and villages

Body of Water

River

UTM Zone 13
NAD 1983

1:850,000

0 10 20 40 Km

Number of Inhabitants per municipality

- 0 - 5000
- 5001 - 10000
- 10001 - 20000
- 20001 - 50000
- 50001 - 100000
- 100001 - 250000
- 250001 - 500000
- 500001 - 750000
- 750001 - 1000000
- 1000001 - 1500000

Areas Prone to:

Ash Fallout

Minimal   Moderate   Heavy

Bombs and Lapilli Fallout

Volcan de Fuego de Colima Lava Flow, Lahar, and Debris Avalanches Hazards Map

Daniel Ortega-Arroyo
12/01/2015

Zapotitlán de Vadillo

Tuxpan

San Marcos

Tonila

Quesería

Suchitlán

Cuauhtémoc

Comala

El Trapiche

Ciudad de Villa de Álvarez

Colima

Pihuamo

Coquimatlán

UTM Zone 13
NAD 1983

Km
0   5   10   20
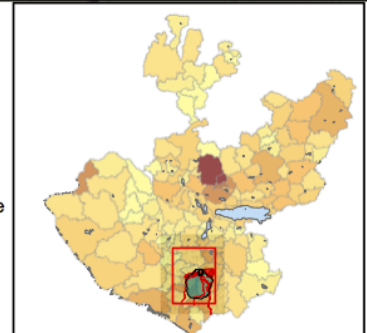1:300,000

Legend

- 🔴 Volcan de Fuego de Colima
- • Ranches and villages
- 🟩 Towns and cities
- — Roads
- ▭ State Boundary
- ▨ Body of Water
- — River

Number of Inhabitants per municipality

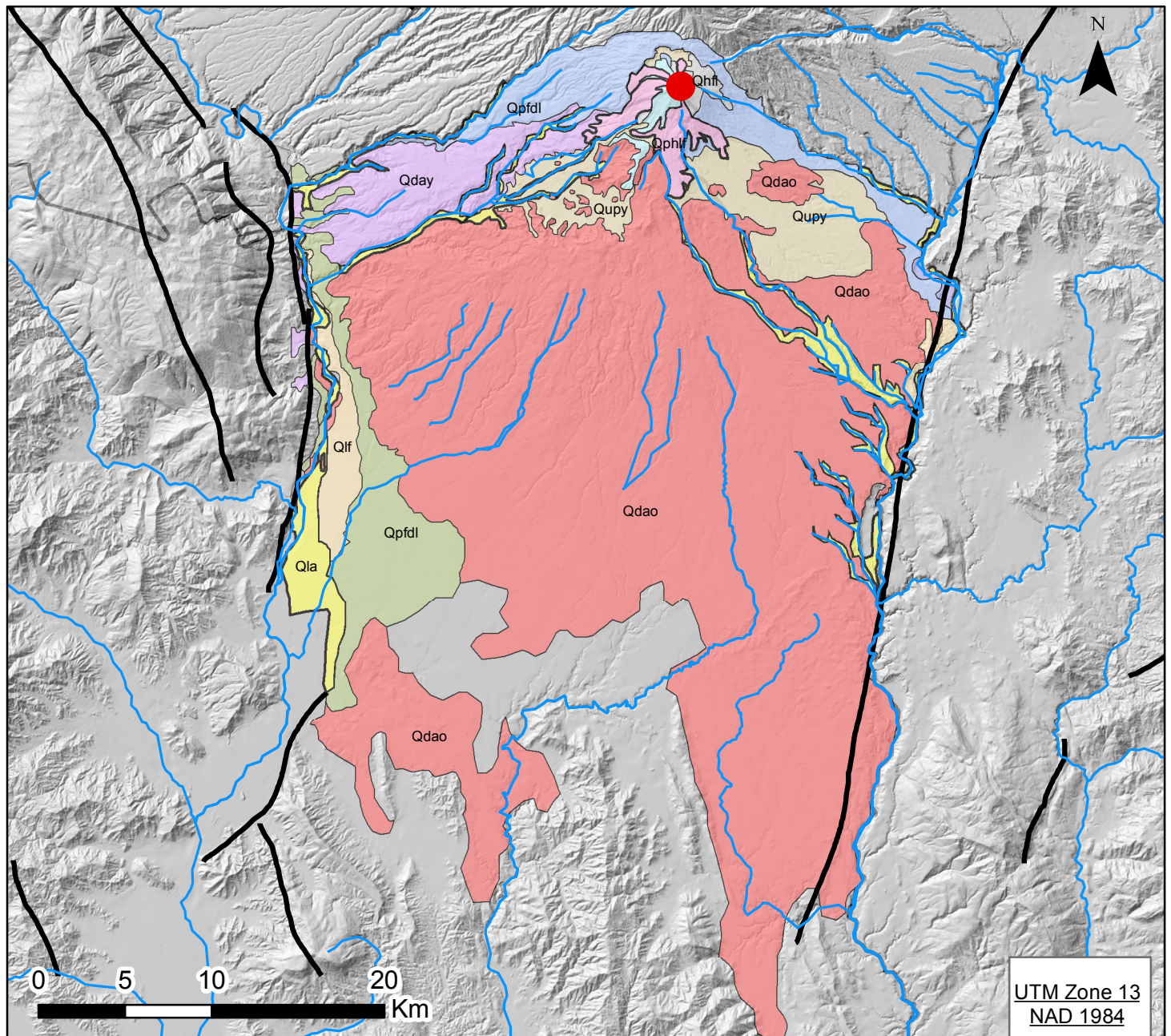|	
0 - 5000	100001 - 250000
5001 - 10000	250001 - 500000
10001 - 20000	500001 - 750000
20001 - 50000	750001 - 1000000
50001 - 100000	1000001 - 1500000

Hazard due to:

- Lahar
- Lava Flow
- Debris Avalanche

Daniel Ortega-Arroyo
12/01/2015

Geologic Map of Volcan de Colima deposits

N

Qhlf

Qpfdl

Qday

Qphlf

Qdao

Qupy

Qupy

Qdao

Qlf

Qdao

Qpfdl

Qla

Qdao

0   5   10   20

Km

1:350,000

Modified from Cortes et al 2005

Legend

Volcan de Colima
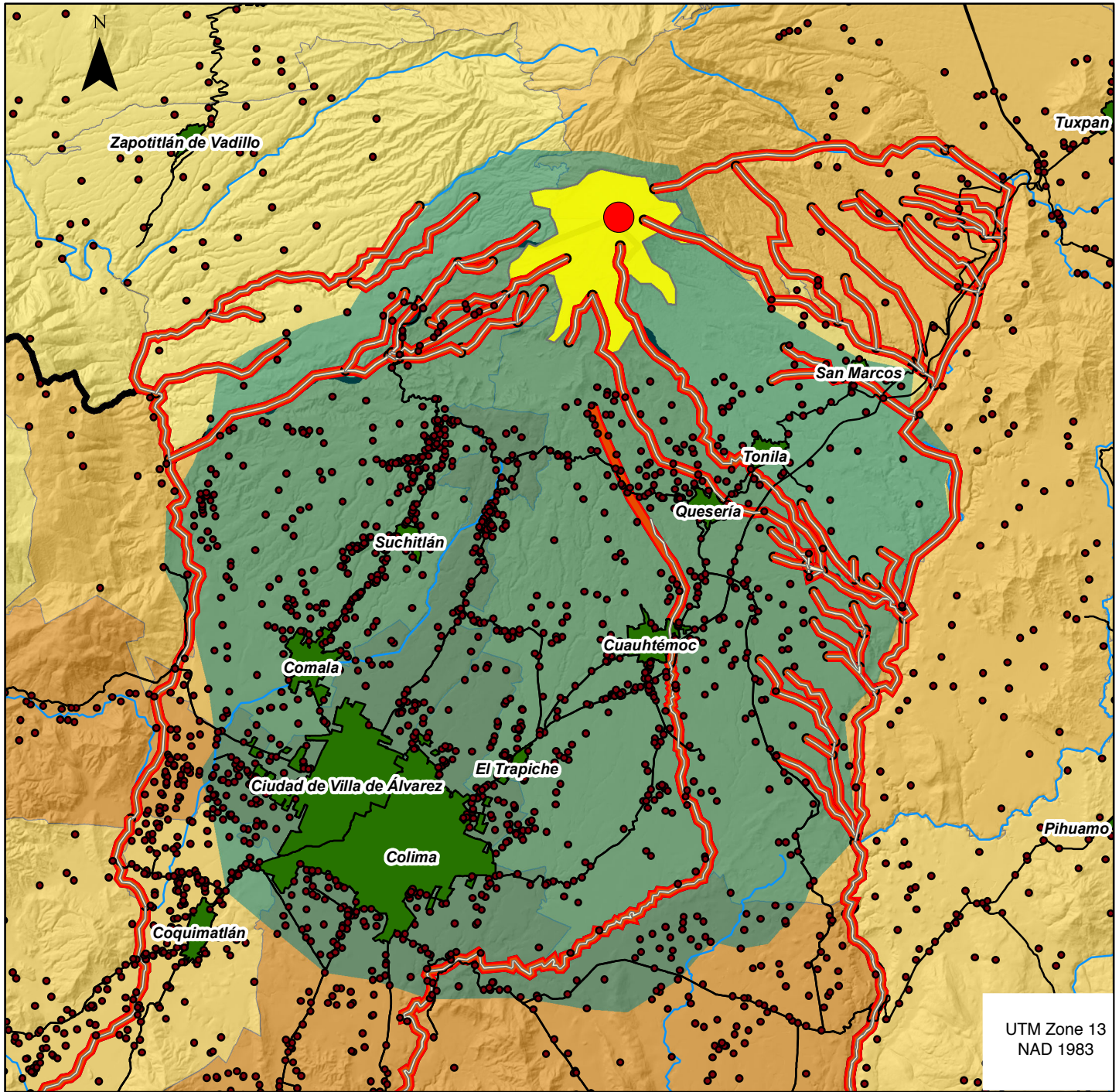
🔴 Volcan de Colima

— Fault

— River

Volcanic deposits

2002-2004 Lava flows

Debris Avalanche 3600yr BP

Debris Avalanche 7040yr BP

Historic lava flows

Lahar deposits and alluvium

Lahard and fluviatile deposits

Paleafuego Debris Avalanche deposits

Paleofuego Lahar deposits

Paleofuego Lava and Pyroclastic deposits

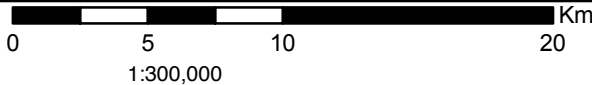Prehistoric Lava flows

Undifferentiated pyroclastic flow deposits

Volcan de Fuego de Colima Lava Flow, Lahar, and Debris Avalanches Hazards Map

Daniel Ortega-Arroyo
12/01/2015

UTM Zone 13
NAD 1983

Zapotitlán de Vadillo

Tuxpan

San Marcos

Tonila

Quesería

Suchitlán

Cuauhtémoc

Comala

El Trapiche

Ciudad de Villa de Álvarez

Colima

Pihuamo

Coquimatlán

Km

0   5   10   20

1:300,000

Legend

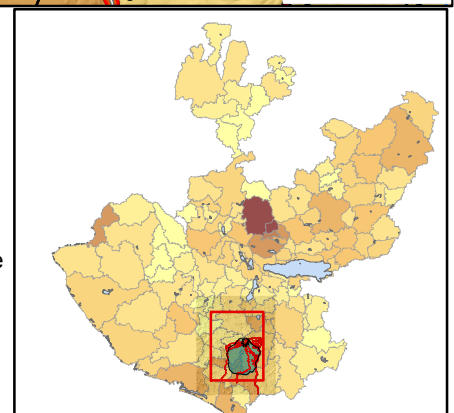● Volcan de Fuego de Colima

• Ranches and villages

▮ Towns and cities

— Roads

▭ State Boundary

▮ Body of Water

— River

Number of Inhabitants per municipality

0 - 5000	100001 - 250000
5001 - 10000	250001 - 500000
10001 - 20000	500001 - 750000
20001 - 50000	750001 - 1000000
50001 - 100000	1000001 - 1500000

Hazard due to:

▬ Lahar

▮ Lava Flow

▮ Debris Avalanche

Daniel Ortega-Arroyo
12/01/2015

Volcan de Fuego de Colima Tephra Hazard Map

Concepción de Buenos Aires

Valle de Juárez

Mazamitla   Quitupán

Unión de Tula

Tapalpa

Ejutla

Sayula   Usmajac

El Limón

San Andrés Ixtlán

El Grullo

San Sebastián del Sur

Autlán de Navarro

Tonaya

Ciudad Guzmán   Tamazula de Gordiano

Villa Purificación

Tuxcacuesco

San Gabriel

El Rincón

Zapotiltic

Lo Arado

Cópala

Santa María del Oro

La Resolana

Tolimán

Tuxpán

Tecomates

Zapotitlán de Vadillo

La Huerta

Tecalitlán

Cuautitlán de García Barragán

San Marcos

Jilotlán de los Dolores

Minatitlán

Tonila

Queseria

Suchitlán   Cuauhtémoc

Comala

Pihuamo

Ciudad de Villa de Álvarez

Colima

Coquimatlán

Jaluco   Cihuatlán

Barra de Navidad

Pueblo Juárez (La Magdalena)

N

Manzanillo

Madrid

0   10   20   40   Km

El Colomo

Rincón de López

1:850,000

Ixtlahuacán

Cofradía de Juárez

UTM Zone 13
NAD 1983

Ciudad de Armería

Tecomán

Legend

● Volcan de Fuego de Colima

🟩 Towns and cities

● Ranches and villages

🟦 Body of Water
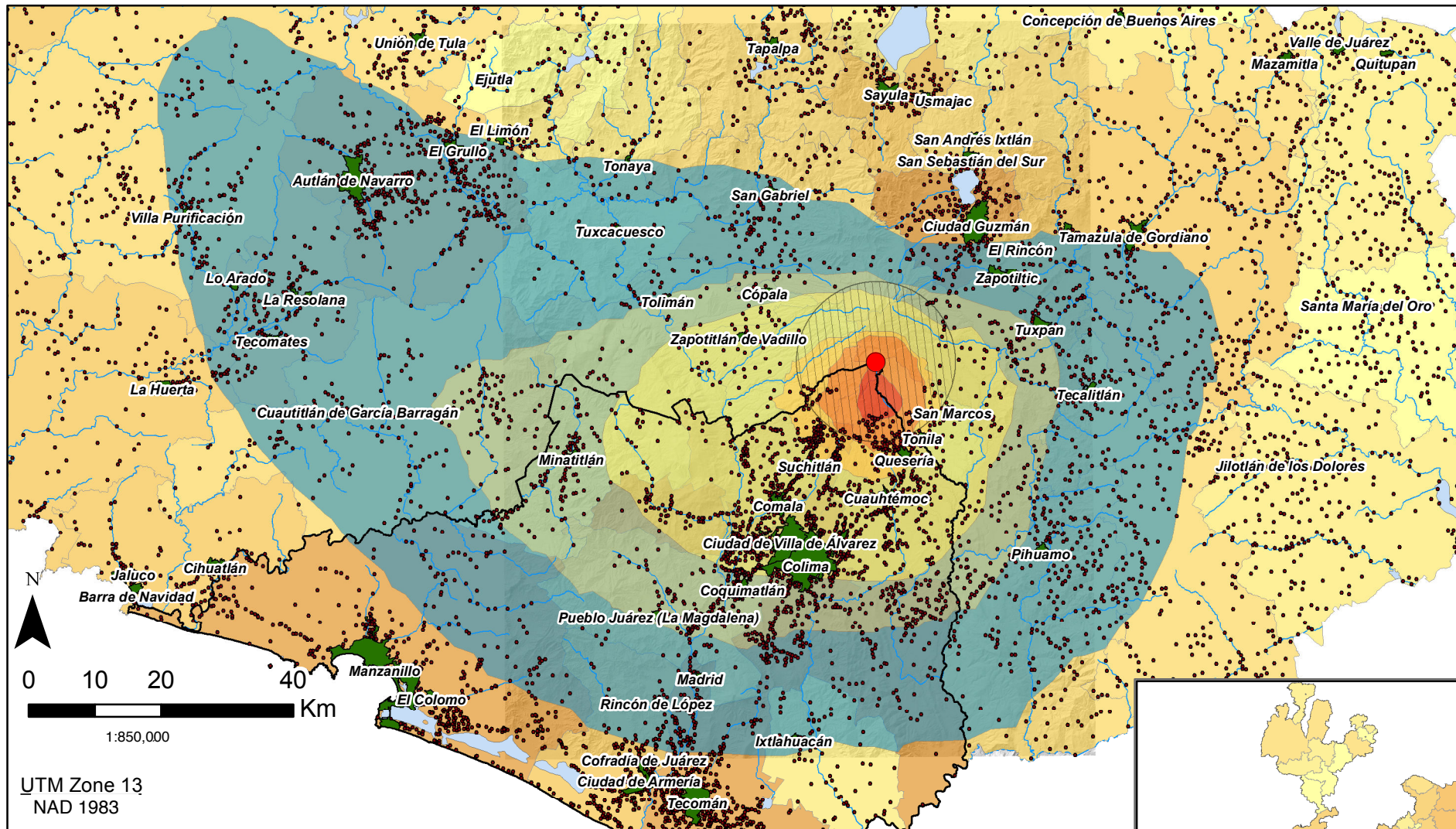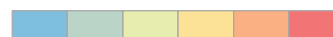
— River

Number of Inhabitants per municipality

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5001 - 10000	250001 - 500000
10001 - 20000	500001 - 750000
20001 - 50000	750001 - 1000000
50001 - 100000	1000001 - 1500000

Areas Prone to:

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Bombs and Lapilli Fallout