The Watershed of the Rio Bravo, Belize

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GIS in Water Resources

Abstract

The Rio Bravo is an understudied river in northwestern Belize. Yet, it is an important location for archaeological studies, and may prove vital as deforestation increases in the surrounding region. This project delineates the river and its watershed using a hydrologically conditioned digital elevation model. The Rio Bravo's watershed extends farther into Guatemala than previously anticipated, which may have far-reaching implications for international water issues, as well as archaeological research.

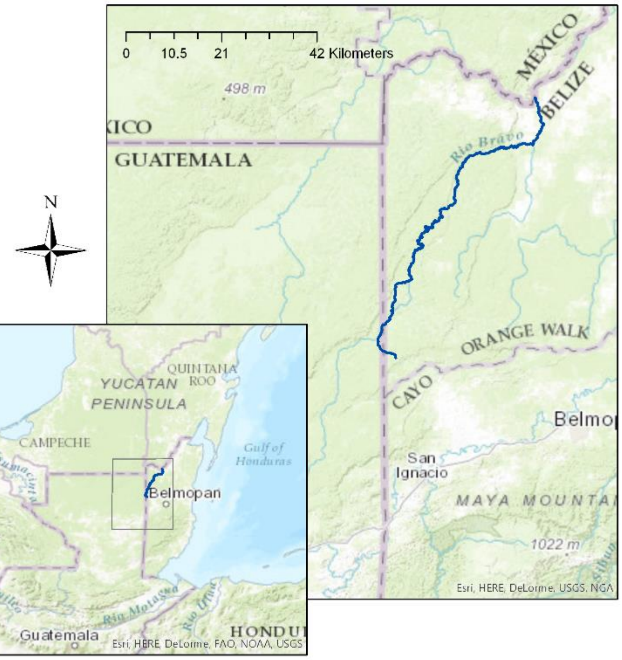

Figure 1: Northwestern Belize study site, with the Rio Bravo shown in blue.

Introduction

Northwestern Belize, and the Rio Bravo, are the focus of this study (Figure 1). The region has a subtropical climate where a wet season prevails from June to December when the International Tropical Convergence Zone (ITCZ) is north of the equator, followed by a dry season in the other months due to the southern migration of the ITCZ (Haug et al., 2001; Chiang et al., 2002). This wet and dry tropical climate leads to the general category of subtropical moist forests, with broadleaf, semi-deciduous forests in the study area (Figure 2; Hartshorn et al., 1984; Brokaw et al., 1993). The forests, and other environments in the region, vary based on topographical characteristics. The topography is influenced by Cretaceous through Tertiary carbonate bedrock, molded by karst, tectonic, and fluvial processes. These processes create a series of escarpments and depressions leading to the coastal plain, on the edge of the study area (Miller, 1996; Beach et al., 2009). These processes are particularly relevant for hydrology work because the geomorphology of this region will have features which affect hydrological analyses; such as sink holes and disappearing streams.

The Rio Bravo, and broader region, features a prominent anthropogenic influence on the environment. Humans began deforesting the region for agriculture around 3000 BC

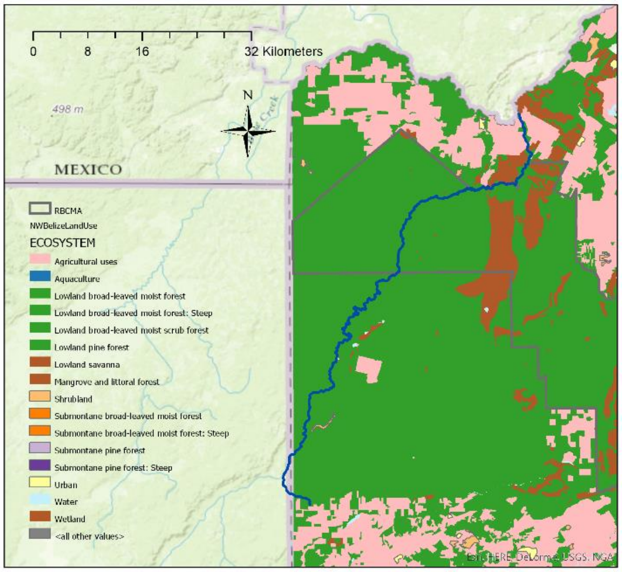

Figure 2: Ecosystems of northwestern Belize with the Rio Bravo and the Rio Bravo Conservation Management Area overlayed. (Data derived from Meerman and Clabaugh 2016)

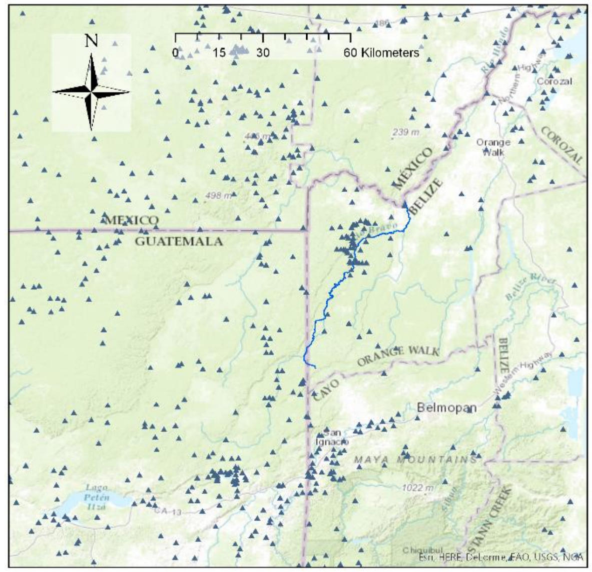

Figure 3: Ancient Maya sites in the three borders region. (Data derived from mayamap.org)

(Leyden, 1987). The clearing continued throughout the prehistoric Maya occupation of the region (1000 BC to 900 AD) (Vaughn and Crawford, 2009), and their sites are still found throughout the region (Figure 3). Regardless, the area has been reforested in the years since Maya occupation. Even as such, some of their agricultural features are still visible and may have an impact on the hydrology of the region. For instance, some ancient Maya reservoirs hold water and could affect the hydrology. Many of these sites and features are present in the Rio Bravo Conservation Management Area (RBCMA), and surrounding forested areas, which are heavily forested because they have been mostly uninhabited since the late 19th century (Figure 2). Recently, Mennonites residing north of RBCMA have had a large presence on the land through the use of mechanized agriculture to fell large portions of the forest (Platt, 1997). Their agricultural practices create forest fragments with large stretches of forest edge, and endangers the environments and waterways of this area.

In undergoing this research, one of my objectives is to better understand the environments of this region before more deforestation occurs. I also seek to create a better map of the Rio Bravo, to inform future ecological and archaeological work. The existing shapefiles depicting this river are not entirely correct. This has become clear as I and other members of my lab group have taken GPS points on the river, and found that those points differ from the river features. The Rio Bravo runs through dense canopy that is difficult to penetrate by land and remote imaging surveys, which is likely the underlying cause of these discrepancies.

Methods and Results

Data Acquisition

In order to delineate the Rio Bravo and its catchments, I used a hydrologically conditioned digital elevation model at 3 arc-second resolution from HydroSHEDs (Lehner et al. 2008). This dataset is derived from Shuttle Radar Topography Mission (SRTM) imagery at 3-arc second resolution. The raw imagery is conditioned through a variety of processes in order for it to be optimal for hydrological research. For this study area, it is particularly pertinent that they fill natural sinks through a mixture of automatic and manual methods. Thus, the karst topography of much of northwestern Belize is properly accounted for in this dataset. They also use a "stream burning" procedure to lower the elevation of water bodies in order for them to be correctly recognized in hydrological models. "Stream burning" creates well-working models, but it is necessary to ensure that a correct vector of the stream is used for the burning process, or it leads to an incorrect model. This is particularly concerning due to the fact that previous vectors exhibiting the Rio Bravo have proven to differ from field comparisons.

I also utilized the Biodiversity and Environmental Resource Data System of Belize (BERDS) for land use maps, protected area shapefiles, and river features. The vector demonstrating a frequently used Rio Bravo feature in many of the figures is derived from the Belize Rivers Shapefile available on their site (Meerman and Clabaugh 2016).

Data Processing

Due to the availability of data in Central America, I processed a broader area of interest for drainage lines and catchments (Figure 4; Appendix 2), and then extracted the catchments that are specific to the Rio Bravo (Figure 5; Appendix 2). In the United States it is possible to use the "Watershed" feature from the ArcGIS hydro server to gain an outline for the watershed and then extract a digital elevation model for that specific area. When I attempted this for my points near the outlet along the Rio Bravo, I was returned with a very small watershed that flows in the opposite direction of the river, and even crosses another river, the Rio Hondo (Figure 6). My dataset for the Rio Hondo is correct because I created a track of this river while boating along it in June 2016. In this instance, I used a Garmin GPSMAP 64 with a 5 meter resolution. Thus, it is clear that the watershed generated by ArcGIS is incorrect, and I subsequently decided to run the hydrology tools for a broader area and then extract the ones that encompass the Rio Bravo.

In ArcGIS Pro version 1.2 I utilized a variety of hydrology tools in order to yield the Rio Bravo watershed, as detailed in Exercise 4 of our class. These included flow direction, percent drop, and flow accumulation (Appendix 2). From there I set a threshold of 5000 cells to the flow accumulation data in order to yield drainage lines. I used the stream link and watershed tools to create stream segments and catchments, respectively, and converted these raster files into vector files for ease of use. At this point, I manually selected the catchments that encompass the Rio Bravo and extracted them into a new layer. I could then automatically select the Rio Bravo by location to these catchments, and yield a drainage line exclusively for the river (Figure 5).

From the features derived from this process, I was able to determine important statistics about the Rio Bravo and its watershed. The Rio Bravo contains 353.2 kilometers of drainage within 2608.7 square kilometers of catchments.

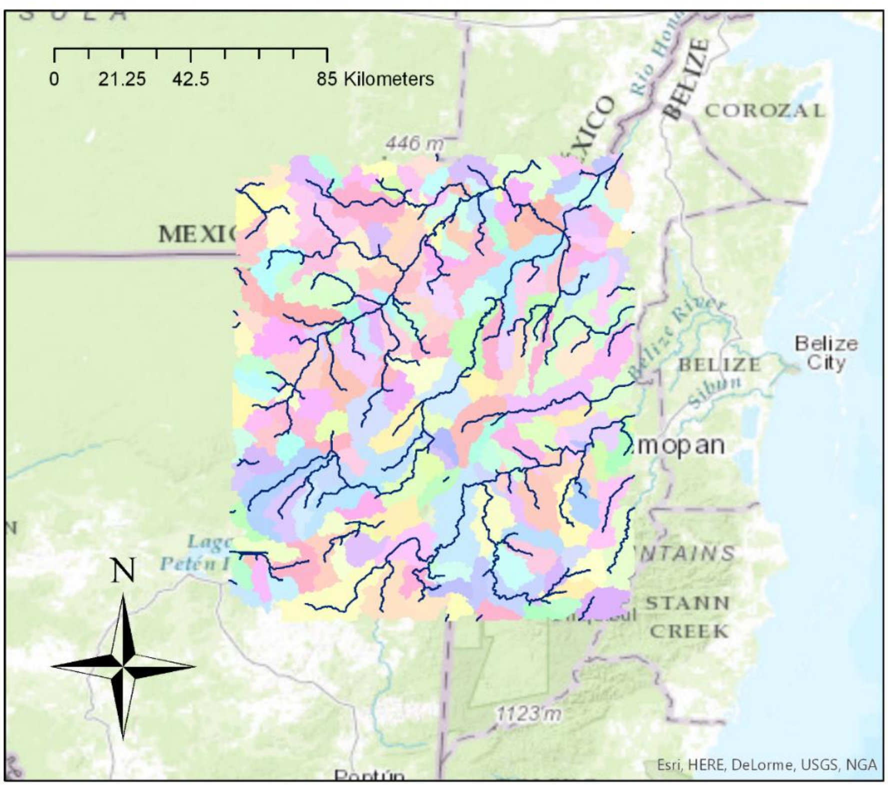

Figure 4: Catchments and drainage lines of the broader region, encompassing borders between Belize, Mexico, and Guatemala.

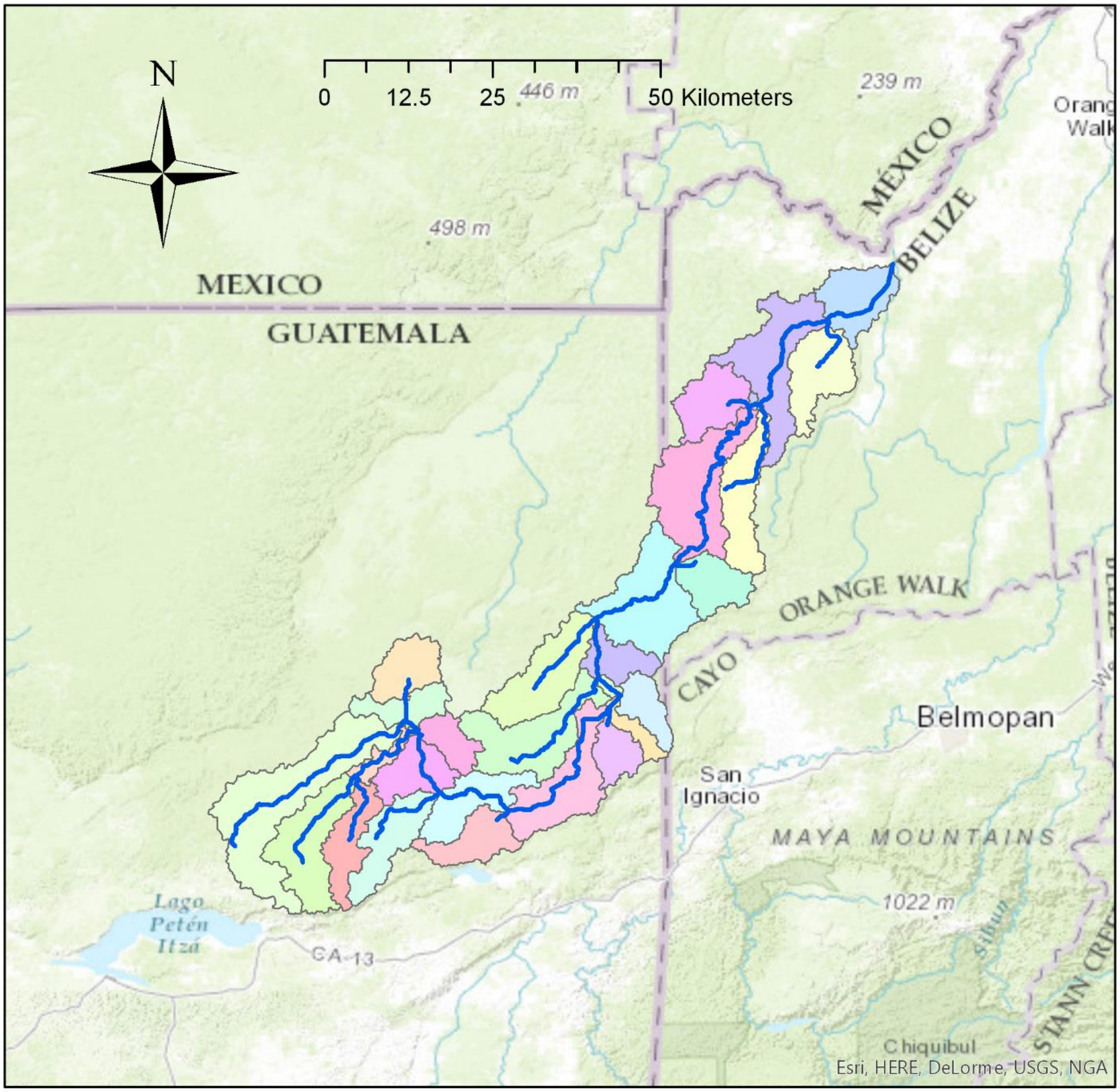

Figure 5: The Rio Bravo and its associated catchments.

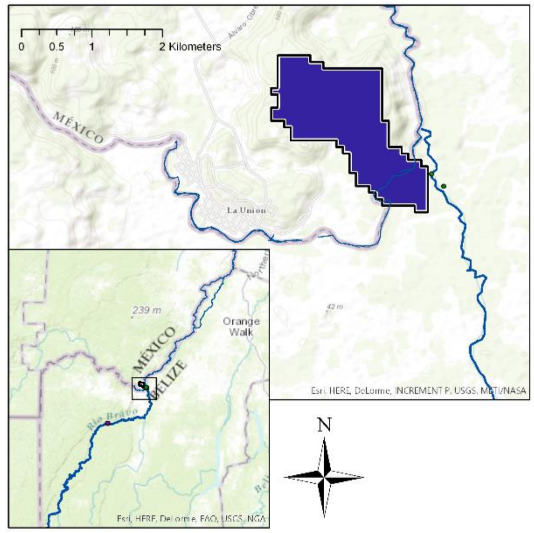

Figure 6: Watershed derived from ArcGIS Hydro server from a Rio Bravo GPS point.

Discussion

The river product developed from this study differs from previous representations of the Rio Bravo in two notable ways; its extent into Guatemala and its path near the junction with the Rio Hondo (Figures 7 & 8). The latter issue seems to derive from the HydroSHED dataset, and its conditioning process, specifically the "stream burning." It is clear that an incorrect vector was used in the processing of this dataset (Figure 9). The track along the Rio Hondo and the two points on the Rio Bravo were collected this past summer, and they are accurate, which indicates that the underlying feature that was burned into the dataset is not accurate. While this is interesting, and a clear issue with the product, it does not completely negate the value of the rest of the watershed that was derived from this dataset. In fact, it appears as if the northern reaches of the river was the only area that was burned in (Figure 10). Thus, the incorrect northern area simply shows the inherent issues present when partaking in this work.

The other aspects of the watershed are particularly interesting, and are still valid to assess. Specifically, the extent of the watershed into Guatemala. This has implications for transboundary water issues, as well as a possible insight into ancient Maya trade routes. Almost the entire extent of the Rio Bravo derived from this project is under old growth tropical forest, with the exception of the section before the junction with the Rio Hondo, which is deforested for agriculture. As such, there is not likely a current impact from this watershed occupying two countries. Yet, there is the potential for international water issues. Many other countries have transboundary water issues, and Belize and Guatemala have a historically tense relationship (Perez et al. 2009), so there is a possibility for disagreement over water rights of the Rio Bravo in the future. Even if water rights are never contested, if deforestation were to increase in Guatemala it could affect northwestern Belize, and the water flow patterns of the Rio Bravo. The extent of this watershed is very interesting, and important for future international development goals.

It is also interesting, and possibly important, for past uses. There is abundant evidence that dugout canoes were used for trade throughout ancient Maya times (McKillop 2005; McKillop et al. 2014). Yet, the exact trade routes are not known. Sites around the Rio Bravo have evidence for trade, in foreign goods found at most sites. This includes obsidian, jade, marine sponges, coral, stingray spines, and cinnabar (Guderjan et al. 1989). It has largely been assumed that the Rio Bravo is not a suitable trade route because it has a relatively strong current, but it is possible that there is a mechanism for allowing trade along this river. The Maya did not have wheels or pack animals for trade, but they have been known to construct impressive features on rivers, such as dams, docks, and diversions. I think it is possible that the Rio Bravo was used for trade in some way. This project has moved me more towards this position because the Rio Bravo watershed connects more Maya sites than previously thought, including Tikal, one of the major centers of the Maya world (Figure 11).

This has far-reaching implications, if there is, in fact, water connecting Tikal to northwestern Belize. The Rio Bravo joins with the Rio Hondo, and the Rio Hondo reaches the Caribbean coast, and from the coast trade can occur throughout Mesoamerica. If this watershed is accurate, Tikal has a connection to the rest of the Maya world not previously known.

Future Work

The continuation of this project entails two major foci: creation of a more accurate depiction of the river and field work to verify the findings. Our research group just attained LiDAR imagery of the northern part of the Rio Bravo, so I hope to incorporate that in order to create a more accurate depiction. This goal can also be obtained through manual processing of SRTM imagery. I ran into issues with SRTM imagery due to the karstic nature of the environment, but, with more expertise and work, it would be possible to develop a method to condition SRTM imagery so it will more accurately represent the river's course. Additionally, an important aspect of any study involving remote sensing is groundtruthing. I hope to groundtruth this river and determine its flow in different parts of its projected watershed. Altogether, resulting in a more accurate representation of the Rio Bravo and its watershed, in order to better understand the implications of its watershed's extent. The Rio Bravo is clearly an interesting river, and possibly important for its past uses and future potential, and I hope to work towards realizing the goal of delineating its course and uses.

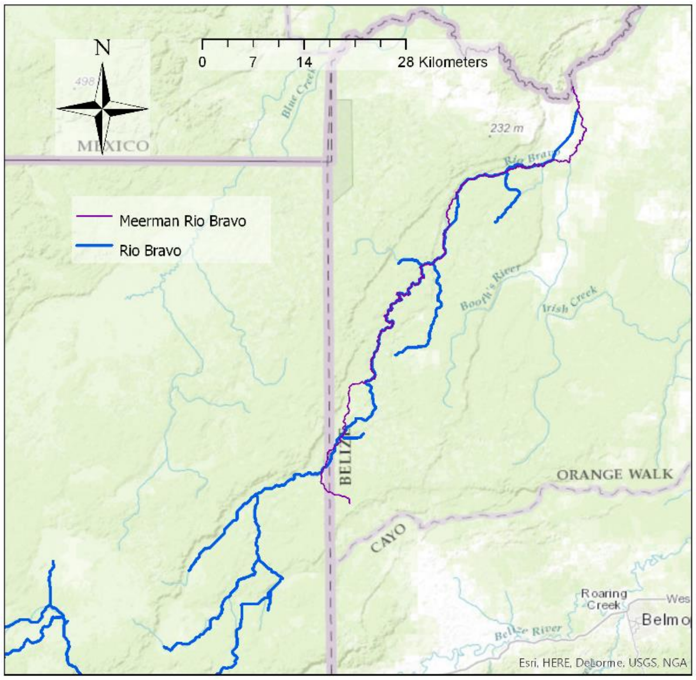

Figure 7: Rio Bravo drainage line derived from this product as compared to a previously used river feature, obtained from Meerman and Clabaugh 2016.

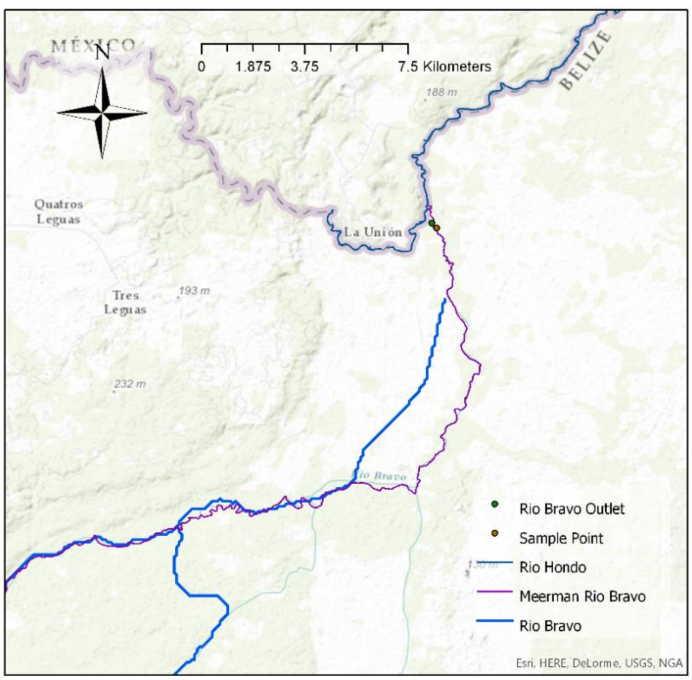

Figure 8: A closer view of the most northern part of the Rio Bravo with the Rio Bravo drainage line derived from this product as compared to a previously used river feature, obtained from Meerman and Clabaugh 2016, and GPS points of the Rio Bravo and tracks of the Rio Hondo taken by the author in June 2016.

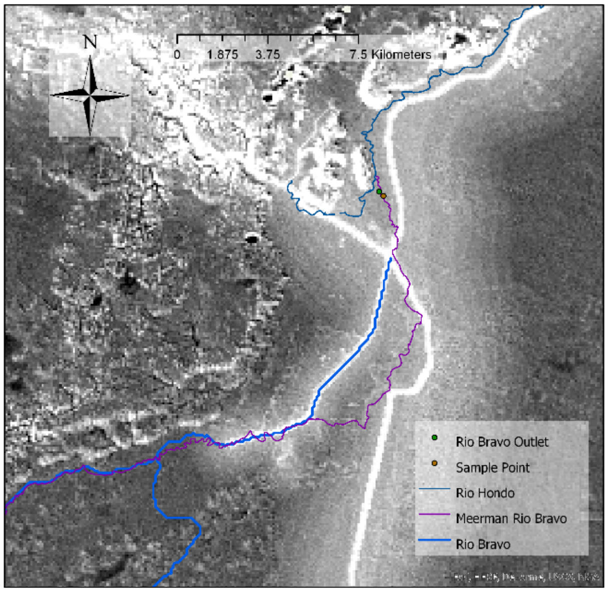

Figure 9: Derived Rio Bravo stream line overlayed on the HydroSHED dataset subtracted from SRTM imagery, in order to highlight the burned in streams. The river and HydroSHED dataset can be compared to known data from the Rio Hondo and the Rio Bravo, as well as previously used Rio Bravo features (Meerman and Clabaugh 2016)

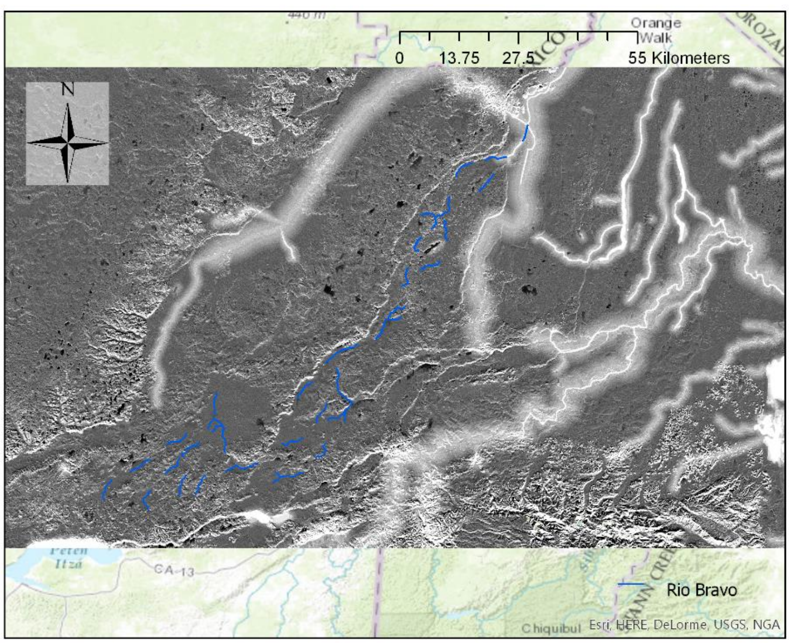

Figure 10: HydroSHED dataset subtracted from SRTM imagery, which it is derived from, highlighting the burned in streams. The Rio Bravo is represented by a dashed line so that it does not cover a burned stream completely.

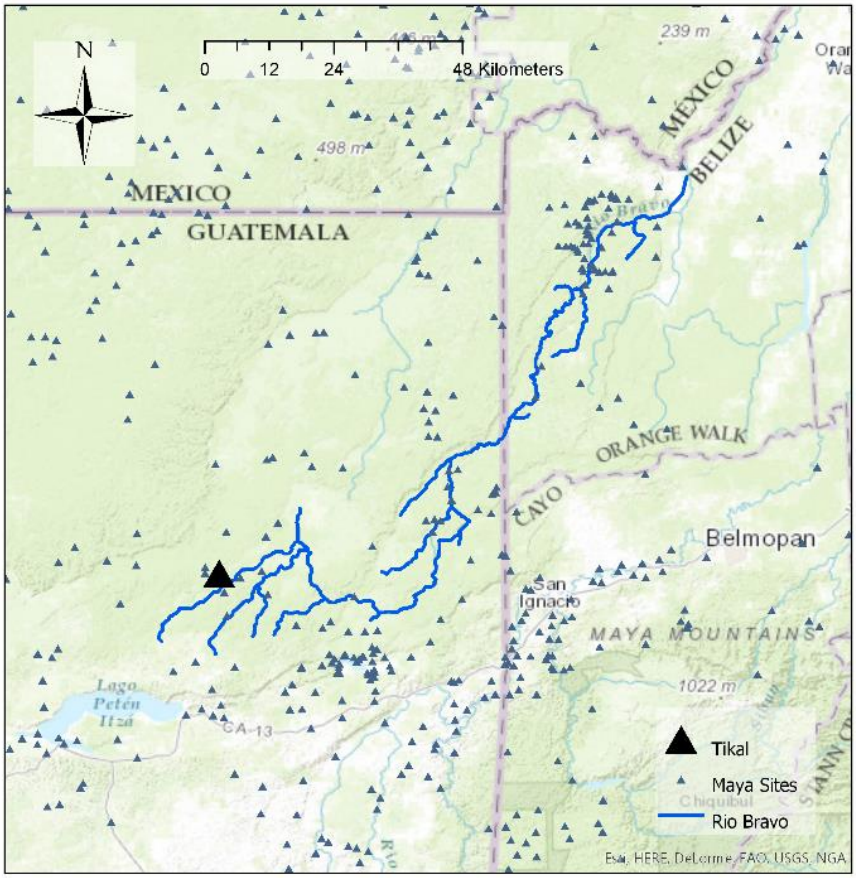

Figure 11: Rio Bravo drainage line with Maya sites and Tikal, a major site, highlighted (Maya site locations derived from mayamap.org)

Appendix 1

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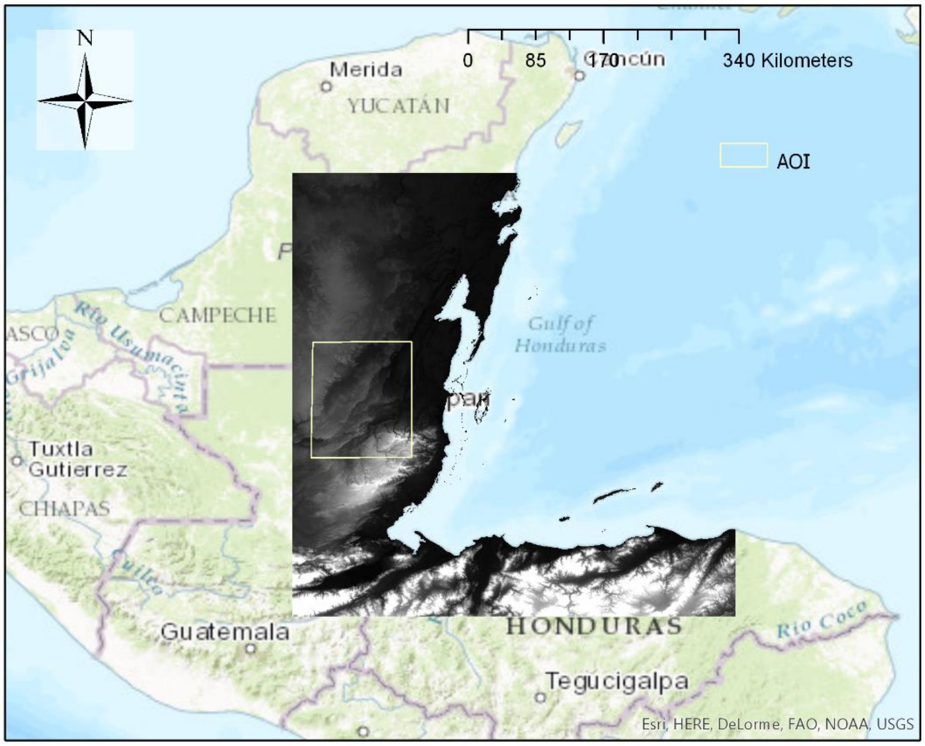
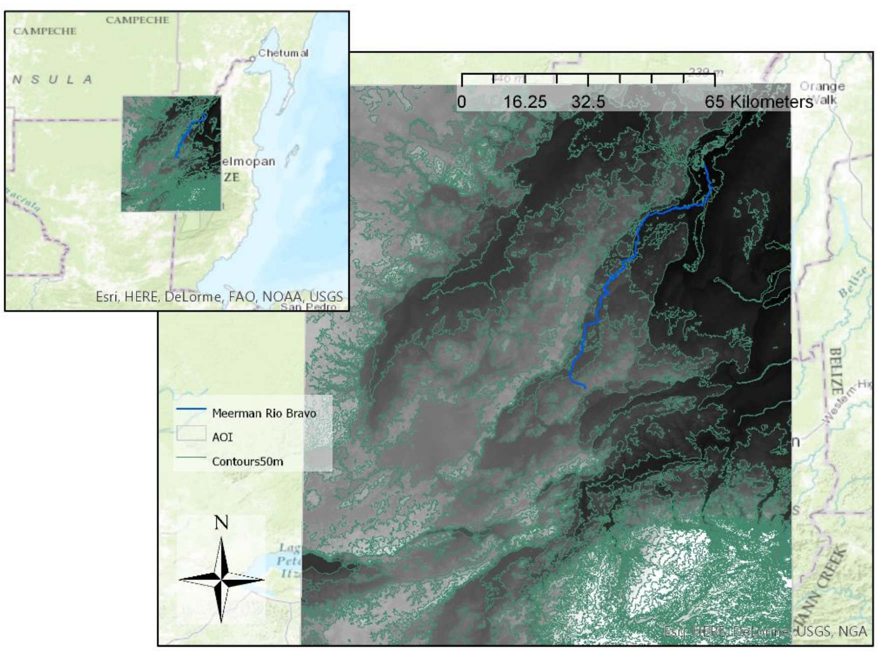
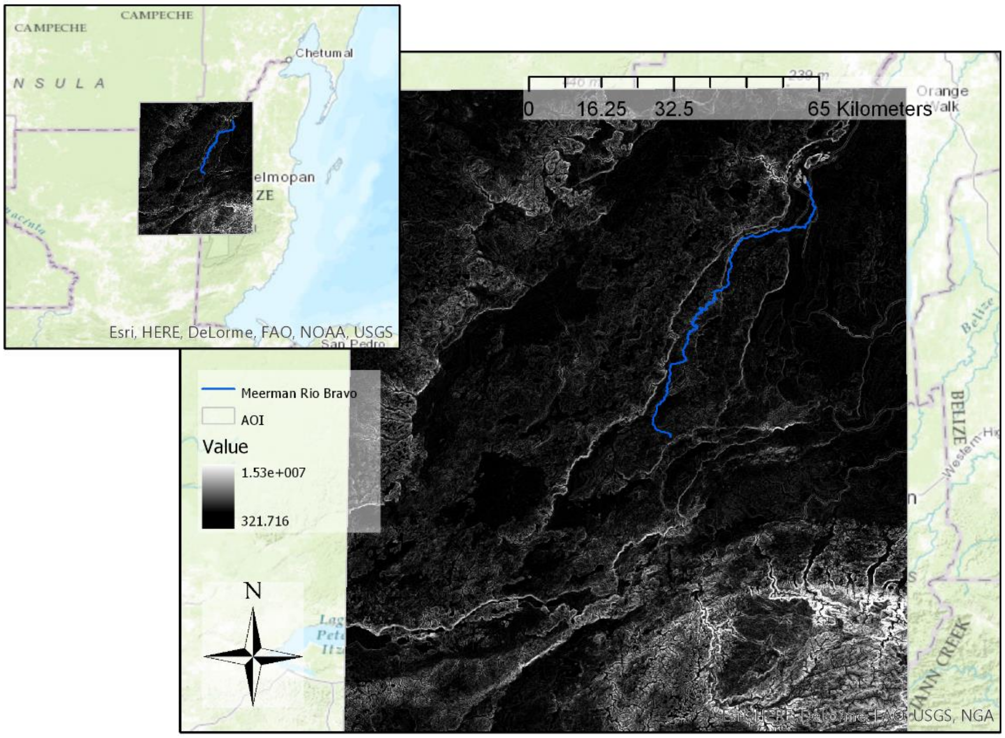
Appendix 2



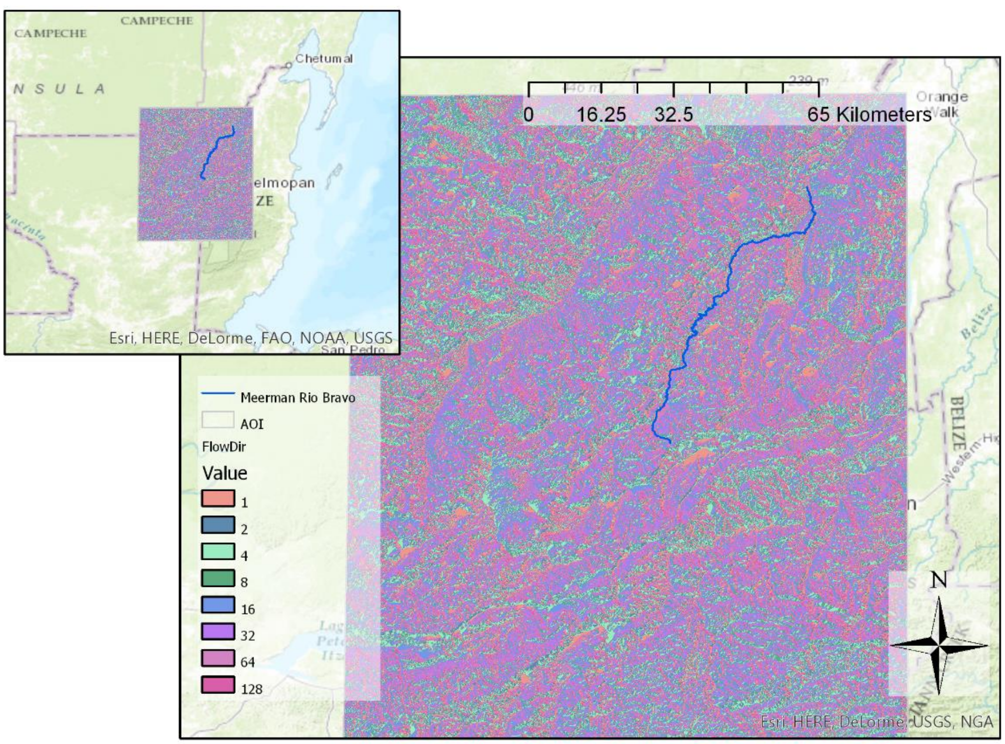
A2.1: HydroSHED dataset with the area of interest overlayed.



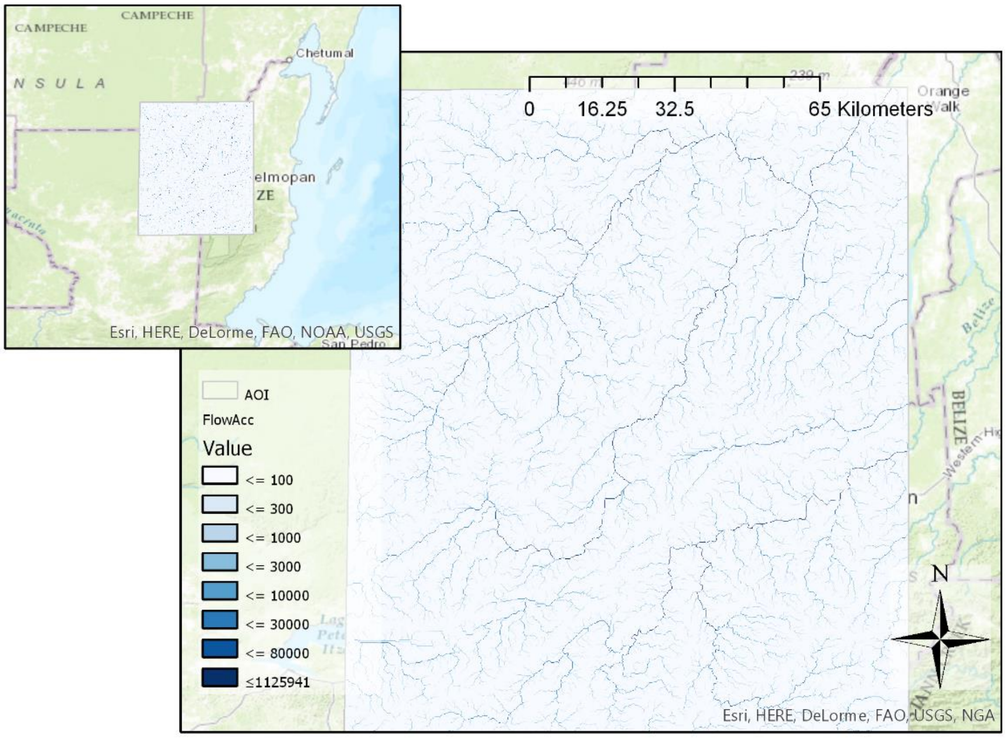
A2.2: HydroSHED dataset within the area of interest with 50 meter contours overlayed.



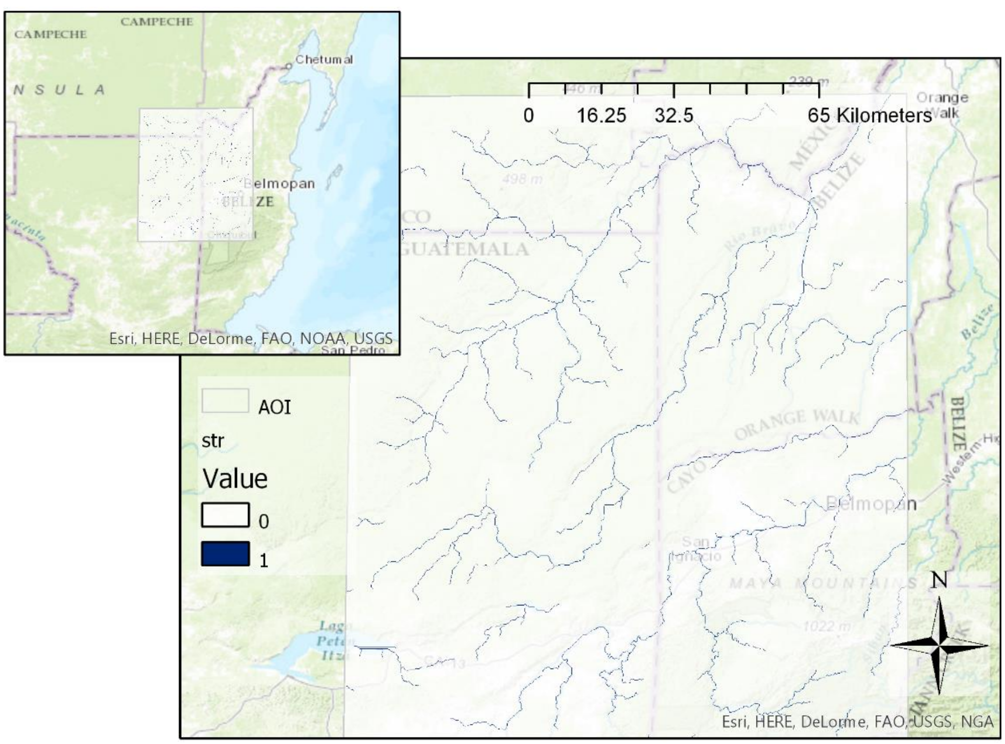
A2.3: Percent drop of elevation for cells within the area of interest around the Rio Bravo watershed



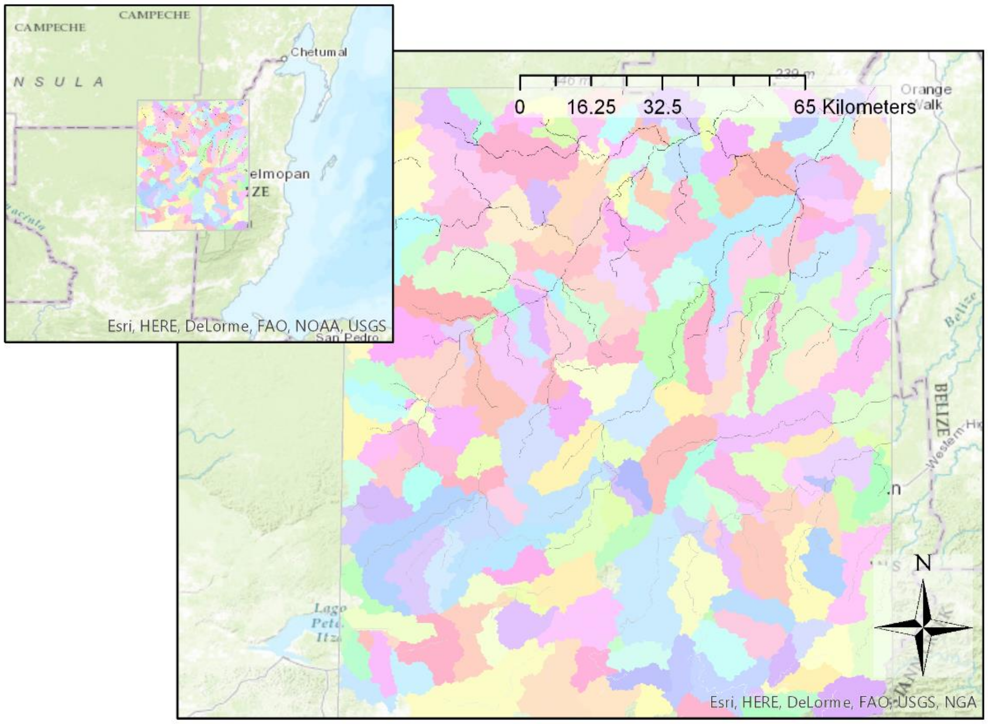
A2.4 Flow direction within the area of interest.



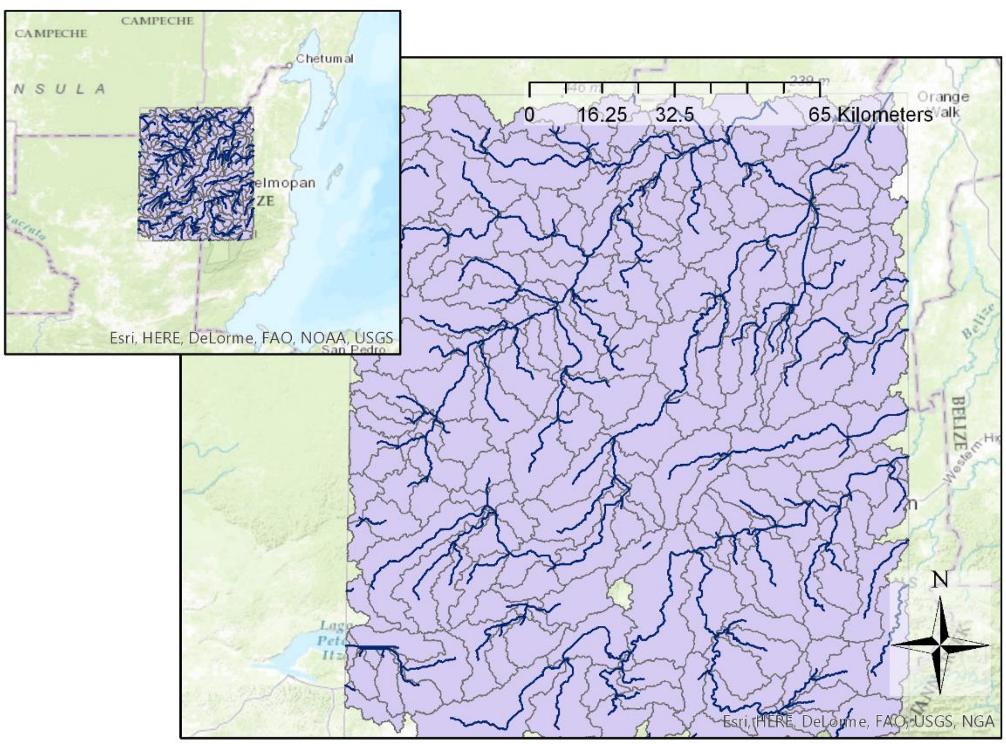
A2.5 Flow accumulation within the area of interest.



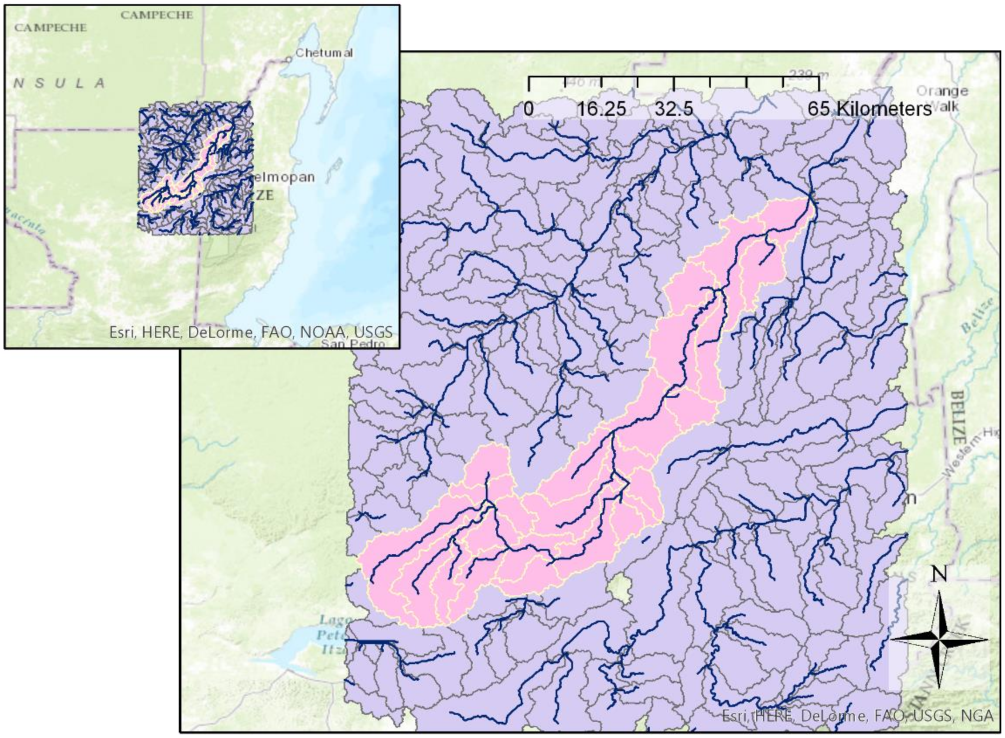
A2.6: Streams defined as cells with flow accumulation values over 5000.



A2.7 Stream links and their catchments.



A2.8 Drainage lines and catchments in vector format, converted from the stream links and catchments rasters.



A2.9 Rio Bravo drainage and catchment overlay onto all of the drainages and catchments in the area of interest