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Title: Rio Espiritu Santo Watershed Delineation

Introduction

A watershed is define as an area of land that drains down slope streams and rainfall until it reaches a common point such as an outlet of a reservoir, mouth of a bay, or any point along a stream channel (Environmental Service, 2006,USGS, 2016). The Nature Conservancy, 2016 explains that these water bodies supply our drinking water, water for agriculture and manufacturing, offer opportunities for recreation and provide habitat to numerous plants and animals (The Nature Conservancy, 2016). However, the urbanization and removal of vegetation increases the velocity and the amount of runoff in the surface and causes erosion, turbidity, and wildlife habitat degradation (Environmental Service, 2006). In addition, it carries away pollutants such as oil, sediments, and metals (Environmental Service, 2006). For these reason, we are interested in study and therefore delineate the watershed of a river, because it has a directly relationship with the society, and the environment and if there is a contaminant we would know its provenance.

Our study site is the watershed of the river in the Natural Reserve Espíritu Santo River. The Natural Reserve is important for its valuable coastal resources (Enciclopedia de Puerto Rico, 2016). It is composed by extensive mangroves, arboreal and herbaceous swamps which are saturated and flooded by shallow waters (Enciclopedia de Puerto Rico, 2016). In addition, there is an extensive coral reef, a prairie of Thalassia which are important to the carbonate production, and the estuarine. The Espiritu Santo River, is the only river open to the ocean where small boats can navigate (Enciclopedia de Puerto Rico, 2016).

Other features that will influence the watershed are precipitation, population, geology and topography. The annual precipitation that receives this watershed is 95 inches and during droughts receives 65 inches (“Cuencas-Principales-en-PR,” 2016). The precipitation nourishes the river through tributary streams such as, Grande, Jimenez and Sonadora whose form the Rio Grande, principal tributary of Rio Espiritu Santo (“Cuencas-Principales-en-PR,” 2016). The only urban zone of the watershed is located in the Rio Grande municipality, but in general the watershed is in a rural zone. (“Cuencas-Principales-en-PR,” 2016). The population the watershed covers are approximately 10,950 from 2010 Census (“Cuencas-Principales-en-PR,” 2016). In terms of groundwater we can say it is limited by the geology and topography, because of the low permeability in volcanic rocks will not allow a high recharge. A similar situation occurs with the alluvial deposits and marine deposits whose also have a low permeability because of the presence of clay and organic material (“Cuencas-Principales-en-PR,” 2016).

Objectives

The objectives of this project is to delineate the Río Espíritu Santo watershed, determine its area, elevation, and slope angle using ArcGIS. In addition, to locate the USGS gage in a map to determine daily discharge.

Methodology

The process of watershed delineation can be done manually using paper maps, or digitally in a GIS software. In order to develop the GIS delineation, it is important to acquire a digital elevation model (DEM) of the area. From the DEM a series of layers will be produced that represents hydrologic characteristics of the landscape. ArcMap contains a Hydrology toolbox under the Spatial Analyst extension that provides several tools to complete the delineation task. Those tools are described as follows:

- **Fill**: This step will fill the sinks of the DEM (ESRI, 2016a)
- **Flow Direction**: Creates a raster of flow direction from each cell to its steepest downslope neighbor (ESRI, 2016b). A flow direction grid assigns a value to each cell to indicate the direction (Library Maps and Information Centre, 2014). This step will determine the destination of the water flow in the surface (Library Maps and Information Centre, 2014). (The flow direction is calculated by examining the eight neighbors of a cell and determining the neighbor with the steepest downhill slope)
- **Flow Accumulation**: The Flow Accumulation tool calculates the flow into each cell by identifying the upstream cells that flow into each downslope cell (Library Maps and Information Centre, 2014).
- **Basin**: Creates a raster delineating all drainage basins (ESRI)
- **Map Algebra to determine streams**: Stream threshold values are used to determine the actual stream channels. This value is highly dependent on the topography, rainfall amount, and land cover. Several values were used to test and determine the appropriate amount, which was 100.

A flowchart was made to present step by step all the process involved to delineate the watershed of Río Espíritu Santo and calculate the area, slope and elevation (Fig. 1.).

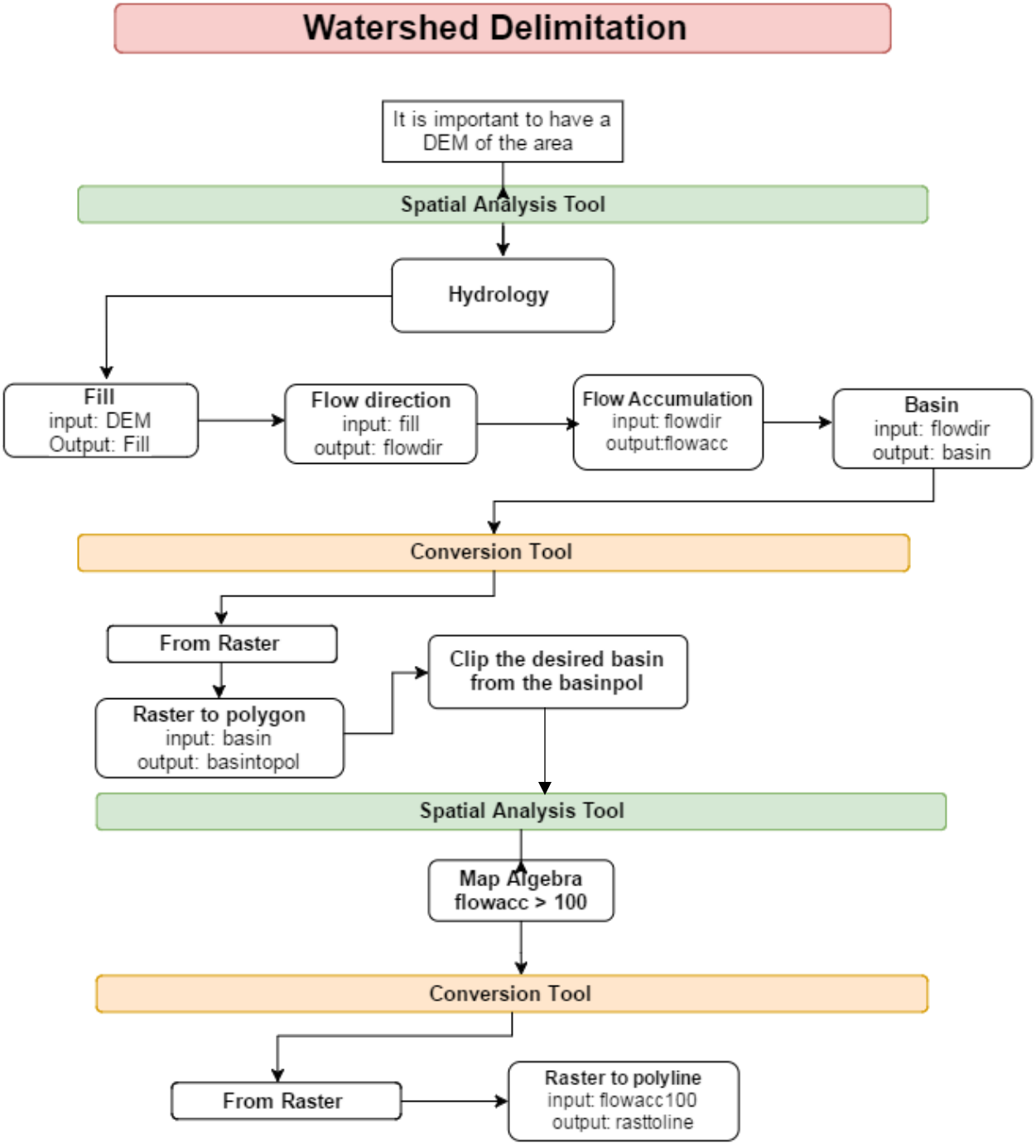
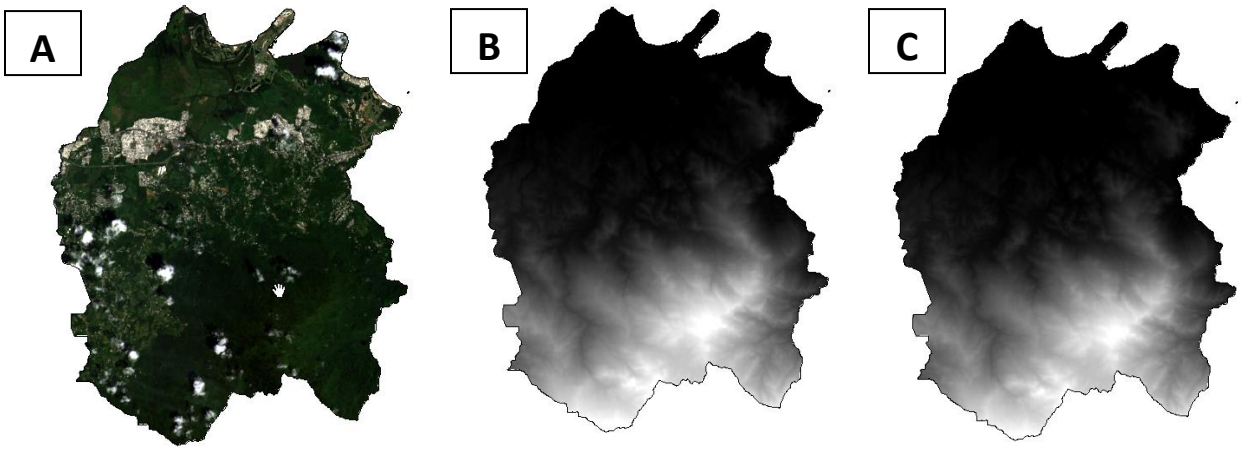


Figure 1. Flowchart showing how to delineate a watershed using ArcMap. A digital elevation model (DEM) file is needed to start the process.

Results and Discussion

Following and applying the steps and processes described above, we geographically delineate the Río Espíritu Santo watershed (Fig. 1). The map shows the area of the watershed that covers 85.23 km^2 which is from the limit between Las Piedras through the mouth river in the Atlantic Ocean, and goes from west near to Canovanas and to east near to Luquillo (Fig. 3). The elevation goes from a range of 1 through 1050 m, where the higher place is in the south area of the watershed and the lower place is in near the mouth river (Fig. 4). The slope has a range where green means a low inclination and red is a high inclination (Fig. 5). The highest slope calculated was 56.82° and is also located at the south of the watershed and the distribution is directly related with the elevation, this is the reason they look so similar.

The water gage station of the USGS was located in the map just in the center of the watershed but slightly to the north (Fig.6). The final map of the watershed delineation is presented in Figure 6B. As an example of the collected data by the USGS water gage station we include a discharge graphic. Blue line is the weekly discharge measured in cubic feet per second, the peak in the graph means a high discharge probably produced by a precipitation event, the triangles are the median daily statistics during 50 years, this means the daily range of the discharge is between 40 and 50 cfs and the red asterisk means that day people went to the field and made measurements with other instruments to corroborate the water gage station is making good readings (Fig. 7). Additional work was done, a 3-dimensional model with a vertical exaggeration of 5X using ArcScene was made to represent the watershed of Río Espíritu Santo.



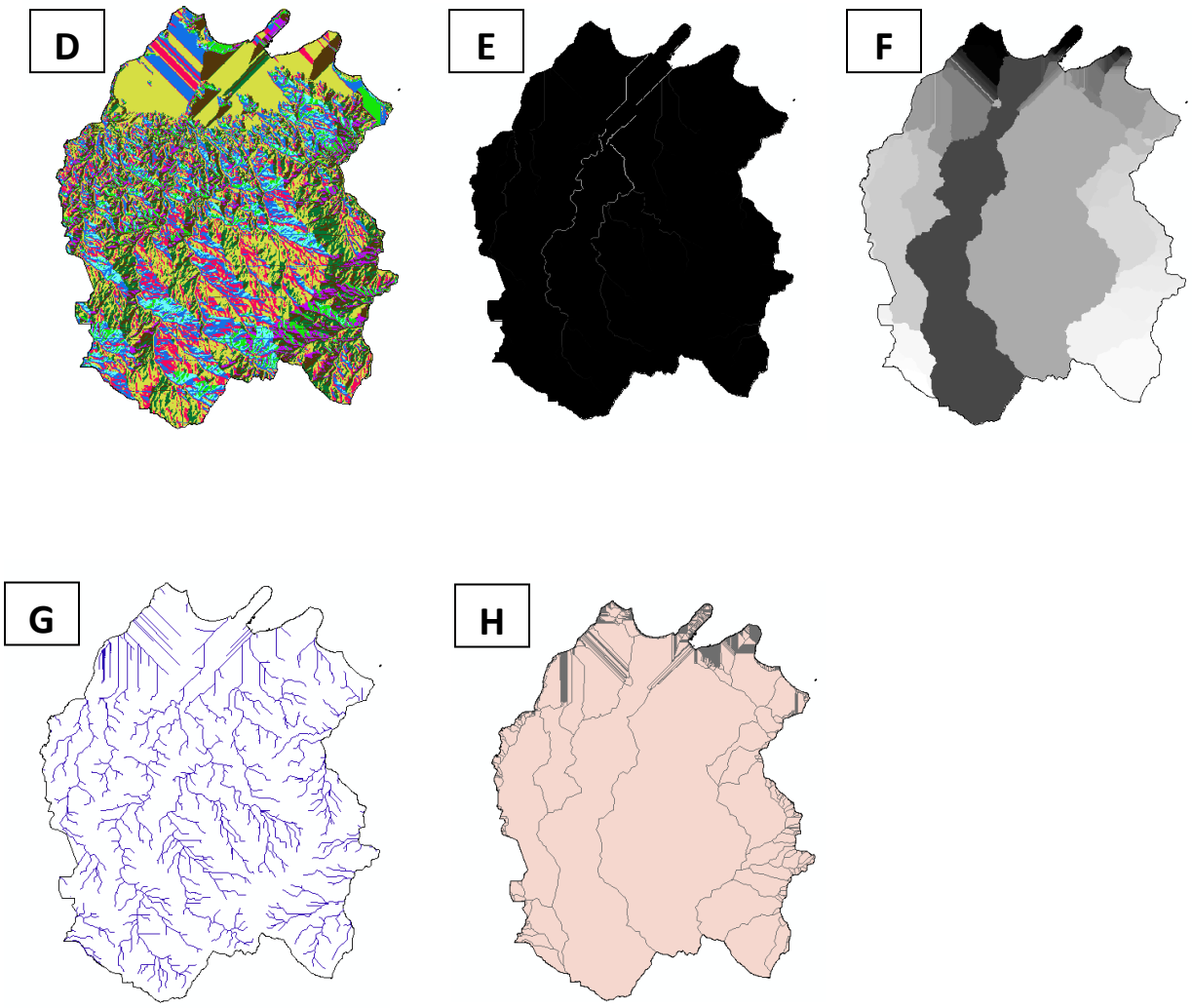


Figure 2. Shows the different outputs of the methodology. (A) First step is the Puerto Rico base map. (B) Digital elevation model (DEM) is needed to delineate watershed. (C) A fill is required to guarantee a correct representation of watersheds and creeks. (D) Flow direction: colors represent numbers and the orientation of the flow, eg. Pink has a value of 16 which means west. (E) Flow accumulation: identify upstream that flow down slope. (F) Basin: creates a raster delineating all drainage basins. (G) Shows all the streams and tributaries channels. (H) Polygon of the watershed.

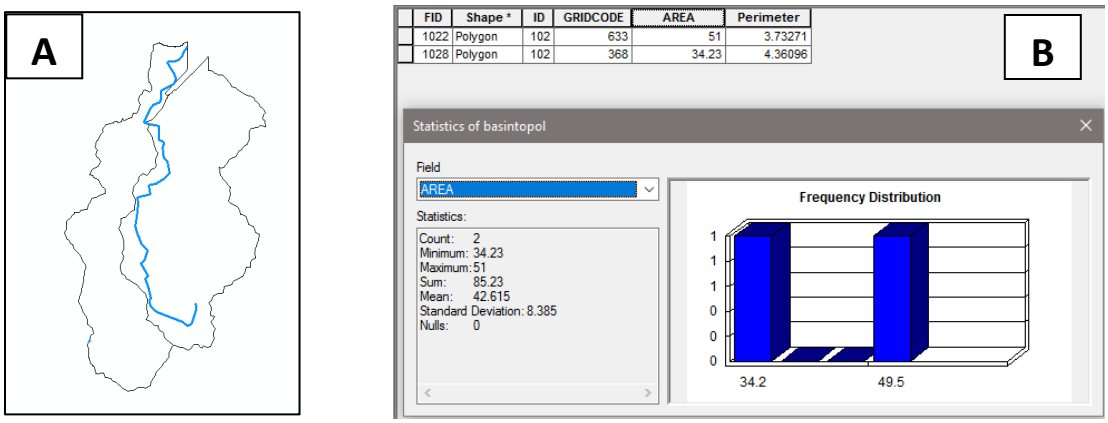


Figure 3. The calculated area of the watershed of the Rio Espiritu Santo, (A) shows the area delineation of the watershed, blue line represents Rio Espiritu Santo; (B) table of attribute and statistical data from ArcMap.

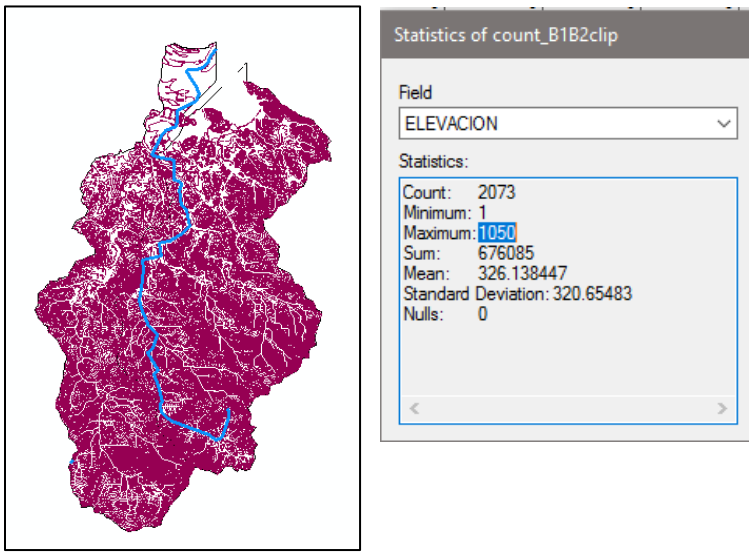


Figure 4. Elevation calculated using the program ArcMap. Lower elevation is 1 m, the highest elevation is 1,050 m, and mean elevation is 326 m. White lines are streams and tributaries, blue line is Río Espíritu Santo, and purple color is the elevation.

Figure 5. Slope in the watershed of Río Espíritu Santo, green represents lower Inclination, yellow means intermediate Inclination and red is the higher inclination.

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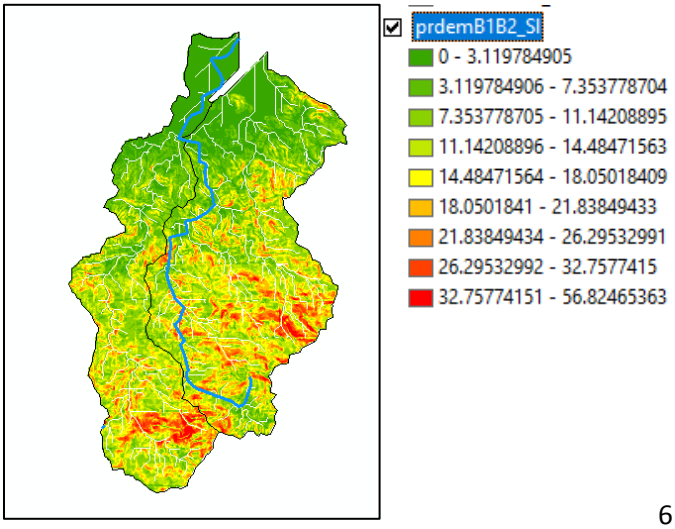

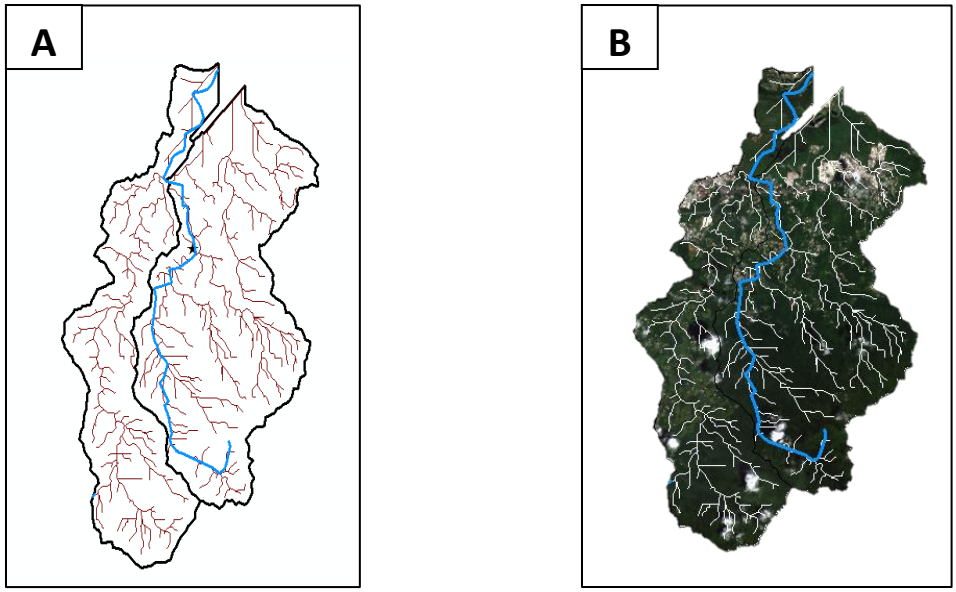

Figure 6. (A) Image of the watershed presenting the location of the USGS water gage station (star), blue line Río Espíritu Santo and brown lines are streams and tributaries. (B) Geographic delineation of the watershed of Río Espíritu Santo, white lines are the streams and tributaries, and the blue line is Río Espíritu Santo.

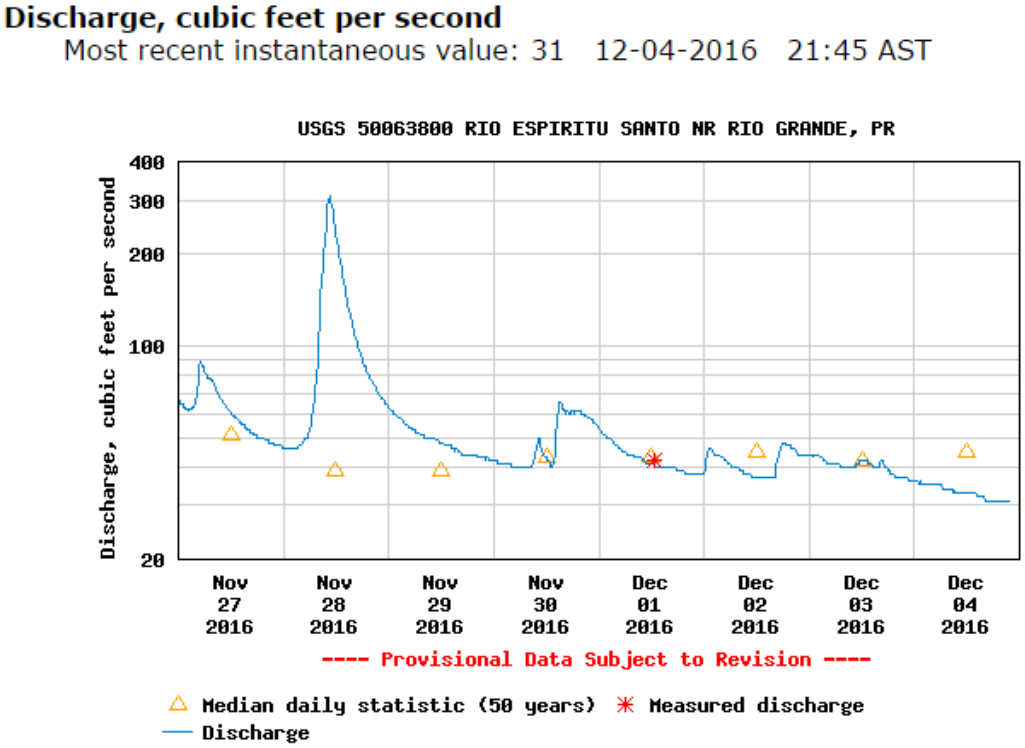

Figure 7. Graphic showing the weekly discharge of Rio Espíritu Santo (blue line), high peak shows high discharge produced by a precipitation event, triangles are median daily statistics during 50 years and red asterisk field measurement.

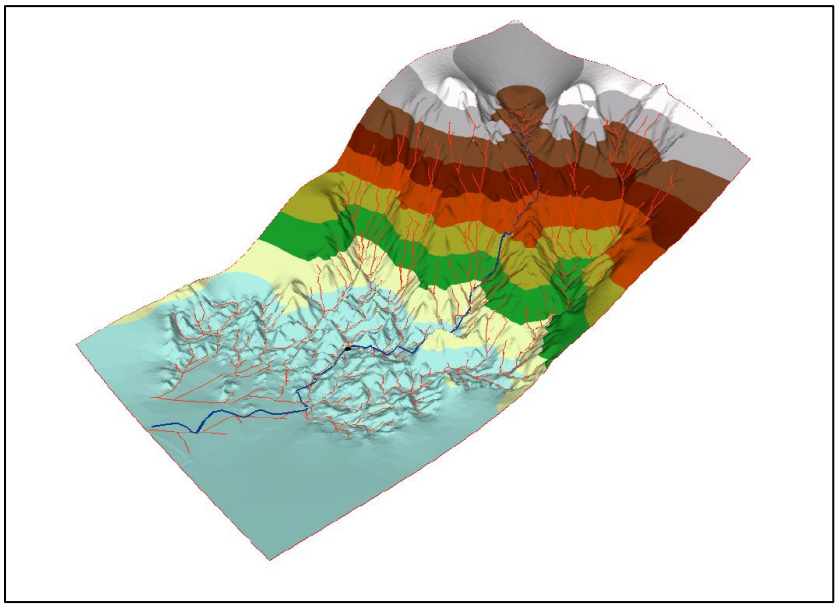

Figure 8. Screenshot of a 3-dimension model of the watershed of Rio Espíritu Santo using ArcScene. Blue line is the river, black dot is USGS water gage station, red lines are streams and tributaries. Vertical exaggeration is 5X.

Conclusion

Using ArcMap, we can conclude that ArcGIS is a complete and helpful software which can be used in several hydrology applications. Using this software, the watershed of Rio Espíritu Santo was delineated. Other important features as slope, elevation, and area were calculated using ArcMap. Studies that involve watershed are important because any perturbation in it will affect multiples sectors as our drinking water, water for agriculture and manufacturing, plants and many other sectors.

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