University of Puerto Rico – Mayagüez Campus

Department of Geology

Research Project in Earth Sciences: Hydrology – Watershed Management

GEOL 6991 096

GIS Applications for Earth Sciences

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I. Introduction

A. Scientific Question

A toxic contaminant suspected to be of industrial nature has been detected in the receiving waters at the Mayaguez water treatment facility. The water being treated is diverted from the Rio Grande de Añasco river. How can environmental engineers apply GIS tools to help determine the source of this pollutant? This can be done through Watershed Management. The first step to any watershed management project requires a watershed delineation to be performed.

B. Background

A watershed is a land area bounded by a divide within which excess precipitation (runoff) collects and flows out through a single outlet into a larger waterbody, namely a river, lake or ocean (Mays, 2011).

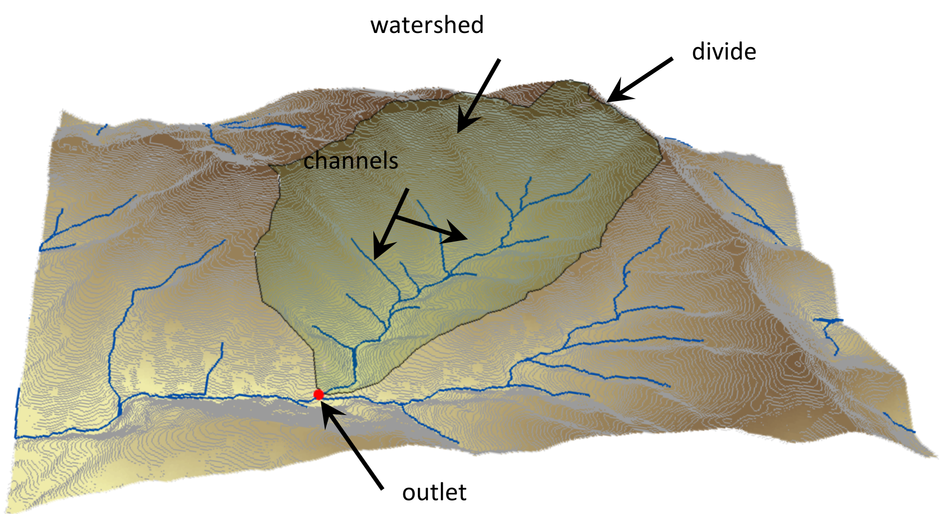

Figure 1: Watershed schematic
Picture from: http://en.acolita.com/watershed-delineation-with-arcgis-10.html

It is important to understand the characteristics of a watershed and the processes that take place within it, to be able to recognize how human activities can degrade or improve its condition. Watershed condition can have an effect in the water quality, wildlife, vegetation (forests or crops), and quality of life for the people within the area (Gupta, 2008).

Performing responsible watershed management provides:

- Flood control
- Water storage
- Erosion control
- Water and soil conservation
- Groundwater recharge
- Pollution control
- Crop growth and development
- Wild life preservation
- Recreational activities (Gupta, 2008).

C. Site Description

The Río Grande de Añasco watershed is located in western Puerto Rico, within the municipalities of Adjuntas, Añasco, Lares, Las Marías, Maricao, Mayaguez, San Sebastián, and Yauco. Its headwaters are in the Cordillera Central mountain range from where it flows west toward the Canal de La Mona, draining approximately 468 km^2 of land. Its major tributaries are: Río Humata, Río Arenas, Río Casey, Río Blanco, Río Mayaguecillo, Río Cañas, Río Guaba, Río Prieto, Río Guilarte, and Río Guayo. There are two lakes within the watershed: Prieto, and Guayo lakes, as well as a dam on Río Guilarte that creates Lago Yahuecas in the eastern part of the watershed (DRNA, accessed 2016).

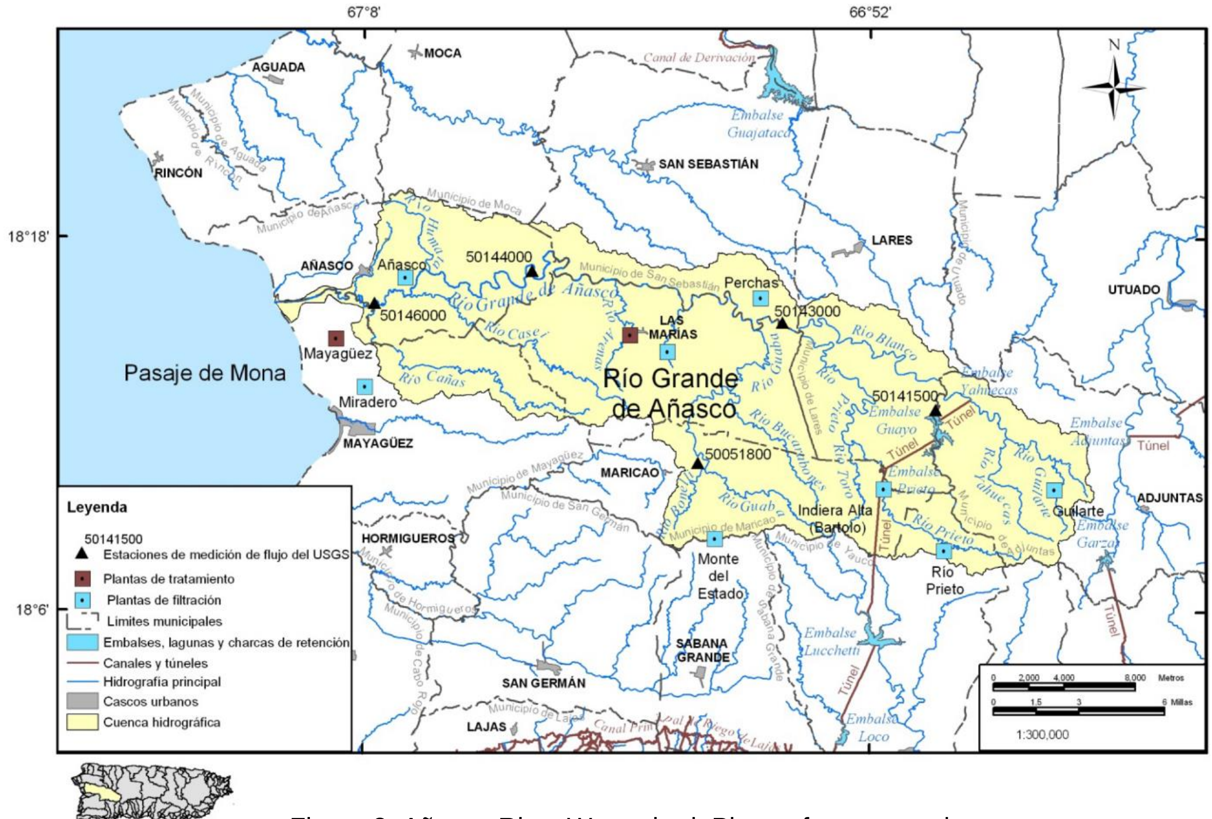

Figure 2: Añasco River Watershed. Picture from: www.drna.gov

Land use in the watershed is comprised of urban and rural populated areas, mostly consisting of agriculture, pastures, and forested areas. The Río Grande de Añasco watershed's topography is mostly mountainous in the headwaters and level in the areas closest to river's mouth. The highest elevation is 1,200 meters above sea level, while the lowest is at its outlet, at sea level. The mean elevation of the watershed is 342 meters above sea level.

The Añasco watershed has a tropical climate at lower elevations that turn into subtropical as the elevation rises. Both temperatures and rainfall are affected by eastern trade winds. Humidity is relatively high in the summer, and most rainfall occurs between May and December. Showers can be locally heavy and can be expected any time of the year, but usually have a short duration.

The Río Grande de Añasco system is always in noncompliance with the local and federal environmental law, for not meeting the applicable water quality standards. This is due to minor industrial point sources, confined animal feeding operations, agricultural practices, and onsite wastewater systems located within the watershed (DRNA, accessed 2016).

II. Objectives

The purpose of this project is to illustrate, step-by-step, how to use the functionality available in the ESRI ArcGIS ArcMap Spatial Analyst Toolbox to delineate a watershed boundary from raster digital elevation model data (DEM). Specifically, to:

- Obtain DEM data
- Create a depressionless DEM
- Determine flow direction
- Draw flow accumulation
- Identify watershed outlet points
- Delineate watersheds
- Obtain land use for the watersheds

The tools are used to derive data that describes the drainage patterns of the catchment. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data are then used to develop a vector representation of catchments and drainage lines from selected outlet (pour) points.

III. Methodology

The procedure for watershed delineation and characterization in an Esri ArcGIS Environment can be achieved through the implementation of the following steps: obtaining the data needed and performing the delineation of the watershed.

A. Obtaining data

1. Download the necessary DEM files for the area of study. Data can be obtained from the http://earthexplorer.usgs.gov/ website.

2. Download the necessary shapefiles for land use, which are available at: http://www2.pr.gov/agencias/gis/Pages/default.aspx from the ‘Portal de Datos Geograficos Gubernamentales’.

B. Delineating watershed

1. *Start ArcGIS* and create a new map document.

2. *Import DEM files*. If the study area is contained in two or more DEM files, they need to be merged. Go to: **ArcToolbox >> Data Management Tools >> Raster >> Raster Dataset >> Mosaic** to combine all DEM tiles into one continuous raster layer.

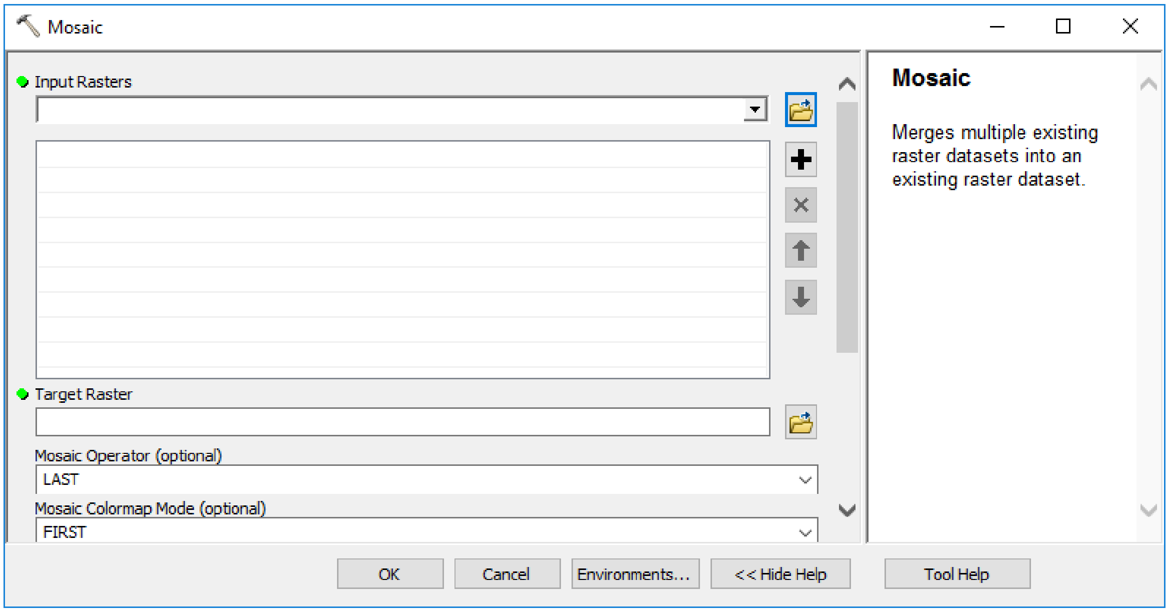

Figure 3: Mosaic function window in ArcMap

3. *Create a depressionless DEM*. A sink is an imperfection in a raster cell which does not indicate the direction of flow to the next cell. Sinks in elevation data are most commonly due to rounding errors in the data. Sinks are removed from the DEM file by navigating to: **ArcToolbox >> Spatial Analyst Tools >> Hydrology >> Fill**. Use the DEM layer as the input to this function. Indicate the file directory where the output layer will be stored, or keep the default name and location.

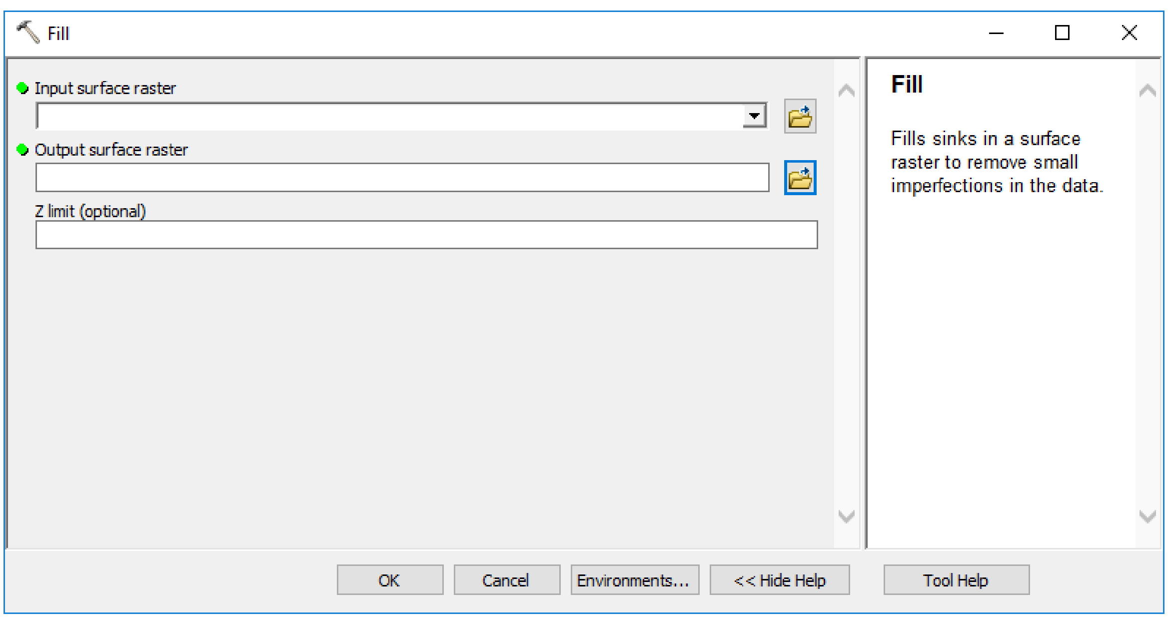

Figure 4: Fill function window in ArcMap

4. *Calculate flow direction*. It is necessary to determine the direction of flow for each cell in the landscape to determine where it drains. This process assigns a value to each raster cell to indicate the direction (either, N, S, E, W, NE, NW, SE, SW) of flow leaving that cell.

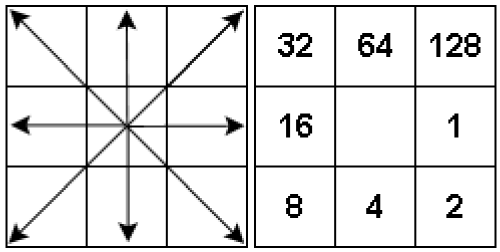

Figure 5: Flow direction used by ArcMap

Go to: **ArcToolbox >> Spatial Analyst Tools >> Hydrology >> Flow Direction.** The output from the **Fill** function must be used as the input.

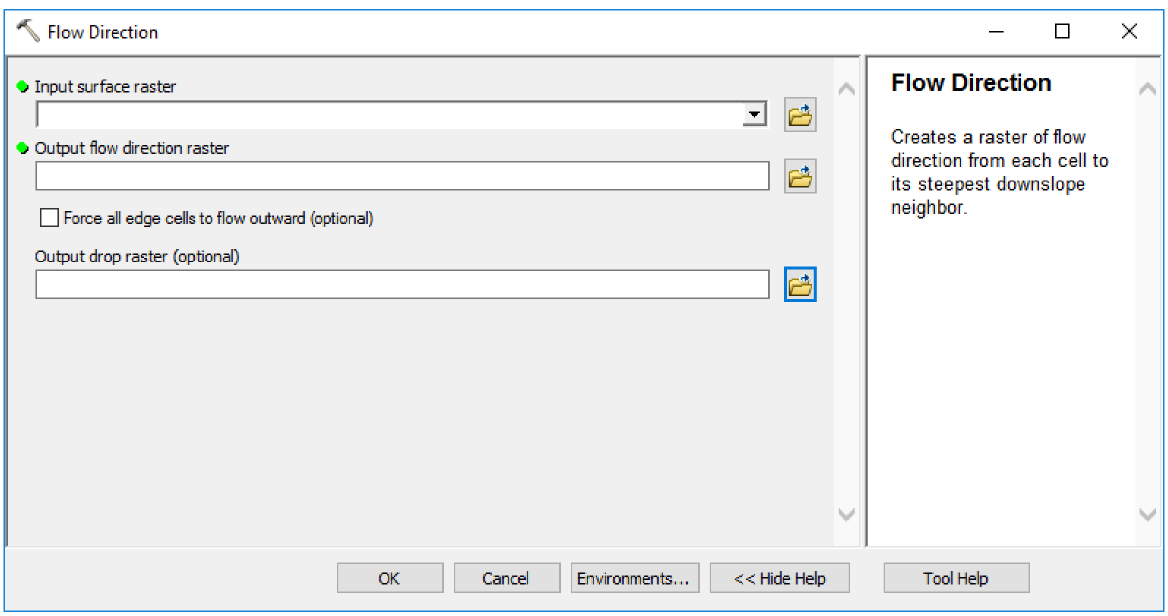

Figure 6: Flow direction function window in ArcMap

5. *Process flow accumulation.* Compute the amount of flow accumulating into each raster cell using the Flow Accumulation function in: **ArcToolbox >> Spatial Analyst Tools >> Hydrology >> Flow Accumulation**. the Flow Direction function must be used as input.

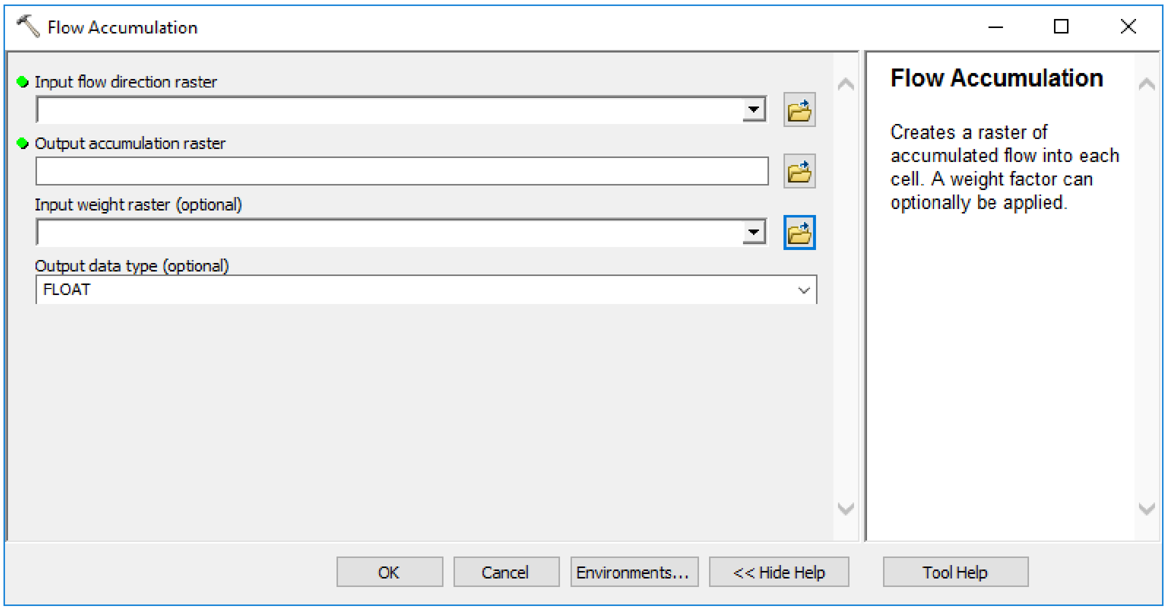

Figure 7: Flow accumulation function window in ArcMap

6. *Create stream network and stream order. This is performed with the* **ArcToolbox >> Spatial Analyst Tools >> Conditional>> Con** *to find a threshold for the network. The output is then converted to a feature in order to obtain the stream order.*

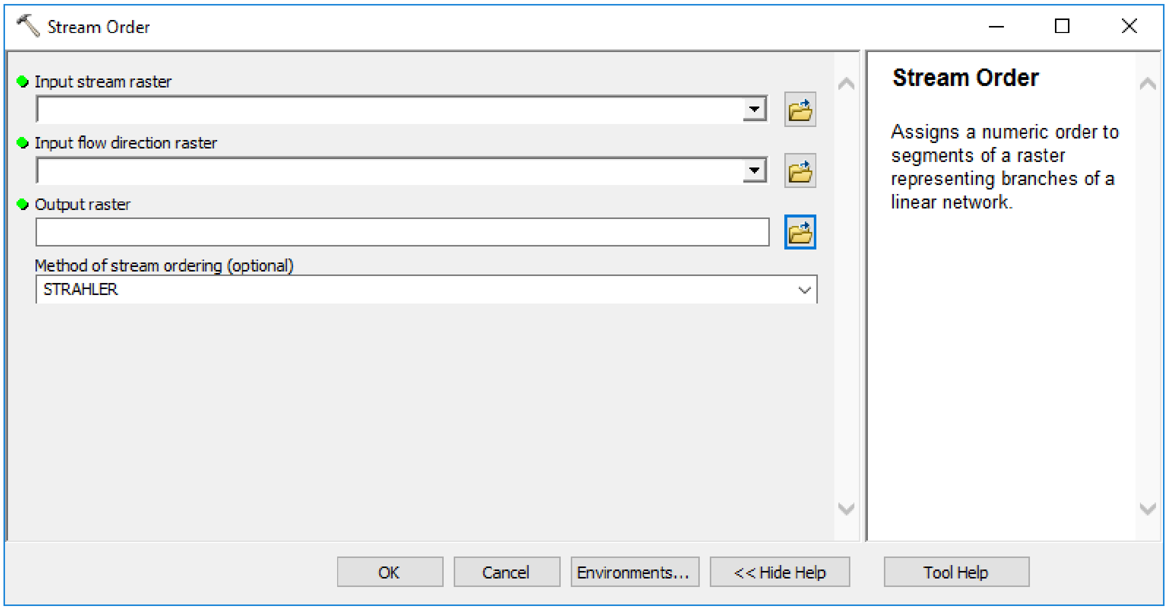

Figure 8: Stream order function window in ArcMap

7. *Create basins. Using the flow direction, main basins are created through:* **ArcToolbox >> Spatial Analyst Tools >> Hydrology >> Basin.**

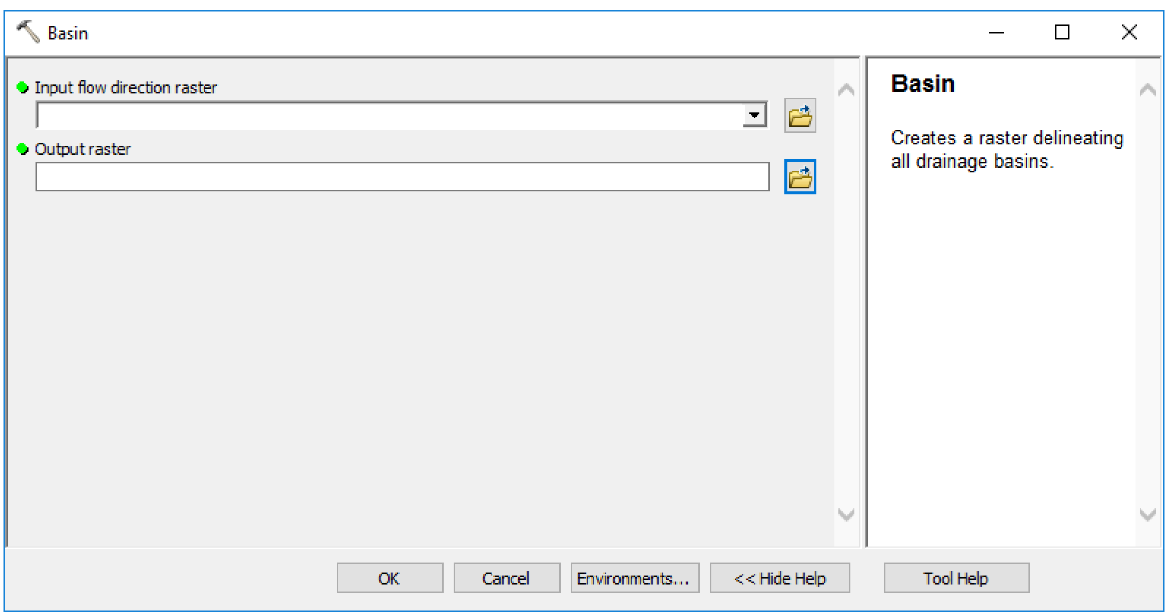

Figure 9: Basin function window in ArcMap

8. *Create pour points and snap for sub basins.* Pour points must be located in cells of high cumulative flow. To create pour points, a new shapefile must be created in the same project directory, by right-clicking the folder, then **New >> Shapefile**. After the shapefile has been created, the points are added by using the **Start Editing** command in the Editor toolbar. The points are attached to the flow accumulation raster using the: **ArcToolbox >> Spatial Analyst Tools >> Hydrology >> Pour point data.**

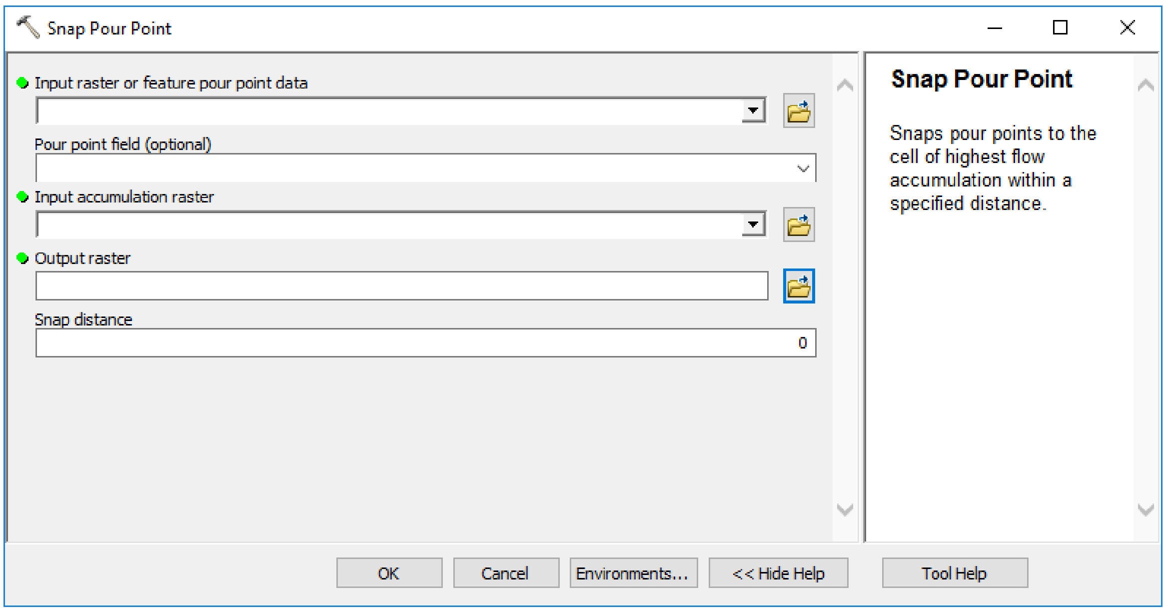

Figure 10: Snap pour point function in ArcMap

9. *Delineate watersheds*. Open the Watershed tool by navigating to: **ArcToolbox >> Spatial Analyst Tools >> Hydrology >> Watershed**. Select the flow direction as the input flow direction raster. The new watershed grid will be added to the data frame.

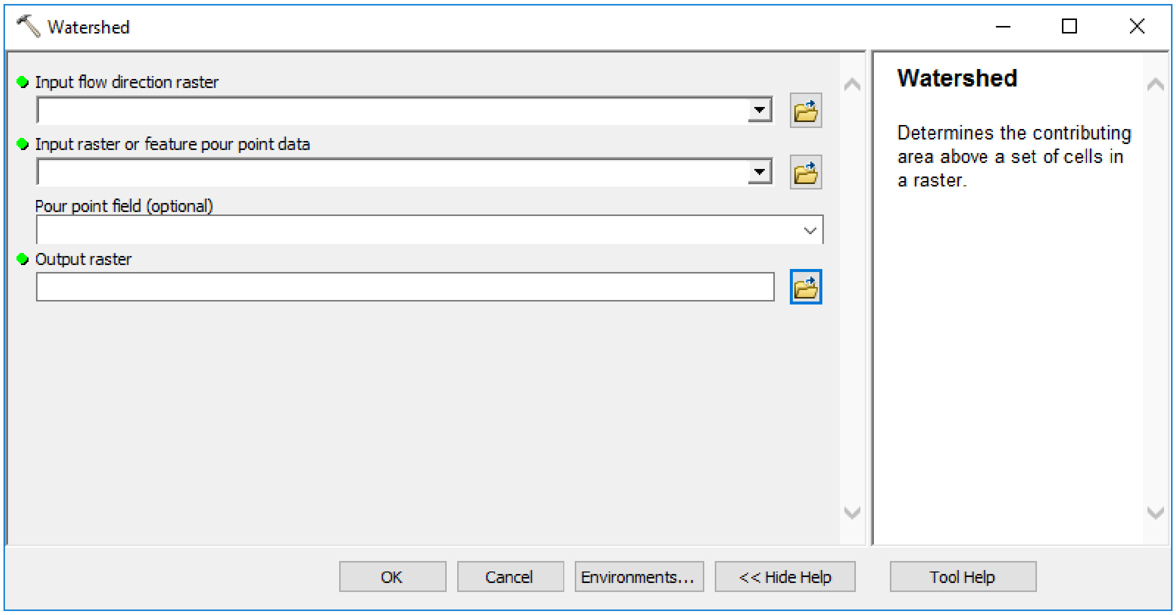

Figure 11: Watershed function window in ArcMap

10. *Study land use in the watershed*. The land use shapefile must be clipped with the watershed output, but it must first be converted into a shapefile. This can be done though **ArcToolbox >> Conversion Tools >> From Raster >> Raster to Polygon**. The land use file can now be clipped through: **Geoprocessing Toolbar >> Clip.**

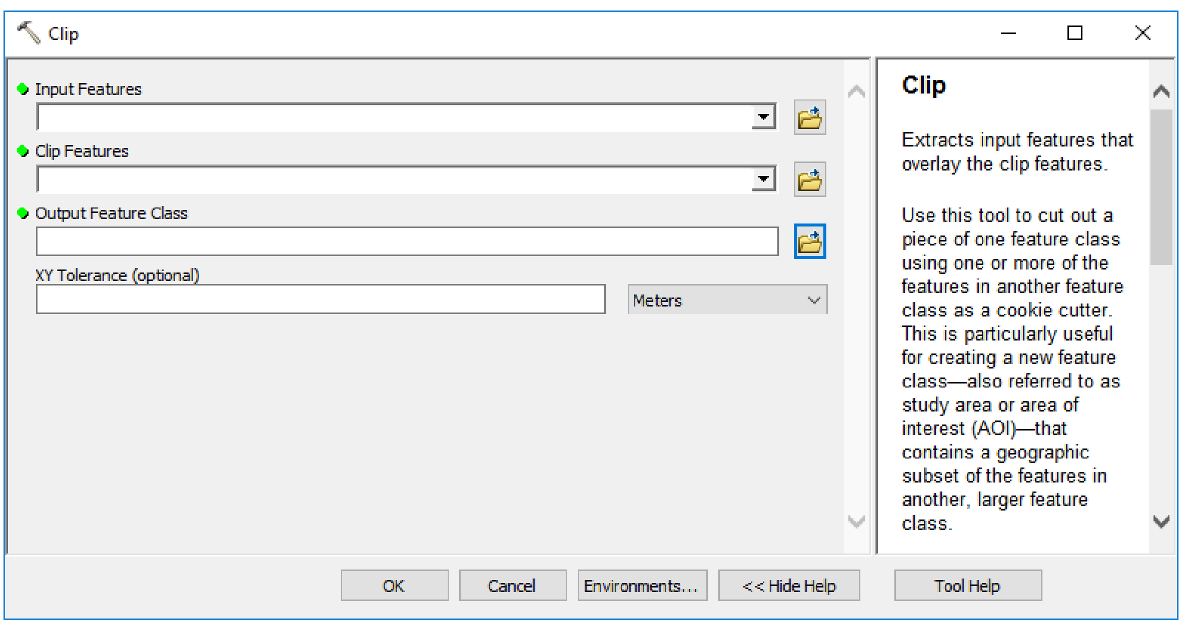

Figure 12: Clip function window in ArcMap

IV. Results and Discussion

The following set of maps were generated in ArcGIS after performing the steps discussed above.

- Obtain DEM data:

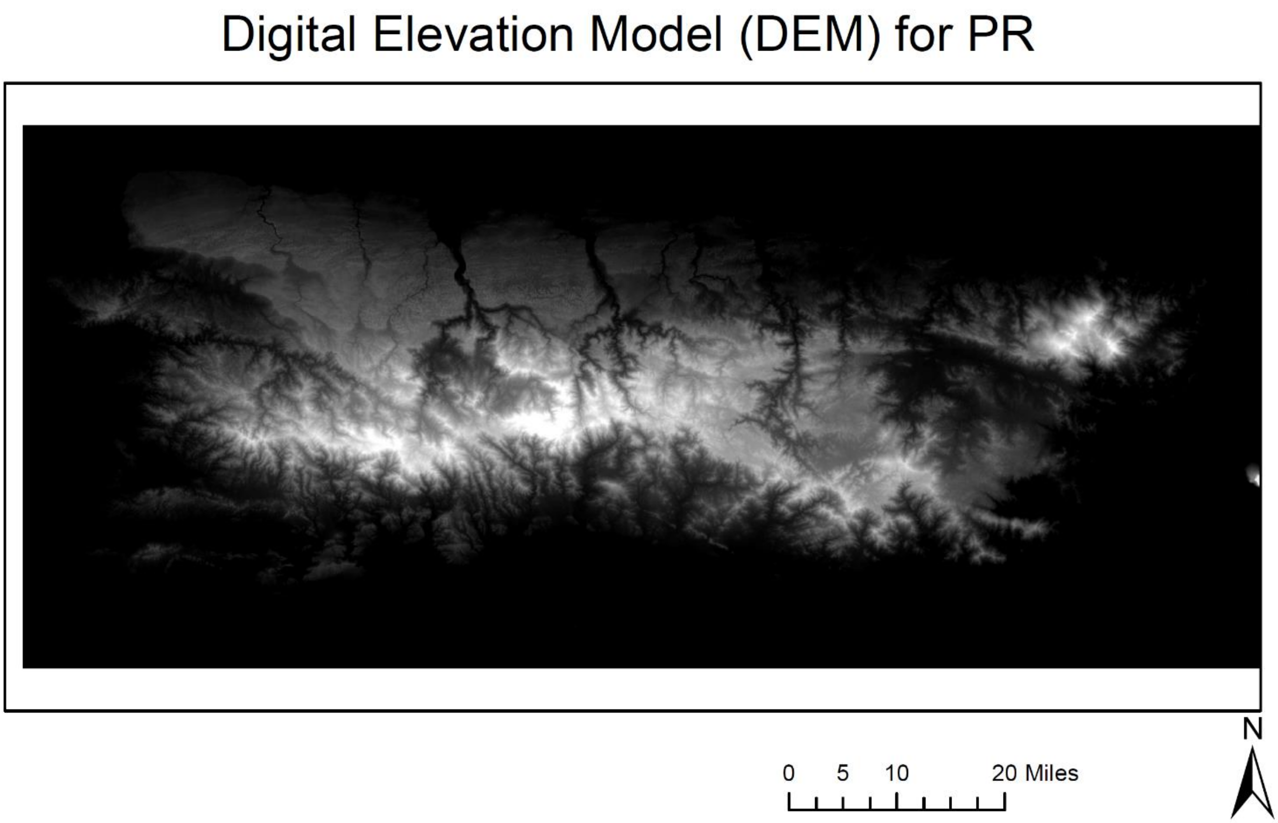

Figure 13: Digital Elevation Map (DEM) map

- Create a depressionless DEM

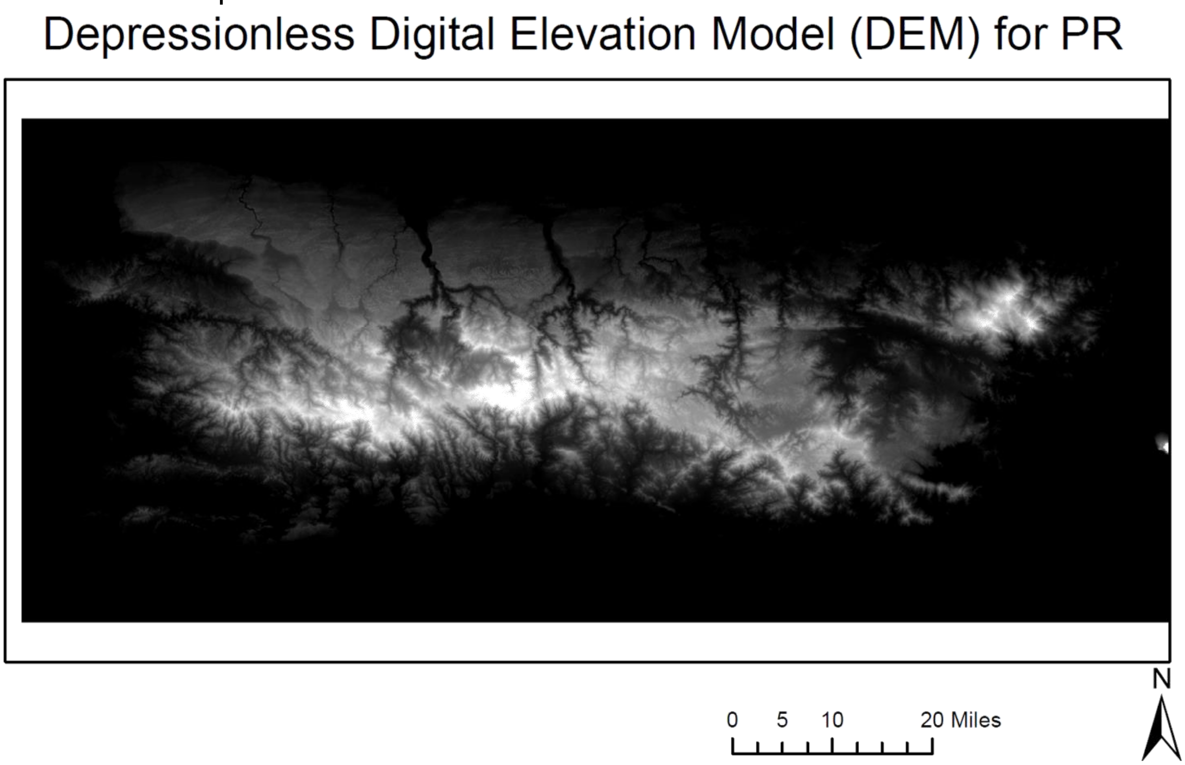

Figure 14: Depressionless DEM map

- Determine flow direction

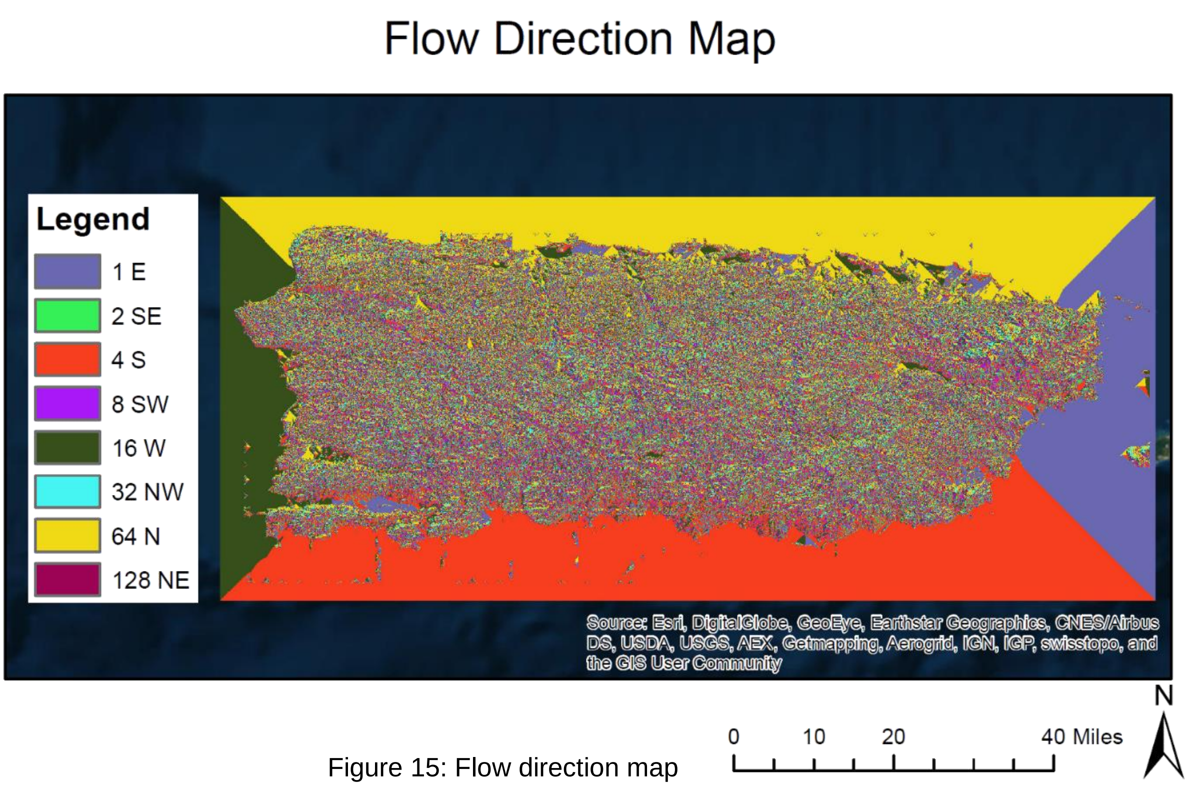

Figure 15: Flow direction map

Draw flow accumulation

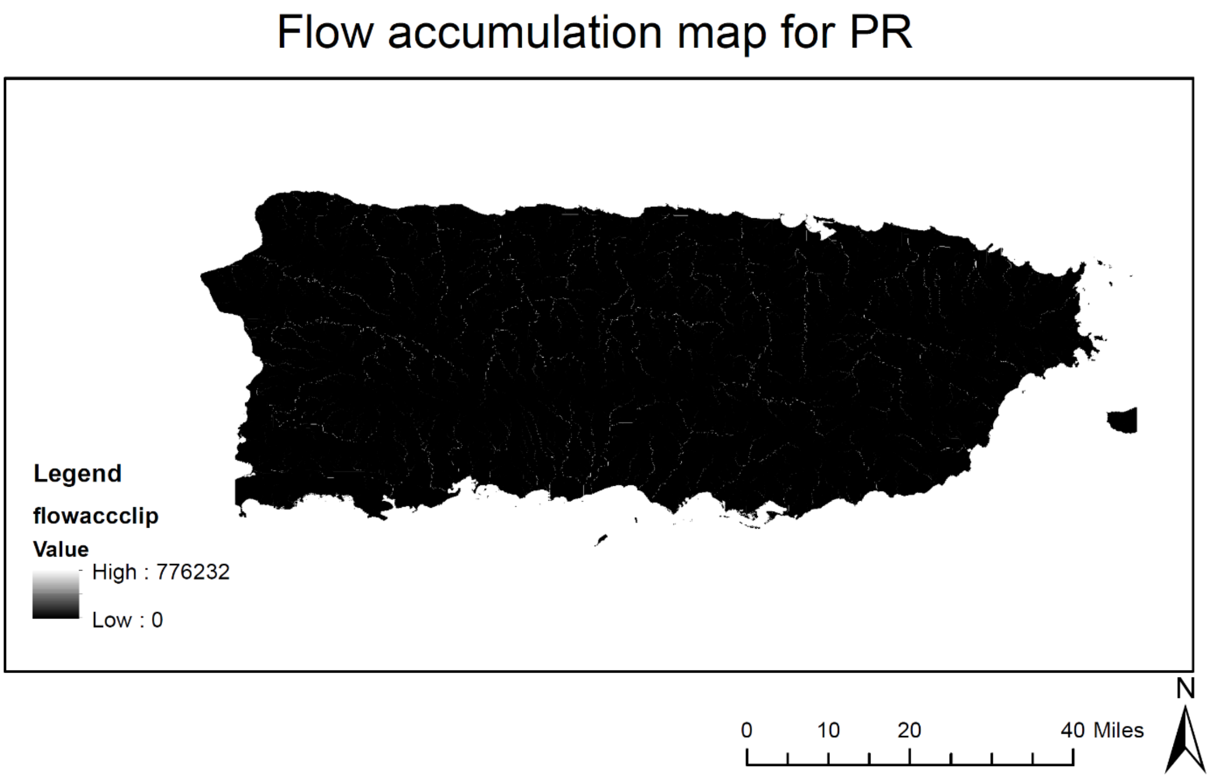

Figure 16: Flow accumulation map

- Obtain stream network and order

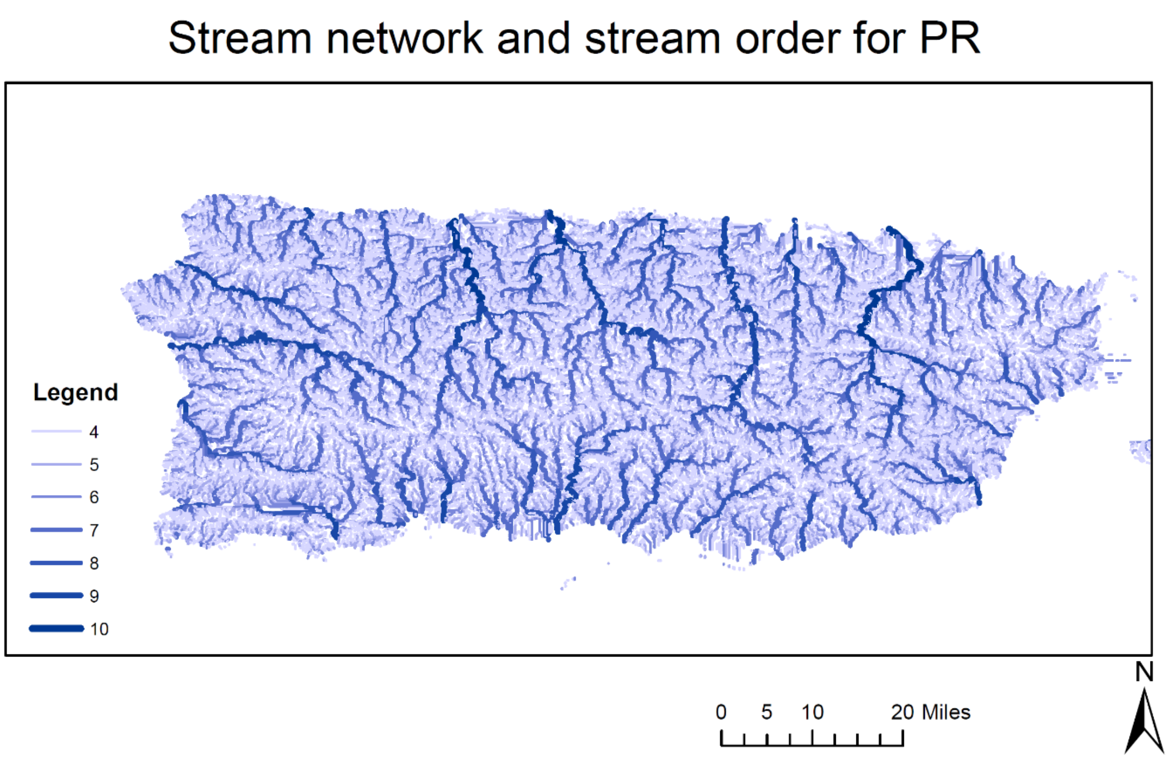

Figure 17: Stream order map

- Delineate watersheds

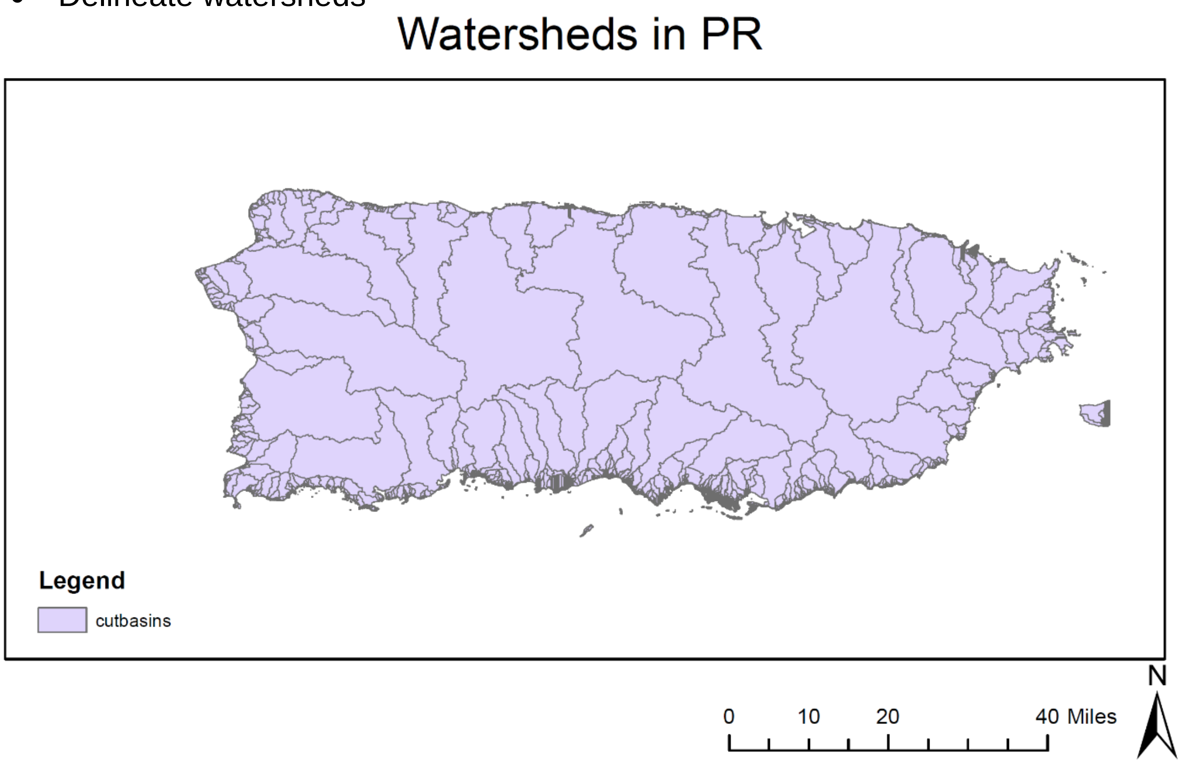

Figure 18: Watersheds in Puerto Rico map

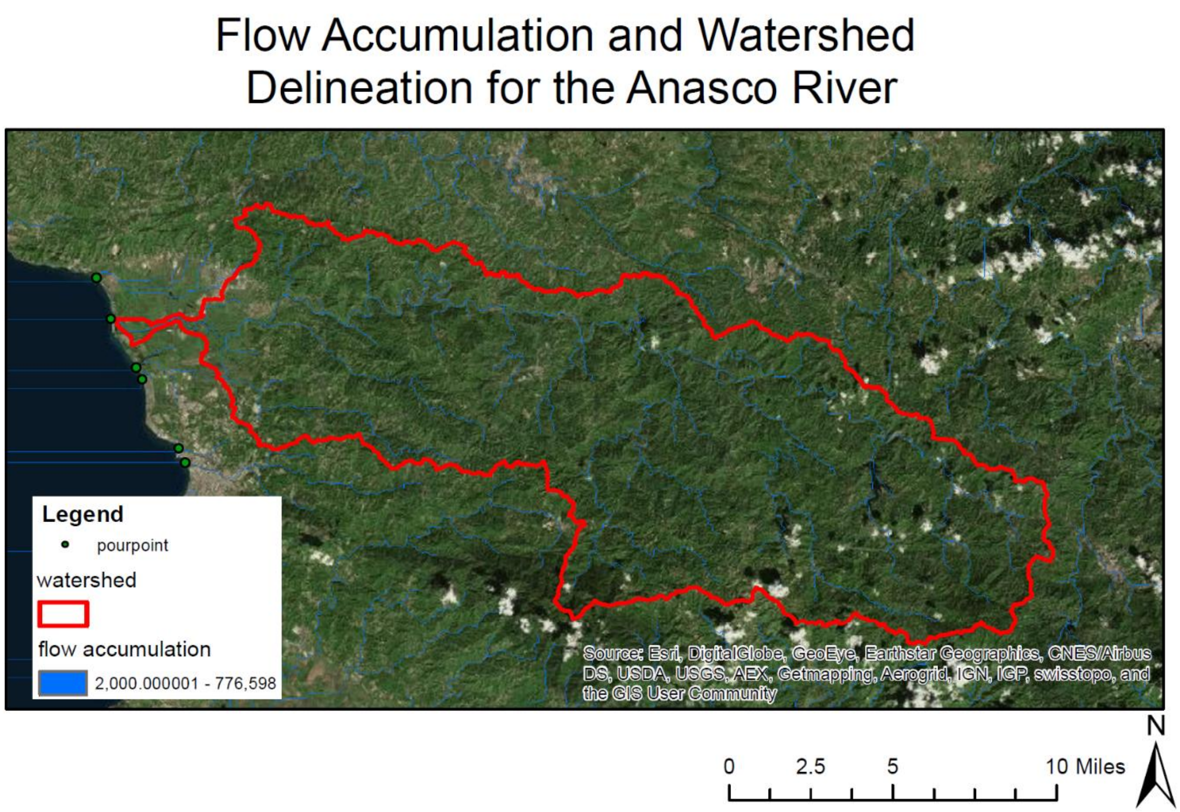

Figure 19: Añasco watershed delineation

- Identify watershed pour (outlet) points

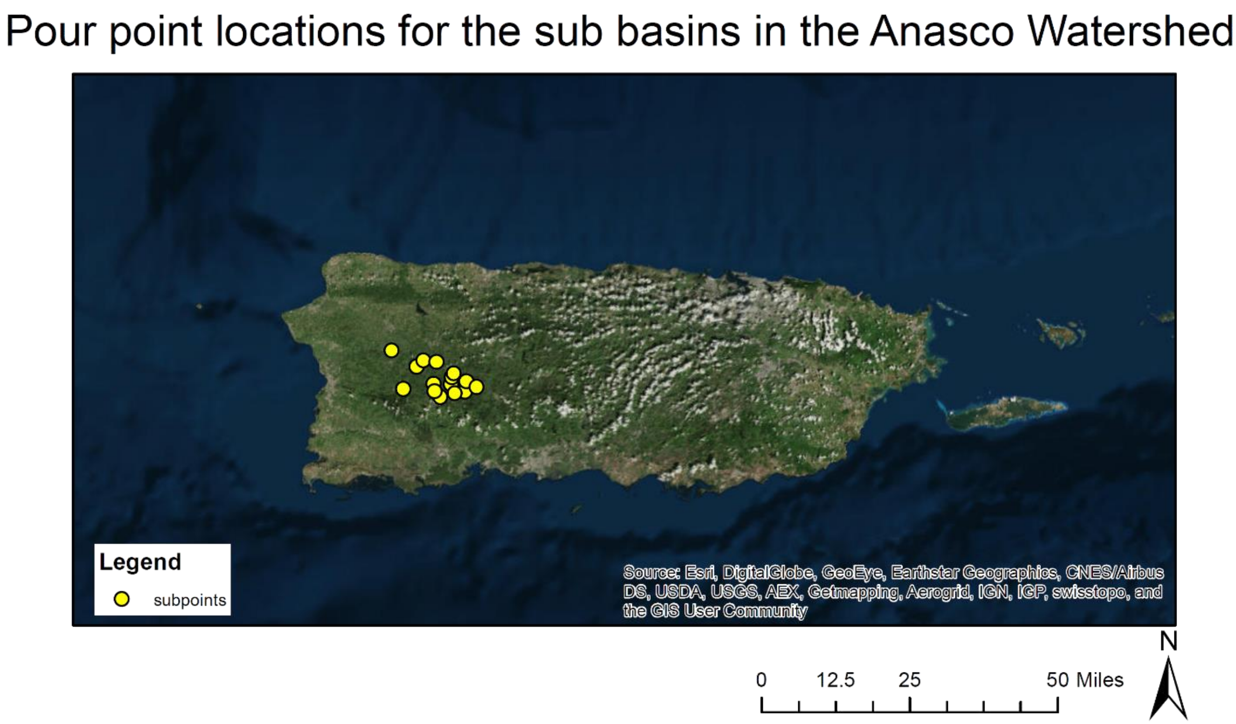

Figure 20: Pour point locations

- Delineate sub basins

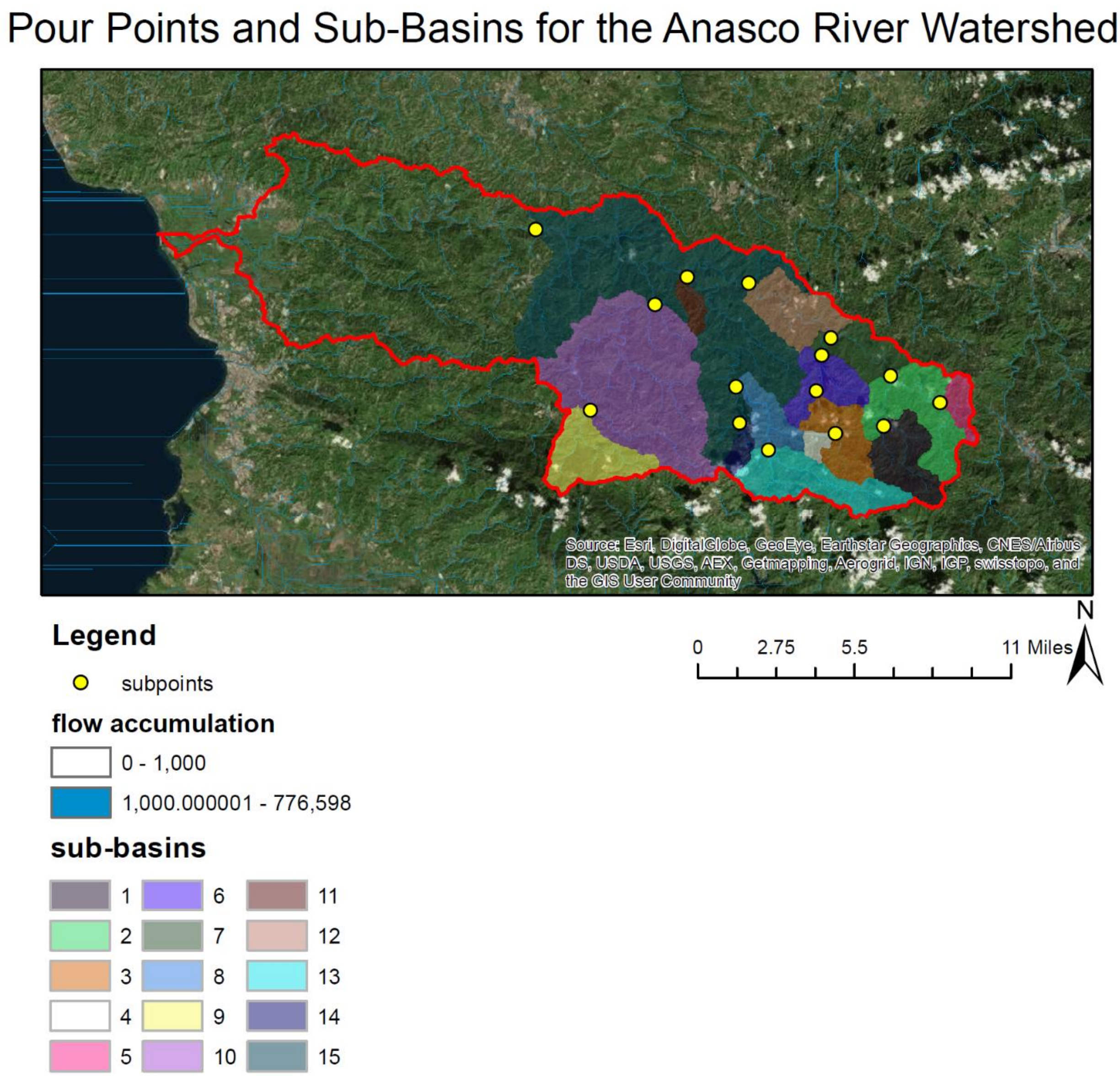

Figure 21: Stream, pour points and sub basins for the Añasco watershed map

- Obtain land use for the watersheds

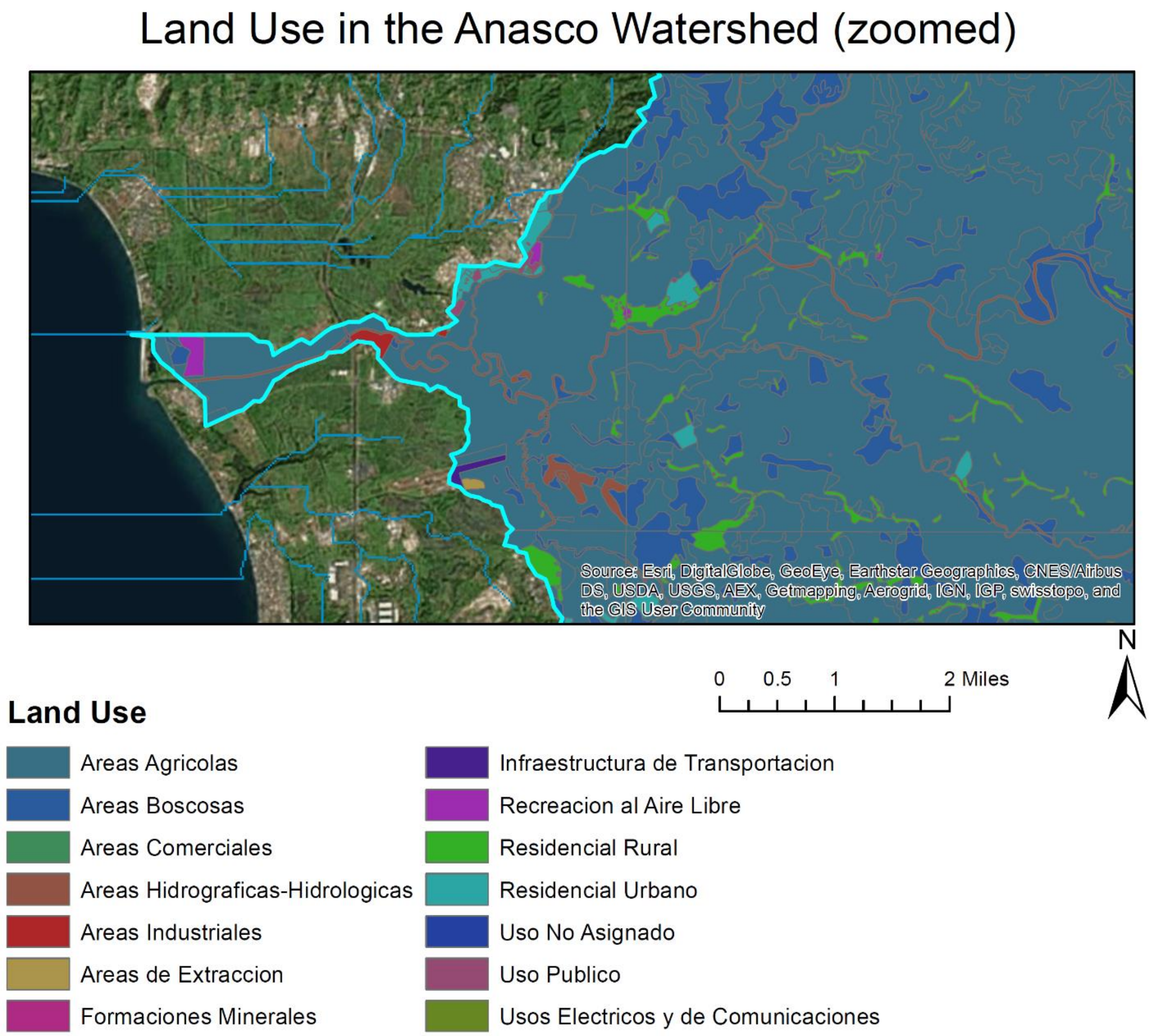

Figure 22: Land use in the Añasco watershed

- Locate pollutant source

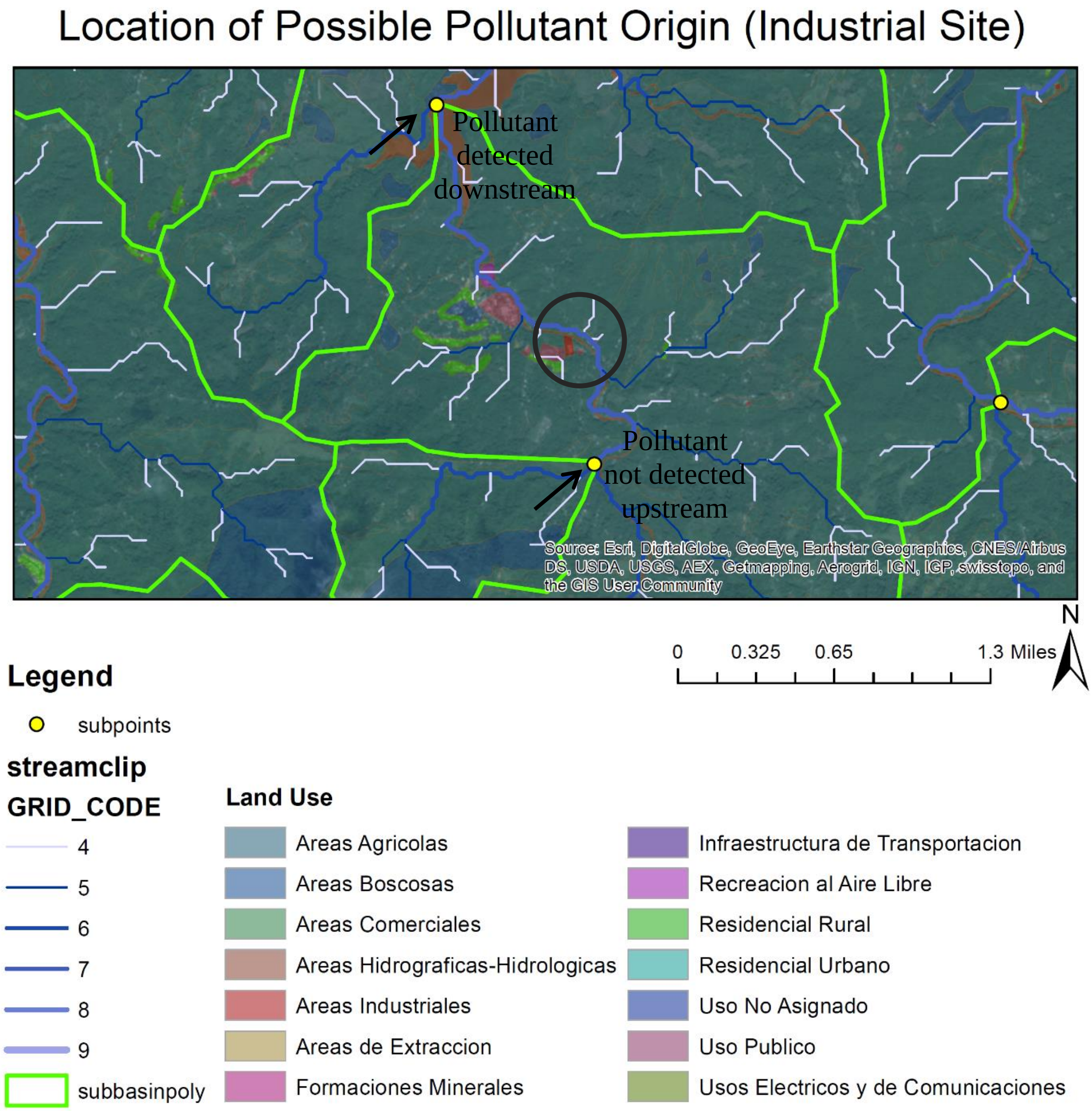

Figure 23: Possible contaminant source

As can be seen, the process of delineating a watershed can provide some very useful descriptions of the landscape. It can help:

- determine which neighboring cell will receive its drainage (flow direction).
- find the flow accumulated at each cell, based on flow direction.
- produce a stream network, by the use of a flow accumulation threshold.
- assign order values throughout the stream network.
- delineate a catchment/basin/watershed, based on flow accumulation.
- Provide a means to determine where the pollutant is entering the stream network, through the use of land use information.

Figure 23 shows the depiction of the possible contaminant source. Once the sub basins are delineated, engineers can examine water samples from the different sub basins to try and pinpoint the source. In the example, the pollutant in found on a sample downstream from an industrial area, which is marked as red in the land use information.

V. Conclusions and Recommendations

Watershed delineation was conducted through the use of ESRI ArcGIS tools, meeting the project's objectives. Furthermore, the use of these tools can be extended to assess additional concerns regarding hydrology and/or watershed management, such as: flood management, control and mitigation; water storage through the construction of dams or injection wells; runoff detention; erosion or sediment management and control; and water quality.

The use of GIS tools for performing watershed delineation has proved to be extremely useful. It reduces terrain processing time dramatically, compared to manually delineating a watershed. It provided valuable information regarding hydrological watershed parameters, as well as the opportunity to overlap layers of information, like stream networks and land use data, to make correlations regarding where contamination is being generated and/or released. The results obtained through the use of this tool can be described as accurate, if they are compared with the DRNA depiction of the Añasco River Watershed seen in Figure 2.

However, the effect of DEM resolution on the watershed characterization can be further studied. The particular DEM data used, reduced computational time and memory storage requirements. In future studies, it is recommended that higher resolution DEM data sets be used so as to provide more accurate results in terms several hydrological parameters, such as channel length and slope.

Additionally, the land use data dates back to 1977. This data should be modified to better represent actual land use conditions.

VI. References

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