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Hydrology of el Gran Lago de Nicaragua

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Exploring the hydrology of the Lake Nicaragua, Punta Gorda River, and Brito River basins in the potential impact area of the proposed Nicaragua Canal.

Photo Credit: Getty Images, the Guardian

CE 394K GIS – Term Project

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Introduction

The United States proposed the construction of an inter-ocean canal in Nicaragua throughout the 1800s but eventually built the canal in Panama. Four months after the Panama Canal's centenary, the Chinese firm Hong Kong Nicaragua Canal Development Investment Company (HKND) broke ground on the proposed USD $50 billion Nicaragua Grand Canal project on December 22, 2014. The Nicaragua Grand Canal will stretch 276 kilometers, reach a depth of 28 meters, and span a width of 83 meters upon completion.

Figure 1 The proposed Nicaragua Canal path stretches from Brito to Punta Gorda, crossing Lake Nicaragua, the largest repository of fresh water in Central America.

The full-integrated project goes beyond just the canal. With the canal and locks on a five-year construction timeframe, HKND also proposes building two ports, a free trade zone, holiday resorts, an international airport, roads, a power station, a cement factor, and a steel factory among other necessary initial construction projects. For these different aspects of the integrated project, HKND's partners include the Changjiang Institute of Survey, Planning, Design, and Research for the canal project design, the China Railway Construction Company for technical feasibility studies, and the China Railway SIYUAN Survery and Design group as the lead design contractor and for the roads project. The total project will cost around USD $50 billion and HKND's chairman and CEO Wang Jing claims to have spent USD $100 million of his own money on the canal project already. Aside from the pressure of financing a long term project with limited knowledge of future benefits, the canal will pass through Lake Nicaragua five kilometers south of Ometepe Island, an area of volcanic and seismic activity, adding the financial pressure of potential infrastructure damage or project closure due to natural disaster.

Political risk also accompanies the canal project. The corruption perception index from Transparency International ranks Nicaragua at 130 of 176 countries, indicating it is a highly corrupt country with problematic rule of law. As no political relationship exists between Nicaragua and China, the legislative assembly of Nicaragua took seven days to pass Law 840 on June 14, 2013, allowing for construction to commence. The law sets a 100 year land concession agreement with HKND (Act 3), indemnifies the firm against any delays from protests or legal challenges, exempts HKND and its subsidiaries from local taxes, allows HKND to posses and use any government owned an privately owned real property, and does not require any compensation to be awarded to Nicaragua if the project is abandoned. While popular support exists for the project in Nicaragua and its potential economic benefits, protests have occurred in the construction region vilifying President Daniel Ortega for giving up the land to the Chinese firm. Progress on the canal serves Ortega's political best interests, as the next round of presidential elections are due in 2016.

HKND contracted the Environmental Resources Management (ERM) to carry out one key facet of the Nicaragua Grand Canal integrate project: the Environmental and Social Impact Assessment (ESIA). The ESIA will focus on the Rivas, the Rio San Juan, and the Región Autonómica del Atlántico Sur (RAAS) departments to determine existing environmental, social, and health conditions of the areas and to predict, assess, and develop mitigation measures for any potential impacts. HKND will use highlights from the ESIA to make necessary adjustments to the project design and management decisions to minimize negative impacts and maximize benefits before the start of the project. ERM completed a preliminary report six days prior to the groundbreaking in December 2014 detailing the environmental impact of preliminary construction, not the canal itself. Though the canal is designed to have no net use of Lake Nicaragua's freshwater supply, 715 million m^3 freshwater dredging will occur in the lake to allow for the necessary canal depth in the lakebed. The Association for Tropical Biology and Conservation (ATBC), the International Union for Conservation of Nature (IUCN), and the Humboldt Center of Nicaragua warned against negative impacts to wildlife and freshwater supply from the Lake due to construction activities.

According to the Washington Post on November 25, 2015, HKND has suspended canal activities until late 2016 for unidentified reasons.

Watershed Delineation

Available Data

Several sources provided layer packages for data throughout Central America. The data used in this project was publicly available.

- **Central America drainage basins and river network:** http://hydrosheds.cr.usgs.gov/dataavail.php
- **Digital elevation models and population coverage by country:** http://www.diva-gis.org/gdata
- **Central America watersheds, land cover, and fish populations:** http://databasin.org/datasets/7e28bde7285244d080ef191e9ad39bdb http://databasin.org/datasets/693f573b98834d1cbcc364e7f0b8e5db http://databasin.org/datasets/ddf92216150240728366 59de0780b078
- **Nicaragua population and poverty statistics:** https://ut-austin.maps.arcgis.com/home/search.html?q=owner:daguilar

Basin Delineation

Drainage basins across the proposed canal path were illustrated using the Watershed Tool. Coordinates for the mouths of the three main rivers were pulled from Google Maps:

- Río Brito: 11º22’5”N 85º56’51”W
- Río Punta Gorda: 11º30’42”N 83º47’11”W
- Río Colorado: 10º46’13”N 83º35’28”W

Río Brito and Río Punta Gorda have their own drainage basins of 252 km^2 and 2823 km^2, respectively. Río Colorado breaks off from Río San Juan at the border between Nicaragua and Costa Rice; the drainage basin from the lake crosses the boundary and drains out through Río Colorado.

Figure 2 The proposed canal will stretch from Brito to Punta Gorda, stretching across three drainage basins.

The basins provided by the Watershed Tool match up well with the basin boundaries from HydroSHEDS data. Data for the flow directions of the basins was also provided. However, for the analysis in this project, flow directions will be delineated using GIS tools as seen in the following section.

Delineation from Digital Elevation Model

Delineation of the Lake Nicaragua, Río Brito, and Río Punta Gorda basins started with data provided by the data source DIVA-GIS. This source is a database supported by several CGIAR institutes including Biodiversity International and the University of California at Berkeley. The hydrological terrain analysis follows the steps laid out in Exercise 4 (CE 394K GIS 2015).

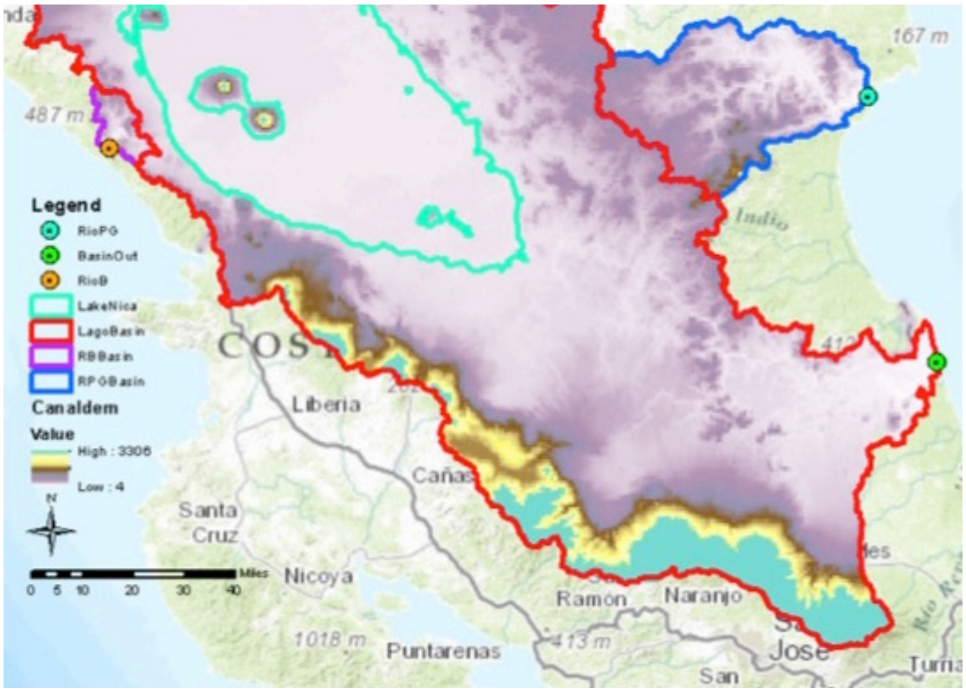

Figure 3 Digital elevation model

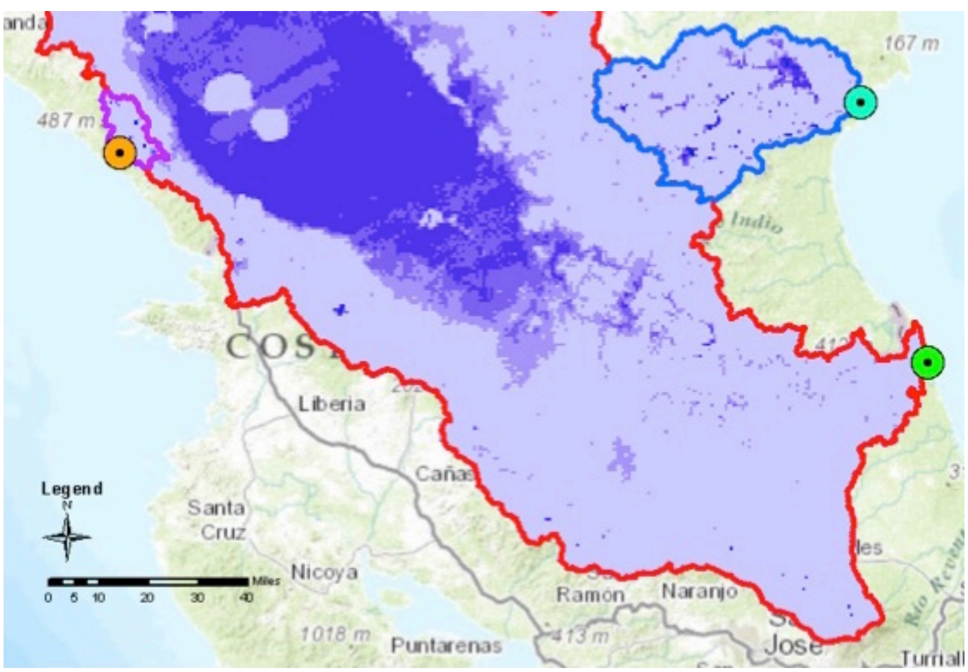

Figure 4 Identify sinks using the Fill and Raster Calculator tools.

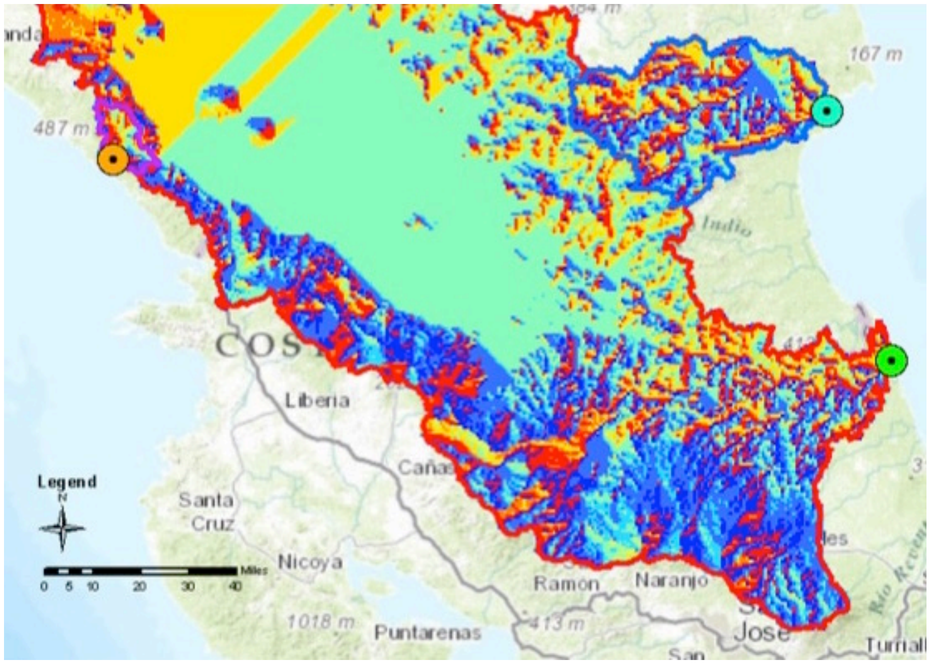

Figure 5 Calculate Flow Directions using the Flow Direction tool.

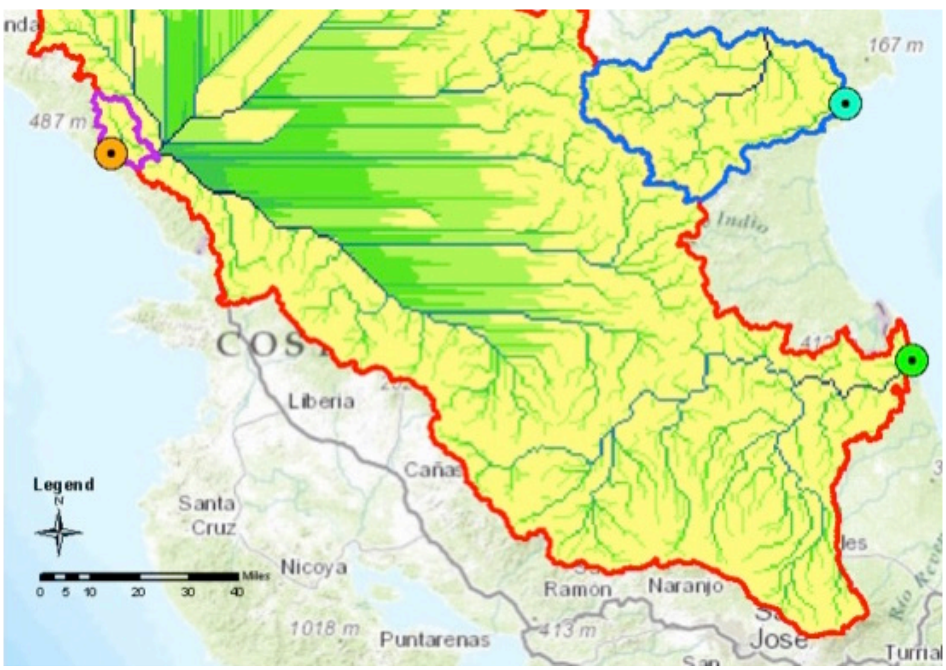

Figure 6 Use the Flow Accumulation from the Hydrology Toolbox.

Figure 7 Delineated streamlines in the basins illustrated using the Raster Calculator and Stream Link tools.

Reconditioning the DEM

Unfortunately, the delineated streams, as shown in Figure 7, present an issue that must be addressed. Lake Nicaragua drains to the south through Río San Juan and Río Colorado. However, the delineated streamlines do not show a connection between accumulation patters in the lake and the stream that drains the water body. Figure 8 shows the comparison between the delineated streams and the river network provided by HydroSHEDS:

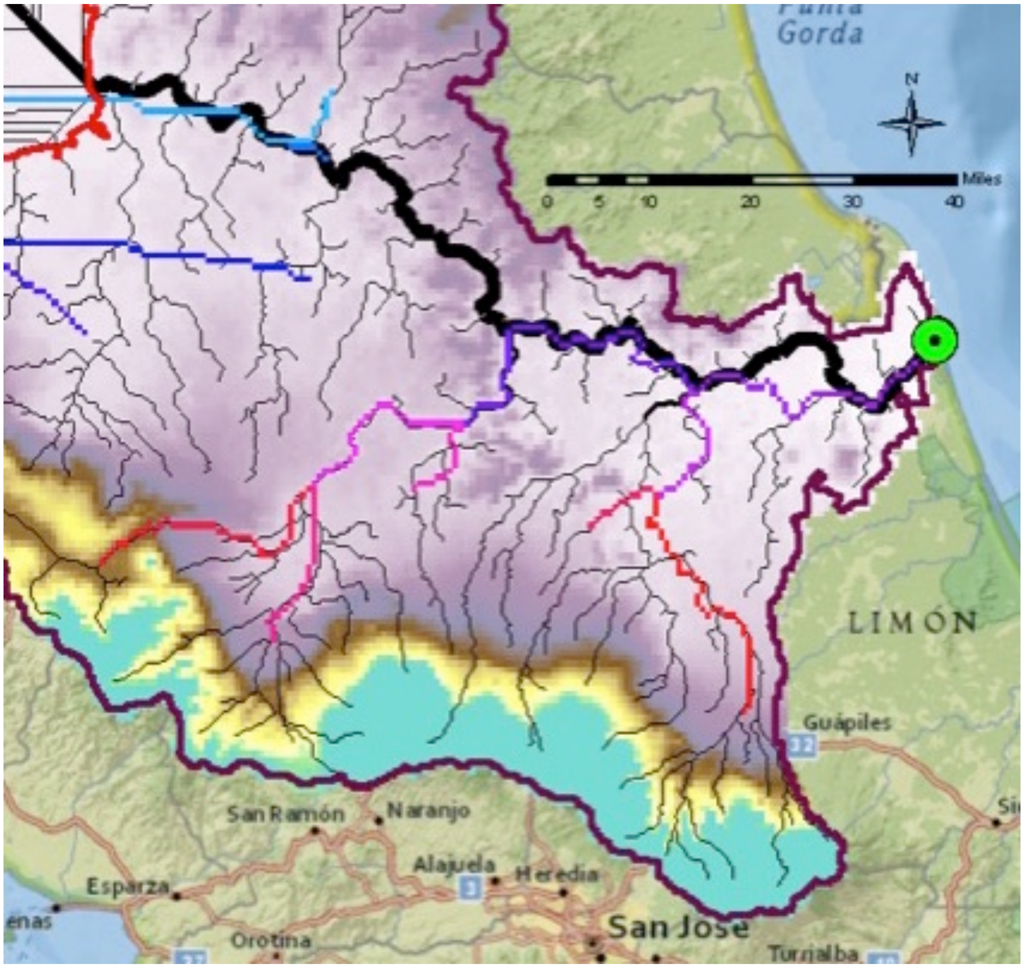

Figure 8 The delineated streams do not accurately represent the river network that drains Lake Nicaragua.

In order to address this issue, the river network must be "burned" into the DEM for the method from Exercise 4 to provide the correct delineation. DEM reconditioning follows the AGREE method provided by 2011 GIS in Water Resources Exercise 4 prepared by Dr. David Tarboton:

1. Using the Feature to Raster tool, change the Flowlines from a feature to a raster and set the Environmental Settings to reflect the basin's DEM:

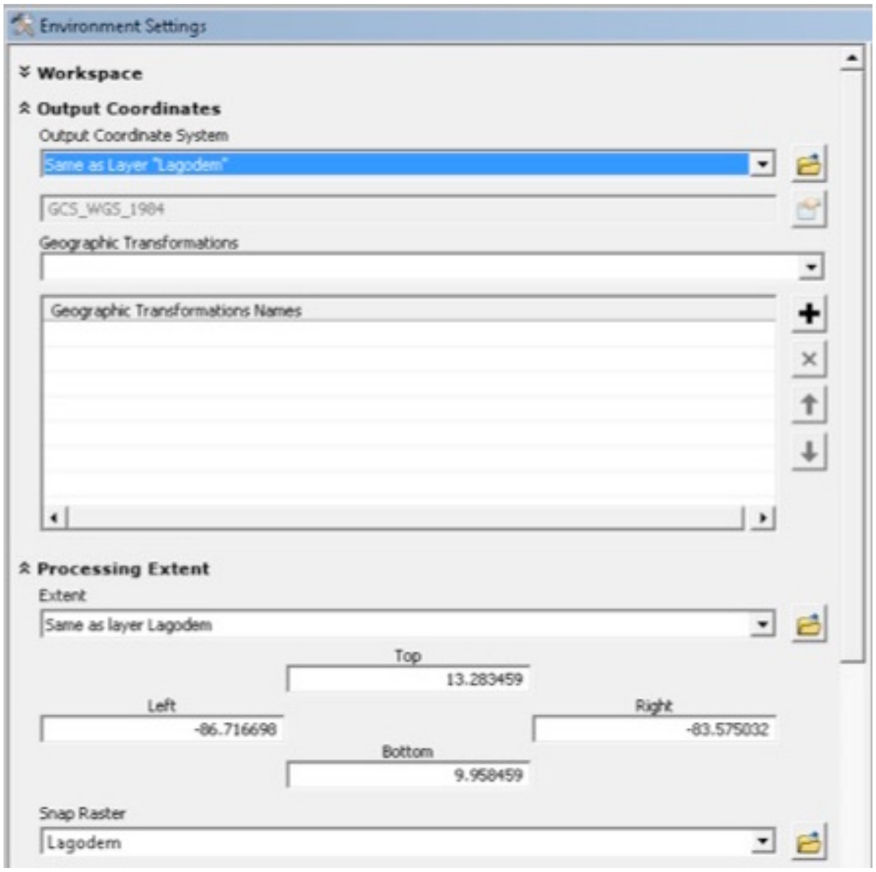

Figure 9 As part of the Feature to Raster tool, Output Coordinates and Processing Extent categories must be set to reflect the basin's DEM, e.g. Lagodem as shown.

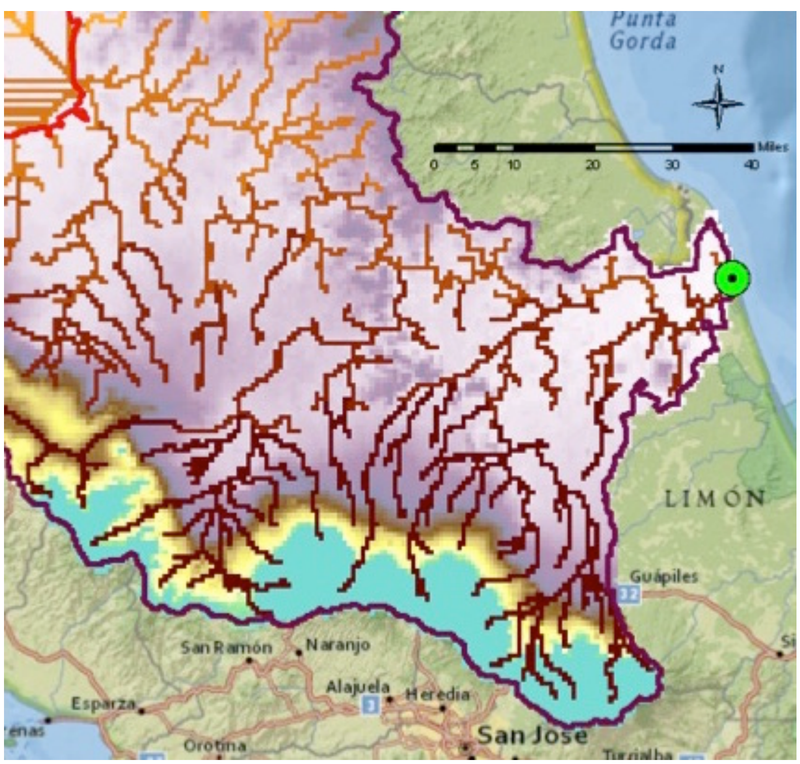

Figure 10 Result of switch the streamlines to a raster

2. Then use the Greater Than tool to identify what part of the new raster is a stream:

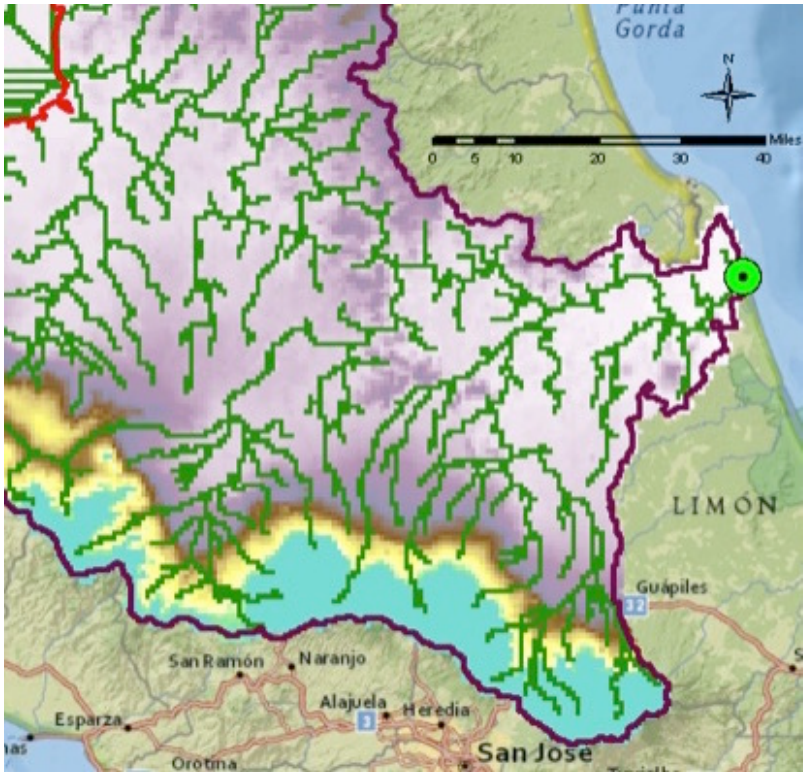

Figure 11 The result of the Greater Than tool which sets the raster into binary values

3. The Reclassify tool will set the NoData category to a value of zero for binary data values:

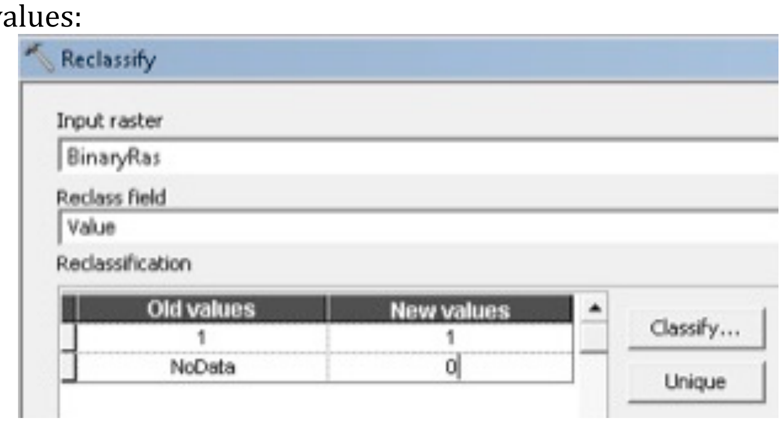

Figure 12 All values in streamline raster must be binary

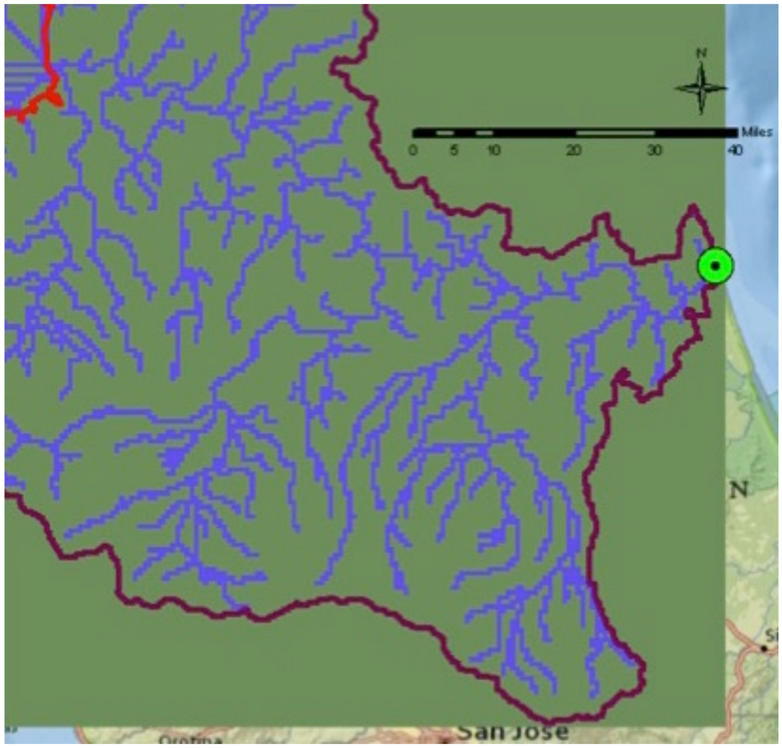

Figure 13 Reclassify tool reflects streams (in purple) as value 1 and "not streams" (in green) as value 0

4. Using the Euclidean Distance tool, calculate the distance from each cell to the nearest source. Environmental settings must reflect the basin DEM again and a maximum distance of 100 m was set to provide detailed distances:

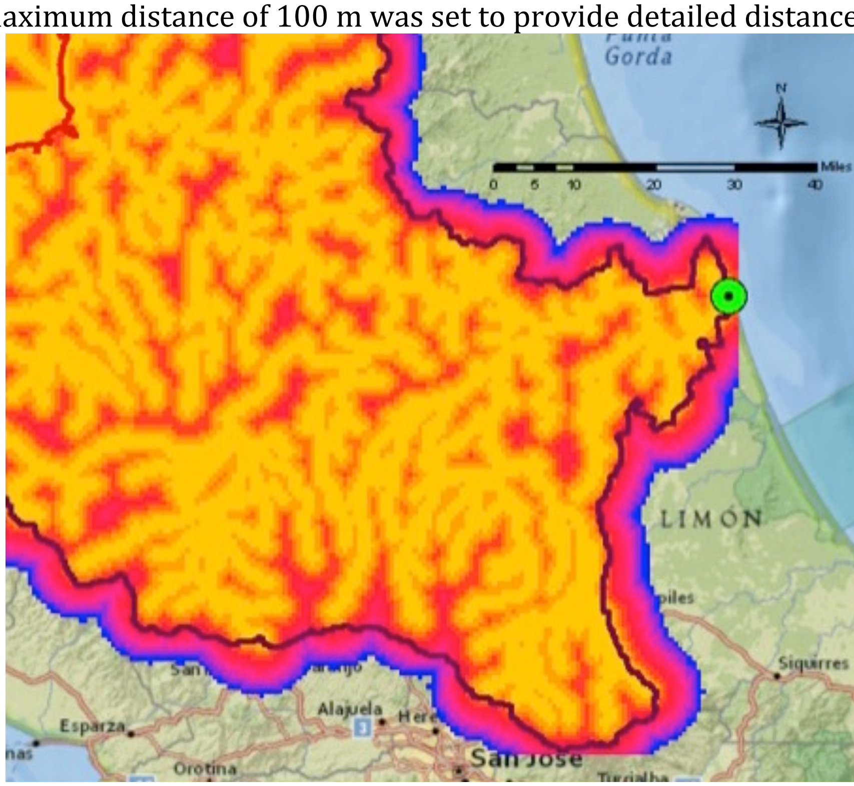

Figure 14 Euclidean distances provide a range of distances from cells to source

5. AGREE reconditioning is performed using the Raster Calculator. In the following calculation, the basin DEM was raised before stream grid cells and tapering were subtracted:

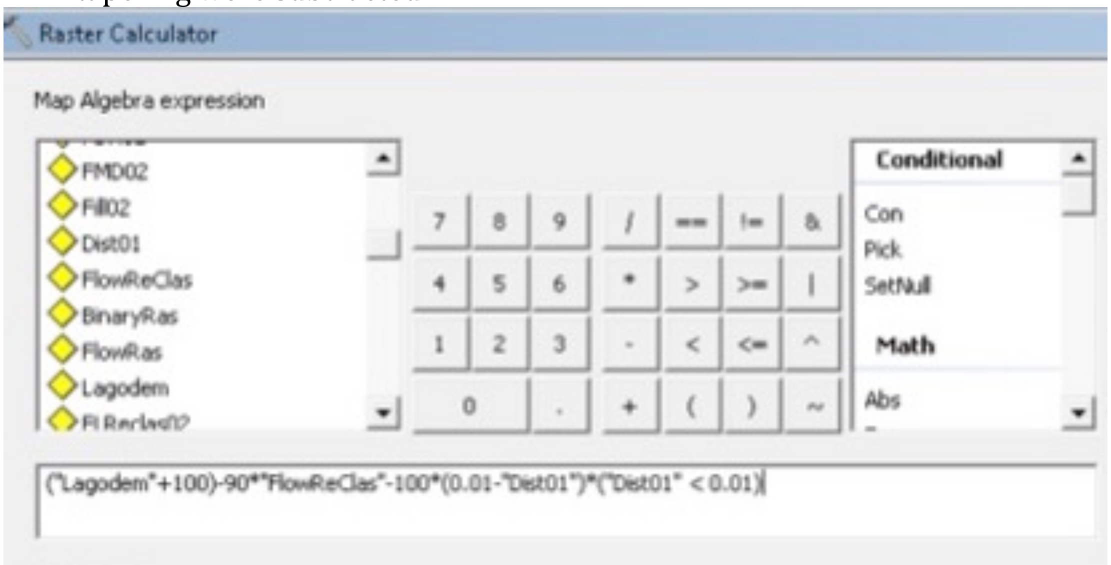

Figure 15 Raster calculator syntax for AGREE reconditioning of the basin DEM

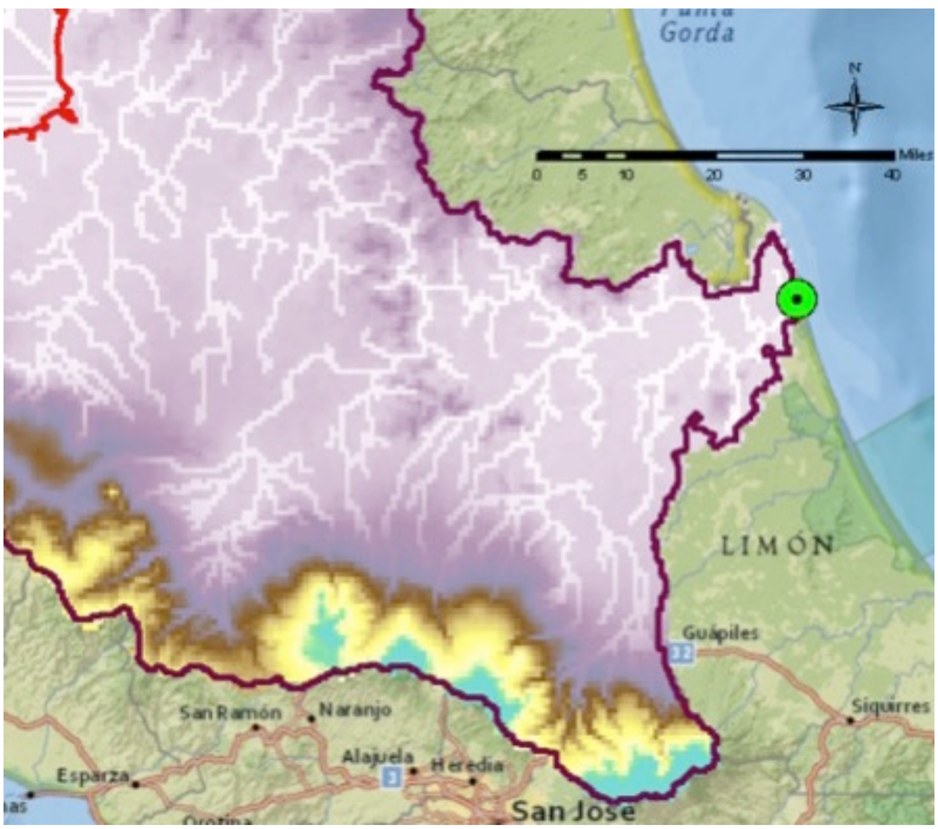

Figure 16 The reconditioned DEM clearly illustrates "burned" streamlines

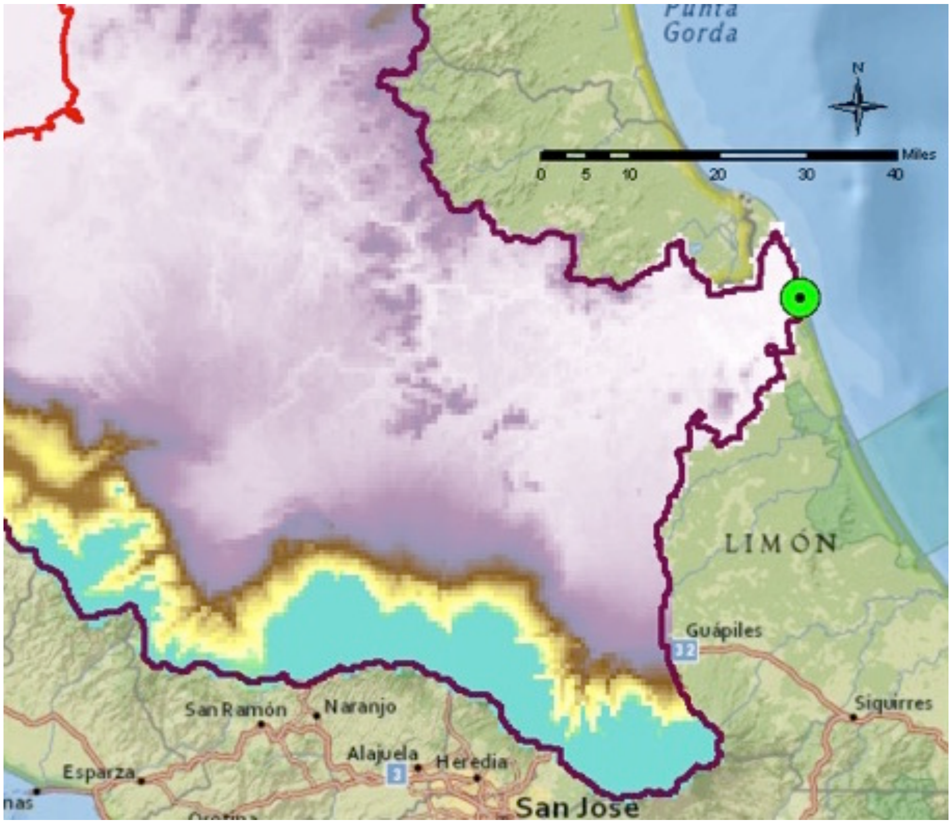

Figure 17 A closer look at the original DEM shows the improvement provided by the "burned" streamlines

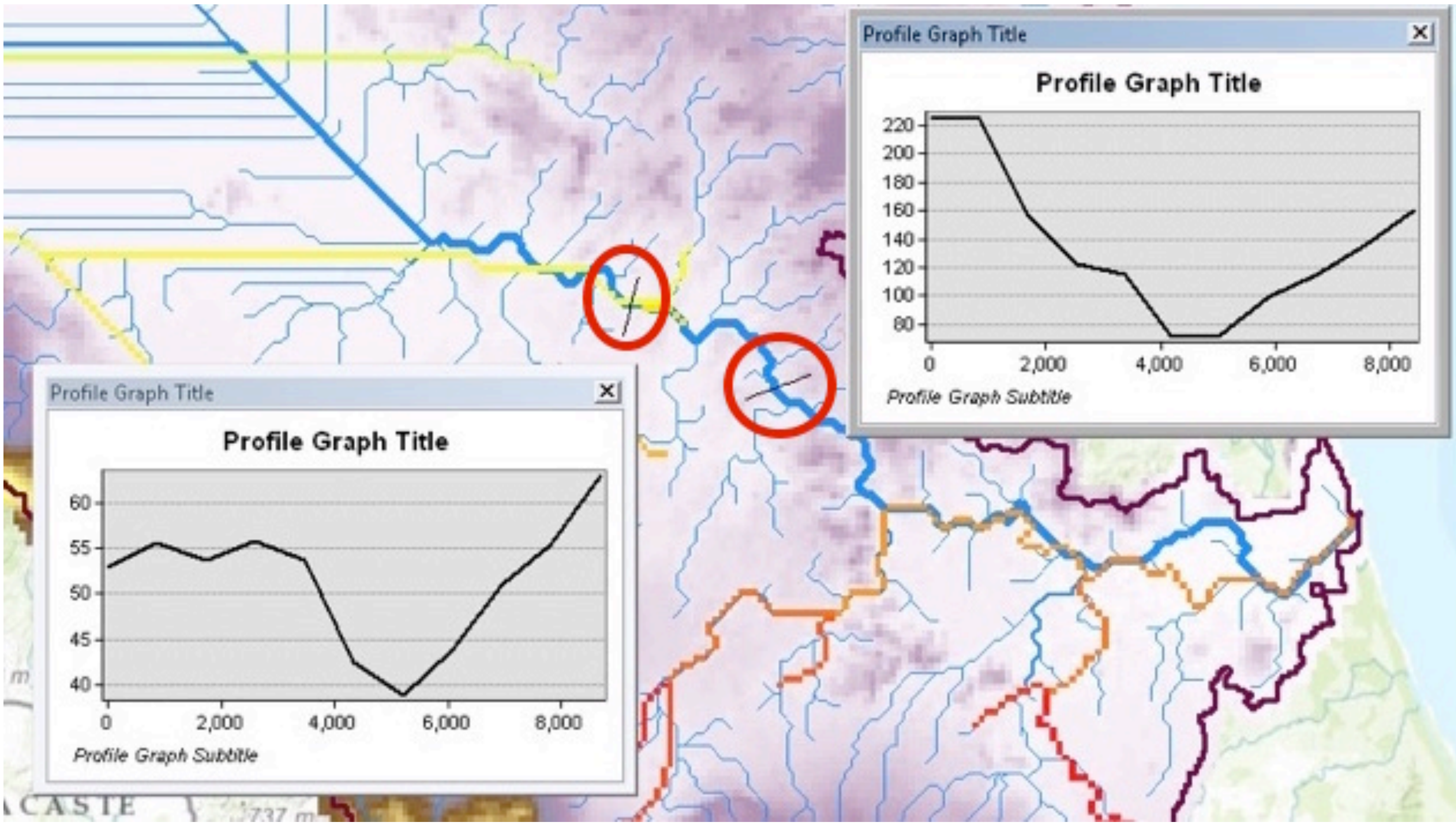

Figure 18 3D Analyst profile allows illustration of the burned streams. The cross-sections analyzed are circled in red.

Using the 3D Analyst Profile tool can see the extent of how well the streamlines were burned into the DEM. The streamlines and original delineated streams are shown in Figure 18 as well to illustrate the "burning." Now that the DEM has been recondition to reflect all streams present in the river network, repeating the hydrologic terrain analysis should provide all appropriate delineated streams. The same method from Exercise 4 (2015) was repeated for this analysis:

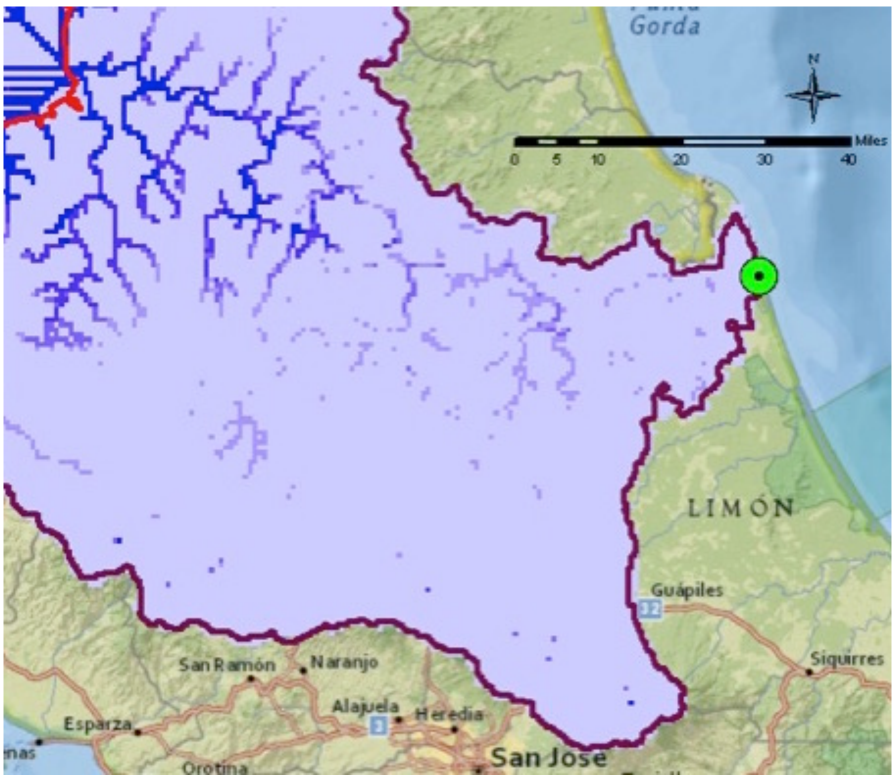

Figure 19 The sinks from the reconditioned DEM reflect the burned streams rather than Lake Nicaragua

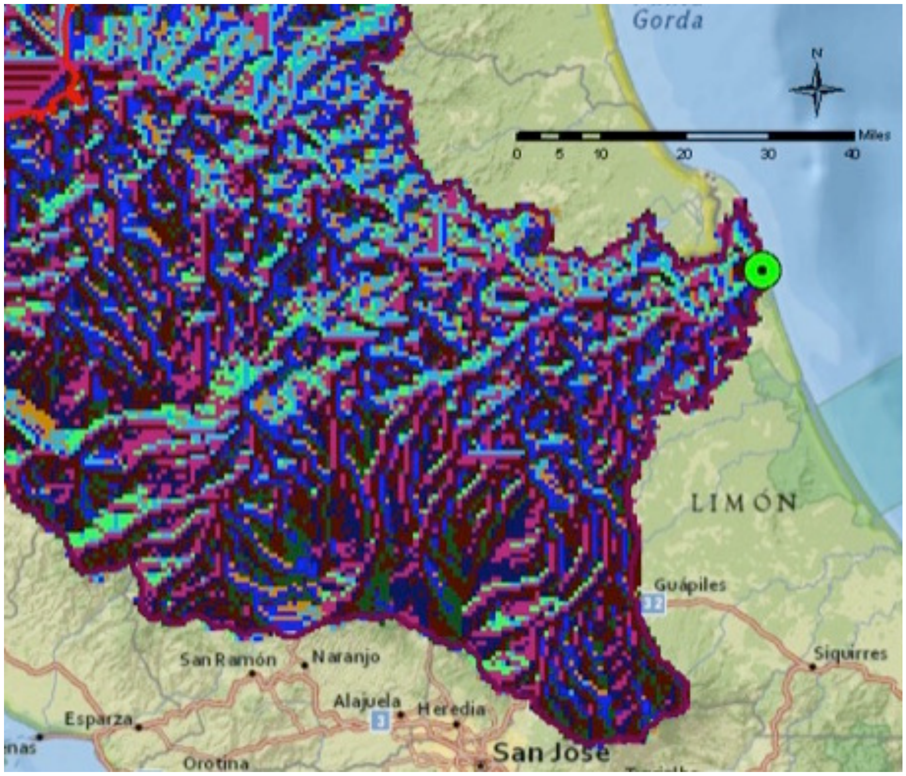

Figure 20 The flow directions based on the reconditioned DEM clearly illustrate the streamlines

Figure 21 The flow accumulation from the reconditioned DEM shows the connected streamlines

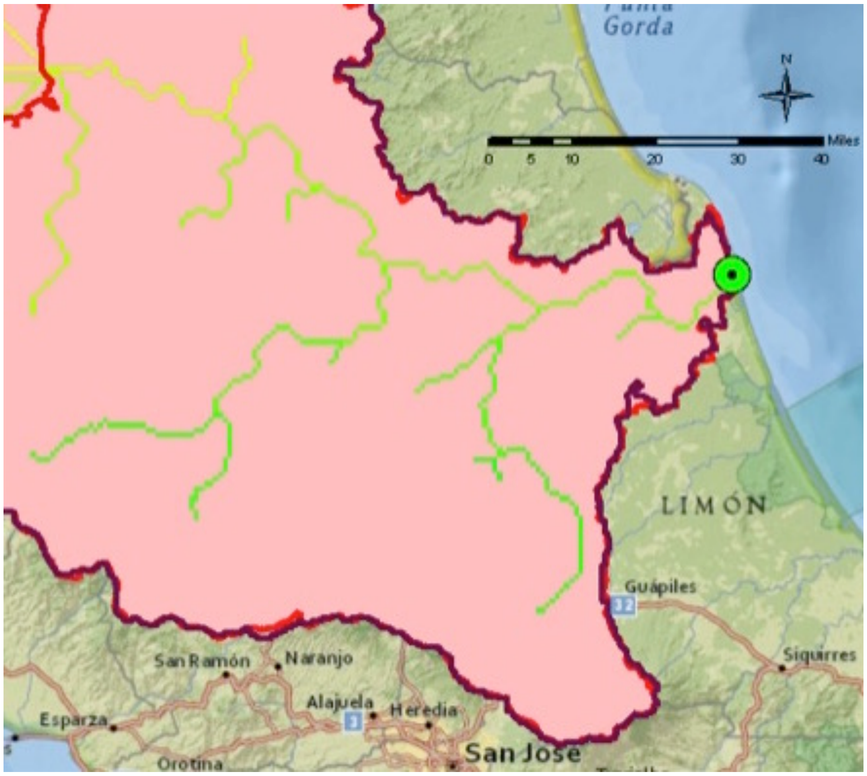

Figure 22 The delineated streams finally represent the full Río San Juan draining from the lake

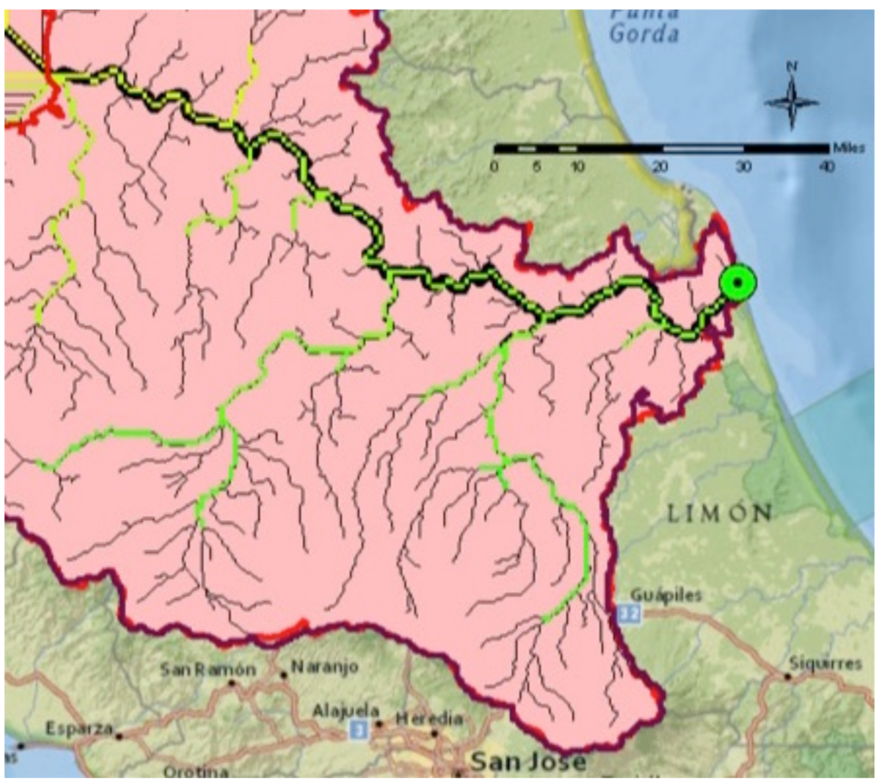

Figure 23 Comparison with the river network confirms the accuracy of the delineated streams

Results

The complete, and appropriate, delineated streamlines (Figure 24) match the river network for all three basins. Though the Lake Nicaragua drainage basin includes the northern administrative provinces of Alajuela, Heredia, and Limón, the water contributed to Río San Juan and Río Colorado in Costa Rice originate in the mountains to the south.

Figure 24 Complete delineated basins that the canal could potentially affect

The Brito, Lake Nicaragua, and Punta Gorda basins should show drainage areas of 252, 40965, and 2842 km^2, respectively, based on the basin areas from

HydroSHEDS. Checking the flow accumulation points for each basin should confirm these areas (Figures 25-27, respectively).

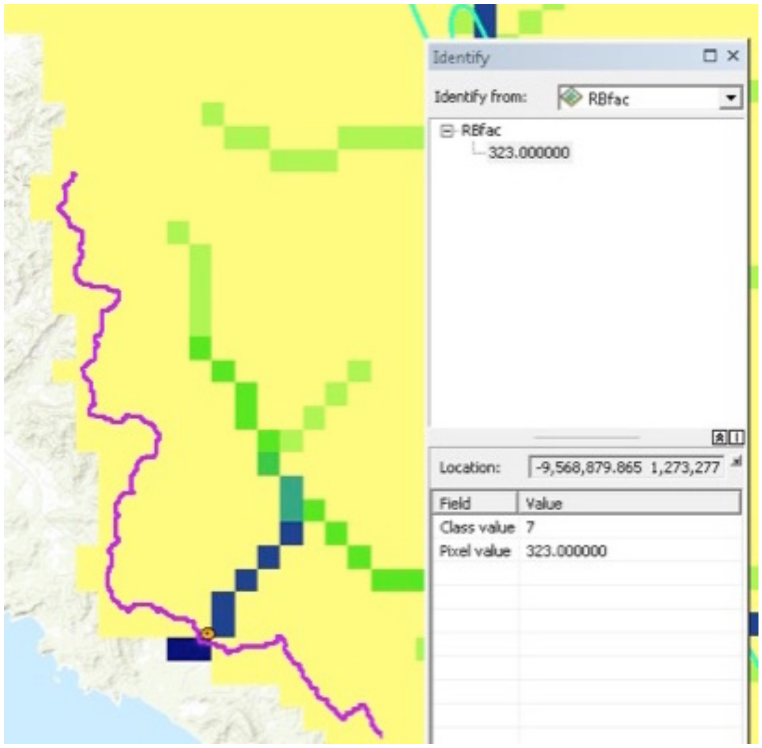

Figure 25 Cumulative flow accumulation for the Río Brito basin

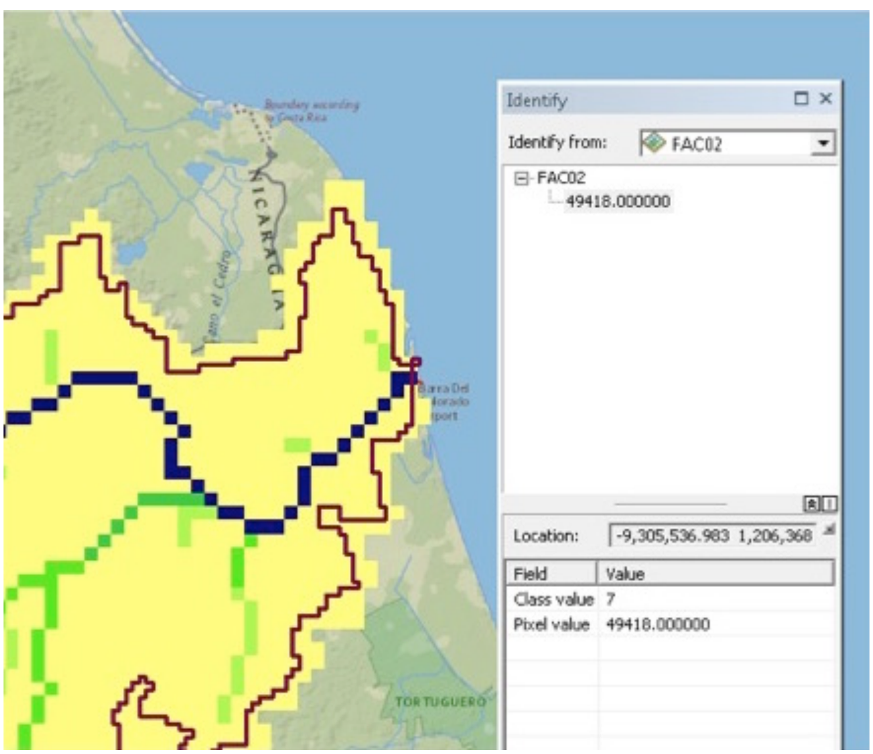

Figure 26 Flow accumulation draining the Lake Nicaragua basin

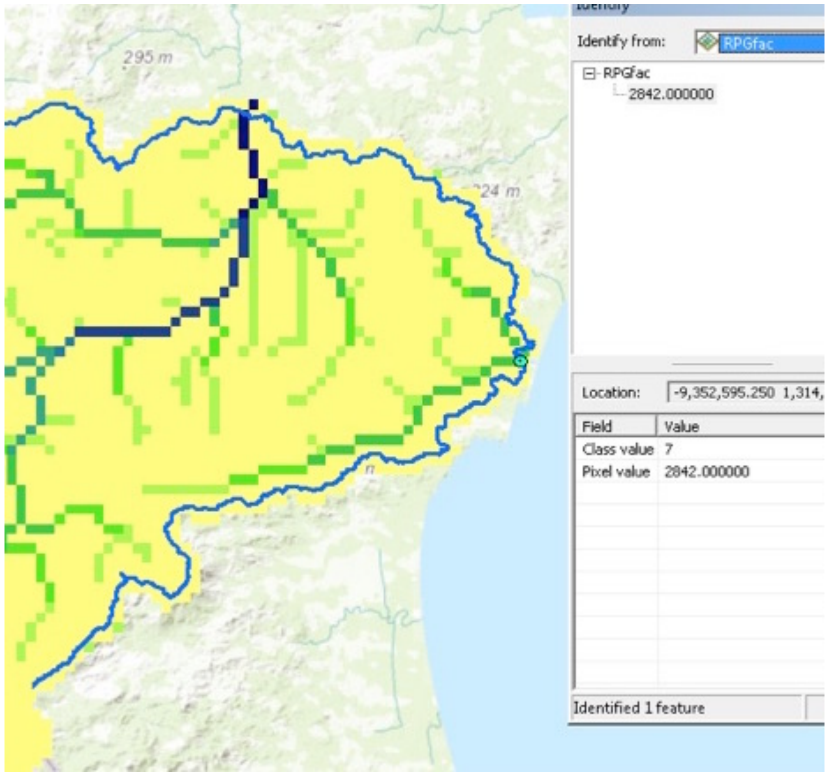

Figure 27 Flow accumulation for the Punta Gorda drainage basin

The delineated flow accumulations for the Brito, Lake Nicaragua, and Punta Gorda basins are 323, 49418, and 2823 km^2, respectively. This is a 24% difference in drainage area for Río Brito; 19% for Lake Nicaragua; and 0.67% for Río Punta Gorda. The Río Punta Gorda basin does not drain out of Río Punta Gorda as expected, according to the hydrologic terrain analysis.

Scope of Potential Effects

Lake Nicaragua holds approximately 110 km^3 of water and is the only freshwater lake in the world to contain oceanic animal life such as bull sharks. Over 100 species of fish are represented in Figure 28.

Figure 28 Approximately 110 species of fish can be found in the basins of study

While the impact on the wildlife is important, it is also necessary to consider the impact to the human population in the area. No major population centers in Nicaragua and Costa Rica would be affected by canal construction or activities. The degree of poverty of the population surrounding Lake Nicaragua paints a different story. The population in the Río San Juan Department has an 80% poverty rate (Figure 30). Therefore there is little financial or political clout behind the population that would be most affected by the canal.

Figure 29 Population data presented in the thousands of people

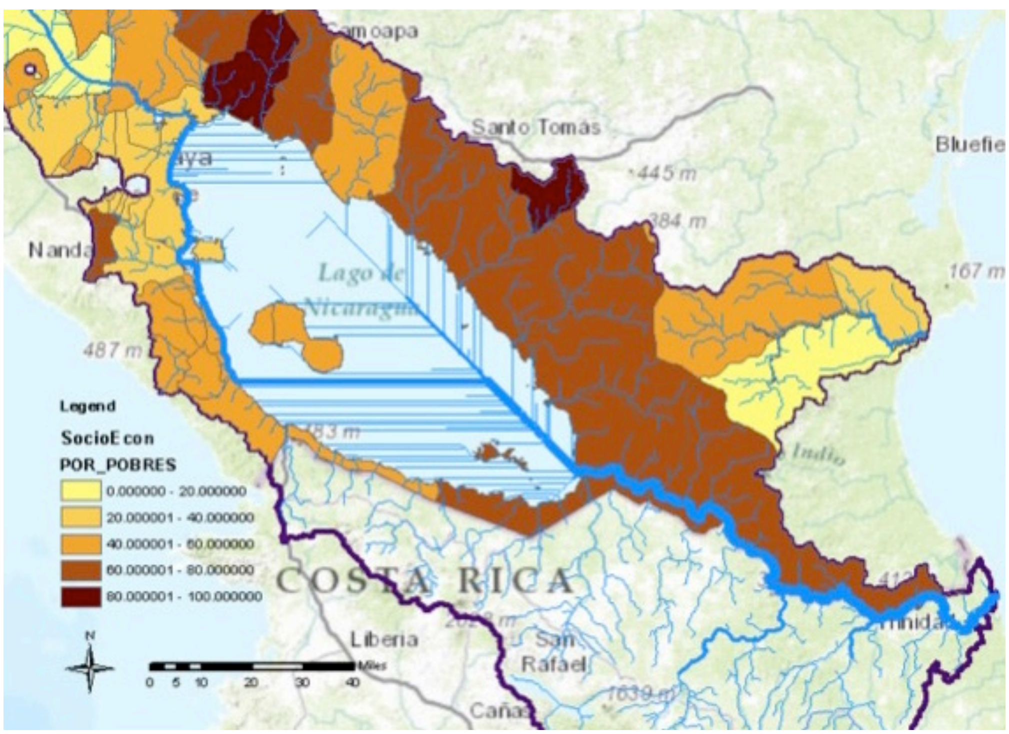

Figure 30 Elevated poverty rates of the population inhabiting the area surrounding the proposed canal path

The land these people inhabit is primarily "closed to open broadleaved evergreen or semi-deciduous forest" or "mosaic vegetation/croplands," as seen in Table 1. The tropical climate receives anywhere from 1500 mm to 5600 mm of rain per year.

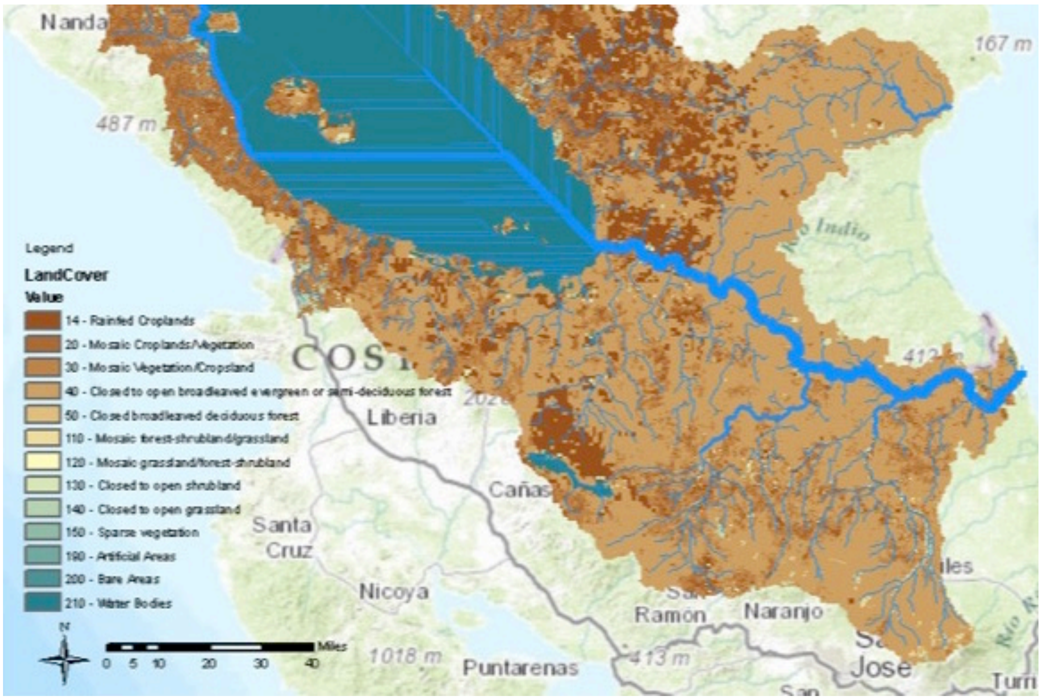

Figure 31 Land cover of the canal impact area is primarily broadleaved evergreen or semi-deciduous forest

Table 1 Precent cover by multiple types of land cover. Primarily rainforest type vegetation

Land Cover	Percent Cover
Rainfed Croplands	7.1%
Mosaic Croplands/Vegetation	11.6%
Mosaic Vegetation/Croplands	20.6%
Closed to open broadleaved evergreen or semi-deciduous forest	32.9%
Closed broadleaved deciduous forest	0.1%
Mosaic forest-shrubland/grassland	0.9%
Mosaic grassland/forest-shrubland	0.5%
Closed to open shrubland	0.2%
Closed to open grassland	4.7%
Sparse vegetation	0.1%
Artificial areas	0.0%
Bare areas	0.0%
Water Bodies	21.1%

Figure 32 Large amount of rain fall on the Lake Nicaragua basin; up to 5600 mm per year

Conclusion

"The Nicaragua Canal will be a project of unprecedented magnitude," says Pablo Fonseca in *Scientific American*. When completed, the canal will have the capacity to accommodate the absolute largest oceangoing vessels. If HKND successfully navigates any economic, political, or geophysical risks and implements their construction plan for the integrated Nicaragua Grand Canal project, the potential economic success could transform the scale of global energy trade and the economies of Nicaragua and Central America. The potential impact area of the canal stretches over 33% of Nicaragua and into Costa Rica, includes millions of impoverished people, and endangers an expansive freshwater network.

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