Detecting anthropogenic landscape modifications using LiDAR at the ancient Maya site of Gran Cacao, Belize

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Introduction

In July of 2016, PfBAP (Programme for Belize Archaeological Project) (Map 1) undertook an airborne LiDAR (light detection and ranging) project to collect data of a section of the project area in northwestern Belize. The basic principle of airborne LiDAR is a plane flies over a predetermined area and emits laser pulses from a laser that is mounted on the plane. Calibrated sensors on the laser mount measure the length of the laser pulses that are returned to the mount to create an incredibly detailed model of the Earth's surface. LiDAR's application in archaeology is being considered revolutionary and has allowed for new, exciting research (Chase et al. 2012). With the utilization of LiDAR archaeologists who work in tropical forested areas are able to see through the canopy for the first time, to see the expanse of ancient societies and detect the modifications these ancient peoples have made to their landscapes. In essence LiDAR allows archaeologists to see the ancient scars that ancient people have left behind through the detection of ancient terraces, roads, fields, canals, architecture and other anthropogenic landscape modifications. This project explores the development of techniques to detect anthropogenic modifications in the landscape using LiDAR as a medium. Specifically, the project aims to develop methods to detect architectural structures and water reservoirs from the landscape using the ancient Maya urban center of Gran Cacao located in northwestern Belize as a test area.

Problem Formation

The use of LiDAR in archaeology is a fairly new phenomenon, with researchers in Europe first using LiDAR in the early 2000s to identify anthropogenic features in landscapes (Fernandez-Diaz 2014). Since the early 2000s, LiDAR use has exploded in Central America with Chase et al. being the first researchers in Central America to implement LiDAR to conduct archaeological research in 2010 (2012). LiDAR data literally allows archaeologists to see through see canopy and see sites for the first time at a regional scale. The vegetation is intensely dense (Figure 1) in areas of Central America, so the application of LiDAR has become very popular among archaeologists in this region. Due to LiDAR being a recent phenomenon in Central America, researchers are still figuring out to what extent the LiDAR data can be manipulated and analyzed in conjunction with archaeological research.

Perhaps one of the most important applications of LiDAR for archaeologists is to be able to detect anthropogenic modifications in the landscape through the analysis of LiDAR data. The detection of these modifications creates a map for archaeologists to guide them where to look for modifications, to guide where to start excavations and to begin to ask questions about how ancient peoples interacted with their environments and landscapes. With the idea of the importance of the detection of anthropogenic features in mind, this project aims to figure how to detect these anthropogenic modifications using various tools in the ArcGIS tool set. Due to there being numerous anthropogenic modifications that the ancient Maya would have made on their landscape, this project focuses on two modifications, architectural structures and water reservoirs.

<u>Project Questions:</u>

- How to identify ancient Maya architectural structures:
  - What steps in ArcGIS can be taken to identify ancient Maya architectural structures?

- Is it possible to detect ancient Maya architectural structures?
- How to identify ancient Maya water reservoirs:
  - What steps in ArcGIS can be taken to identify ancient Maya water reservoirs?
  - Is it possible to detect ancient Maya water reservoirs?

Essential Background

The Ancient Maya

The ancient Maya ethnic group resided in the culturally defined geographic region known as Mesoamerica (McKillop 2004, Sharer and Traxler 2006) (Map 2). This region encompasses the modern-day nations of Mexico, Guatemala, Belize, Honduras, and El Salvador (McKillop 2004, Sharer and Traxler 2006). Mesoamerica of course has been home to many more ancient people other than the Maya. However, these cultures all share cultural similarities, creating the culturally defined geographic region (McKillop 2004).

In regard to the Maya, more specifically they resided in the geographic region that is known as the Maya Region (McKillop 2004, Sharer and Traxler 2006) (Map 3). The spans of the Maya Region encompassed some 324,000 sq. kilometers (McKillop 2004). The ancient Maya resided in this region from approximately 3,000 to 1,000 BP, with agriculture arising before the Maya at 5,000 BP (Beach et al. 2002, Beach et al. 2015). The region then can be further broken down even more into three primary geography zones: The Volcanic Highlands in the center, the Pacific Coastal Plains in the south, and the Tropical Lowlands in the north (Sharer and Traxler 2006). Each geographic zone is unique environmentally, each can be broken down further into subzones (Sharer and Traxler 2006).

Gran Cacao, Belize

The ancient Maya site of Gran Cacao was initially recorded by archaeologists in 1993 by the PfBAP in the Three Rivers Region of northwestern Belize (Adams 1995) (Map 4). Since the recording of the site, relatively little archaeological research has been conducted at the site, except for a few notable projects by Levi, Durst, and Lohse (1994, 1996, 2006). Gran Cacao presents a unique opportunity to understand the Post Classic period (1,100 - 500 BP) or the time after the ancient Maya Collapse (1,200 BP) in the Three Rivers Region. The site is one of the few sites in the region that has evidence of Post Classic architecture, and evidence of occupation during the Post Classic. Little occupation during the Post Classic has been noted elsewhere in the region, mass abandonment of the large urban centers has been suggested to have occurred in the Terminal Classic (1,200-1,100 BP), after the Maya Collapse. If Gran Cacao indeed was occupied during the Post Classic, the site could provide essential information about what occurred in the Three Rivers Region after the Maya Collapse.

The site of Gran Cacao lies inside the northwest Belizean portion of the Three Rivers Region. The Three Rivers Region is part of the geographically defined area of the Maya Lowlands that encompasses the modern nations of Guatemala and Belize (Dunning et al. 2003, Scarborough et al. 2003). Scarborough and Valdez suggest that the region is a microcosm of the greater southern Maya Lowlands (Scarborough et al. 2003). The region captures the ecological and elevation variability of the Belizean coastal plain and the Guatemalan interior Petén Plateau (Scarborough et al 2003) (Map 5). The Three Rivers Region section of PfBAP can be separated into four ecological zones: The La Lucha Uplands, the Rio Bravo Terrace Uplands and associated escarpment, the Rio Bravo Embayment, and the Booth’s River Uplands and associated depression (Dunning et al. 2003, Scarborough et al. 2003) (Map 6). The diversity of landscapes and its associated resources in the Three Rivers Region makes the region one of the most useful research areas for assessing ancient Maya landscape modification, interactions and impacts.

Gran Cacao lies inside the Booth's River zone (Dunning et al. 2003). The Booth's River zone is the zone that is most to the east in PfBAP (Dunning et al. 2003, Scarborough and Valdez 2003). In this zone, considerable ancient activity has been indicated to have occurred (Scarborough and Valdez 2003). Agriculturally tracts of raised fields have been observed aerially, and core evidence indicates both the growth of maize and manioc by the Late Preclassic (2,000-1,600 BP) (Dunning et al. 2003, Scarborough and Valdez 2003). In this zone lies the large center of Dos Hombres, along with less understood sites of Gran Cacao, Great Savanna, Sierra de Agua, and Quam Hill (Scarborough and Valdez 2003). Out of all the zones this zone is where more research is needed due to the presence of multiple large sites that we know relatively little about (Scarborough and Valdez 2003).

Collection of LiDAR

The LiDAR was collected in July of 2016 by the National Center for Airborne Laser Mapping (NCALM), in association with University of Houston and University of California, Berkley. Approximately 200 square kilometers of LiDAR were collected in this flight. A Titan MW Lidar Sensor running at 300 kHz was used to collect the data. The plane flew at a height of 600 AGL with a swath width of 400-500 m. The overlap between the adjacent swaths was 50%. The scan angle fluctuated between 15-25 degrees. Researchers from PfBAP and MRP (Maya Research Program) provided the funds necessary to obtain the LiDAR data.

After the collection of the data NCALM supplied all products as .tif images with the following specifications. The products received by NCALM included. las files of the entire flown area, as well as a DEM of the entire flown area. Additionally, provided by NCALM includes the height accuracy on open and hard flat surfaces would be between 4-8 cm and horizontal accuracy between 15-20 cm. The number of points collected per square meter is 20 points per square meter, and each cell of the DEM is .5 x .5m. Lastly, the data used the WGS84 16N coordinate system and is projected as a transverse Mercator.

Preprocessing

Selection of Study Area

One of the primary uses that archaeologists use LiDAR for is to delineate site boundaries, by beginning to parcel up the landscape into areas that would have fallen under the leadership of certain ancient Maya sites and the site's elites. When discussing the idea of borders between ancient Maya sites, it can be a little complicated. Due to there not being any boundary walls, physical structures or lines delineating where one site begins and ends, it is difficult to define the exact expanse of the site. Even more importantly to consider, these borders that archaeologists construct may have held no meaning to the ancient Maya, or their concept of borders between sites may have been more fluid or more rigid than what archaeologists have been able to ascertain thus far. Further research through excavation will be needed to be able to begin to understand the expanse of Gran Cacao, and the relationships between Gran Cacao and other sites in the region

With this in mind, when looking at the LiDAR from Gran Cacao, it is not easy to define the expanse of the site. Looking from the north, east, and west of the site, it easier to draw boundaries of the site due to the lack of structures or settlement in these areas. However, to the south and southwest of the site, it very difficult to draw these borders. To the southwest of Gran Cacao, lies ancient Maya site of Dos Hombres. Between the two sites there is a steady stream of settlement, the distance between the two sites is about 12. 5 km. The settlement is not as dense in this area as it is around the urban center of Gran Cacao, but nonetheless, there is still constant settlement between these two larger sites. Due to this the area defined as the urban center of Gran Cacao is the area where the settlement is most concentrated and lacking agricultural features thus defining it as the urban center of Gran Cacao. The area that has been defined as the Gran Cacao urban center is 6.8 sq. km in area. To create the area defined as the urban center of Gran Cacao the Draw tool was used to draw a polygon around the urban center. The DEM provided by NCALM was clipped from the entire data set to the 6.8 km sq. area polygon.

Processing and Analysis

Detection of Ancient Maya Architectural Structures

The first step to the detection of architectural structures was to determine what could be used to detect and differentiate architecture from natural features and other anthropogenic features. The method of detecting architecture through slope angle developed by Prufer and Thompson was employed in this project (2016). Prufer and Thompson through their extensive boots on the ground survey and LiDAR analysis quantified that most ancient Maya architectural structures had a slope range from 20-35 degrees (2016). Using this range as a benchmark, a slope raster was created, then manipulated to only show data that fell in the range of 20-35 degrees (Map 7).

The next step was to convert the raster into editable polygons in order to pick out any polygons that were not structures and to edit polygons that may have not accurately captured the shape of the structures. First the slope raster, which was stored as floating points had to be converted into an integer raster. To do this first the Raster Calculator was used to remove decimal values from the raster. The raster was multiplied by 1,000,000, due to the raster having six decimal values. Next the Int tool was used to create an integer raster. After the integer raster was created, the Raster to Polygon conversion tool was employed to create an editable layer of structures, with polygons around most of the structures already being drawn and detected from the slope degree.

However, some of the structures were not captured by the slope range or the polygons were not completely correct in capturing the shape and expanse of the architecture. There are a couple explanations as to why all structures were not captured by the slope range. One explanation is of course not all buildings are going to completely uniform and fall within this slope range. A second explanation is that some of these structures could be thousands of years old, and through time the structures have not preserved well. This seems to be especially true for smaller structures (<100 sq. m), the slope range struggled most in detecting smaller structures and their expanses. Third, in relation to the previous explanation, structure size affects the detection of the structure and their expanses. The slope range was great for detecting medium to large structures (>100 sq. m) and these structures' expanses. Lastly, the looting of some of the structures has affected the slope of the structures, making them undetectable using the slope range. When looter's dig into structures, the pits are often in the form of a trench, which would affect the slope of the structure.

In order to capture all structures and have their shapes be accurately represented, new polygons were manually added to the structure layer. Then some of the polygons that were drawn by the slope range needed to be edited in order accurately define the shape and expanse of the structures. In addition, features that were not structures were picked up in this process, so these polygons had to be discarded. The final product resulted in a layer that identified as many as possible of the potential ancient structures through use slope as the benchmark to detect the structures (Map 8).

Overall this method of detecting ancient structures was a success. In total through this process 1,073 structures were detected in the Gran Cacao urban center. The average size of the structures is 396 sq. meters, the largest structure is 8,505 sq. meters and the smallest 15 sq. meters. This process was beneficial because it saved a substantial amount of time of finding the structures, compared to visually examining all of the data then drawing polygons around every single structure. Additionally, the slope degree layer was able to detect structures that would have not been able to pick up on visually. This process made the detection of structures a little more objective, with structures being identified through slope degree, instead of being visually identified by the user. A comparative of the final identified structures and structures detected through slope degree can be viewed in Map 9.

Detection of Ancient Maya Water Reservoirs

In order to detect ancient Maya water reservoirs in the landscape, the Fill tool from the Hydrology tool box was used to create a Fill raster. After the Fill raster was created, the next step was to use the Raster Calculator to detect depressions in the landscape that may have served as water reservoirs. Using the Raster Calculator, the Fill Raster was subtracted from the Gran Cacao urban center DEM, to detect the depressions in the landscape. The result from the Raster Calculator created a raster with floating points, making the raster not have an attribute table, nor be editable or be allowed to be turned into a polygon layer. The next step involved converting the raster from a floating-point raster to an integer raster. First, the Raster Calculator was employed again to remove decimal values from the raster. The raster was multiplied by 1,000,000 due to the raster having six decimal points. After this the Int tool was used to create an integer raster. Once the integer raster was created, the tool Raster to Polygon was created to make the raster into an editable layer of depressions.

In order to pick out anthropogenic depressions from natural depressions, depression depths of water reservoirs established by Brewer et al. were used (2017). Brewer et al. measured ancient Maya reservoirs in central Belize and found that the majority of ancient Maya reservoirs were at least .5m deep (2017). Using this metric, all depressions with a depth of .5m or deeper were selected. Other depressions that were less than .5m were discarded from the attribute table (Map 10). Additional manual deletion of depressions occurred due to .5m or deeper depressions occurring that were clearly not water reservoirs, such as the river that runs through the urban center being picked up as a potential water reservoir in this process. After the manual deletion and inspection of the data, the remaining depressions were classified as potential water reservoirs (Map 11). In total 92 potential ancient Maya water reservoirs were identified, with the largest being 14, 562 sq. m, the smallest 2 sq. m, and the average 312 sq. m. Finally, a map was constructed to add the identified architectural structures and potential water reservoirs into one map (Map 12). Further analysis will need to be conducted to see if there is any relationship between structure location and water reservoir location.

Looking to the Future

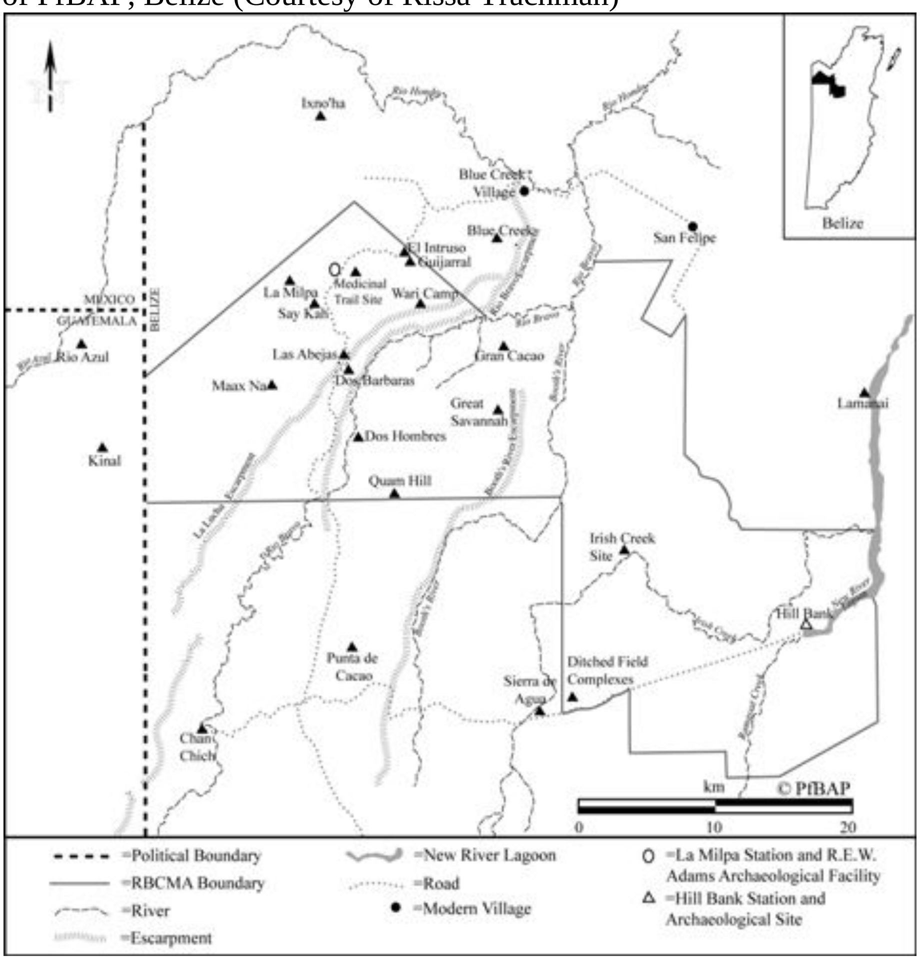
The purpose of this project was to develop methods to identify anthropogenic features in the landscape of the Gran Cacao urban center, specifically architectural structures and water reservoirs. With the implementation of the methods developed by using slope to detect structures and using depth of depressions to detect water reservoirs, the proper methods were successful in detecting these features. However, these methods can be further refined with the development of more fine-tuned detection methods in the future.

In addition, ground truthing of a sample of the identified features needs to occur to access the accuracy of the methods employed. One of the most important steps in a LiDAR project is ground truthing (Chase et al 2012, Evans 2013, Hutson 2015). If there is an anomaly or a feature that is not easily distinguishable or identifiable in the landscape one cannot truly know what it is until archeologists have inspected it in person to determine if it is a cultural feature or not (Chase et al. 2012, Hutson 2015). After the acquisition of the LiDAR data, it is essential for archaeologists to go out into the field to verify or contradict what one is able to see from the LiDAR data. The next step of the research is to actually have boots on the ground to verify what is on the ground is accurately reflected in the LiDAR data. A team of archaeologists will need to go into the area around the Gran Cacao urban center to verify some of the features.

After the verification of the existence or lack of existence of the architectural structures and potential water reservoirs, the next natural step of the research is to ask questions about the accessibility of water to households around the Gran Cacao urban center and how these water reservoirs may have helped the resiliency of the site during and after the Maya Collapse. Thinking about water accessibility even though a household may have been near a water source, does not mean that the household would have had access or been allowed to utilize that water source. Following this line of thought, research in the future could be focused on how water was controlled and utilized in the Gran Cacao urban center, and how these reservoirs may have helped the site be resilient.

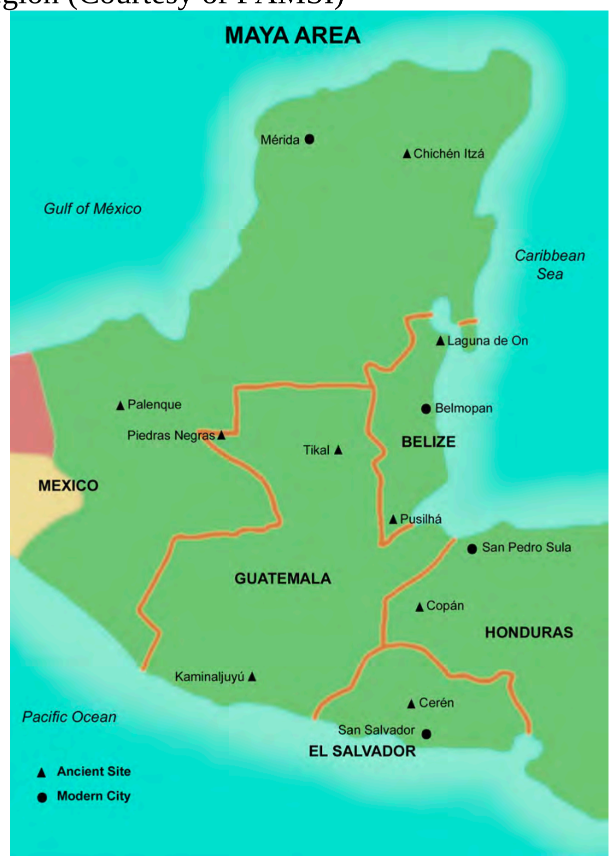
List of Maps

Map 1: Map of PfBAP, Belize (Courtesy of Rissa Trachman)

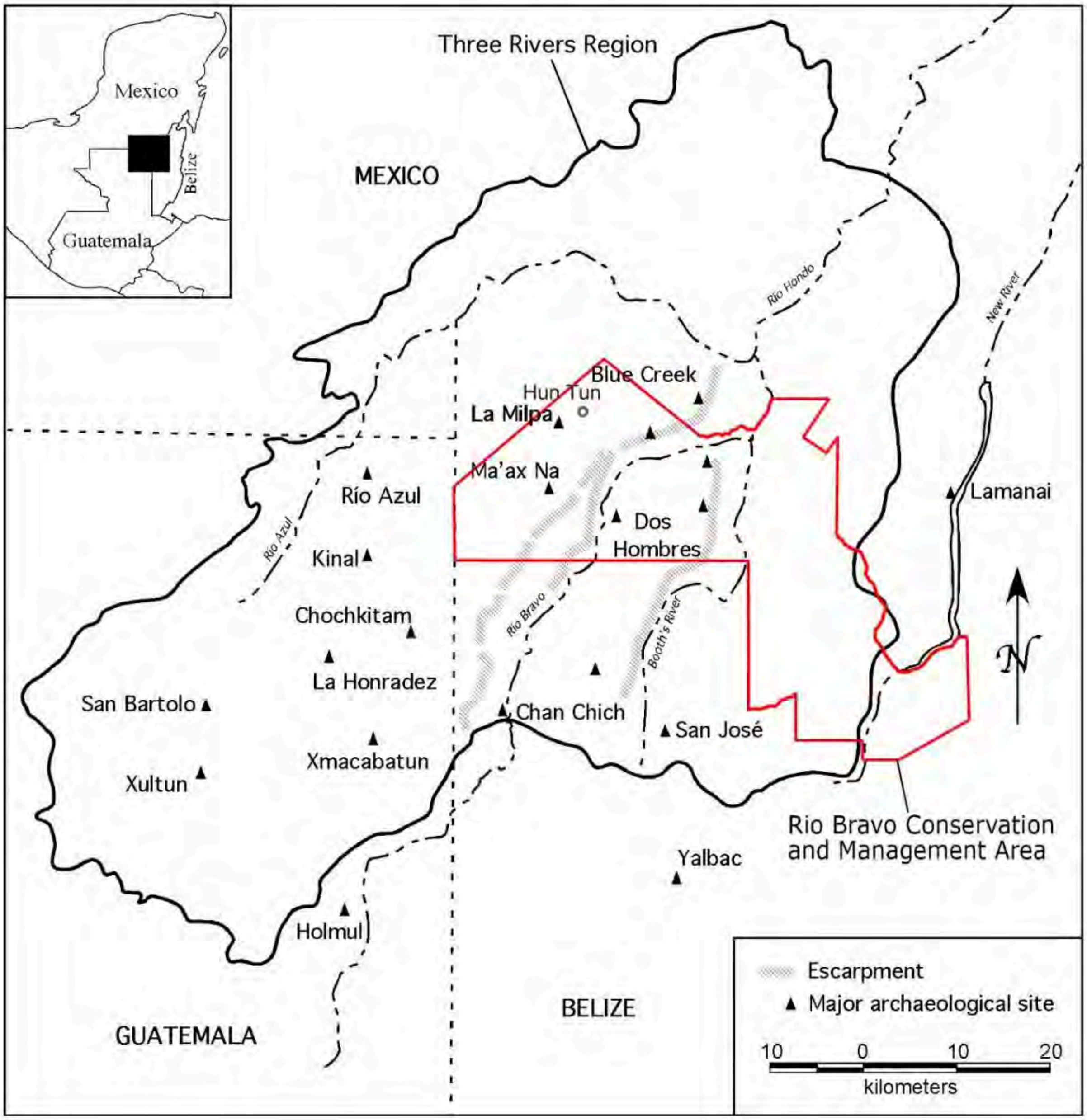


Map 2: Map of Mesoamerica (Courtesy of FAMSI)

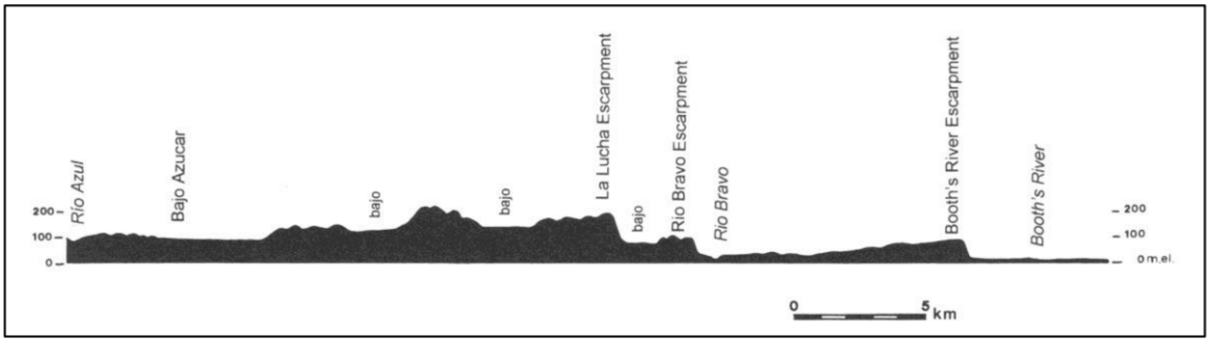
Map 3: Map of Maya Region (Courtesy of FAMSI)



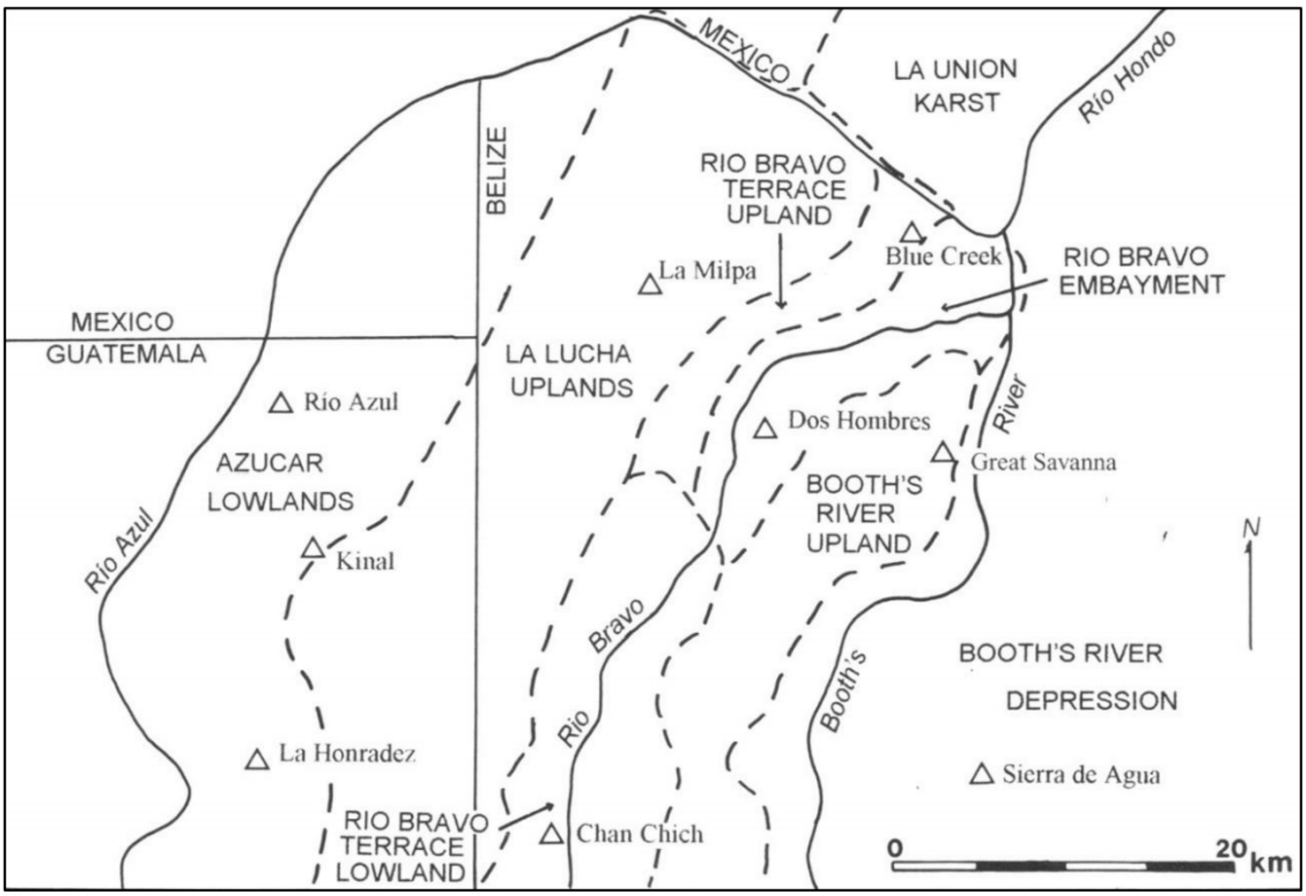
Map 4: Map of Three Rivers Region and PfBAP (Courtesy of Deborah Trein)



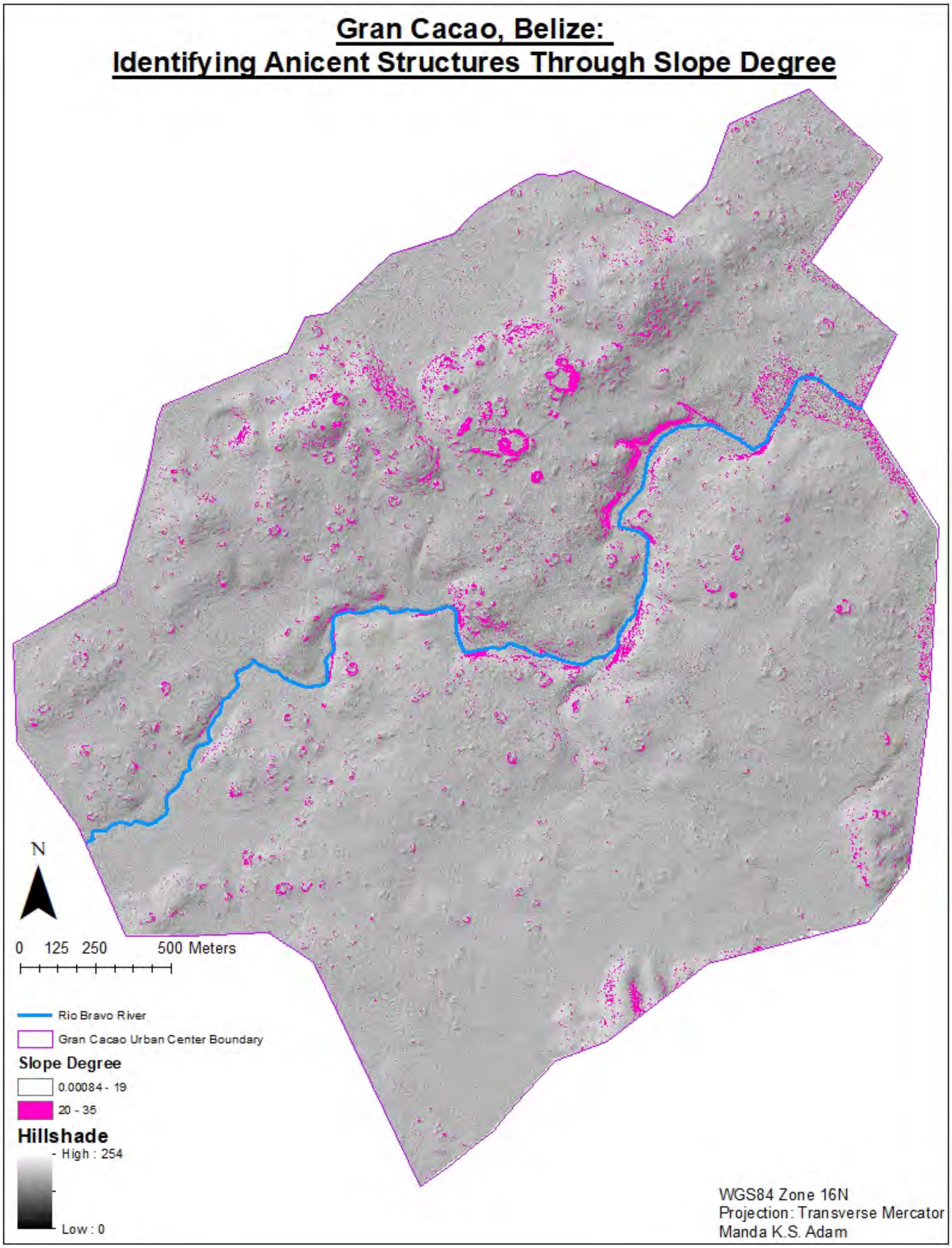
Map 5: Elevation of Three River's Region (Courtesy of Deborah Trein)



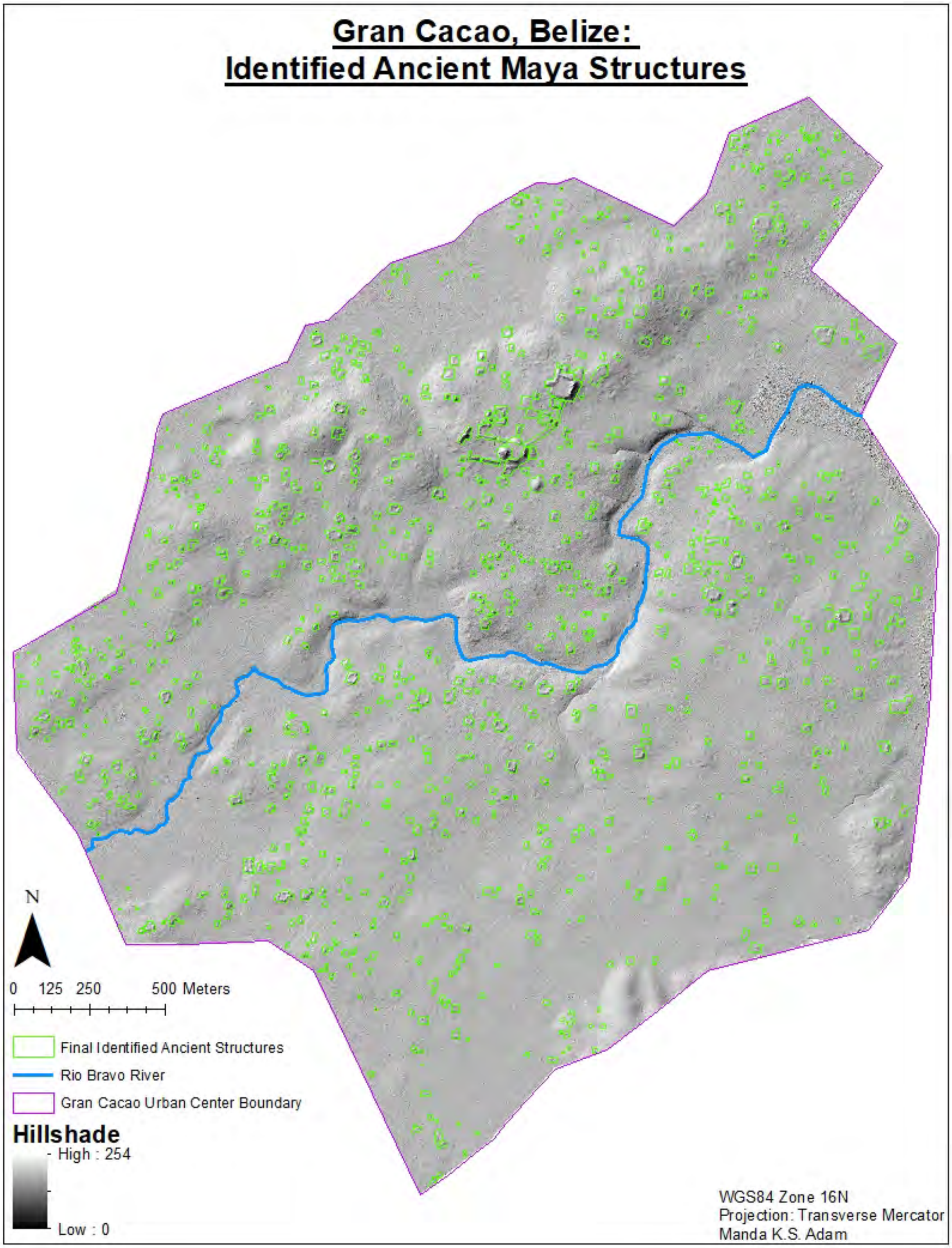
Map 6: Ecozones of the Three Rivers Region (Courtesy of Deborah Trein)



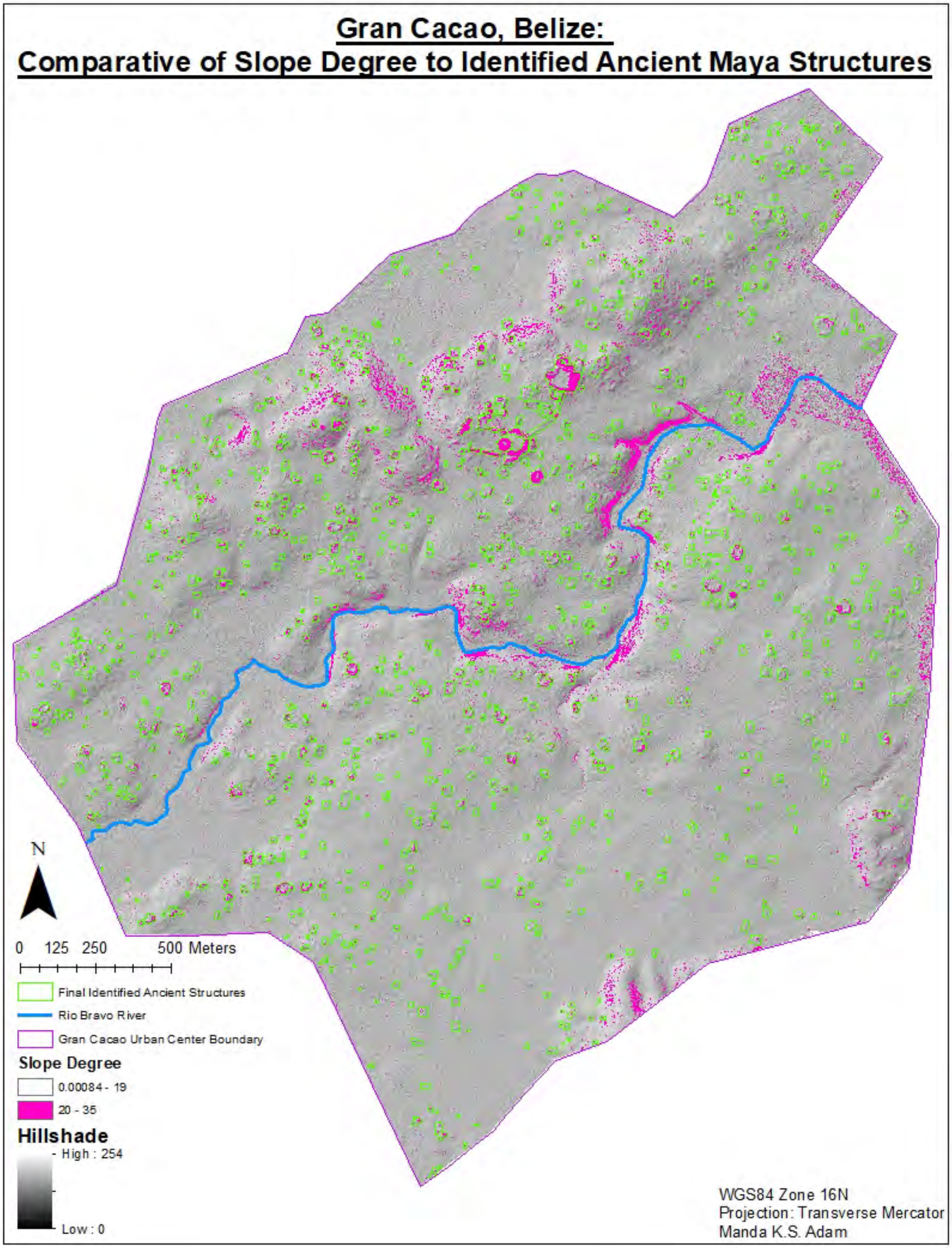
Map 7: Gran Cacao, Belize: Finding Ancient Structures Through Slope Degree



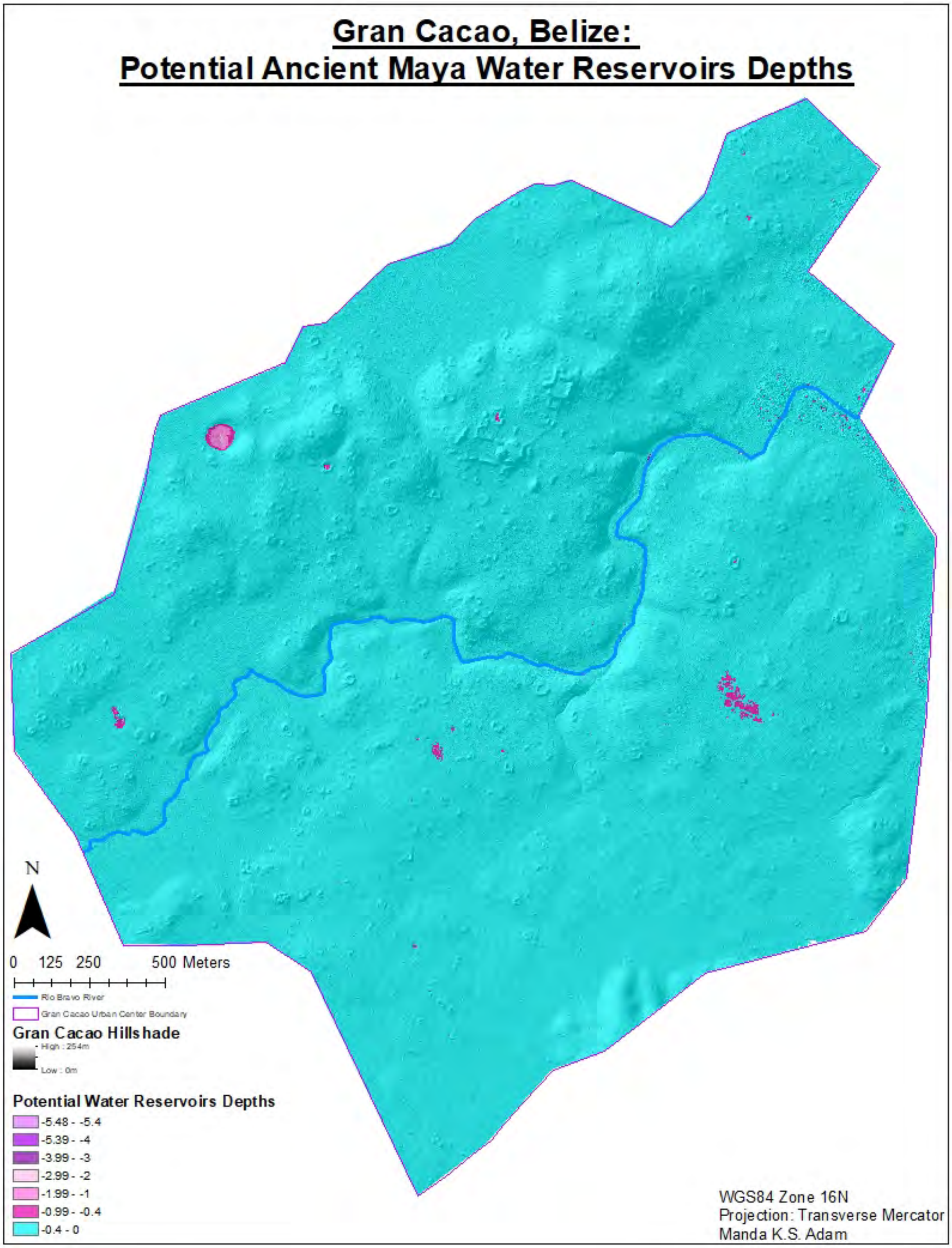
Map 8: Gran Cacao, Belize: Identified Ancient Structures



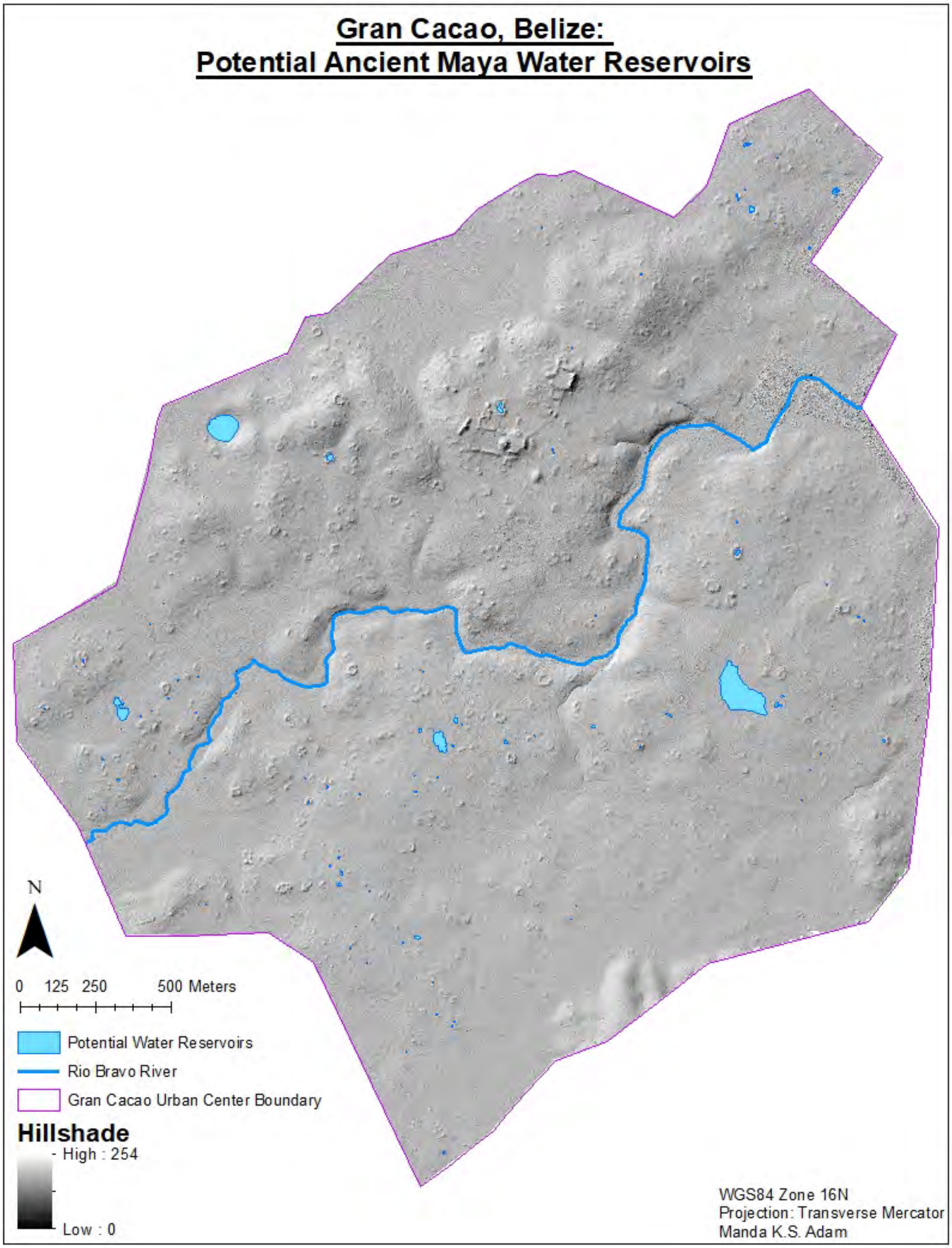
Map 9: Gran Cacao, Belize: Comparative of Slope Degree Identified Ancient Structures



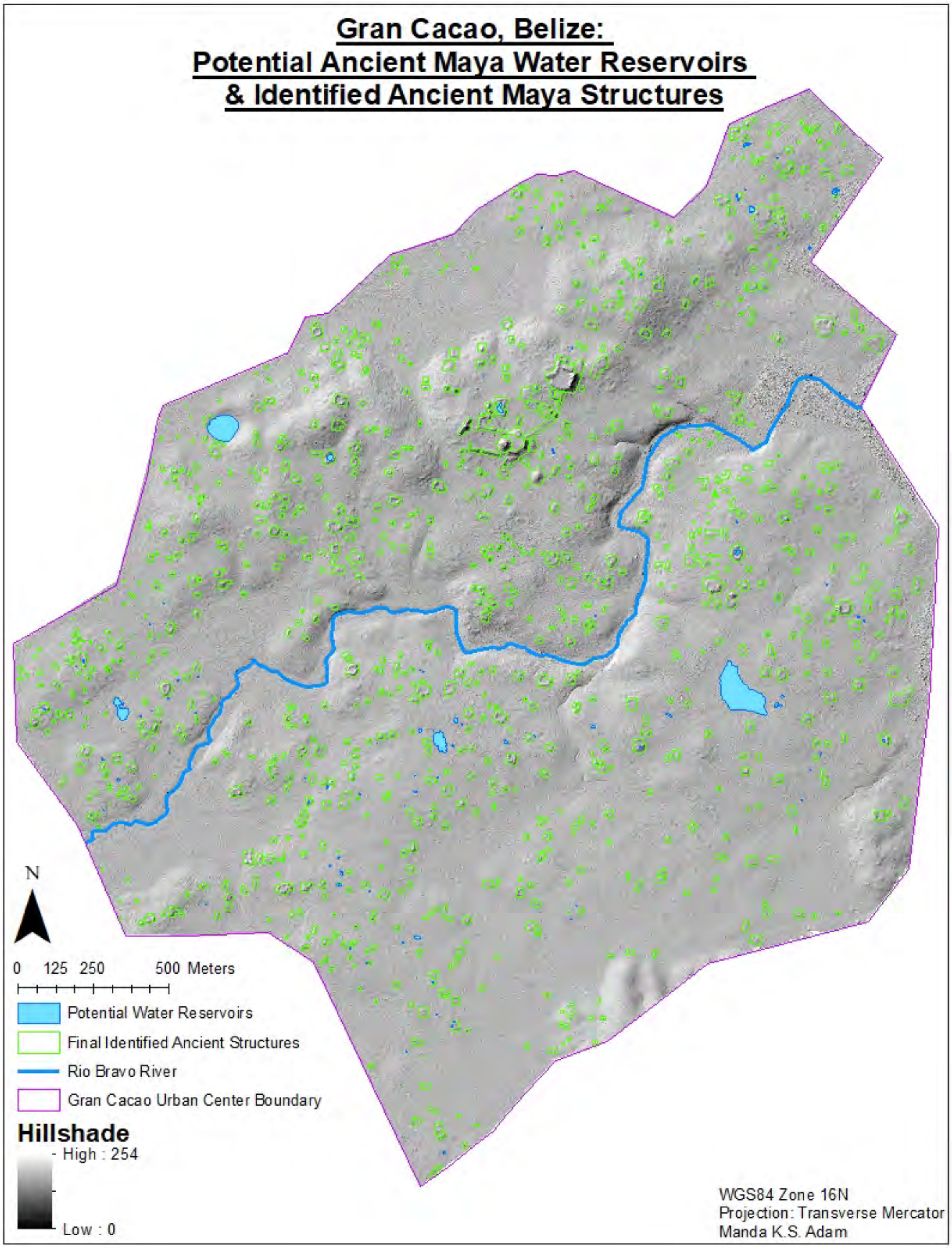
Map 10: Gran Cacao, Belize: Potential Ancient Maya Water Reservoirs Depths



Map 11: Gran Cacao, Belize: Potential Ancient Water Reservoirs



Map 12: Gran Cacao, Belize Potential Ancient Maya Water Reservoirs & Identified Ancient Maya Structures



List of Figures

Figure 1: Photo showing denseness of vegetation of Belizean rainforest. Taken by the site of Dos Hombres (Taken by Author)

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