THESIS

TERRACES AT ANGAMUCO: ANALYSIS OF URBAN AGRICULTURAL LANDSCAPES THROUGH LIDAR AND GIS

Submitted by

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ABSTRACT

TERRACES AT ANGAMUCO: ANALYSIS OF URBAN AGRICULTURAL LANDSCAPES THROUGH LIDAR AND GIS

Angamuco was a long standing ancient Purépecha city located in Lake Pátzcuaro Basin, Michoacán, Mexico. Occupied for at least 1300 years, this archaeological site represents an accumulation of urban features including monumental architecture, a vast road network, wide-ranging domestic and public architecture, and extensive agricultural terracing. Years of pedestrian survey, several excavation seasons, and LiDAR scans of the city have produced a robust record of the dense features of the city. Using these data, in-depth GIS analysis of the spatial qualities of terraced features was possible. Through a robust investigation of 25% of the site, a total area of 178,232m^2 was found to be terraced. This sample was then extrapolated onto the entirety of the site, giving an estimation of 712,928m^2 of terraced area for the malpaís of Angamuco. Total area, dimensions, and spatial associations suggest that the agricultural system at Angamuco was created through a bottom up process. This likely represents multiple generations of small groups investing time and labor to make their land more productive and sustainable over long periods of time. Furthermore, productivity models suggest that small groups were utilizing these terraced zones for personal consumption, elite crop production, or minimal market transactions. Future research will further elaborate on specific growing qualities such as crop type, irrigation practices and fertilization techniques in order to better understand the agricultural system at ancient Angamuco.

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I would first like to thank my advisor Chris Fisher for the opportunity to be a part of this amazing project, for all of his valuable advice, and for a few laughs along the way. This project would not be possible without all of the hard work of LORE-LPB project members past and current, their successes in the field and in the lab are much appreciated. Thank you to my committee member Stephen Leisz, who's remote sensing and GIS knowledge has been an invaluable resource. I would also like to thank Rodrigo Solinis-Casparius for all of his insight and assistance. A special thanks goes out to the CARS crew and CSU grad students who I worked with on a daily basis over the past few years: Lucy, Denise, Marie, Paul and Bear thanks for everything! I am eternally grateful for the support of my parents who always encouraged me to follow my dreams. And finally, I could not be more thankful for my partner Sean, none of this would have been possible without his tireless support and encouragement.

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Chapter 1: Introduction

In this thesis I will examine the past agricultural landscape at Angamuco, an archaeological site located in Michoacán, Mexico. I will accomplish this by conducting an in-depth analysis of terraces using LiDAR data acquired for the site. This spatial analysis will show the location, form, and total area of terraced zones. Using this information, I will explore the comprehensive agricultural system during the course of the lifespan of the city of Angamuco. Quantitative measurements, productivity models and examination of past work at the site will all be used in tandem in order to draw conclusions about this system. The following research questions will guide my analysis of the terraces at Angamuco.

Research Questions:

The main objectives of this thesis will be to address the following four research questions regarding agricultural intensification features at Angamuco:

1. How can we identify and quantify terraces at Angamuco?

2. What is the function of terraces at Angamuco and what were they growing?

3. When were they built? Is there evidence of multiple stages of construction or were they built at the same time?
4. Who is responsible for the construction, maintenance, and economic gain of the agricultural features at Angamuco?

1. Introduction

The invention of agriculture forever altered the course of humanity. The ability to grow food and create surplus has allowed for the security to occupy permanent settlements and quickly grow population sizes. Nevertheless, agriculture and agricultural intensification have received minimal attention in archaeological studies over the past several decades. Recent developments in society have made this topic more relevant and more easily analyzed. The climate crisis and food security issues need solutions and fast; archaeology is in a unique position to offer insight to long term environmental change and solutions. New remote sensing technologies such as LiDAR give researchers the ability to uncover and quickly analyze large settlements and landscapes that have been overlooked in the past.

The introduction of LiDAR into the discipline of archaeology has been a recent phenomenon with it only being in its early stages in the 1990's (Leisz 2013). However recent, this technology has had profound impacts on the discipline of archaeology, changing the way that researchers are able to perceive past people's lives. Classic pedestrian survey, though still a common technique in archaeology, has the potential for human error, is massively time consuming, and comes with a number of issues including limited access to geographical areas. LiDAR helps to negate some of those issues by creating a permanent scan of all of the features both on the ground and the vegetation.

2. LiDAR Overview

LiDAR is the common acronym for light detection and ranging. Airborne LiDAR is a remote sensing technology that emits light lasers from an aerial platform, either plane, helicopter, UAV, or satellite, to measure distance to the nearest object. The moment a light beam encounters a physical object the light is reflected to the platform and time is converted to distance (figure 1).

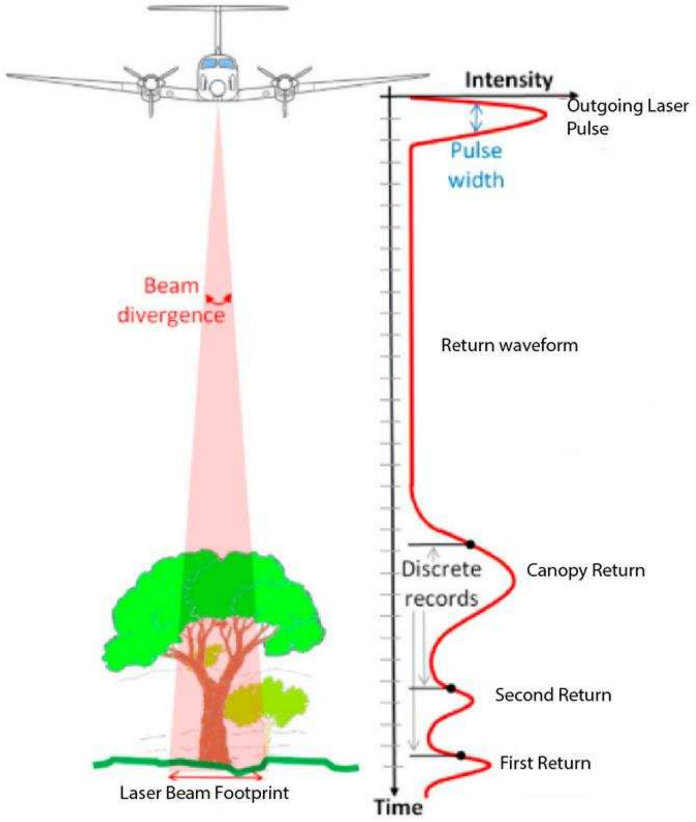


Figure 1: Diagram demonstrating how LiDAR works, adapted from Fernandez et al. (2014)

This process is repeated millions of times over a predefined region and the result is a three-dimensional point cloud of the scanned area below the aerial platform. From this point cloud a number of different visualizations can be created to represent topographical detail. This technology is useful to a number of disciplines. The ability to accurately capture tree canopy data is important for a number of reasons, and the ability of light to penetrate the forest canopy can also reveal the surface of the ground below. This same technology can be used near coastal water and is referred to as bathymetric LiDAR.

The ability of LiDAR to penetrate forest canopies in densely covered regions is one of the aspects that makes this technology so transformational to many disciplines. In areas where there are dense forests, access is often limited to on the ground investigation. Remote sensing technologies such as aerial photography and satellite imagery have long been used in these areas for scientific disciplines such as ecology, forestry, geography, geology, and archaeology but have only been able to record the top of canopy information.

The beginnings of airborne LiDAR as we know it today comes from the 1970's when the use of lasers attached to a plane was utilized first by researchers in Venezuela and shortly thereafter by the Soviet Union. In the first case, the goal was to do land survey for construction of a water reservoir. As a result of the data collected the team was also able to derive canopy height of the scanned forest areas (Nelson 2013). This early project was able to demonstrate the multifaceted uses for this data.

With the loosening of regulations related to the Global Positioning System (GPS) and inertial measurement units (IMU's) in the late 1990's, and the integration of this technology with inertial measurement units (IMU's) the effectiveness and utility of LiDAR began to skyrocket. Advancements were quickly made in the technological apparatuses as well as the analysis of and visualizations from the point cloud data. While forestry remained a critical focus of LiDAR research, agriculture and military applications were what caused rapid technological improvement of LiDAR instruments. Ground resolution became much more detailed even in densely forested areas, with the ability to detect small features on the ground.

Currently, LiDAR is used by a number of disciplines academically, governmentally, and commercially. Commercially, agriculture is one of the largest consumers of the data that this technology can provide. Detailed information on slight topographic changes such as slope and elevation can be used by farmers to identify the best crop management and irrigation practices. Land developers and real estate companies are also using this technology to prospect and plan for large tracts of land. Forestry programs are using data to track land cover changes, monitor seasonal wildfires, and record changes in bloom patterns. Academically this technology has had an immense impact. Programs like the Bureau of Economic Geology at UT Austin have purchased their own LiDAR instruments and are conducting research in programs across the university including applications in permafrost mapping, shoreline changes, bathymetric depth analysis, wildlife management, geomorphology of rivers, and archaeological prospection just to name a few.

As LiDAR becomes more readily available to all of the aforementioned disciplines, its utility will continue to grow, and many other disciplines are likely to find new and inventive ways to explore the utility of this technology. The application of this data to help answer research questions and solve problems can only expand. The discipline of archaeology is just one of the latest fields to take advantage of this technology. Its relevance in archaeology and elsewhere is just beginning to be illustrated.

3. LiDAR and Archaeology

Excavation only allows archaeologists a small glimpse of past people's lives. Limited sample sizes, taphonomic processes, time-averaging, and deterioration of perishable items are only part of the problem. The use of aerial photography was an early technology used to change the way archaeologists looked at sites. As soon as the invention of photography in 1839 curious onlookers have attempted to create get a bird’s eye view of landscapes by attaching cameras to objects that could fly (Leisz 2013). In archaeology this was accomplished in the 1880’s by attaching cameras to balloons to get a bird’s eye view of archaeological sites (Reeves 1936). In 1906 Lt. P. H. Sharpe took a now famous aerial photograph of Stonehenge by using the camera and balloon method. Pigeons, kites, rockets, and hot air balloons were just a few of the methods that were employed by archaeologists to achieve the god's eye view of archaeological sites (Fields et al. 2014). These methods allowed a more holistic view of sites including entire landscapes, rather than relying solely on the material data that is removed from small excavation units.

As technologies improved through the decades so did aerial views of archaeology. Entire landscapes could now be examined in a cohesive collection. Historical aerial imagery taken from planes largely collected through military campaigns as well as satellite data were included in archaeological investigations (Leisz 2013). Landscape archeology was first introduced in the 1970's, but post-processual theorists are responsible for the explosion of research in this area. Though the definition of this sub discipline can vary, it tends to focus on land use patterns, population levels, climate, settlement patterns, and technologies (Aston 1985). Using LiDAR for landscape archaeological investigation allows researchers to create new questions and find new answers to problems that were not possible in the past.

Though landscape archaeology has been a sub-discipline of archaeology for several decades, LiDAR has recently transformed the discipline. The detailed topographic maps that this technology can provide for vast areas allows for a comprehensive investigation of an entire cultural landscape. Vegetation can be completely removed or included in the analysis of area as appropriate for the specific research question. While the data is collected at one point in time, by applying different algorithms for varied visualizations this allows for new interpretations of the same landscape. As current research in virtual reality and LiDAR landscapes continues to improve this will allow archaeologists and others to experience past landscapes like never before. Some theorists have argued that archaeology is already undergoing an epistemological revolution thanks to the capabilities offered by LiDAR (Chase et al. 2012). As this revolution in archaeology plays out, the many advancements that are possible with this technology should be examined in great detail.

4. Agriculture in Lake Pátzcuaro Basin and Angamuco

Like many other regions around the world agricultural intensification studies in Lake Pátzcuaro Basin (LPB) have taken a back seat to more grand topics such as the monumental architecture located at the imperial capital of the Purépecha Empire, Tzintzuntzan. In fact, early research in the LPB claimed that there were no intensification features in the region at all, and the rulers of this area had the majority of their food imported through tribute and market exchanges (Pollard and Gorenstein 1980). While this theory has proven untrue through several other avenues of research, there is still relatively little data on agriculture in the region in the past (Fisher et al. 1999, Puzzetti 2010). This is partly due to modern agriculture and development. The lands in LPB are quite fertile due to the former lakebed and volcanic soils, making it an ideal location for growing food today. As in the present, the people of the past certainly used these nutrient rich soils to their advantage.

In 2010 the LORE LPB research team located a large archaeological settlement in the southeastern portion of the basin. Because of the rugged topography of the site it had been largely undisturbed by the modern development nearby. Extensive pedestrian survey and two LiDAR scans have shown how massive this settlement is, covering at least 26km^2. Named Angamuco, this city has extensive architecture and agricultural intensification features such as terraces. Previously studied agricultural intensification features in this region have been largely isolated, offering very little associated settlements and architecture. Angamuco is a unique case study because it is a densely built urban environment with extensive monumental and domestic architecture in addition to wide-ranging terraced zones. This thesis will explore those agricultural features in depth in order to examine the first known urban farming settlement in LPB.

Chapter 2 of this thesis will set up the environmental and cultural context in which Angamuco was situated throughout the Post-Classic period. The environmental context will provide a basis for understanding the changes throughout time and the agricultural potential of the region. The cultural context of both Angamuco and the wider LPB will establish an understanding of the complexities of the urban environment.

Chapter 3 will provide an overview of the development of agriculture, from domestication to intensification. It will cover broad definitions as well as provide specific frameworks for LPB and Angamuco. This will help to better understand the persistence of food ways during Post-Classic Angamuco.

In Chapter 4 I will give an overview of common agricultural intensification strategies. In Mesoamerica some of the most common agricultural intensification strategies include terraces, canals, and raised field agricultural features. All of these strategies have been employed in LPB in the past. They are commonly used to combat climatic variations, land degradation, or population stressors, though they could also be used as a risk management tool. I will describe these features in detail in order to set up the examination of the agricultural landscape at Angamuco.

Chapter 5 will describe the methods that I utilized to extract and analyze the terraces on the malpaís. The initial processing of the LiDAR, creating visualization techniques and the identification and quantification of terraces are all detailed.

Quantitative and qualitative methodological processes to analyze the entire built environment of Angamuco are described. Hydrological models are run for the entire malpaís, and finally productivity models are run for the terraced areas of Angamuco.

In Chapter 6 I will present the results of the methodologies presented in Chapter 5. Terrace attributes such as total area, physical descriptions, and location will all be discussed. The hydrologic modeling for irrigation at the site will be discussed, as well as the results of crop productivity at Angamuco. Chapter 7 will elaborate further on the results of my methods, adding an anthropological lens to the spatial data that was generated.

In Chapter 8 I will shift focus a bit to discuss the valuable information that archaeology can contribute to contemporary food security issues in the face of the climate crisis. I will discuss how combining archaeological data and the wisdom held by contemporary indigenous groups can provide priceless advice on sustainable agricultural practices for the future.

In Chapter 9, my concluding remarks will summarize and briefly elaborate on the results produced by this analysis. The expectation of this work is to provide a basis for future urban farming studies at Angamuco and other regions in Mesoamerica.

Chapter 2: Background

1. Introduction

In this chapter I will explore the environmental and cultural context in which Angamuco was situated during its peak throughout the Post-Classic period. By summarizing both of these contexts, I will help to better establish the agricultural potential of the city and further explain how the environmental aspects of the city and surrounding region impact the cultural characteristics of the Purépecha living at Angamuco.

2. Environmental Context

Lake Pátzcuaro is in a basin located in modern day northern Michoacán, Mexico about 50km away from the capital of the state, Morelia. The region is located in volcanic highlands, with an average elevation of 2035m ASL (Platt Bradbury 2000). The entire basin occupies a total area of 928km^2 (figure 2). The basin contains numerous islands that appear when the lake levels fluctuate (Fisher and Leisz 2013). There are also a number of landforms created from volcanic lava flows, locally called by the name malpaís, meaning badland. The lake and the basin have been extensively researched and numerous environmental reconstructions of the basin have been made possible due to the hydrologically closed nature of the area.

Figure 2 Lake Pátzcuaro Basin, adapted from Farshad and Barrera-Bassols (2003). Source: 19°37'03.47" N and 101°37'46.67"W. Google Earth. 12/31/2020.

The terrain of the basin is mainly made up of volcanic basalt in the higher elevations, and thick red soils and nutrient rich sediments from various alluvial deposits. The larger region outside of the basin, is much more diverse. Western Mexico is geographically very diverse. The western coast of Mexico is located along the Pacific Ocean offering sandy and rocky beaches. Just inland from the coast the Sierra Madre Occidental mountain range runs parallel to the Pacific throughout western Mexico. This mountain range offers steep mountains and volcanoes with creating a diverse micro-landscape. In this mountain range there are also several rivers that provide needed resources including two major rivers that connect western Mexico with other prominent regions in the Americas. Running parallel to this range is the Neo-Volcanic Axis. This mountain range runs west-east from the Pacific coast to the Gulf of Mexico. Throughout this region there are numerous lake basins that offer rich resources that are attractive for human settlements. In addition to this this area has plentiful mineral resources including obsidian and copper.

The geographic diversity in western Mexico as well as the variety of resources, make this area attractive to people both past and present. The volcanic ash along with past lake beds creates an environment in which the soil is rich in nutrients making many areas ideal for agriculture. The numerous water sources aid in this endeavor as well. The access to coastal provisions makes for the possibility of a diverse diet, and the abundant mineral resources allow for various human exploitations.

Beginning in the 1940's Lake Pátzcuaro Basin was considered the best studied lake in Mexico and this tradition has continued on today. In 1944 cores were taken in the southern region of the basin gathering information on pollen, geochemistry and diatoms (Deevey 1944). This research was reiterated by Hutchinson et al. (1956) in the following decade. At this time radiocarbon dating was not yet the norm, so any chronological modeling was strictly related to the sediment deposition. Another core taken in the 1980's closely analyzed pollen particles and gathered radiocarbon dates directly from these samples (Watts and Platt Bradbury 1982). Radiocarbon dates and further geochemical proxies were taken from a 14-meter core in the LPB in 2000 in order to expand upon the previous studies (Platt Bradbury 2000).

Lake Pátzcuaro Basin (LPB) is a humid temperate zone with current average temperatures between 12-18 degrees Celsius. Winter temperatures average 12-13 degrees Celsius. Generally, the winter is dry and stable, but polar air can bring in some precipitation and low temperatures with occasional frost days. The temperature never remains low enough to cause freezing of the lake. The summer temperature averages 20 degrees Celsius in May-June. Currently, the basin receives 900-1250mm of rain a year. This rain occurs in a monsoonal pattern, with the majority of rain falling in the mid to late summer months (Platt Bradbury 2000).

Contemporary environmental proxies are not necessarily representative of the past. LPB has gone through numerous climatic shifts that would have directly affected lake levels, rain fall patterns, and mean temperatures. Because the basin is hydraulically and climactically closed, the lake is considered an amplifier, meaning that small climatic changes can create dramatic shifts in the local environment.

The modern Pátzcuaro Lake is much different than in the past. It is currently morphologically shaped like a “C”, with the long axis reaching 20km and the max width reaching 11km. It covers a total area of 130km^2. The depth varies in different regions of the lake, but the max depth is 12m and averages 5m (Platt Bradbury 2000). In 1942, at the time of Deevey’s limnological investigations, the lake level sat at 2039m asl and currently Lake Pátzcuaro sits at 2034m asl. Over the last half a century various changes in the region have caused major lake level decreases. Modern erosion, drainage projects, agricultural use, and decreased rainfall have impacted the physiography of the lake and surrounding basin. Both of these numbers from the modern era,
are significantly different from Postclassic lake levels that would have been between 2028-2030m asl in the Early Postclassic and 2045m ASL in the Middle and Late Postclassic (Pollard 2008, Fisher I.P). Earlier environmental reconstructions suggested that during the Epiclassic to Middle Postclassic periods, the lake level had regressed

quite significantly, putting it at 10-13 meters below the Late Postclassic levels (O'Hara 1993, O'Hara et al. 1993). However, recent archeological evidence has disputed these claims, suggesting that the lake was much higher during these times due to human modification that was conducted in order to help correct past environmental deterioration (Fisher 2009, Fisher IP).

Due to the lacustrine deposits and volcanic soils, the LPB has nutrient rich soils in many lower elevation locations that are ideal for agriculture. Early agriculture was abundant enough in the region to show up in pollen records as early as the Mid-Holocene (Platt-Bradbury 2000). This shows the long-existing tradition of local residents using this environment to their advantage. Environmental descriptions of soil types by contemporary local farmers in this region have been broken down into five major soil types, each with 15 subtypes, and eight varieties. These categories cover soil cover, texture and color differences. In addition to these physical descriptors there is also a use of landscape positions, and general use (Barrera-Bassols and Zinck 2003). This classification system collected from indigenous Purépecha farmers goes far beyond modern geological categories that rely solely on genetic, textural, chemical, or mineralogical composition (Duarte et al. 2018). Soil type in LPB certainly differs from region to region based on a number of factors including elevation, shoreline proximity, and geologic composition, however local farmers have developed the classification system in order to describe these complexities.

Often researchers compare this region of western Mexico to the Basin of Mexico however, they differ in a number of ways. Soil types in these regions are unique from one another, LPB elevation is lower than the Basin of Mexico, and the average rainfall of LPB is almost double that of the Basin of Mexico with 450-1000mm per year versus 900-1250mm per year, and LPB receives more frost days (35-55 days) (Fisher 2007, Pollard 1993, West 1948). It is important to highlight the climatic differences between these two areas in order to differentiate the agricultural potential.

3. Zones and Soil Type

Soil types in Pátzcuaro Basin have been extensively studied both for geochemical make up as well as for indigenous descriptive properties. The geographically varied composition of the basin makes the soil types just as varied. Some of the recorded soils in LPB include: Charanda, meaning red earth in Purépecha. These soils are located on the lower mountain slopes as well as the basin floor. They are formed from weathering of volcanic rock, are high in clay content, and does not readily retain moisture (Fisher 2000). There is also tupuri, meaning yellow earth in Purépecha. These soils are highly productive, with fine texture and high moisture retention. These soils are also formed from weathering volcanic rock and are found on the slopes of volcanic hills (Fisher 2000). Modern soil science has named volcanic soils formed from tephra, andosols. They are generally described as having high organic matter, being resistant to erosion and runoff, with high moisture retention. It is because of these qualities that they are considered a highly productive soil to use for agriculture (Demelle et al. 2015).

There are six environmental zones within the basin, each with distinct soils types. The first is the open water zone, this zone extends to the shoreline, thus used primarily for fishing and other lake resources. The second zone is the tule-reed marsh located along the peripheries of the lake and are prone to seasonal changes: flooding and draining. The soils in this zone can be characterized as lacustrine and alluvial. Both of these areas are currently not suitable for agriculture, though many resources can be procured from these landscapes (Pollard and Gorenstein 1980, Pollard 1993).

The third zone is the lakeshore, this area is mostly flat making it ideal for agricultural purposes. The soils in this zone can also be characterized as alluvial because of lake level fluctuations, thus adding to the agricultural potential. The boundaries of this zone have changed over time, and during the Postclassic period likely stretched to the edge of the malpaís of Angamuco. The fourth zone contains the lower slopes of the Sierra zone, including volcanic hills, mountains and lava flows (Pollard 1993). These slopes often have fertile soils such as andosols that are suitable for agricultural purposes.

The fifth zone contains the upper slope of the Sierra zone. For most of the basin this represents the highest slopes. These slopes are also often used for cultivated fields, containing weathered volcanic soils and some alluvial basins (Pollard 1993). The last zone represents the highest elevations in the basin and is the alpine zone. This represents only a small portion of the basin and is often not suitable for agricultural purposes due to thin and eroded soils.

Modern ethnographic data in the basin has expanded upon these environmental zones and applied more descriptors to agricultural potential as it relates to the land. Barrera-Bassols and Zinck (2003) outline modern Purépecha farmer's soil classifications, using a mix of categories including physical typology of soil, texture, color, position on land scape, relief, and slope. In addition to the study discussed above, one review classifies the land into three main agricultural categories largely based on soil type: Class I contains irrigated plots with naturally fertile lacustrine and alluvium soils with inputs of charanda and t’upuri soils (Pollard and Gorenstein 1980).

Class II is irrigated only with rainfall, and the soil are described as uirás, in addition to charanda and tupuri. The type of land could be terraced in order to increase productivity and increase time between fallowing. Class III agricultural land is generally located at higher slopes and thus has more frosts per season and greater potential for erosion. The soils here are thin, charanda, tupuri, and yellow-brown andosols that are rain dependent and need to be fallowed often (West 1948, Pollard and Gorenstein 1980).

Angamuco is located on a malpaís, meaning badland, and was formed by an ancient lava flow. Because of this geologic composition the soils located at the site are highly productive. There are both charanda and tupuri soils located on the slopes at the site and on the more level surfaces. The site is also located in Pollard’s (1993) fourth zone designation. These characteristics make Angamuco an ideal location for growing food or other agricultural plants.

4. Environmental Degradation

Because of the vast amounts of paleo-environmental research within Lake Pátzcuaro Basin there is an extensive history of landscape use and change. Environmental degradation is clear in the paleo-environmental record and in the past researchers attributed this to agriculture. However, more contemporary research has shown that this was not due to agriculture, instead it can be attributed to colonization and growing population centers.

Major eras of erosion and landscape degradation can be attributed to two phases: Classic period (120AD-775AD) and Hispanic occupation (1520AD-1960AD) both of which had low levels of population densities. During the phases in between, largely the Postclassic period the basin maintained landscape stability (Fisher et al. 2003). The Postclassic period contained the highest levels of population and human-induced landscape modifications; these modifications including large-scale terracing, actually helped to repair past degradation. The degradation and erosion that followed during the period following colonization is likely due to large-scale abandonment of agricultural modifications (Fisher 2005, Fisher 2009). Without proper maintenance of sustainable agricultural features such as terraces, and introduction of European style agricultural methods, erosion and lake level drops followed quickly.

This evidence challenges previously held assumptions that urbanism and agricultural practices are responsible for negative environmental impacts (O’Hara 1992, O’Hara et al. 1993). Instead it shows that larger indigenous populations modified and controlled past landscapes in order to create sustainable and productive agricultural practices and landscapes that lasted for many generations.

5. Cultural Background

The Purépecha Empire was located in Mesoamerica, specifically contemporary western Mexico and the geopolitical core of this empire was located in the Lake

Pátzcuaro Basin. At its peak, the empire spanned across western Mexico into multiple modern states (figure 3), and had extensive trade routes that included various other groups across the Americas, including but not limited to the American Southwest, the Aztecs and the Maya.

Figure 3: Extent of the Purépecha Empire during the Late Postclassic outlined in teal, adapted from Pollard (1993) projected over Esri ArcPro World Topographic Base Map 2021.

In western Mexico, people had access to precious minerals such as obsidian offer an abundance of opportunities for trade, and the availability of copper in this region is plentiful allowing for the Purépecha to control metal trade throughout the Americas at their peak. Even pre-state, this region and the people who lived there had access to an abundance of resources making this area ripe for political control.

Mexican archaeology is well known in pop-culture. The Maya and Aztec empires have cultivated much media attention through movies such as Star Wars: Episode IV and Apocalypto feature the massive pyramids and sprawling cities built by these past people. Contemporary with these two groups was the Purépecha Empire. Their territory was located in western Mexico and bordered the Aztec territory. At the peak of the empire in the Late Postclassic their territory stretched at least 75,000km^2 covering modern Mexican states including Michoacán, Jalisco, Guanajuato, Colima, and Guerrero (Pollard 1993). The size, power, and feats of the Purépecha Empire necessitates more focus on this prehispanic group, so that they can become as well known and studied as their contemporaries.

Archaeological investigations of LPB have been ongoing for almost a century. Early investigations in the region focused on the city of Tzintzuntzan, the imperial capital of the Purépecha Empire in the Late Postclassic period. Here in Michoacán, the Spanish invaded and settled less than one year after invading Tenochtitlan, modern day Mexico City. Both colonial records and early archaeology focused on the Purépecha state, and the aspects of that culture after state formation. However, more recent research has shown that LPB was inhabited long before this, and cities and densely populated urban areas were thriving before the formation as well (Fisher and Leisz 2013).

While the late Postclassic has been the most researched time frame of this cultural group due to the well-preserved capital of Tzintzuntzan, the history of this region goes back much further. Radiocarbon dates taken from sediment cores containing maize pollen suggest that the basin was inhabited as early as 1500BC (Pollard 2008). From this point on sedentary populations lived, farmed, and built on the land. By the late Postclassic, coinciding with the consolidation of the Purépecha Empire, the LPB region alone had over 90 communities, with low estimates putting the minimum population of between 60,000-105,000 people (Pollard 2003).

6. Timeline

Archaeological evidence in the Lake Pátzcuaro Basin indicates that major population growth and political organization began in the Late Preclassic, or Loma Alta period, 150BC-350AD (Pollard 2008). Evidence of agricultural intensification through maize phytoliths, has been documented for this time period (Watts and Bradbury 1982). At this time small villages were the norm, with no central political leadership, and individual villages were run by chiefdoms and religious leaders.

By the Epiclassic period, 600-900AD there were several large settlements in the southwest portion of the Lake Pátzcuaro Basin. Archaeological investigations show intensive agricultural features directly relating to this locale and time period. It was not until the middle Postclassic that dramatic political changes took place both in the basin and the larger geographical region. It was at this point that political centralization began to take place. There are several theories on why the population in this area grew so suddenly: It could have been due to migrations from other areas, climatic shifts, labor needs, or the general wealth and resources of the region.

7. Angamuco

One of the cities that demonstrated the wealth of this region in the Middle Postclassic was Angamuco. Angamuco was identified by archaeologists in 2007 during a survey of the basin south of the city of Tzintzuntzan. Located on the far eastern boundary of the basin, and to the south of the capital, the site is located upon a late Pleistocene malpaís. Initially the site was thought to be a small, well preserved settlement. Over the next couple of years, further survey and some excavation uncovered a densely populated urban center with monumental architecture including pyramids and plazas, a vast network of roads, massive stone walls, water control features and terraces. After several years of pedestrian survey and mapping, two LiDAR scans were flown over the malpaís for a total coverage area of 35km^2. This data showed that the entire 26km^2 malpaís had been significantly modified through architectural, structural and agricultural features. The survey, excavation, and LiDAR data have allowed for extensive research to have been conducted by a group of LORE-LPB archaeologists.

Through the various investigations a chronology of the site has been made possible through ceramic typologies, AMS dates and other archaeological research. Though this chronology is being steadily updated with each new discovery, the Middle Postclassic period seems to be the height of the city, with sizable populations before this period, and all the way into colonization of the area. Significant occupation of the site seems to have begun at around 250CE and lasted for 1300 years (Solinis-

Casparius 2019). The site is organized into two different areas: the lower and upper zones, with occupations shifting between these two areas. Starting in the Classic (250-600CE) period, most of the occupation was centered in the lower zone. This would have been useful for agricultural purposes and access to water sources such as the lake and reservoirs around the base of the malpaís. Later, during the Epiclassic period (600-900CE), settlement was expanded to the upper zone. This could have been due to environmental and climatic shifts, or due to a rapidly expanding population.

The Middle Postclassic (1100-1350CE) saw drastic population changes and modification of the landscape. Recent evidence has shown that lake levels were at a high point of 2043-2045m ASL at this time (Fisher I.P.). Lake reconstructions show that the Pátzcuaro Lake shore was approximately 2.1km away from the edge of the malpaís at this time (figure 4) (Steele and Westberry 2020). This would have expanded the available resources for the city including travel, food, agricultural benefits, and trade resources. It was during this period that elite occupation of the lower portion of the site was at its peak likely to harness the stabilized resources at their disposal.

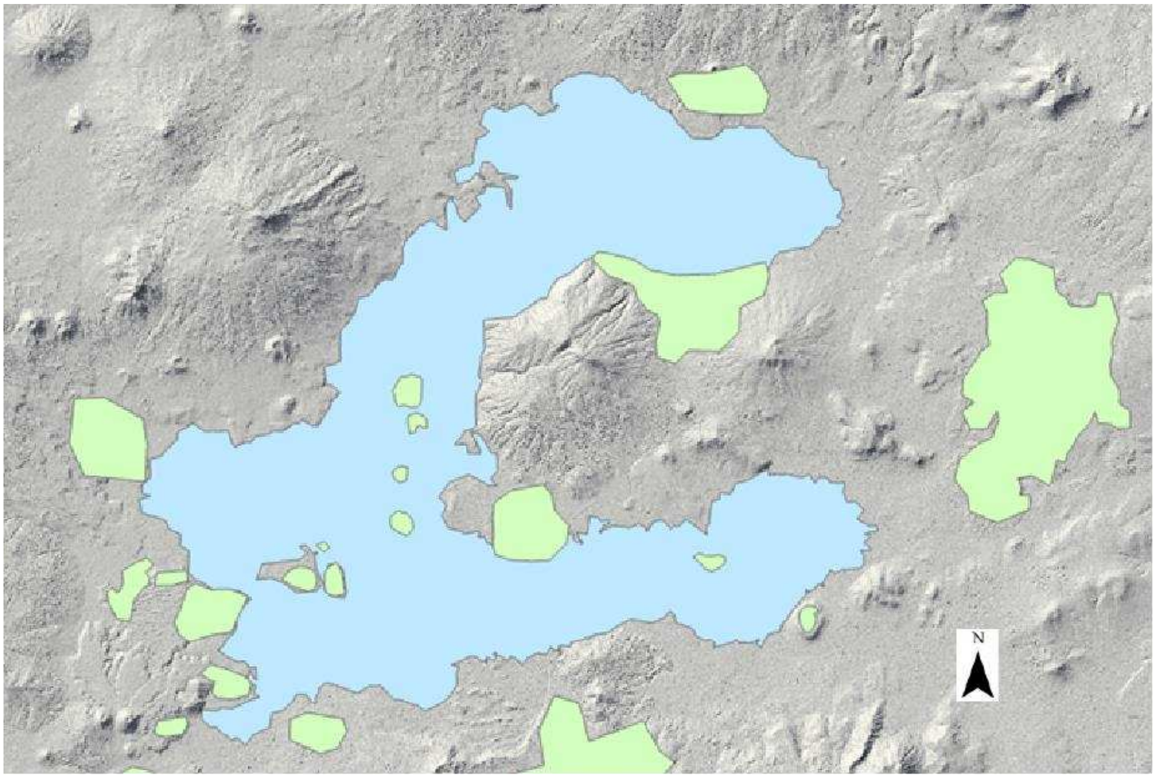


*Figure 4: Postclassic Lake extension near the edge of Angamuco. Lake represented in blue, with archaeological sites in green. Shapefiles projected over DEM created by NASA and Stephen Leisz**.*

The Late Postclassic (1350-1525CE) saw the unification of the Purépecha Empire. This was reflected in the architecture at Angamuco, through changing monumental architecture such as yácatas, or key-hole pyramids (Fisher and Leisz 2013, Fisher et al. 2019). Lake levels stayed stable during this time, and the city remained densely occupied by both elite and non-elite populations.

After the Spanish invaded and colonized Tzintzuntzan, they settled elsewhere in the Lake Pátzcuaro Basin. Though Angamuco was not immediately abandoned, shortly after 1521 the city was overthrown and abandoned by the Purépecha residents. Following the abandonment there was a colonial occupation in the southern portion of the site. The occupation of the city is summarized in the table below (Table 1).

Table 1 Angamuco Occupation Phases adapted from Pollard (2008).

Established Angamuco Occupation Phases			
Years	Period	Phase	Description
100BC-350CE	Late Pre-Classic	Loma Alta	Occupation in other areas of LPB
350-500CE	Early Classic	Loma Alta 3	Early settlers move onto the lower malpaís
500-700CE	Middle Classic	Jaracuaro	Expansion of settlement into the upper malpaís and higher elevations
700-900CE	Epiclassic	Lupe/La Joya	
900-1100CE	Early Postclassic	Early Urichu	Extensive settlement expands to all areas
1100-1350CE	Middle Postclassic	Late Urichu	Elites settle back on lower malpaís
1350-1525CE	Late Postclassic	Tariacuri	Consolidation of Purépecha Empire, resettlement
Post 1521CE	Colonial		Conquest and abandonment

Previous research on Angamuco has focused on the urban aspects of the site such as pyramids, road networks, neighborhoods, and household architecture. It is through these projects that Angamuco can truly be called an urban center. Monumental architecture at the site is prevalent. Through ground survey and LiDAR analysis, 26 pyramids of varying sizes have been identified. Of these 26 pyramids, six were yácatas (Friedl 2019). Yácatas generally have a keyhole shape consisting of a combination of a rectilinear and circular bases. Below is an image of the main yácata and associated plaza located on the lower malpaís at Angamuco (Figure 5). These features are unique and represent the Late Postclassic Purépecha Empire. They are thought to be used for ritual celebrations or administrative purposes (Acosta 1939). Also located at Angamuco are at least 20 rectilinear pyramids of varying sizes, measuring between nearly 30m to 15m on the secondary axis (Friedl 2019).

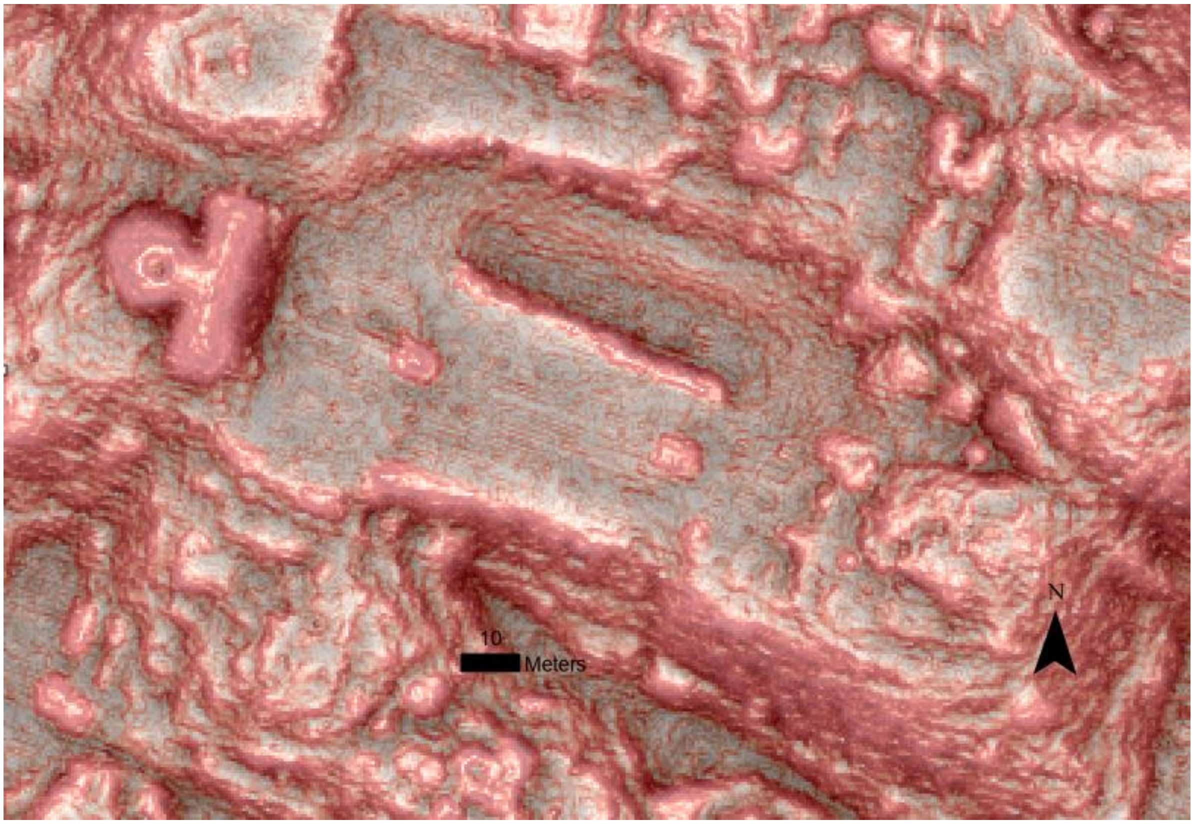


Figure 5: Yácata with associated ceremonial center located on the lower malpaís at Angamuco. (See Appendix A for Geospatial metadata and Visualization information PRRIM***).*

In addition to pyramids a number of other features fall into the monumental architecture category. These include ceremonial centers, open plazas, sunken plazas, alters, and raised roadways. A complete investigation of the monumental architecture has not yet been accomplished, however a detailed analysis of the roadways at Angamuco was undertaken by Solinis-Casparius (2019). His results taken from both field survey and LiDAR data show that the city has an extensive road network covering around 157km. The width of these roadways varies from a smaller version at 0.5-1m to large raised platforms measuring over 5m (Solinis-Casparius 2019). The roadways at

Angamuco show how interconnected the site was and how they helped to facilitate a number of urban and economic activities.

These features in addition to numerous other household level and public architecture show that this city was truly an urban center. The total number of significant built features (greater than 5m$^{2)}$ at the site is as high as 87,407 (Harris 2019). This analysis shows how densely built the city was, and yet still does not recognize other built environments such as water management features and agriculturally modified areas. Angamuco had an extensive water management system throughout its occupation. LiDAR analysis shows that there are 811 potential water storage features at the site including, wells, residential reservoirs, and margin reservoirs. Many of these are surrounded by the raised road system either to help with storage issues, or to allow pedestrian access around these areas when water storage is high (Simpson 2019). In addition to water features on the malpaís, large reservoirs have been located around the edge of the malpaís, as well as numerous active and inactive springs and canals. The spatial arrangement of these hydrologic features shows that water access was plentiful across the city and would have allowed for access to ritual, household, or economic activities involving water.

Beyond the water management research at Angamuco, a few seasons of survey, and one excavated terrace bench not much research on agricultural potential has been accomplished. In one study, Solinis-Casparius (2019) noted that some of the larger roadways at Angamuco were used not only for travel, but also had a high potential for planting crops such as maguey or beans. Research on other sites around the basin have uncovered evidence of intensive agricultural features such as terraces, raised fields, and canal irrigation features (Fisher 1995, Fisher et al. 1999, Pezzutti 2010). Survey at Angamuco in 2010-2013 located a large number of agricultural and habitational terraces and canals surrounding the malpaís. This thesis will further develop the research on these agricultural features.

Taken together the archaeological research conducted at Angamuco shows that the city was a complex urban environment consisting of potentially uncountable built features. The city was clearly planned and served numerous functions including religious, administrative, agricultural, and economic.

Chapter 3: Agricultural Intensification

1. Introduction

Agriculture has always played a significant role in the lives of people living in Mesoamerica. From the initial domestication of plants to contemporary cash crops, agriculture is a fundamental cultural feature in the lives of many. In this chapter I will give a brief overview of the development of agriculture in order to better understand the establishment and persistence of food ways at Postclassic Angamuco.

2. Domestication

Food ways are a pivotal function of any culture both past and present. Not only is sustenance necessary for survival, the relationship between cultural practices and food ways are completely intertwined. Going back as far as early hominins changes in diet and access to certain foods, are thought to be responsible for the growth of the brain and evolution to Homo sapiens (Speth 1989, Leonard and Robertson 1994). This persisted for millennia while nomadic groups all over the world traveled throughout diverse regions in pursuit of food both foraged and hunted. Seasonal, annual and generational revisits to the same locations often created a more plentiful flora supply due to refuse, pruning, or some other sort of environmental manipulation, either purposeful or accidental.

The origins of agriculture have been debated through generations of scholars. The exact how and why of the genesis of agriculture is not fully understood. What we do know is that there are many centers around the world where agriculture was independently conceived. The hypotheses on how many centers of agricultural origins there are range from the classic notion of five centers to upwards of twenty different locations (Flannnery 1973, Reed 1977, Fuller et al. 2014). Archaeological evidence shows that most of these areas are tropical or subtropical with high biological diversity (Piperno and Pearsall 1998). These definitions of agricultural origins are ever changing, but numerous lines of data show that people in many regions around the world began to manipulate their environments in order to grow food starting around 9,500 BC. The types of crops domesticated varied by region and included a diverse range of taxa.

The motivation for agricultural domestication could be from a variety of factors. There is certainly a strong correlation with population growth, however, which of these two factors came first? Do people adopt agriculture because of stressors such as population growth, or does the adoption of agricultural practices cause stability and allow for populations to grow? The answer is probably somewhere in the middle, with no defined singular processes, and likely varies widely from culture to culture. Extensive research on civilizations that adopted agriculture much later in time, such as the Southwestern Native Americans, show that many of these groups often adopted agriculture as a risk management tool to offset the variability of hunting and gathering strategies, while at the same time not fully abandoning the strategies (Sinensky and Farahani 2018).

Climactic variations likely played some role in the adoption of agriculture; around the time of the development of agriculture there was a climatic shift, the end of a glacial age which ushered in climatic stability, warming around the globe, longer growing seasons, and increased rainfall. All of these factors would have been a positive motivation for people to move into agricultural practices. However, environmental determinism is certainly not the singular answer for this shift to agriculture: individual cultural factors should always be considered in shifts in decision making as well. Enduring groups of people living in the same areas of agricultural origins chose to continue on with hunting and gathering, long after nearby groups had fully transitioned to sedentary agricultural practices (Roth 2018).

3. Mesoamerica

Mesoamerica was one of the centers of independent origins of agriculture. It is likely that the foundations of agriculture in this region began as early as 10,000 ybp (Zizumbo-Villarreal and Colunga-GarciaMarin 2010). When the term Mesoamerica was coined by Paul Kirchoff (1943) one of the main parameters that he used to identify the cultural zone was the cultivation of a specific set of foods. These included maize, beans, squash, cacao, and maguey. In Mesoamerica, maize along with Kirchoff's other staples, was the crop that would transform cultures for millennia to come. The ancient ancestor of maize, teosinte began to be manipulated by past people in Mesoamerica as early as 8000 BC (Matson 1991). Teosinte was quickly adapted and selectively bred in order to create a more morphologically sound structure and allow for more edible parts. The evolution of teosinte into maize or *Zea mays* was so astounding that it has caught the attention of theorists, archaeologists, and geneticists, for over a century. Charles Darwin, the father of evolution himself, even performed experiments with maize plants and theorized on the possibilities of its evolution.

The original structure of wild teosinte was a grass like plant with a single stalk containing seeds that were tucked into clusters on the stalk. As this plant was genetically altered more seeds were selected morphing into a two stalked grass, and eventually into primitive tiny cobs containing unprotected kernels. The differences in these plants are shown below in (Figure 6). This allowed for easier consumption and a more plentiful crop. The early archaeological evidence for this early transformation is found in cave sites around Mexico (Flannery 1973). Once teosinte was adapted into maize, it quickly became a staple in Mesoamerica. Currently, the earliest known maize macro-botanicals were found in Guila Naquitz Cave in Oaxaca, Mexico, and date to about 6,250 cal. ybp. Other cave sites in similar geographical and environmental contexts have revealed very similar dates (Merrill et al. 2009). While the exact time frame for domestication is debated there are dates for teosinte manipulation as early as 8000 BC, and fully evolved maize by 6,250 ybp we can see that people were selectively breeding plants for better nutritional value very early into the initial human population of this region (Matson 1991). From there the spread of maize throughout Mesoamerica likely took place along rivers, tributaries, and other water ways as has been documented in other regions by massive amounts of macrobotanical, geochemical, and archaeological data (Sinensky and Farahani 2018).

Illustration of plant structures: teosinte
on the left, maize on the right.

Edible portion of plants: teosinte
on left, maize on right

Figure 6: Illustrations of teosinte and maize structural differences, adapted from Yang et al. (2019).

The importance of this crop not only to Mesoamerica, but to all of the Americas cannot be overstated. Origin stories, coming of age life stages, rituals, and deities are all aspects of past peoples of the Americas culture that are associated with maize (Washburn 2012). The individual elements of these cultural effects vary in different cultural groups; in Mesoamerica the Maya, identified so deeply with maize that they called themselves the people of maize and their origin stories state that the first people were created from yellow and white maize. It represents an unbreakable connection to the earth and land. This one plant signified both a religious and secular cornerstone of Mayan lifeways (Huff 2006). As far north as the American Southwest, the Hopi origin story tells a defining story of the knowledge, accomplishments, and trials associated with this way of life. The guardian spirit of the Hopi is Masaw, who gave his spirit to the people in the form of a planting stick, a bag of maize seeds, and a gourd of water. This was meant to define the true spirit of the Hopi, diffusing through every aspect of their lives, including the cyclical nature of the growing and harvesting, representing ceremonial cycles of birth, coming of age, and death (Wall and Masayesva 2004). Throughout many millennia maize has provided sustenance, informed identity, and tied people intimately to the land.

4. Agricultural Intensification

A concise definition of agricultural intensification is a process where attention is focused on a given piece of land often in the form of labor, with the goal of increasing crop productivity per unit of land (Fisher 2007). This attention could come in the form of labor, capital, technologies, or fertilizers. In some areas this could be tilling the land, adding fertilizer or increasing watering strategies. In Mesoamerica, these techniques include irrigation features such as canals, chinampas, and terraces. It is assumed that building features such as these on a large scale requires vast amounts of labor. However, it has been demonstrated that small groups in the American Southwest used similar agricultural strategies and manipulated their environments while maintaining low population numbers. This demonstrates that a sedentary group of people, no matter the size, can manipulate their environments and create strategies in order to increase productivity of the land.

Early agricultural techniques in Mesoamerica were passive and likely involved both farming and hunting and gathering systems. However, sedentism with a full adoption of agricultural practices quickly became a staple of many Mesoamerican groups. What caused this shift in certain groups is unknown. Classic theorists such as Boserup (1965) use an evolutionary model showing that population pressures are the main driving force behind the transition to intensive agriculture. The stressor of population growth creates pressures that cause food deficits, forcing people to grow more food. The variable to produce more food is more labor. The frequency of cropping is increased as well as the adoption of multicropping. When there is the inability to spread to more land, more labor must go into each unit of land to make it more productive, using capital, time and energy to increase the productivity of a given piece of land. This theory utilizes a push factor, that is, a resource imbalance is the prime mover in this scenario. This concept has been debated at length. Other theorists have called this theory unilinear and economically biased, forcing archaeologists to look at it from a typological viewpoint (Morrison 1994).

Boserup’s model of agricultural intensification is known as a push model, a resource imbalance is needed to ‘push’ an agricultural change. Another theory is the pull-based approach as the reason for intensification. This theory states that intensification is a response to socio-economic systems promoting the need for surplus in order to fill the role of tribute demands, facilitate market exchange, or for risk-management purposes. Both aforementioned theories use the ‘bottom up’ model. In this model agricultural technologies will predate state formation, as they are driven by internal responses. In opposition to this is the top-down model, which states that agricultural intensification and the built landscape that comes with it are imposed by the state. This requires a large labor force that generally builds features in swift, large, and single or just a few compact episodes.

Another theory of agricultural growth is landesque capital coined by the economist Amartya Sen in his thesis in 1959. This theory argues that there is a difference in labor inputs and land improvements, and that both can increase agricultural production, but that they should be differentiated between (Sen 1959). Later this theory was further expanded upon to include a multigenerational context. Skill, technology, and labor are all incorporated into improving agricultural productivity, while maintaining the sustainability of the land and soils (Brookfield 2001). This landesque capital creates an accumulation of innovation over generations that produces highly productive and sustainable agricultural landscapes.

5. Agrarian Smallholder Model

The agrarian smallholder model is an example of both a bottom-up introduction of agriculture and landesque capital. This model described by Netting (1993) states that individual households, or sometimes small groups of households have tenure rights over the lands that they live and work on. These households make investments in their land and households in capital and labor in order to increase the value and agricultural productivity. These household were responsible for their own production and directly benefited from it. This individual input often resulted in surplus that could then be used to grow their personal wealth even further. These benefits were then passed down through generations, while continually reinvesting in the productivity and sustainability of the land.

The households invested in the agrarian small holder model were part of larger communities, often densely populated regions or cities with varying degrees of social complexity. It is important to note that though these households could be part of a larger political system, their production efforts, singly or as small groups were not regimented by a higher political power. Instead their efforts were initiated in order to directly benefit themselves and coming generations.

Mesoamerica had several different state level societies at the time of colonial contact that all had intensive agriculture and substantially modified landscapes. While some of this modification was directly related to state level imposition, agricultural intensification in this region took place long before these states as political powers existed. The bottom up strategies of landesque capital and the agrarian smallholder model seem to be fitting hypotheses for intensification strategies around much of Mesoamerica. Archaeological investigations and AMS dates from many different areas of the region support this hypothesis.

Agricultural intensification in Mesoamerica was likely a bottom up process. However, this does not mean that landscape modifications and agricultural technologies were not adapted to face challenges at times. Climatic variations such as drought, increased rainfall, or temperature variations were very much a reality of past people, just as they are today. Cultural changes and demographic shifts were also a variable that past people and their agricultural strategies were forces to adapt to. Indigenous ingenuity allowed for past people in Mesoamerica to build a prospering anthropogenic landscape, which archaeologists are just beginning to understand today.

6. Lake Pátzcuaro Basin and Angamuco

Agricultural intensification in the Lake Pátzcuaro Basin took place in different phases. The Purépecha Empire certainly had an impact on the production of crops after its formation in the Late Postclassic period. The top-down approach of ordering the construction of agricultural features such as terraces on islands like Apúpato can be clearly seen in the archaeological record (Pezzutti 2010), to be discussed further in Chapter 7. However, much earlier evidence of significant agricultural intensification and the features associated with it exist around the southeast portion of the basin. Ancient canals and remnants of raised field features surround former islands in the dried lakebed (Figure 7). These features date to as early as 120 CE and were in use until at least 1010 CE (Fisher 1995, Fisher et al. 1999). This extended timeline put the agricultural features predating political concentration, and thus are a product of a bottom-up intensification strategy.

Figure 7: Potential ancient canals and raised bed features visible on the former lakebed. Source: 19°35’22.03N and 101°41’35.07” W. Google Earth. 3/21/2007.

The construction and occupation of Angamuco also suggest a bottom-up intensification process. As mentioned previously the city of Angamuco is densely built with architecture and agricultural features. Terraces are found covering a high percentage of the site. The chronology of the site suggests that these features were built prior to political centralization and state formation, thus representing a bottom-up strategy, possibly imitating Nettings (1993) agrarian smallholder model. This theory will be elaborated on further in Chapter 7.

Agricultural features at Angamuco are prominent in all areas of the city, including the lower malpaís, the upper malpaís, and the land surrounding the malpaís. Modern infrastructure development such as building and agriculture have impeded on some of the remnants of this city, and preservation issues due to natural erosion and weathering have also created some landscape changes. However, despite these challenges terraces and canals are still prominent on the landscape. Canals and other water management features surround the malpaís, while terraces dominate on the malpaís. The possibility is high that other past agricultural features such as raised fields, seed beds, and rock gardens existed during the cities occupation and remnants of these may be possible to be seen in the archaeological record.

Chapter 4: Agricultural Strategies

1. Introduction

Agricultural strategy is a term used to describe courses of action that people can take in an attempt to create a more secure agricultural system. Agricultural strategies are developed both in contemporary society as well as past societies for a number of purposes; the desire for economic gain through increased productivity is often one of these purposes. Challenges such as climatic variations or population stressors could also be a motivating factor for creating such strategies. Often these strategies come in the form of intensive landscape modifications. These modifications can assist in increasing crop productivity, offsetting climatic variations, or correcting past land degradation. In Mesoamerica some of the most common agricultural intensification strategies include terraces, canals, and raised field agricultural features. Lake Pátzcuaro Basin has demonstrated evidence of all of these features. The following chapter will outline each of these features in detail in an attempt to set up the examination of the agricultural landscape at Angamuco.

2. Terraces

Agricultural terraces are the most common strategy for past people and agricultural intensification. All around the world you can find different forms of terraces;

Asia, North America, South America, Europe, Africa, and Australia all have some form of archaeological agricultural terrace system. Some of the oldest forms of terraces are located in present day Mexico. Cerro Juanaqueña is a terraced village complex located in northwestern Mexico. This site is unique for several reasons, first it is massive in size, containing at least eight kilometers of terraced walls. Second this site is around 3,000 cal. Ybp, making it the oldest known terraced complex in the Americas (Hard and Roney 1998). These modified landscapes are often built on sloped land and platforms of flat surfaces are cut into the slope in order to serve a number of purposes, the most practical of which is to improve crop growth on a sloped surface. They also prevent erosion and soil loss, create irrigation techniques, protect against frost and retain moisture and nutrients for long periods of time. While building these landforms is labor intensive, once constructed labor upkeep is minimal and the benefits they offer outweigh the initial labor investment.

The chronologies for terraces vary greatly across the world, but some of the earliest chronologies date to at least 3000 ybp (Donkin 1979, Doolittle 1990). However, it is likely that these features originated in the Fertile Crescent along with some of the earliest agricultural intensification much earlier (Beach et al. 2002). Terraces are often built on sloped ground, but there are many different types. Despite their structural differences, agricultural terraces all perform similar functions in order to more productively grow crops.

There is not one single widely accepted classification system for terraces. They can be classified by function, shape, landscape location, or construction. These classifications can vary further by region and site. According to Donkin (1979), there are three main types of agricultural terraces named by landscape form. These include contour terraces, cross-channel terraces, and valley floor terraces. Contour terraces run parallel to sloped hill sides. The contours are created by relating the height of the wall to the steepness of the slope and width of the bench. They may contain a rim to hold water and prevent soil erosion (Donkin 1979, Jain and Singh 2003). Cross-channel terraces, also called check-dams, are generally built across a stream or fluvial area. The terraces are constructed to slow and divert water flow and sediment into a large catchment. Construction of these types of terraces required low investment and is often attributed to either household level construction or early settlements (Donkin 1979, Smith and Price 1994). The final type of terrace in this classification system is the valley floor terrace. As their name suggests, they are located at the bottom of a valley and are quite rare in the archaeological record, either due to preservation issues or utility. The streams are not disturbed, and the walls of the terraces are located at right angles to the direction of the water source. Irrigation is likely pulled from runoff of higher slopes (Donkin 1979). Each of these terrace typologies focuses on only one aspect and often overlaps with other classification systems.

There are many other classification systems that exist for naming different types of terraces. One such classification system uses function as the qualifier for division, and separates terraces into three different classes: diversion, retention, and bench (Morgan 1986). The following line drawing is a classic example of bench terraces, though they could also be referred to as contour terraces (Figure 8). This system is seemingly self-explanatory and works well for modern terraced fields. However, when identifying terraces in an archaeological context, this system could be problematic. Due to deterioration, erosion, or other landscape changes assigning function to past features can be challenging. Instead, archaeologists generally chose to use a combination of naming systems, this is often Donkin's (1979) geomorphological names coupled with general descriptive qualifications. This can help to avoid problematic errors with assigning unknown function and helps to account for the massive amount of variation in types of terraces.

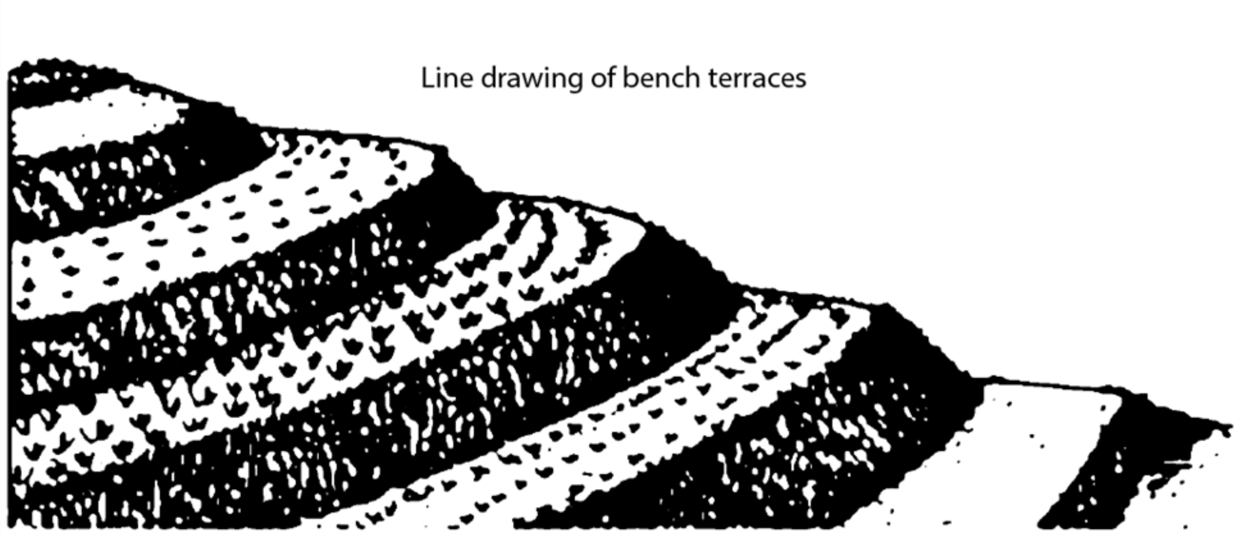


Figure 8: Line drawing of bench terraces, could also be referred to as contour terraces. Adapted from Crozier and Koch (1986).

3. Raised Field Agriculture

Raised field agriculture is a highly productive method for growing crops. These fields are generally a defined area of elevated soils that are often either surrounded by ditches of water or close to a water source. The design of these features serves several purposes that are beneficial to growing crops. These include environmental control factors such as irrigation, frost protection, fertilization, erosion and flood control.

These raised field agricultural features were present all over the Americas at the time of contact. Colonial documentation describes these features in Mesoamerica in great detail. According to Palmer and Wolf (1972, as cited in Weigand 1993) there are 382 mentions of irrigated agricultural features in colonial ethnohistoric records, many of these being raised field features. The most detailed accounts of these features occur in the Basin of Mexico near present day Mexico City. Physical written descriptions as well as sketches and drawings are some of the evidence that exists from this time period (Figure 9). Though these features were prominent strategies for productive agricultural practices in the past, today they are often understudied by archaeologists and ecologists. This is largely due to preservation issues and disturbance from modern infrastructure.

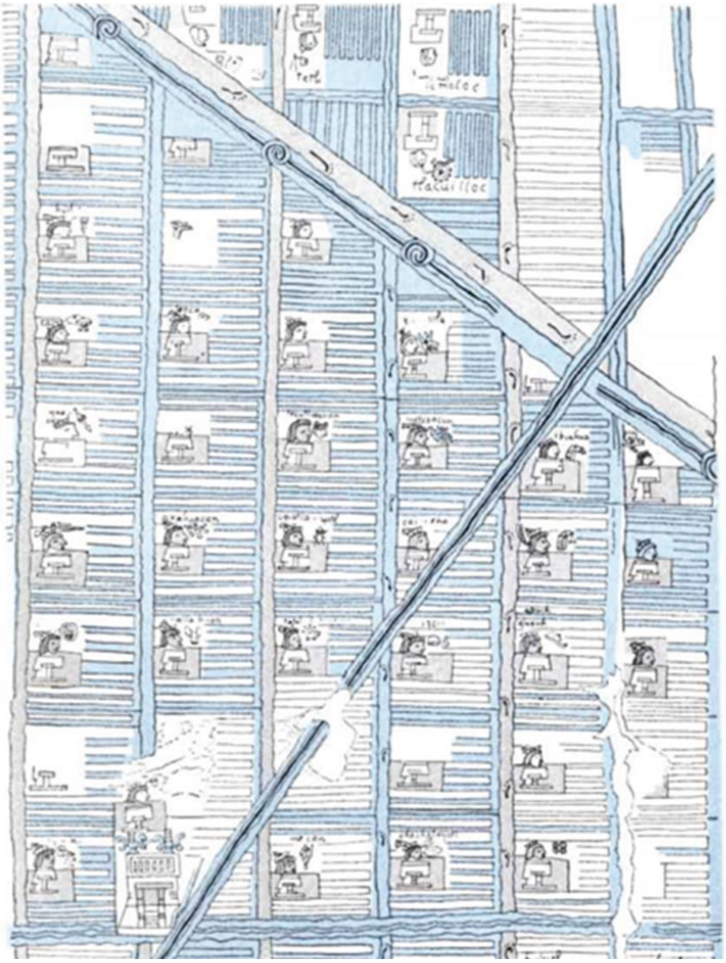


Figure 9: Portion of a map of a chinampa city in Tenochitlan-Tlatelolco showing garden owners and associated houses (Coe 1964).

Raised field agricultural features can vary somewhat in dimension and form. However they are often square or rectangular and highly uniform in nature. They are usually surrounded by a network of canals that split up blocks into islets. The sizes can range anywhere from 10m wide by 50-100m long to 1m wide by 3m long. Generally, they are at least 40 cm high in order to allow for subirrigation, though they have been documented as high as 85cm above the groundwater (Ebel 2019, Fisher et al. 1999, Robles et al. 2019, Weigand 1993). The variation in these features is not regionally specific and instead seems to vary by individual locations.

Raised field agricultural features in the Basin of Mexico are referred to as chinampas. This phrase comes from a Nahuatl word “chinamitl” meaning woven fence of canes (Robles et al. 2019). Though the word commonly used for these features is Nahua and was practiced extensively by the Nahua at the time of contact, these features did exist in the region before the Triple Alliance. Archaeological evidence in and around the chinampas at Xochimilco shows a continuous use of these features from around 2000 ybp. An initial ceramic occupation from 200AD and Teotihuacan II figureheads excavated from the chinampas, dating to the very beginnings of the city of Teotihuacan, suggest initial construction and use near the very beginnings of the city of Teotihuacan. In addition, the canals are oriented at 15 to 17 degrees east of true north, and this is consistent with the orientation of the streets at Teotihuacan (Coe 1964).

Much later in time, these specific chinampas are incorporated into the Aztec Empire and are considered one the main agricultural fields for this territory. These fields have direct colonial documentation and a select few are still in use today for economic purposes. Ornamental flowers and food crops are the main products that are grown on the contemporary gardens. It is also a tourist destination for many visitors to the region. The people who work these floating gardens as they are often called are referred to as chinampasneros and have intimate knowledge of traditional practices that they still implement into their strategies to this day.

Another archaeological site, the city of Xaltocan, located in the northern portion of the Basin of Mexico, east of Mexico City, has demonstrated archaeological chinampas that predate the Aztec state. The chinampa agricultural features here date to the Early and Middle Postclassic period (900AD-1350AD). These were largely abandoned after Aztec control was implemented over the region (Morehart 2012).

While colonial documentation as well as archaeological evidence is less frequent in western Mexico than the Basin of Mexico, there are a few interesting examples of raised field agriculture. One example is the site of Teuchitlán, located in the state of Jalisco. Archaeological remnants of raised fields and canals here show a formally planned series of extensive agricultural features. Unlike the chinampas in the Basin of Mexico, these are more often connected to springs and rivers rather than standing lake water. They are also directly related to dry field terraces as well as habitation and ceremonial centers. Combining the proven cultivated area with the productivity of these agricultural features, they represented a significant economic advantage with the ability to supply at least 40,000 people with food (Weigand 1993).

All of the above sites along with many others in highland and lowland contexts demonstrate that raised field agriculture was widespread throughout the Americas, both before and during the contact and colonial period. While many of these chinampas and similar raised field agricultural systems were lost due to land degradation and non-use, some were put into use by the colonial Spanish. In some cases, the only remnants of these features exist in careful examination of remotely sensed data, while others are still in use by indigenous groups today. Further, more features still have been incorporated into or plowed over by commercial farming tracts.

Raised field agriculture is a highly productive method of farming. Sub-irrigation and canal storage allow for proper levels of irrigation in rainy seasons and dry seasons. Sub-irrigation is defined as a penetration of water stored in a canal through the stacked soil platforms to the root level (Weigand 1993) (Figure 10). This type of irrigation is possible only with certain types of soil and root systems and was particularly effective in parts of Mesoamerica. While this system does require significant upkeep by farmers, it is highly productive and thus a profitable economic investment. The fields also contain a method of self-fertilization. Moving nutrient rich soil from the bottom of the platforms to the top, not only helps to fertilize, but also is a technique of upkeep for the ditches. This method was supplemented with manure for more fertilization.

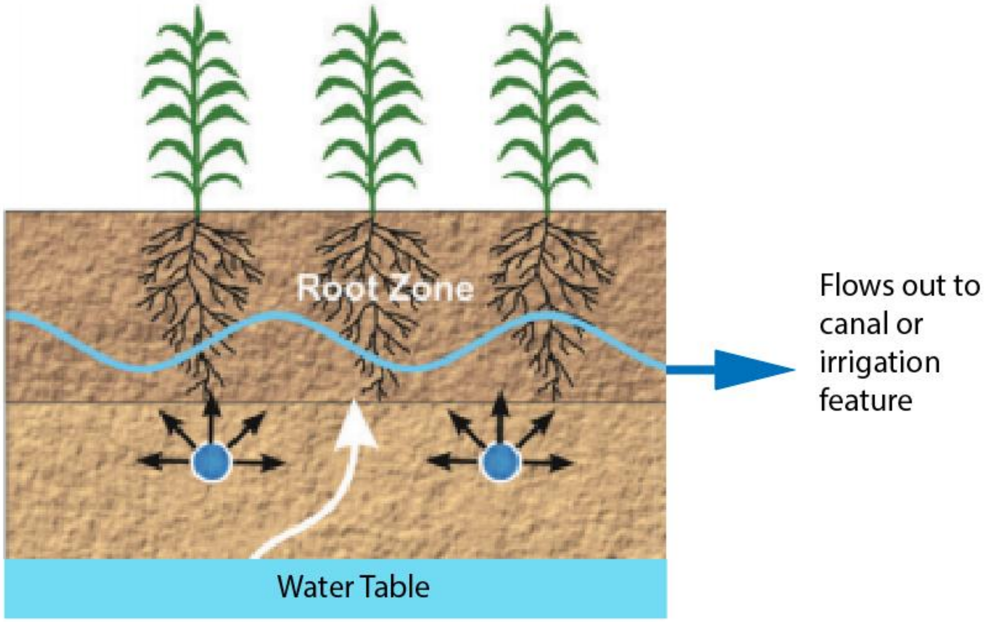


Figure 10: Illustration demonstrating the subirrigation process, adapted from Irmack (2018).

Like other agricultural features in Mesoamerica, raised fields were used to grow a variety of crops. Maize, amaranth, beans, squash, tomatoes, and chilies certainly would have been some of the major crops supported (Zizumbo-Villarreal et al. 2016). Using contemporary western Mexican maize varieties as a proxy two to three harvests of maize would have been possible a year using raised field irrigation. Local amaranth varieties could have been harvested three times a year (Weigand 1972). In addition to the many crops that could have been grown, the fields supported a number of other resources including insects, salamanders, fish, algae, birds and ritual flora.

4. Canals

The word canal is often used interchangeably with descriptors such as ditch, aqueduct, or channel (Doolittle 2011). While all of these terms are technically correct, the term canal has been widely used in the Americas. Canals are generally defined as an artificial waterway that moves water into an agricultural area (Doolittle 1990). However, canals are a technology that can serve multiple functions and have different forms. The general use for this type of technology is water transport. They can exist in arid or semi-arid regions as well as more wet environments. The most famous of this technology exists in the American Southwest in the Hohokam culture group. The Hohokam built massive canal systems that stretched on anywhere from 5.5-33.6km and provided irrigation for over 100,000 acres in an arid desert region that allowed the largest population of pre-contact Southwestern indigenous people to flourish from 600AD-1450AD. The canals that the Hohokam constructed used a sophisticated system of narrowing and expanding to move water through a mostly flat area. Other canal systems function by using topographical changes to their advantage. Slope allows water to move freely through the built features. Other types of canals use variation in rain patterns and rising water tables to move water from one area to another.

Canals that are associated with raised field agriculture are also different from the previously mentioned types. These canals are an important part of raised field agricultural systems. Generally, they divert water from a standing body of water such as a lake or river into nearby fields. They use check dams or cross channel terraces to control the flow of this water. The types of canals directly associated with raised fields have been divided into three different forms: primary, secondary, and tertiary. Primary canals generally function as central freshwater arteries and can further be classified as primary due to their size and shape. Secondary canals are used to transport water from the primary canal into the heart of the irrigation system. These can be highly planned and regular or form a more complicated network. Tertiary canals are the smaller ditches that feed water to individual fields. They are often long and narrow and come in various sizes (Morehart 2012). Other primary canals often functioned as transport canals between different major systems.

The size and structure of canals can vary greatly. The canals of the Hohokam region are massive in size with some of them measuring 13 feet wide and 12 feet deep. When canals are associated with raised fields, width is related directly to form but they are generally much shallower: around 1 meter deep (Fisher et al. 1999, Coe 1964). Canals directly related to terraces are also quite shallow, less than 1 meter deep, and generally fairly narrow, though they can stretch for several kilometers. Their particular design is to control flow velocity and volume (Farrington 1980). While these are all general descriptions of canal technology, it is by no means an exhaustive list. Further, these technologies can exist in tandem with one another to serve individual environmental or cultural needs.

In Lake Pátzcuaro Basin all of these strategies: terraces, canals, and raised fields have been identified in the archaeological record. When examined together they represent a complex system of agricultural intensification that spanned centuries. This would have allowed groups living in the region to deal with the sometimes drastic climatic fluctuations and provide a constant food source both for sustenance purposes and economic stability. The demonstrated success of these strategies predating the Purépecha Empire would have allowed for an easy transition for the Empire into economic prosperity through a tribute system.

5. Postclassic West Mesoamerican Indigenous Food Goods

The strategies described above were implemented in order to grow a number of crops utilized for various reasons including food goods, medicinal uses, religious or ritual purposes, creating textiles, and economic reasons. For the purpose of this thesis I will focus mainly on the regionally grown food.

West Mexico being one of the centers of agricultural origins in the Americas, has a long history of a wide variety of crops. Maize as previously mentioned has received much attention in literature and archaeological research. This is partly due to the great preservation of *Zea mays* phytoliths in the archaeological record. It has also been transformative for many cultures across the Americas and continues to have great influence on many indigenous communities representing a large percentage of contemporary diets. This crop has been genetically modified over millennia in order to be best suited for individual environments. Ethnographical research in Purépecha communities around the Lake Pátzcuaro Basin show that there are currently at least 69 different types of maize currently being grown in local gardens. These types are broken down into categories based on color, water regime, use, and origin of seed (Orozco-Ramirez and Astier 2017). Whether this is an accurate representation of past maize varieties in the region or not has yet to be archaeologically proven. However, it is likely that this modern number is lower than past maize varieties that would have been individually tailored for specific communities, landscapes, and water tables.

Maize is and was a staple in the lives of Purépecha communities. Finding its way into plentiful amounts of dishes, maize represents a substantial percentage of the diet of past and present peoples. Maize is a great source of carbohydrates and calories and is often referred to as the cereal grain of the Americas, drawing comparisons from European archaeological contexts. It also contains protein, fiber and numerous other vitamins and minerals that vary from type to type. While maize farming is somewhat decreasing in LPB communities today due to the cash crop avocado, it still remains the main crop represented in indigenous communities both for substance and economic reasons (Orozco-Ramirez and Astier 2017).

Because maize is such a versatile and resilient crop, it can be grown in a number of contexts. There are varieties that are heat and drought resistant, with demonstrated experimental productivity data (Bocinsky and Varien 2017). Considering the amount of rainfall and diverse landscapes of LPB and Angamuco, it is likely that a number of varieties were grown in order to take advantage of the range of landscapes. Rainfall fed terraces, rock bed gardens, and canal irrigated fields all likely contained some form of maize. All forms of maize store well, with husk on maize lasting up to three years, husked cobs lasting six months and shelled maize lasting up to a year (Smyth 1991).

This crop would have represented a significant part of diet long after the growing season.

Another important crop grown both contemporarily and in Postclassic West Mexico is maguey. Maguey, also native to Mesoamerica, has several different types including wild varieties and domesticated plants. Generally speaking, the domesticated version are much larger than wild species, and maguey plants in Mesoamerica are much larger than their relatives in the American Southwest. These plants can be used in a number of different contexts including for textiles, ritual use, as food, and for aguamiel. The figure below demonstrates a farmer sucking aguamiel from a maguey blade, likely in order to create pulque (Figure 11). In West Mexico maguey is considered an elite crop and was likely used in all of the above contexts. Many ethnographic and colonial sources describe bloodletting as a ritual sacrifice using maguey leaves as blades (Graulich 2005). In addition to this, ceramic pots in Colima dating to as early as the Classic period have residue of chemically altered aguamiel suggesting distillation for spirits, with burials also suggesting an elite context (Zizumbo-Villarreal et al. 2009).

Figure 11: Depiction of a farmer sucking aguamiel from a maguey blade in order to make pulque. Plate 6: How they destroyed a village (Craine and Reindorp 1970).

The nutritional aspects of maguey are also worth noting. Maguey flesh can be roasted and eaten, when cooked 100g of flesh yields 347 calories and 4.5g of protein (Parsons and Parsons 1990). It also contains a number of vitamins and fiber. In addition to the cooked flesh, aguamiel, the sweet sap produced by the maguey plant, has a number of beneficial nutritional values. In one tablespoon of aguamiel there is 0.08g of protein, 5.35g carbohydrates, 20 calories and a number of amino acids, vitamins, and minerals (Davidson and Ortiz de Montellano 1983 as cited in Parsons and Parsons 1990). Aguamiel was used in a number of ways including making pulque, a fermented alcoholic beverage.

Maguey plants take many years to mature for production, with estimates from as soon as five years to anywhere to 20 years, pictured below is a young maguey plant showing how long this maturing process can take (Figure 12). Thus, any cultivation of maguey is an intensive process, that likely spans multiple generations. These plants can be grown at the household level to provide fiber for textile as well as sufficient aguamiel to produce pulque (Parsons and Parsons 1990). They have also been demonstrated to be grown for elites in a top down, state imposed, monocropped approach in Postclassic LPB (Puzzetti 2010). Maguey is an excellent crop to grow on terraces and in thin soil to help prevent erosion. It also requires little pruning or other attention in order to reach maturity.

Figure 12: Young maguey plant pictured at Angamuco. Photo credit Louise Steele, January 2020.

In addition to the two important crops discussed above, squash, beans, and chilies were also important staples in Postclassic west Mexico. All of these crops were also domesticated in Mexico, thus have millennia of adaptation to the area. These plants can produce several crops a year and are generally small enough to be grown in any location. The nutritional values of maize, beans, and squash have been discussed at length. Together these foods provide complete proteins, amino acids, and other nutrients. In addition to the nutritional benefits, when grown together they help to keep the soil enriched, deter pests, and support each other structurally. This system known as the milpa system throughout Mexico, was noted by the Spaniard's in the ethno-historical record upon contact.

Using ethnographic accounts, ethnohistoric records, and archaeological evidence, researchers were able to reconstruct a number of dishes that were likely consumed in Postclassic west Mexico. The principal dishes that were reconstructed were atoles, popcorn and pinoles, pipianes, chili pepper salsas, steamed tamales, baked tamales, vegetable soups, tortillas, sopes, dobladas, and toasted tortillas. These represent just a sampling of the 108 of dishes that were recreated (Zizumbo et al. 2016). This is by no means an exhaustive list, but rather a glimpse of the varied diet that would have been possible using locally domesticated and grown food crops.

Chapter 5: Methods

1. Introduction

In this chapter I will describe in detail the methods that I used to analyze the terraces at Angamuco. First, I will give an overview of the LiDAR scans that were flown to map the malpaís and surrounding land. Next, I will convey the GIS methods that I used from creating visualizations, to quantifying the terraces and surrounding landscape. Finally, I will outline the productivity model that I created for the agricultural output of the city.

2. LiDAR at Angamuco

There have been two LiDAR flights that have mapped the entirety of the malpaís and beyond. In total the area mapped was just over 35km^2. The first flight took place in 2010 and mapped 9km^2 total, with 6km^2 of that area located on the lower malpaís. The point cloud provided by Merrick and Company was processed using MARS 7 proprietary software (Fisher and Leisz 2013). In 2015 a second LiDAR flight was undertaken by the National Center for Airborne and Laser Mapping (NCALM). This flight used WGS84 as the horizontal datum, and the coordinate system was UTM Zone 14. The 2010 LiDAR scan did not use WGS-84 and was later reprojected and merged so that the z-values matched for both data sets. The 2015 flight encompassed the whole of the malpaís plus areas just off of the malpaís and to the west covering another archaeological site, Urichu. The total area scanned was 35km^2. This data was provided to the LORE-LPB project in point cloud format (Fisher 2018).

3. GIS Methods

The first step in processing the LiDAR data from Angamuco was to convert the point cloud into a DEM. This step was conducted in Global Mapper 20. The points were filtered to ground points/last return, then converted into an elevation model via TIN with a 25cm resolution. This DEM was then exported as a float/grid and opened in ArcGIS Pro. This program was used for much of the further analysis.

The visualization technique that was used as the basis for manual interpretation, titled Pseudo-Red Relief, was created by Harris (2019) adapted from Red Relief Image Maps (RRIM) (Chiba et al. 2008). The purpose of this visualization is to layer three different elements of landforms derived from remotely sensed data: slope, positive openness and negative openness in order to better visualize slope, concavities and convexities simultaneously. Combined these factors allow for better extraction of smaller features represented on the ground versus larger features such as natural landforms.

The steps for creating this visualization are as follows: in the spatial analysis toolbox of ArcGIS Pro, I selected neighborhood, then focal statistics. The input was a 50cm resolution DEM and the output was a smoothed DEM. The neighborhood was circle radius of 3, stats were mean. This smoothed DEM output was then exported as a .tiff.

The next step was to download and access an open- sourced outside toolbox entitled Relief Visualization Toolbox (RVT) developed by Zaksek et al. (2011). The smoothed DEM was input into the RVT as a tiff. Two of the layers created from this toolbox positive: openness 16 bit and negative openness 16 bit were then exported back into ArcPro. Then to create ifactor (Figure 13) I utilized the map algebra raster calculator tool and subtracted negative from positive and divided by two. Then I created a slope of the smoothed DEM by using spatial analysis, surface, and slope. I then adjusted the symbology of the image to a stretched image, with a 50% transparency and a red color ramp. This created a Pseudo-Red Relief visualization. The image of this visualization is attached below (Figure 14).

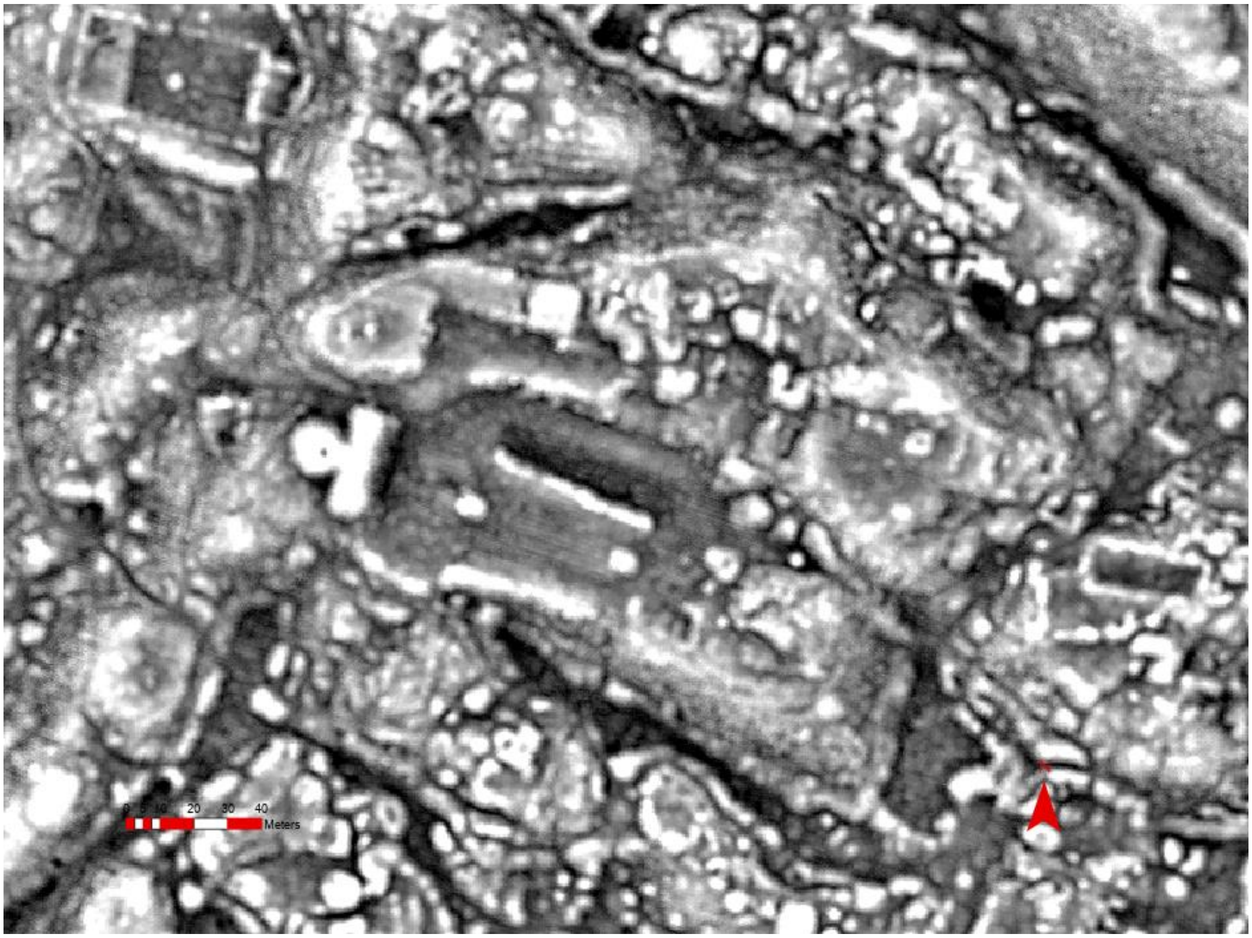


Figure 13: iFactor visualization over the area around the main yácata. (See appendix A for geospatial metadata).*

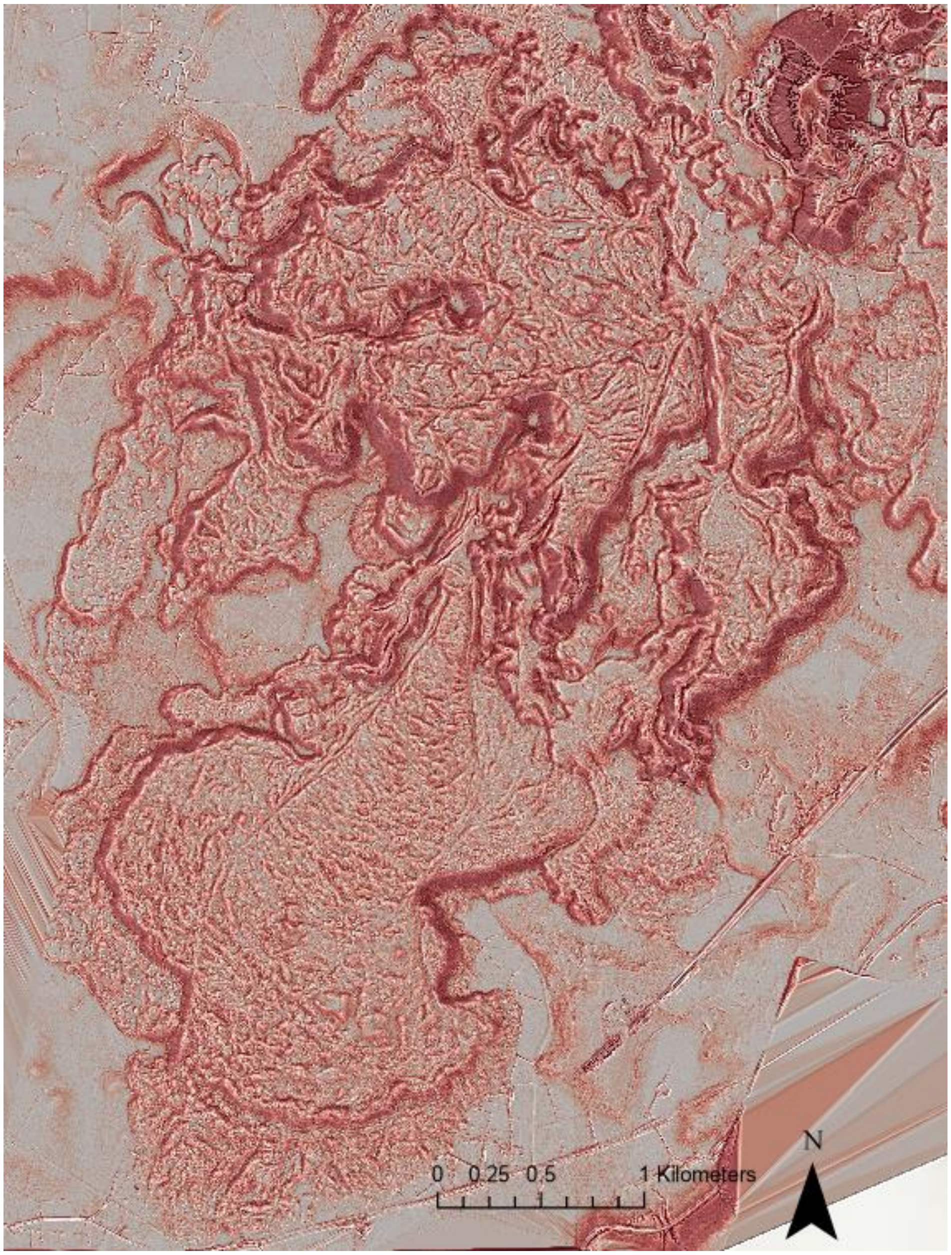
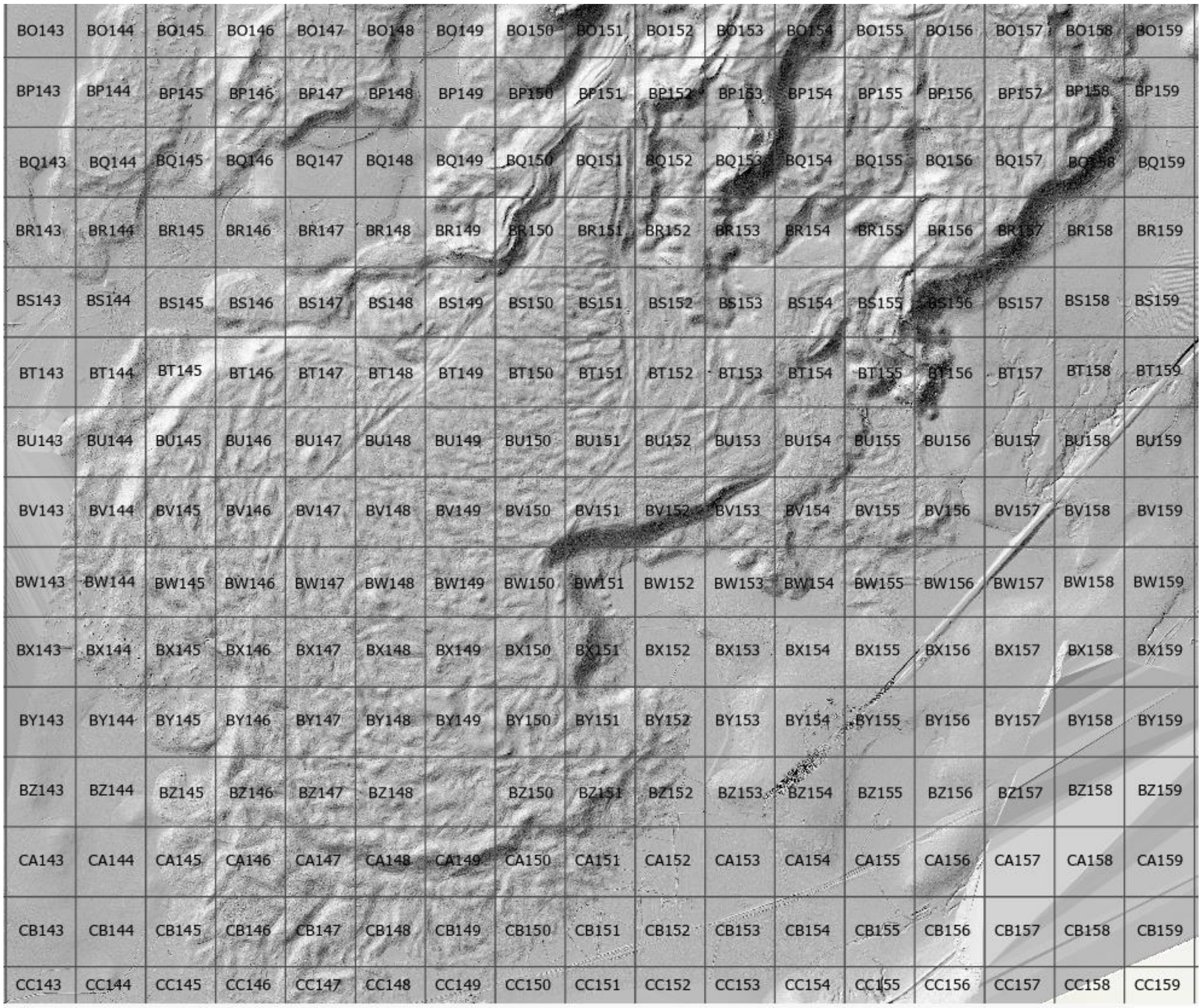


*Figure 14: Pseudo Red Relief Image Map (PRRIM) visualization*** layered over Angamuco malpaís. (See appendix A for geospatial metadata*).*

In order to begin analysis of the LiDAR data covering the city of Angamuco, I covered the malpaís with a grid system consisting of 250x250m squares. This grid system was created in 2017 by the LORE-LPB team and uses a double letter and number nomenclature system (Figure 15). The grid covers the entire LPB basin, and thus for the purpose of this research needed to be clipped to the area around Angamuco. In order to achieve this, I traced a polygon around the malpaís, and clipped the grid to this shape. The grid that was created was in the shape of a rectangle, therefore several of the squares were not located directly on the malpaís. After manually excluding these squares, it was calculated that there are 276, 250x250m squares located directly on the malpaís. These tiles represent 17,250,000m^2.



BO143	BO144	BO145	BO146	BO147	BO148	BO149	BO150	BO151	BO152	BO153	BO154	BO155	BO156	BO157	BO158	BO159
BP143	BP144	BP145	BP146	BP147	BP148	BP149	BP150	BP151	BP152	BP153	BP154	BP155	BP156	BP157	BP158	BP159
BQ143	BQ144	BQ145	BQ146	BQ147	BQ148	BQ149	BQ150	BQ151	BQ152	BQ153	BQ154	BQ155	BQ156	BQ157	BQ158	BQ159
BR143	BR144	BR145	BR146	BR147	BR148	BR149	BR150	BR151	BR152	BR153	BR154	BR155	BR156	BR157	BR158	BR159
BS143	BS144	BS145	BS146	BS147	BS148	BS149	BS150	BS151	BS152	BS153	BS154	BS155	BS156	BS157	BS158	BS159
BT143	BT144	BT145	BT146	BT147	BT148	BT149	BT150	BT151	BT152	BT153	BT154	BT155	BT156	BT157	BT158	BT159
BU143	BU144	BU145	BU146	BU147	BU148	BU149	BU150	BU151	BU152	BU153	BU154	BU155	BU156	BU157	BU158	BU159
BV143	BV144	BV145	BV146	BV147	BV148	BV149	BV150	BV151	BV152	BV153	BV154	BV155	BV156	BV157	BV158	BV159
BW143	BW144	BW145	BW146	BW147	BW148	BW149	BW150	BW151	BW152	BW153	BW154	BW155	BW156	BW157	BW158	BW159
BX143	BX144	BX145	BX146	BX147	BX148	BX149	BX150	BX151	BX152	BX153	BX154	BX155	BX156	BX157	BX158	BX159
BY143	BY144	BY145	BY146	BY147	BY148	BY149	BY150	BY151	BY152	BY153	BY154	BY155	BY156	BY157	BY158	BY159
BZ143	BZ144	BZ145	BZ146	BZ147	BZ148		BZ150	BZ151	BZ152	BZ153	BZ154	BZ155	BZ156	BZ157	BZ158	BZ159
CA143	CA144	CA145	CA146	CA147	CA148	CA149	CA150	CA151	CA152	CA153	CA154	CA155	CA156	CA157	CA158	CA159
CB143	CB144	CB145	CB146	CB147	CB148	CB149	CB150	CB151	CB152	CB153	CB154	CB155	CB156	CB157	CB158	CB159
CC143	CC144	CC145	CC146	CC147	CC148	CC149	CC150	CC151	CC152	CC153	CC154	CC155	CC156	CC157	CC158	CC159

Figure 15: Number and letter labeled 250mx250m grid over a hillshade of Angamuco (see appendix A for geospatial metadata).*

In order to provide a substantial representation of the site 25%, or 69 tiles were chosen using the Random Feature toolbox, imported into ArcGIS Pro from the USDA

(Ferguson 2011). Each of these 69 tiles were then analyzed to locate the presence of agricultural terraces using the following guidelines: slope, aspect, relief, and visual interpretation (Figure 16). The goal of this analysis was to establish simple presence or absence of terraces for each tile.

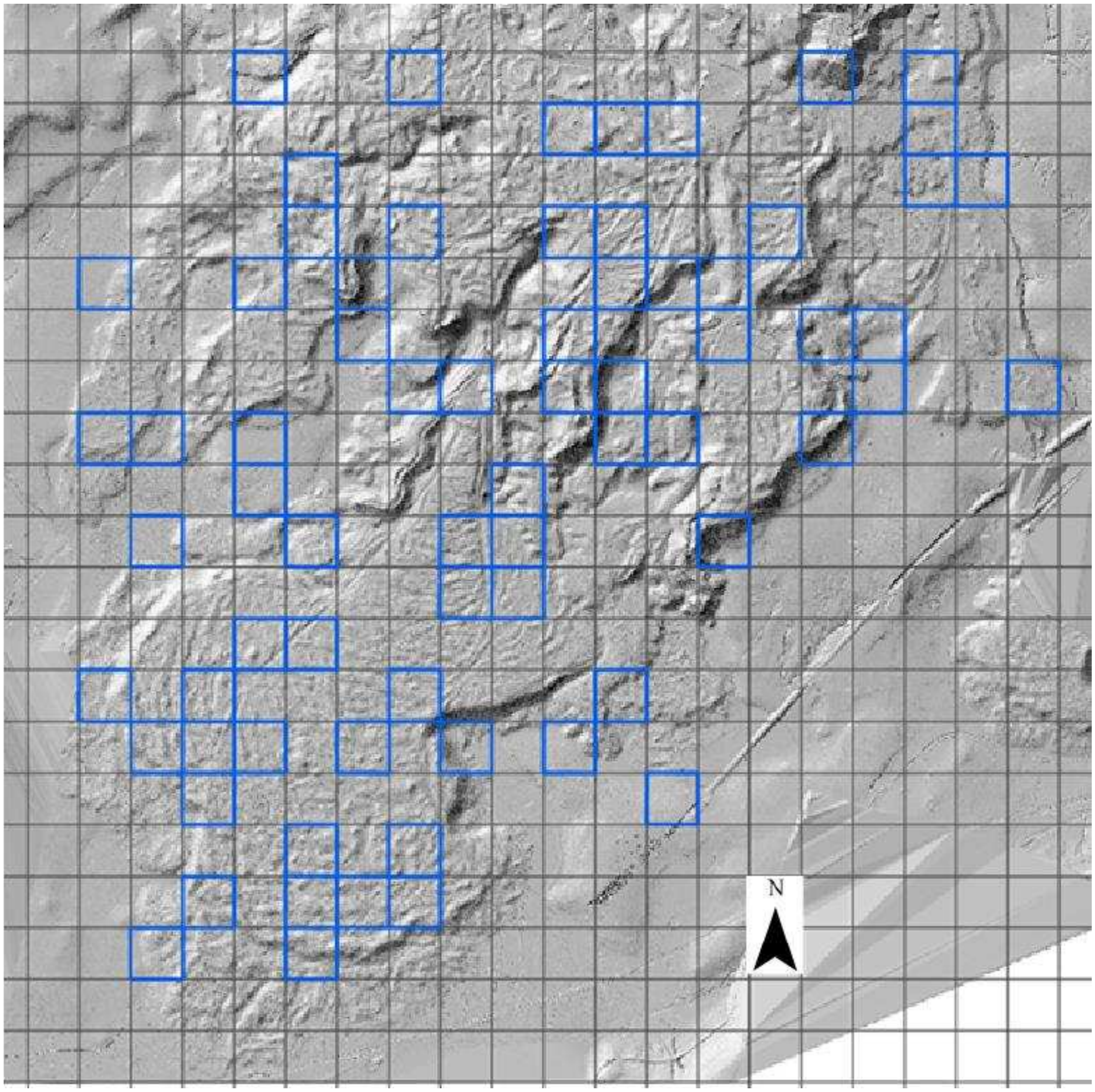


Figure 16: Selected 250x250 meter tiles in blue that were used for analysis (see appendix A for geospatial metadata).*

In order to define an appropriate degree of slope to identify terraced areas, I used the previously field verified terraced areas as a model. 73 different agriculture terrace zones had been previously outlined in several different shapefiles. Several of the shapefiles already had polygons around the terraced zones, while others had only polylines tracing individual terraced benches. In order to convert the individual polylined benches into polygons an area of 5m was selected around them using the Buffer Analysis tool (Figure 17). Afterwards, each of these polygons were converted to a raster using slope as the value field.

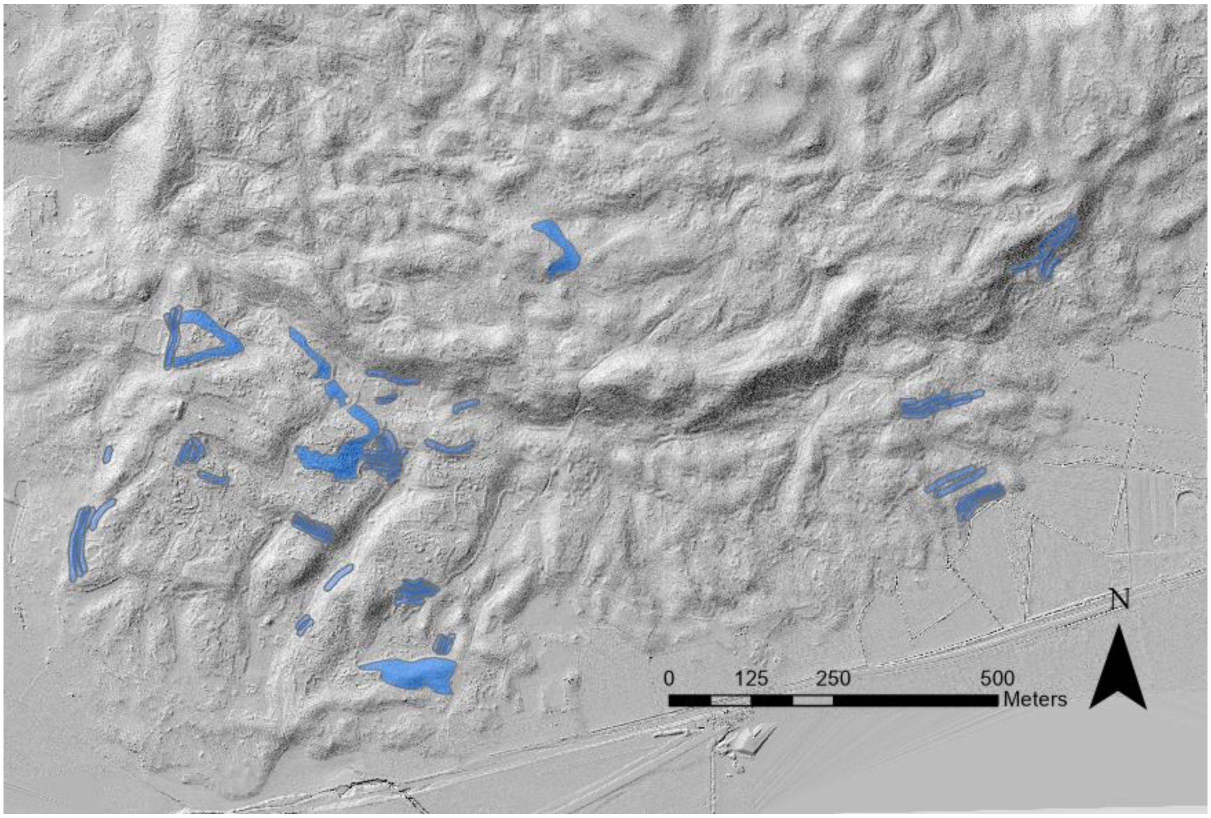


Figure 17: Location of the ground truthed terrace zones used to establish appropriate schematics for identifying terraces in this analysis (see appendix A for geospatial metadata and visualization metadata****).*

Zonal statistics were then calculated for each of these terraced zones. The mean of all of the maximum slope values was calculated to be 46.055 degrees and was then established as the upper threshold for the possibility of terraced land. The grand mean of slope values was calculated to be 23.808 and was used for the lower threshold of slope of terraced land. These upper and lower numbers were entered into the symbology of the slope layer and a gradient of colors were applied to represent the values in between the minimum and maximum values.

Appropriate aspect for identification of agricultural terraces was defined by sun angles in the northern hemisphere as well as the general slope of the malpaís. In the Northern Hemisphere the southern and western facing slopes receive more sun making them warmer and generally more suitable for agriculture. In addition to the angle of the sun, the soils are generally more nutrient rich on southern and western facing slopes due to climatic effects such as wind and freeze thaws. The direction of the lava flow when initially forming the malpaís had effects on the aspect and agricultural potential as well. The general slope of the malpaís is in a southwest direction. This flow direction made the eastern and northern slopes much steeper and rugged, thus agriculture is much less likely on these slopes.

Visual interpretation was also an important observation in determining the presence or absence of agricultural terraces. Clear stepped patterns were easily recognizable on certain parts of the site. If these patterns also had the appropriate aspect and slope, then they were marked as terraces. However, because of erosion and deterioration due to the 500-year abandonment of the site, many terraces are not easily visible either during pedestrian survey (Figure 18) or through LiDAR interpretation. LiDAR data can make these extractions easier due to digital removal of vegetation that can obscure visualizations on the ground, however there are still issues in certain areas where erosion has been significant.

Figure 18: Photo of terraces at Angamuco with LORE-LPB team members standing on two different levels. Copyright LORE-LPB 2010, Angamuco.

Once the presence or absence of agricultural terraces was established detailed analysis of the terraced areas was undertaken. Total area of terraces, average width of recognizable benches, presence or absence of granaries, correlation to water features, and surrounding features were all noted during this step of analysis. The total area of terraces was established by drawing polygons around the identified terraced zone. Multiple polygons were added together for measurements of each 250x250 tile. The average bench size was calculated using the clearly defined benches. Often times this was only possible on a few benches per tile, and smaller benches were not distinct enough to be recognized. The presence or absence of granaries were established using methods derived by Ahrens (2013) to be discussed further in Chapter 7.

In addition to quantifying individual features in the terraced zones, I also used previous expert derived GIS analysis and ground truthed data to examine the surrounding landscape. Any built features of relevance were noted during this analysis. These features included: any type of road, especially huatziri or raised roads, water features including canals, wells, reservoirs, and springs, and significant architectural features.

After the terraced zones were identified and annotated, relief was calculated for the terraces. This was accomplished by calculating maximum and minimum elevation in each polygon and subtracting the two values, the result was the simple relief of each individual polygon. Maximum and minimum values were displayed by creating points to represent each value. This was accomplished by using the zonal statistics toolbox and creating a raster for max elevation. Then, using raster calculator the expression Con ("DEM"=="Max_Elevation", DEM) was input in order to create the maximum point of elevation in raster form and this raster was then converted to a point. These same steps were followed for the minimum value of each polygon. The two points were displayed for each polygon. The data for maximum and minimum elevations was exported into excel for ease of mathematical manipulations. Simple relief was calculated for each polygon to represent the height of the terraced zone.

After collecting and recording the aforementioned data from each terraced zone several calculations were run in order to analyze the general values of terraces on the site. Total terraced area in selected polygons was calculated. I then treated my sample as representative of the entire site because of the robust size of the sample and then proportionally extrapolated from this to estimate the total percentage of agricultural terraces located on the malpaís.

In addition to quantitative data about the terraces, I calculated quantitative data about other built features in the city. Using the raw data from past analyses of the city I calculated total area of several different feature classes in order to quantify the entire built environment of the city. First, four shapefiles representing past engineered water reservoirs, created by Simpson (2019) were uploaded and total area of standing water was calculated (Figure 19).

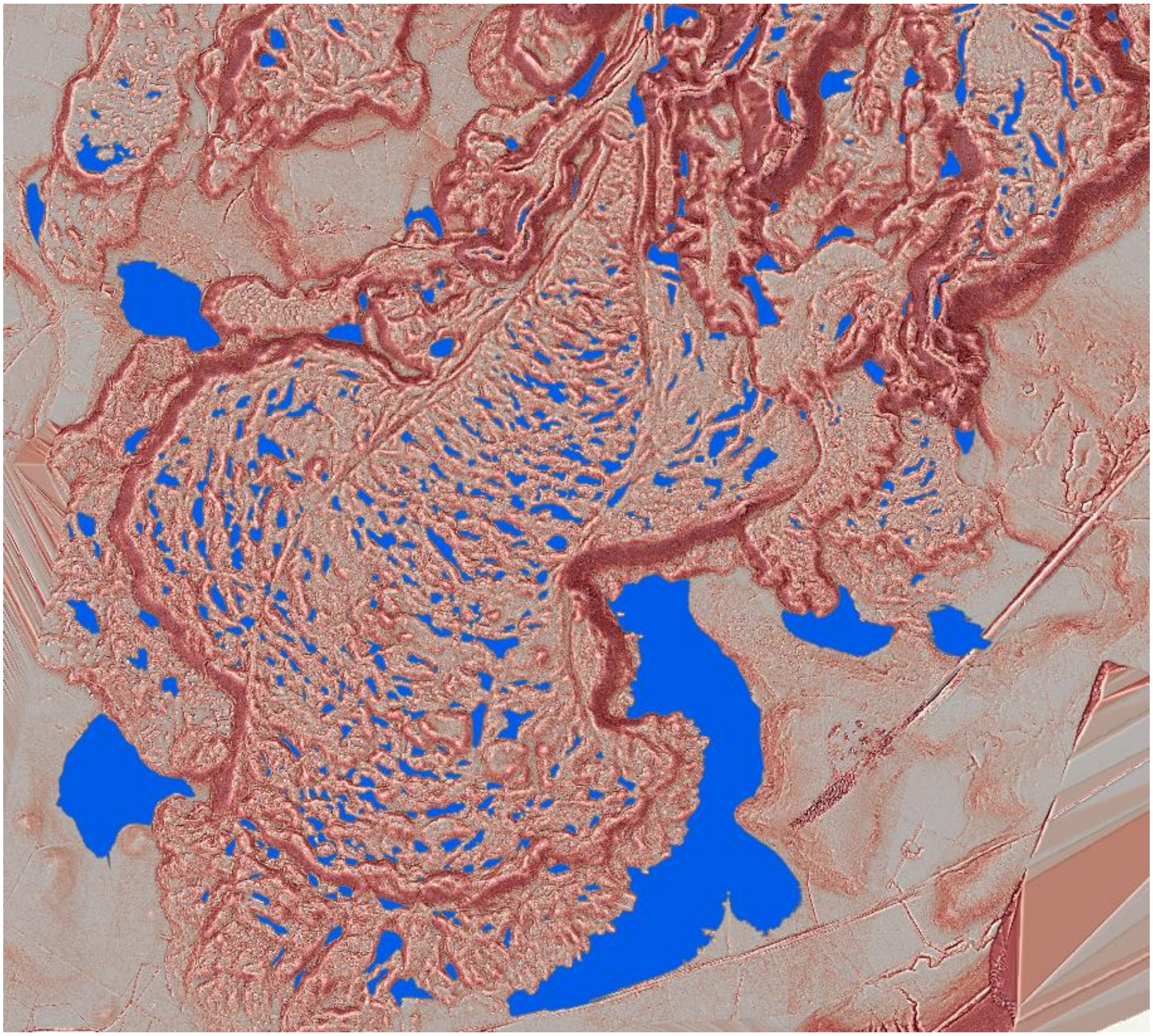


Figure 19: Past water reservoirs represented in blue at Angamuco. Shapefile from Simpson (2019). See appendix A for geospatial metadata and PRRIM visualization information***).*

The second layer that was calculated and added to the total area of built features was created by Harris (2019). Harris used an automated algorithm to extract near perfect lines and circles that represent architecture across the entire city. The raw data from this extraction was then buffered by one meter in order to better cover entire architectural features rather than just the minimal outlines (Figure 20). The total area of these features was then calculated and added to the total built environment.

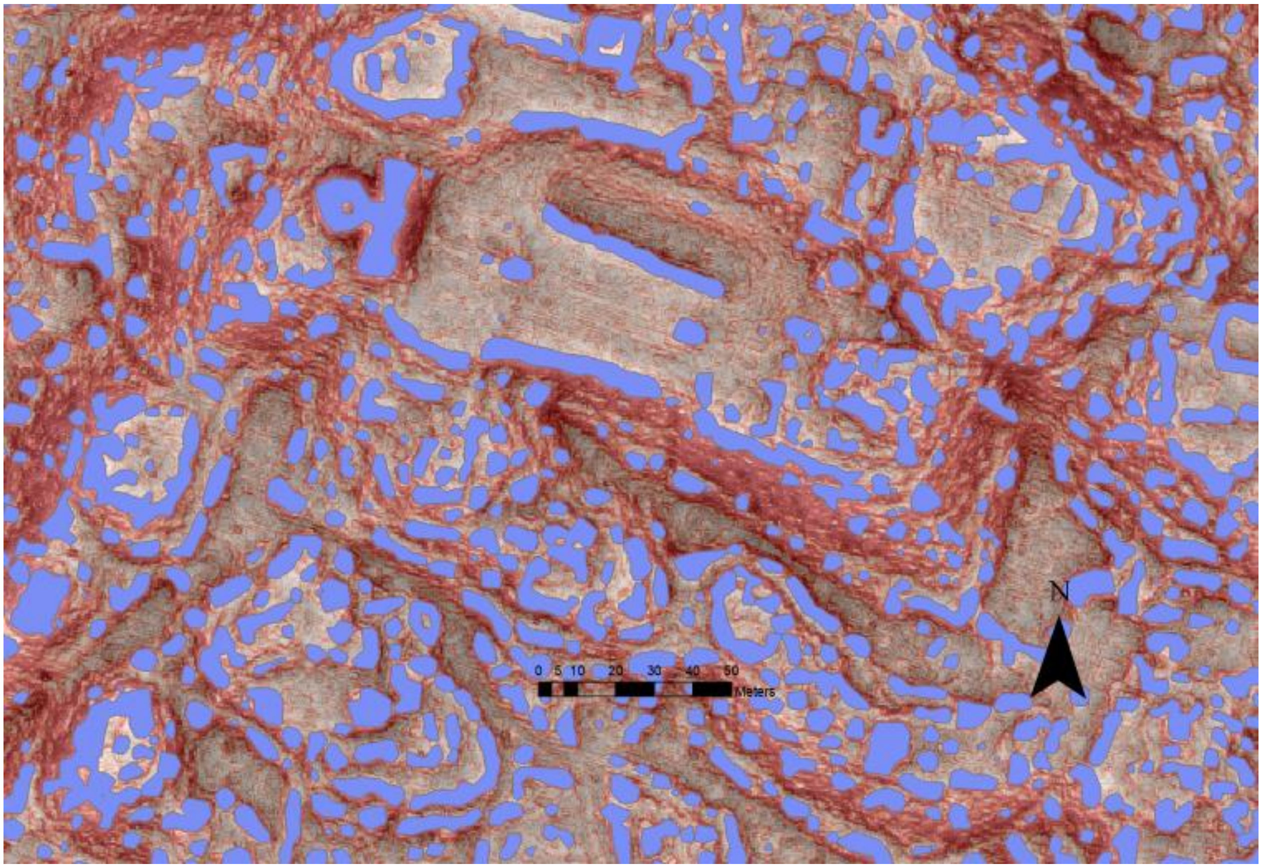


Figure 20: One meter buffer of Harris's (2019) architectural features. See appendix A for geospatial metadata and PRRIM visualization information***.*

The last set of features that were added to this composite feature analysis were the road networks outlined by Solinis-Casparius (2019). Solinis-Casparius outlined a vast series of roads both through field verification and a digital extraction technique. Because of the different methods of extraction there were several different shapefiles containing outlined roads. Many of these roads overlapped in the various shapefiles. In order to combat this problem and get an accurate representation of area of the city covered by roads I merged all of the shapefiles into one. Then I dissolved overlapping features by the x and y coordinates. I buffered the polylines to represent width of roads. I chose the appropriate width, 2.35 meters, for this buffer by creating a weighted average of the widths of the ground truthed road segments. The total area of the roads was then added to the accumulation of built features. Together, the terraced areas, water reservoirs, architectural features, and the roads represent the built environment of Angamuco.

4. Hydrology

In order to further investigate the possibility of irrigated terraces at Angamuco, a number of hydrological models were created. The first steps in creating hydrology models was to create a basic watershed model (Figure 21). A watershed is used to show the flow of water from upslope areas to a catchment or the lowest point of a raster, often a DEM. In addition to archaeological analysis, this type of GIS model can be used for various applications such as existing hydrologic assessment for hazard mapping and planning and development (Daniel et al. 2010).

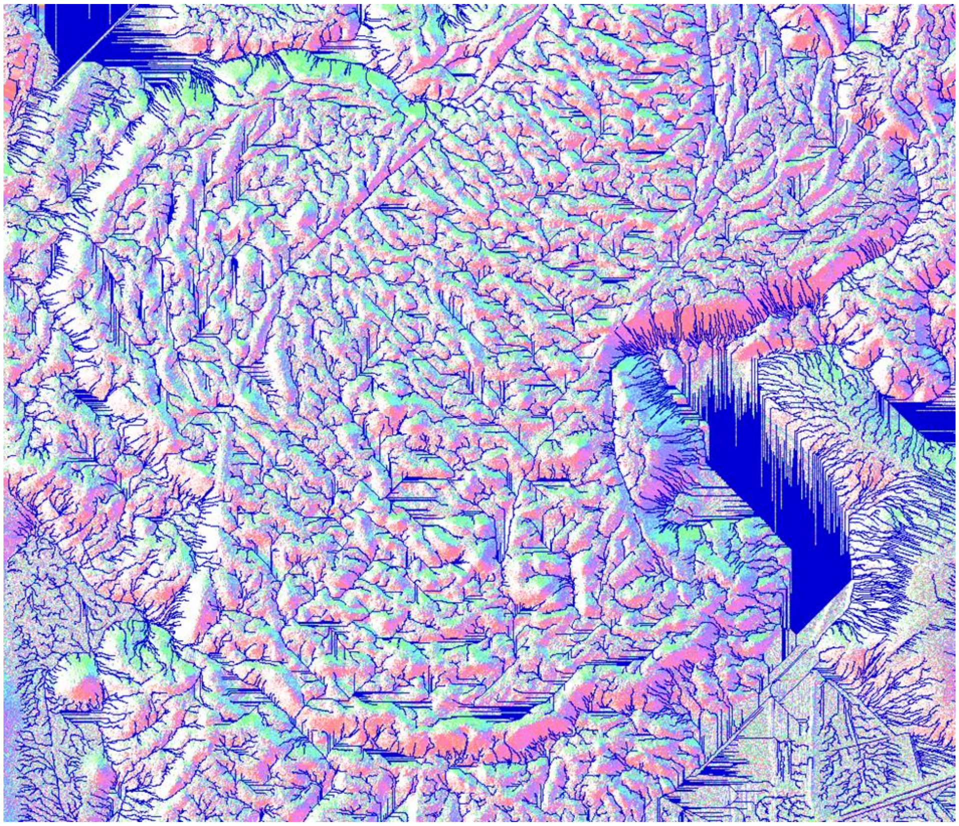


Figure 21: Watershed of the lower malpaís of Angamuco. See appendix A for geospatial metadata.*

The first step used to create a watershed for Angamuco was to run a one meter fill or pit removal on the DEM in order to fill in any sinks that would have prevented water from running continuously over the entire site. This step can correct any small errors in the data, such as a single pixel missing data (Chase and Weishampel 2016). The second step was to run a Flow Direction tool in order to determine which direction water would travel from one cell to another. Using the output of the Flow Direction, a Flow Accumulation was then created to show how much water would flow from different cells into one accumulated area (Figure 22). High accumulations can be used to identify streams or canals (Macrae and Iannone 2016).

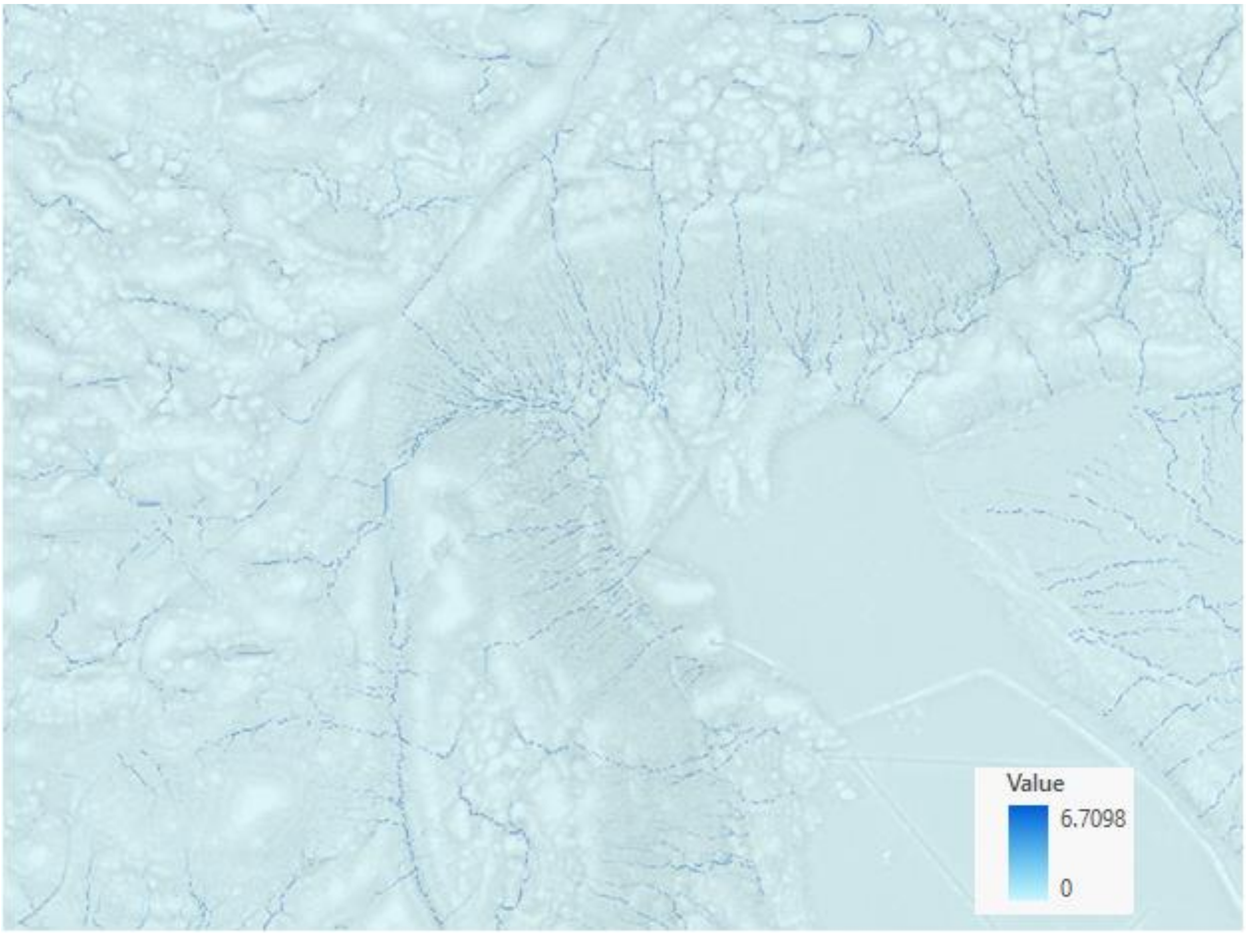


Figure 22: Image of flow accumulation over the eastern edge of the malpaís. See appendix A for geospatial metadata.*

Several indices were then created in order to better view the hydrological landscape. In addition to the above watershed rasters, slope was run in degrees, then converted from degrees to radians (Figure 23) using the following formula in raster calculator.

$$\frac{Slope * \pi}{180}$$

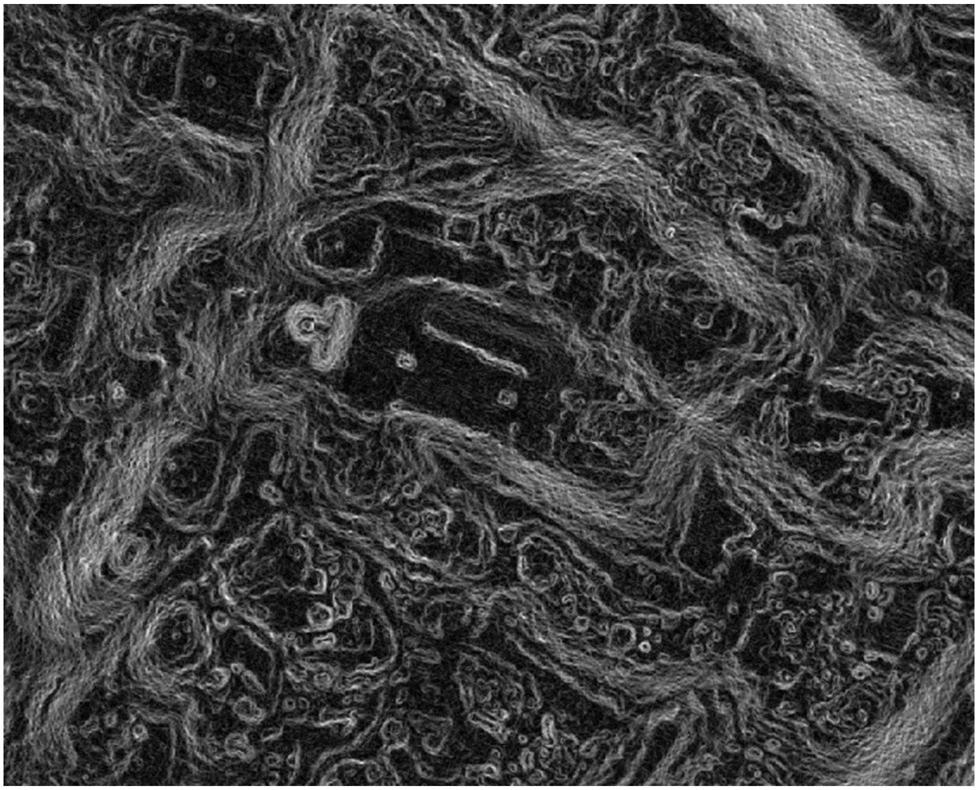


Figure 23: Slope displayed in radians over the main yácata area. See appendix A for geospatial metadata.*

The first index created was the Topographic Wetness Index (TWI) also called the topographic convergence index (TCI). This index uses upslope cells as well as slope to measure the moisture for each individual cell (Bevin and Kirkby 1979). Using raster calculator and the following formula, I created TWI for the entire malpaís.

$$\text{TWI} = \ln \frac{\alpha}{\tan \beta}$$

Where α represents the local upslope area draining through a certain point, and tanβ represents the slope in radians. This equation represents long term moisture retention abilities of given areas. Below is a visual representation of this index on terraced hillsides (Figure 24).

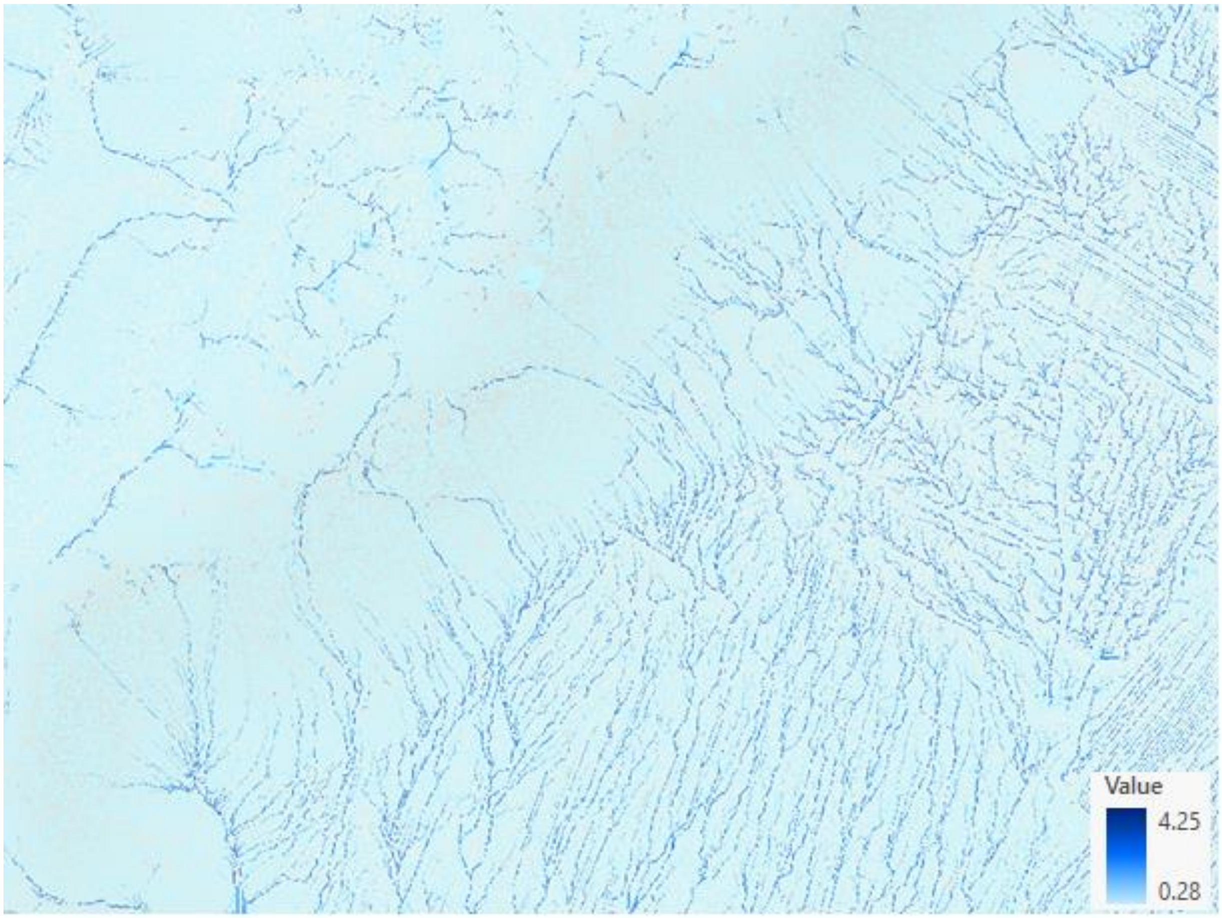


Figure 24: TWI showing heavy moisture in blue on the slopes and underneath the slope on the eastern edge of the malpaís. See appendix A for geospatial metadata.*

The second index that was created to model hydrological movement on the malpaís was the stream power index (SPI). This index models rate of water flow and erosion power over topological variations, using slope as the most important qualifier (Moore et al. 1993). The following formula was used to calculate SPI for the entire malpaís.

$$\ln(CA \cdot \tan G)$$

Where CA is the catchment area and G is the slope gradient in radians. The figure below shows this variation over the malpaís (Figure 25).

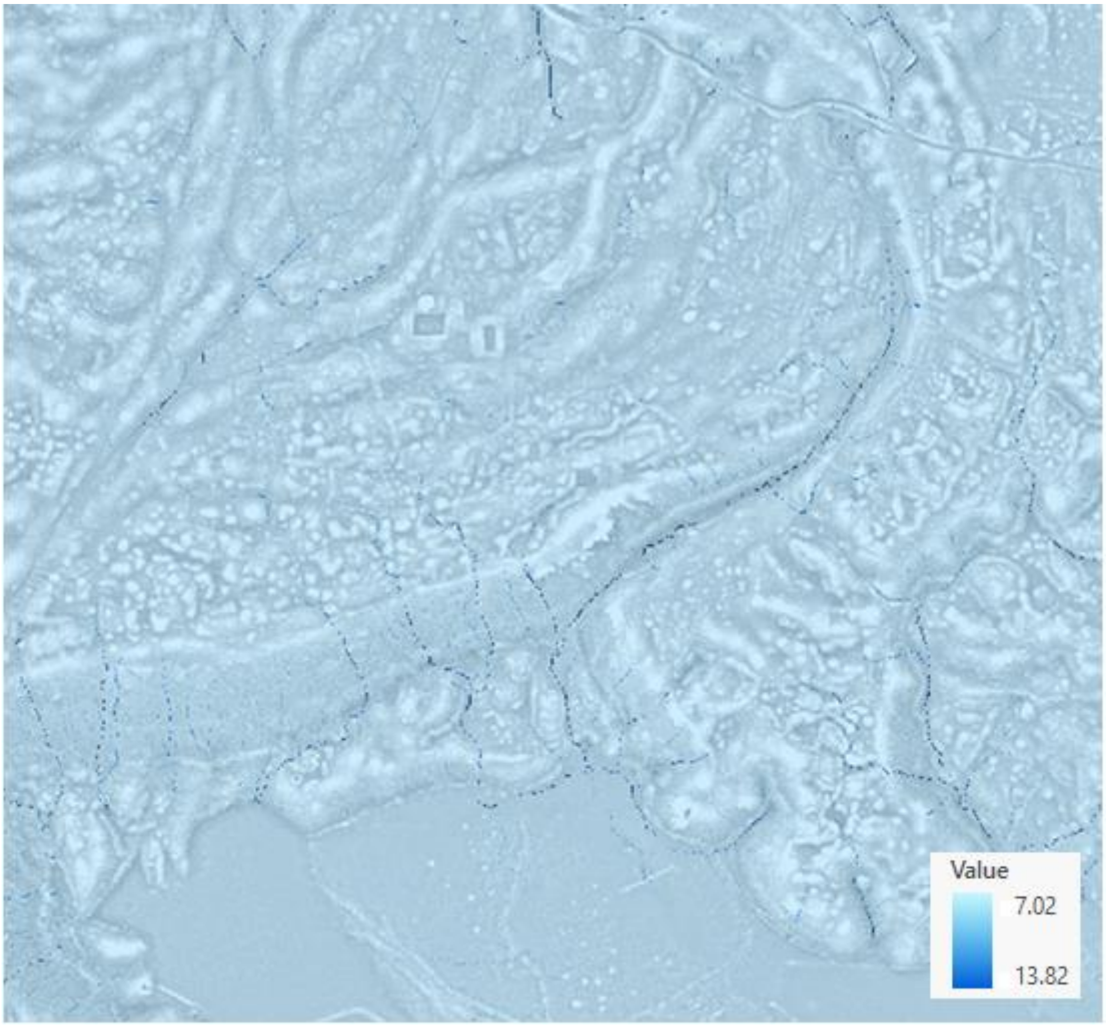


Figure 25: SPI showing water movement through existing canals and over the sloped edges of the malpaís. See appendix A for geospatial metadata.*

The final index that was created in order to visualize hydrological activity on the malpaís was the sediment transporting capacity index (STI). This index is used to model possible erosion by concentrated water flow. It characterizes the process of erosion and deposition. It uses local slope and contributing area (Moore et al. 1992). This index is similar to SPI, however, is it more concentrated on sediments rather than water flow itself. And relies more heavily on the upstream area rather than slope alone. Using raster calculator, the following formula was used in order to model this visually.

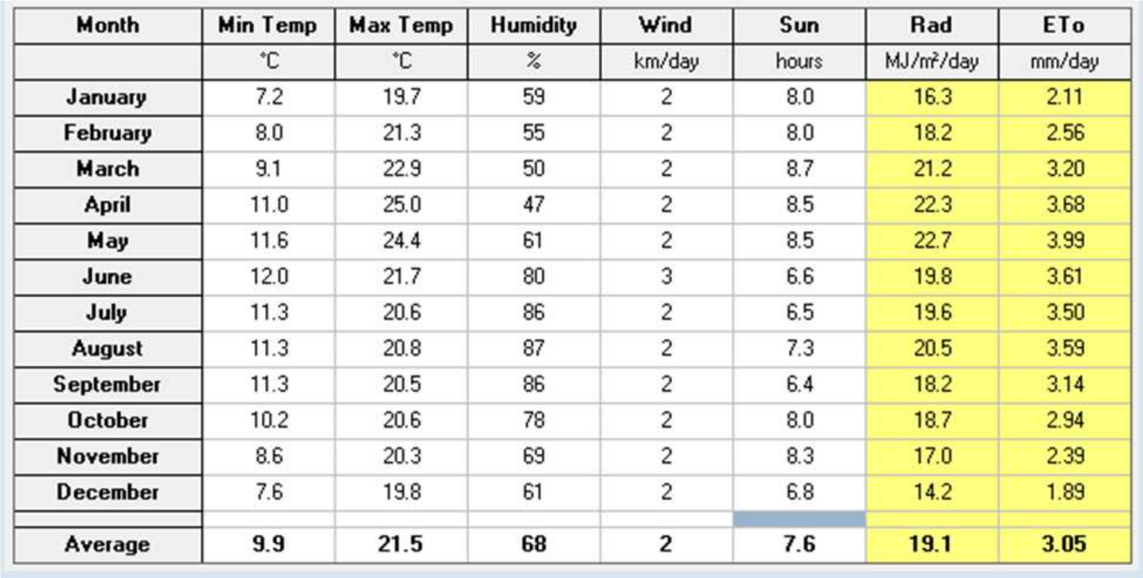
$$STI = \left[\frac{A_s}{22.13}\right]^{0.6} \cdot \left[\frac{\sin\beta}{0.0896}\right]^{1.3}$$

A_s represents the specific catchment area, and β is the slope angle. The following graphic (Figure 26) shows the areas of high and low sediment movement on the west edge of the malpaís.

Figure 26: STI showing the relative stability of sediments on the eastern edge of the malpaís. See appendix A for geospatial metadata.*

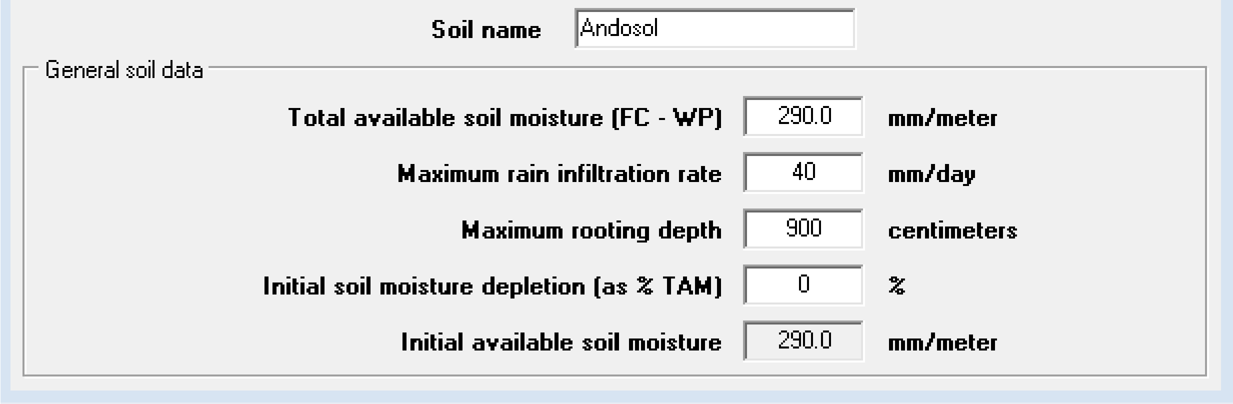
5. Crop Productivity Model

Using maize as the staple cereal example, I calculated crop yields for the terraces at Angamuco. The first step was to gather climatic data for the Lake Pátzcuaro Basin using datasets from ECMWF. Minimum monthly temperature and maximum monthly temperature, in addition to average monthly measures for humidity, wind speed, and daily sunshine hours (Figure 27). These quantitative datasets were entered into CROPWAT 8.0 in addition to an andosol soil profile provided by the Food and Agriculture Organization of the UN (FAO), (Figure 28). Evapotranspiration rates and maize water needs were modeled for the spring and fall harvests using CROPWAT 8.0. Harvest dates were selected using modern ethnographic data about Purépecha farming in the basin (Barrera-Bassols and Zinck 2003, Orozco-Ramirez and Astier 2017).



Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m^2/day	mm/day
January	7.2	19.7	59	2	8.0	16.3	2.11
February	8.0	21.3	55	2	8.0	18.2	2.56
March	9.1	22.9	50	2	8.7	21.2	3.20
April	11.0	25.0	47	2	8.5	22.3	3.68
May	11.6	24.4	61	2	8.5	22.7	3.99
June	12.0	21.7	80	3	6.6	19.8	3.61
July	11.3	20.6	86	2	6.5	19.6	3.50
August	11.3	20.8	87	2	7.3	20.5	3.59
September	11.3	20.5	86	2	6.4	18.2	3.14
October	10.2	20.6	78	2	8.0	18.7	2.94
November	8.6	20.3	69	2	8.3	17.0	2.39
December	7.6	19.8	61	2	6.8	14.2	1.89
Average	**9.9**	**21.5**	**68**	**2**	**7.6**	**19.1**	**3.05**

Figure 27: CROPWAT 8.0 Data Entry for Pátzcuaro



Soil name Andosol

General soil data

Total available soil moisture (FC - WP) 290.0 **mm/meter**

Maximum rain infiltration rate 40 **mm/day**

Maximum rooting depth 900 **centimeters**

Initial soil moisture depletion (as % TAM) 0 **%**

Initial available soil moisture 290.0 **mm/meter**

Figure 28: Andosol soil profile provided by the FAO.

Yield measures of maize were then modeled for the terraced area at Angamuco for a two-harvest system. This was accomplished by using modern crop yields of traditional farmers in Michoacán. These farmers use non-irrigated, rain-fed growing methods and use ‘local land races’ of maize. The data gathered for these numbers were two five-year periods that were individually averaged. For the years 1980-1984 the average rain-fed crop yield was 1.4 metric tons of maize per hectare and for the years 2006-2010 this number was 2.5 metric tons (Sweeney et al. 2013). For the purpose pf this thesis I averaged those two numbers and used 1.95 metric tons per hectare as the output for the spring harvest at Angamuco. According to Sweeney et al. (2013), productivity measures were not that different for fall harvests, with 1.3 metric tons of maize per hectare on average from 1980-1984 and 2.7 metric tons from 2006-2010. For my own productivity measures, I averaged these two numbers and used 2 metric tons per hectare as the output for fall harvest at Angamuco. These numbers were then applied to the identified terraced areas at Angamuco to represent the possible total output of maize.

6. Conclusion

For this analysis I incorporated three distinct types of investigations, including GIS visualizations and analyses, hydrological investigations, and productivity modeling. GIS analyses was used to identify and quantify terraced zones. Hydrological modeling showed water movement throughout the site and over the edges of malpaís, and productivity of terraces was calculated for crop yields of maize. In the following chapter I will present the results of these analyses.

Chapter 6: Results

1. Introduction

This chapter will summarize the results of my methodologies presented in the previous chapter. Quantified results of physical attributes, area, and comparative total composition of the site will all be outlined. The initial results of hydrological modeling will be briefly discussed, in addition to the crop productivity analysis.

2. Terrace Attributes

The results of my initial analysis of establishing general presence or absence of terraces in specific zones are as follows: the total terraced area of the randomly selected tiles is 178,232m^2. There were 69 individual 250x250 meter tiles selected representing 4,312,500m^2; this represents 25% of the 17.25km^2. The total city has been measured at 26km^2, however, for this analysis I am only focusing on the area located directly on the malpaís. The total number of tiles that contained terraces were 46 and total number of tiles that had no terraces were 23 (Figure 29). The total terraced area of the selected tiles is 178,232m^2, or 4.13% of the selected area (Figure 30). This number, 178,232m^2, was then extrapolated onto the entire site giving an estimation of 712,928m^2 of the entire area of the malpaís being covered in terraced slopes.

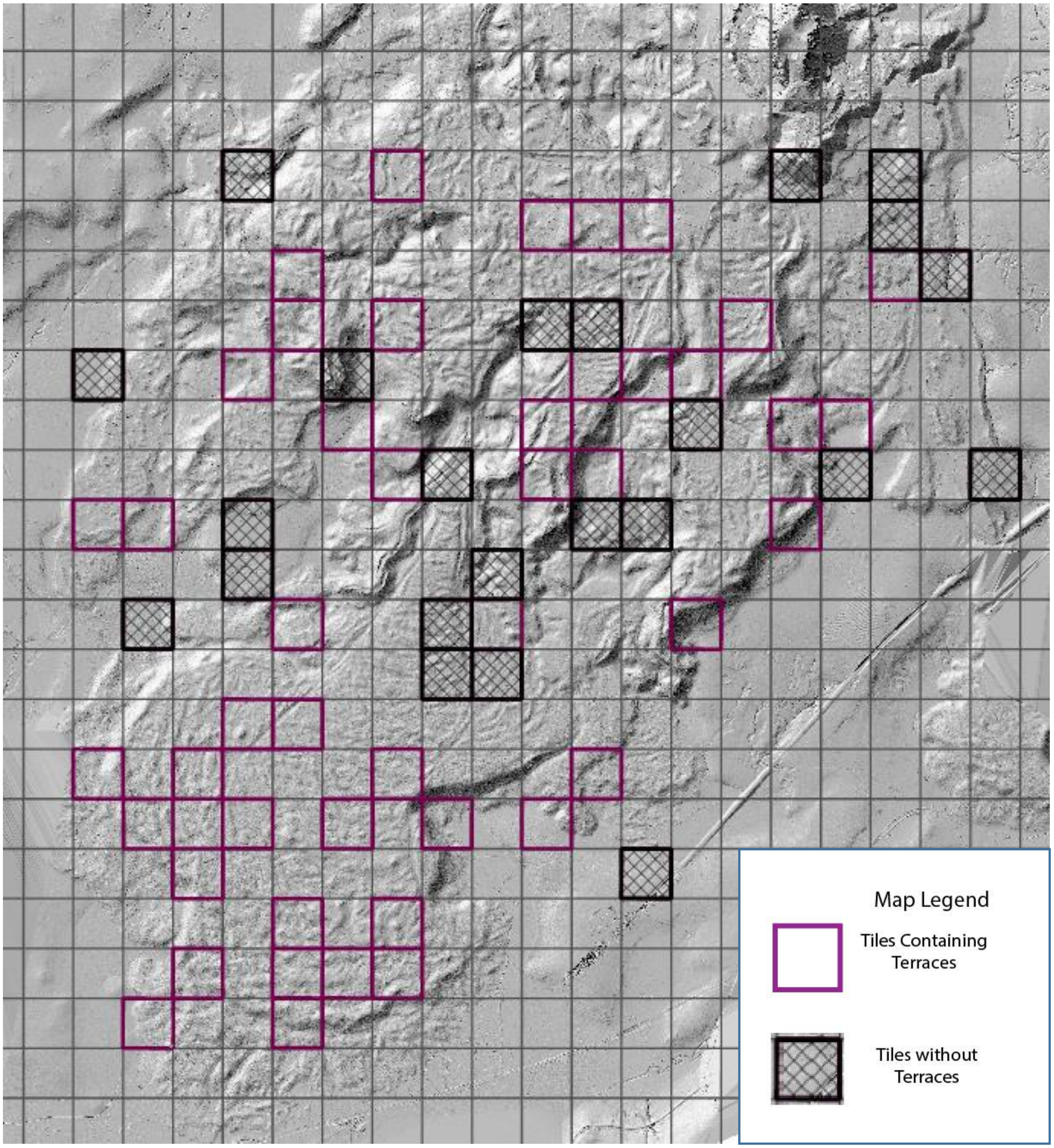


Figure 29: Image showing the location of tiles that did and did not contain terraces during this analysis. See appendix A for geospatial metadata.*

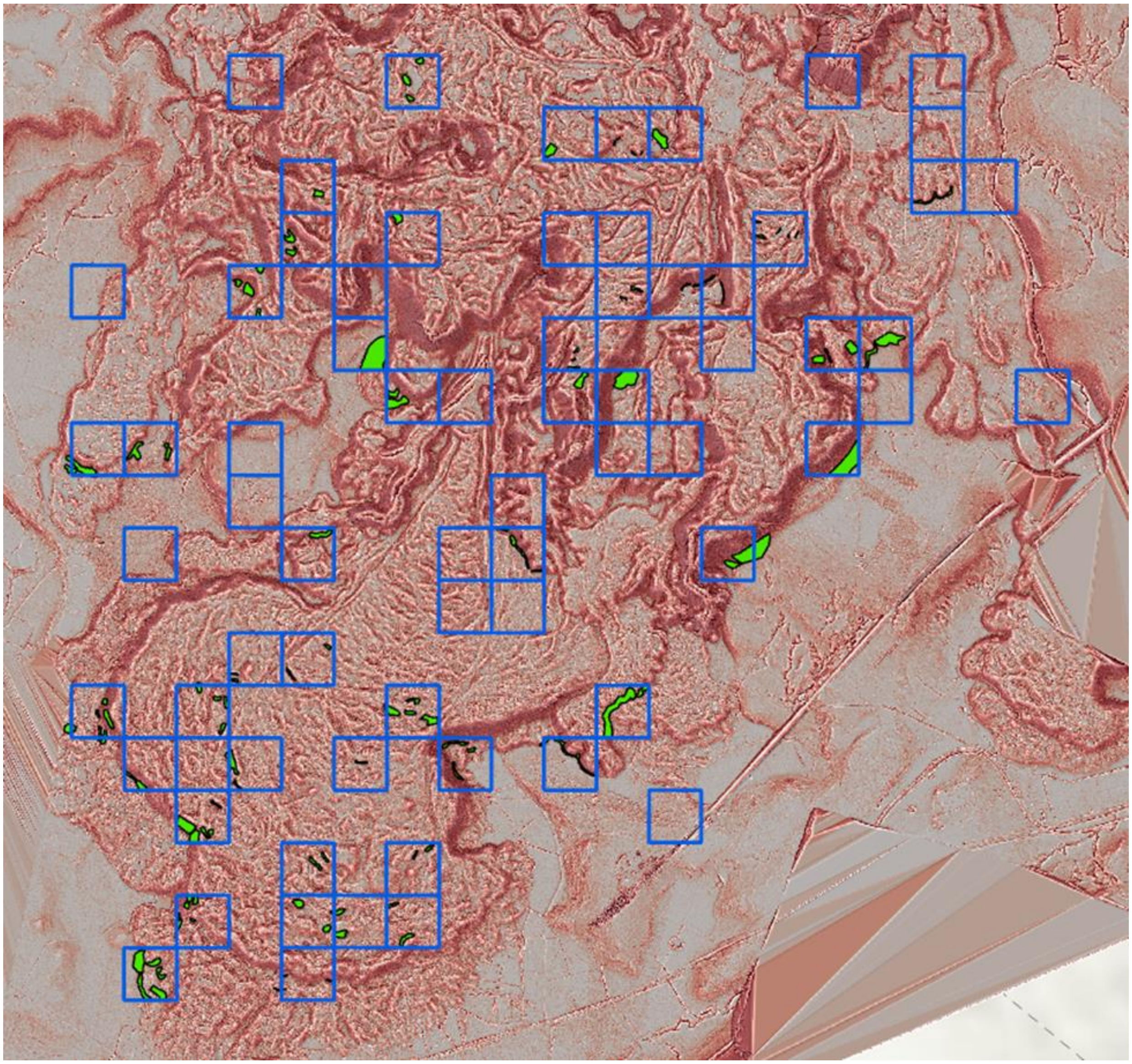


Figure 30: The location of analyzed terraces outlined in black and filled in green surrounded by selected tiles in blue squares. See appendix A for geospatial metadata and PRRIM visualization information***.*

The terraces that were observed were largely dry, or rain fed. However, preliminary results show that it is likely that at least some of these terraces were purposefully irrigated. In depth analysis of the irrigated terraces are largely outside of the scope of this investigation. The brief initial analysis that I conducted of these irrigated features will be discussed later.

Several attributes of the identified terraced zones were analyzed and documented. Individual bench width was an important factor both for identification purposes and further examination. The average width of all of the benches of the presumed agricultural terraces is 2.531 meters, though the range was upwards of 6 meters to sub meter size (Figure 31). These bench widths varied greatly depending on the elevation, location, and type.

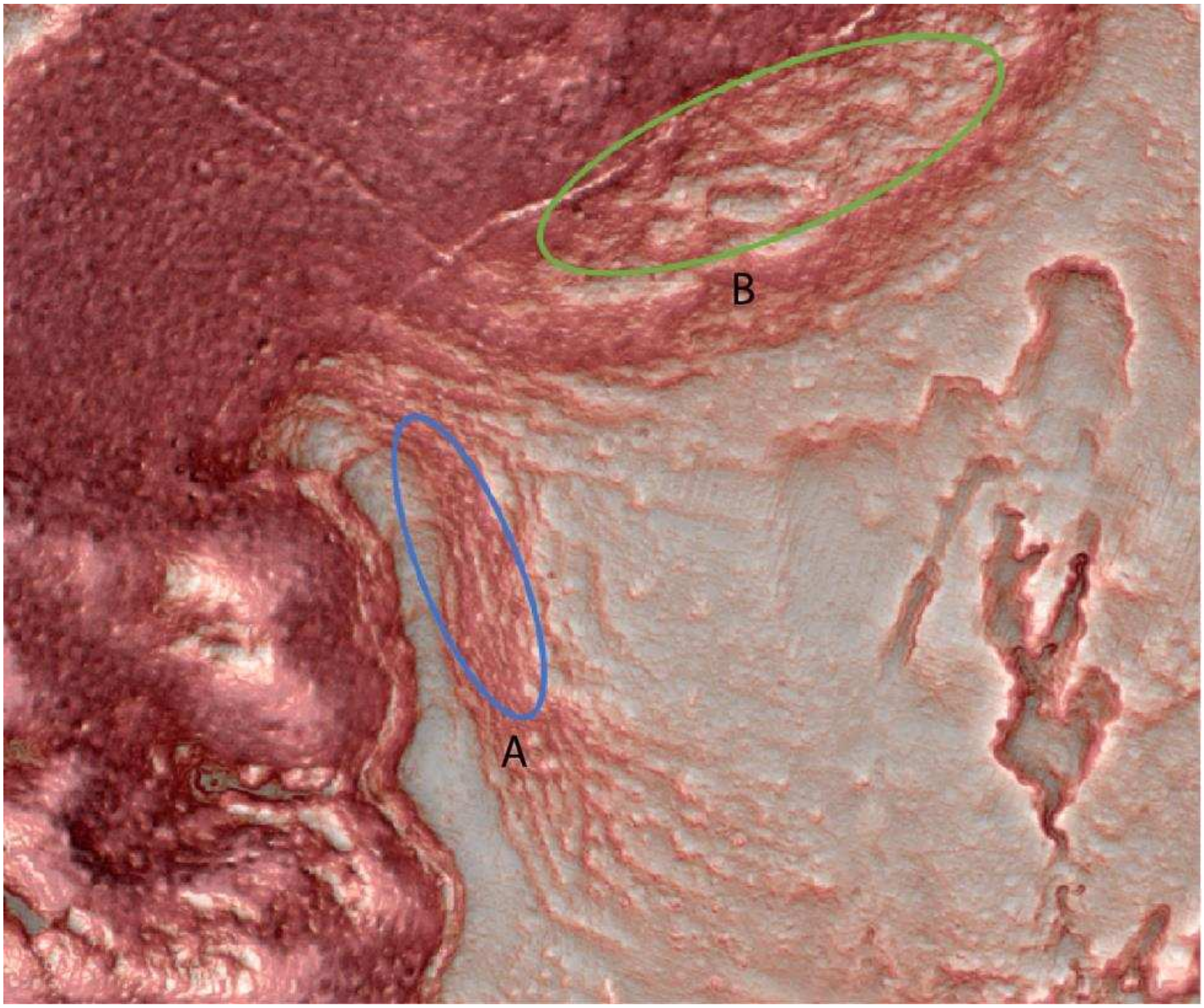


Figure 31: Image showing the variation of terrace bench width within the same area, tile BS156. Narrow terraces labeled as A and wider terraces labeled B. See appendix A for geospatial metadata and PRRIM visualization information***.*

The relief of the terraced zones varied greatly as well. The range of recorded simple relief was from 1.03 meters all the way to 26.88 meters, with an average relief of 7.06 meters. These numbers largely ignore any terraced areas that were only one or two platforms high and instead focused on terraced zones that contained multiple levels, as they are much more readily identified in the LiDAR data. Figure 32 demonstrates how small terraces can be and thus difficult to identify, while figure 33 shows the extent of how tall and clear the terraced zones can be.

Figure 32: Photo of a single platform terrace, total relief around 0.5-meter, Copyright LORE-LPB 2011, Angamuco.

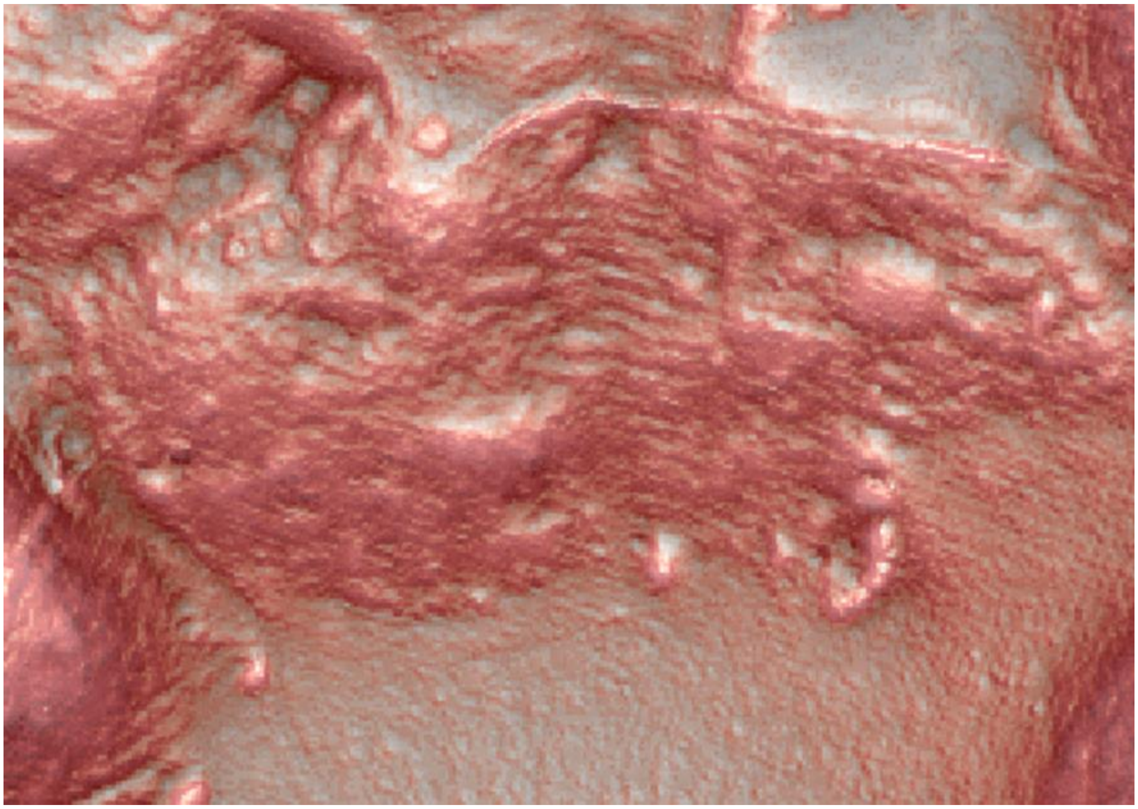


Figure 33: Terraced zone with multiple platforms, total relief is 18.9 meters. See appendix A for geospatial metadata and PRRIM visualization information***.*

Another attribute that I noted was the presence or absence of granaries. Of the 46 tiles that contained terraces I was able to locate granaries in 36 tiles. The 10 tiles that I was not able to locate granaries could be a result of deterioration or the LiDAR scan not picking up their presence because of their form or size.

Aspect was an additional important element that was considered and examined. All of the recorded terraced zones have an aspect of southeast, south, southwest or west. The figure below highlights two slopes that face one another. While both have appropriate slope percentages, only the northern slope has the suitable aspect of south and southeast displayed in the colors cyan and green respectively, versus the southern slope that has an aspect of north and northwest, displayed in red and purple (Figure

34). Any possible terraces that had an aspect of east, northeast, or north were automatically excluded from the results.

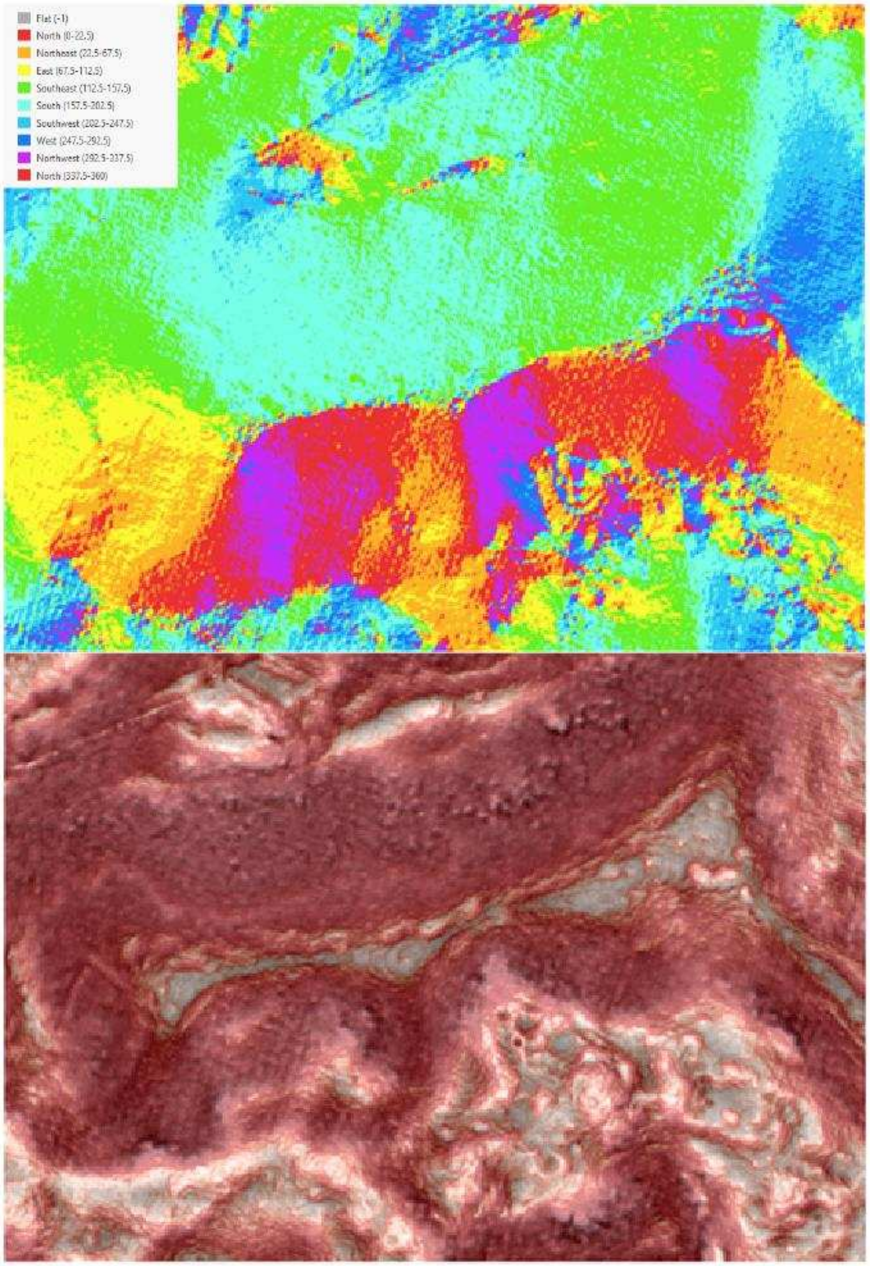


Figure 34: Aspect of slopes showing the appropriate and inappropriate slope directions with a PRRI image below for reference. See appendix A for geospatial metadata and PRRIM visualization information***.*

3. Location of Terraces

There were several clear patterns in the locations of terraced zones on the malpaís. The middle section of the malpaís seemed to be a dividing point in the area and number of terraces. This section of the site contained no visible terraces in the tiles that were analyzed. This same division has been identified in other contexts as well. The malpaís was formed in two volcanic flow episodes creating an upper and lower malpaís division represented by different topography and geology (Bush 2012). This division is represented in image A. The road network at Angamuco outlined by Solinis-Casparius (2019), also outlines this division with a major road running east to west, represented in image B. The noticeable gap in terraced land is in this exact location as well, represented by image C (Figure 35). Above this dividing point there were 11 tiles that contained 19,827.33m^2 of terraces. South of this divide there were 12 tiles that contained 25,930m^2 of terraces. The largest difference in both location and area were the edges of the malpaís. These edges contained 23 tiles and 132,473.73m^2 of terraced area.

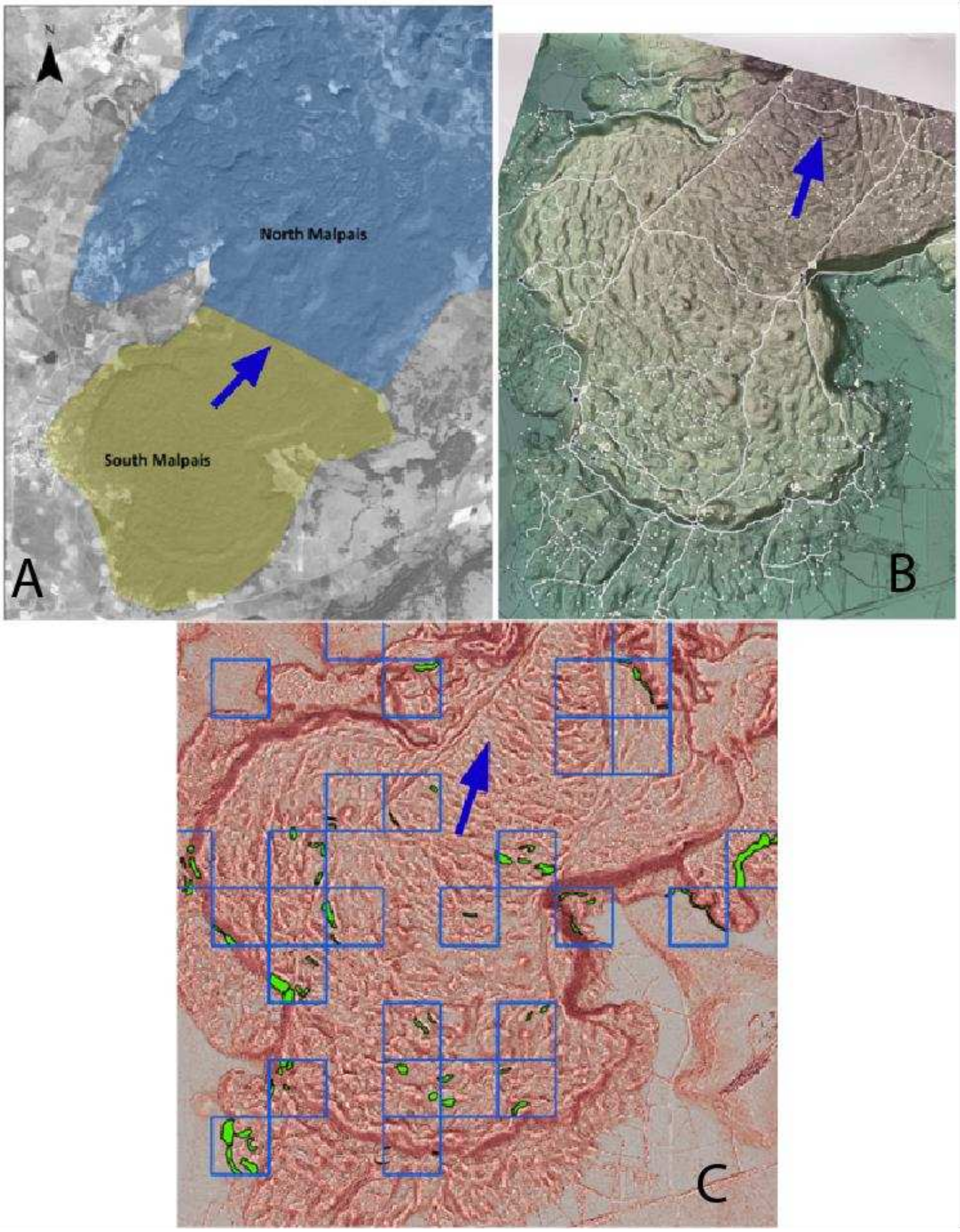


Figure 35: Three images showing the dividing line between the upper and lower malpaís. Image A imagery processed by the Alaska Satellite Facility PRISM ©JAXA 2010 (Bush 2012). Image B, main roads at Angamuco created by Rodrigo Solinis-Casparius. Image C identified gap in terraced zones. See appendix A for geospatial metadata and PRRIM visualization information***.*

In addition to varying location patterns on the malpaís, the terraced zones on the edges of the malpaís were also significantly different. The sheer area is significantly different, but also the benches had the most variation ranging from less than 1 meter to over 6 meters. The terraced zones were also much larger. However, the most distinct difference between the terraces on the edges of the malpaís versus the terraces on the malpaís, was the evidence of irrigation features. Canals and other drainage features seem to be moving water from the interior of the city to the edges of the malpaís and flowing over terraced zones.

Table 2: Location of terraces in relation to the malpaís

Terraces by Location			
Location	Number of Tiles	Area in Meter^2	Percentage of Terraces
Upper Malpaís	11	19,827.33	11.12%
Lower Malpaís	12	25,930.94	14.55%
Malpaís Edges	23	132,473.73	74.33%
Totals	46	178,232.00	100%

4. Total Built Area

The total built area of Angamuco was calculated using previous analyses and the resulting GIS shapefiles. Architecture was calculated as 159,090 features; however, this number is inflated because of the automated method used to extract features often breaks one larger feature into several smaller pieces (Harris 2019). This method also extracts only the edges of the features, a one meter buffer was applied to these edges in order to better represent total features. The total area of these architectural features was 6,262,742m^2, representing 24.09% of the total site.

Water features were another of the built features that were added to the total developed area of the site. Simpson (2019) extracted 809 total reservoirs. Using the polygons of all of the reservoirs I calculated total area of all of these, and it came to 2,086,658m^2, representing 8.02% of the entire site.

The third built feature category that was added to the total built area of Angamuco were the roads. Huatziri, or the raised roads at the site had a total of 403 fragments. The area of these were calculated for a total area of 108,235.7m^2, representing 0.42% of the entire site. The other categories of roads had a total length of 157km, and a total area of 368,905m^2. This represents 1.42% of the total site. The huatziri and roads together cover 1.84% of the entire site.

Taken together all of these features represent the total built area of the city of Angamuco. Terraced zones comprise 4.13% of the city, architectural features cover 24.09% of the site, water reservoirs encompass 8.02% of the site, and roads cover 1.84% of the site. These features together cover 38.08% of the entire site (Figure 36). The composite image of all of the built features at Angamuco below, demonstrates just how densely built this city is (Figure 37), and of the total built area representing 38.08% of the site, 8.08% of that is covered in terraced zones (Figure 38).

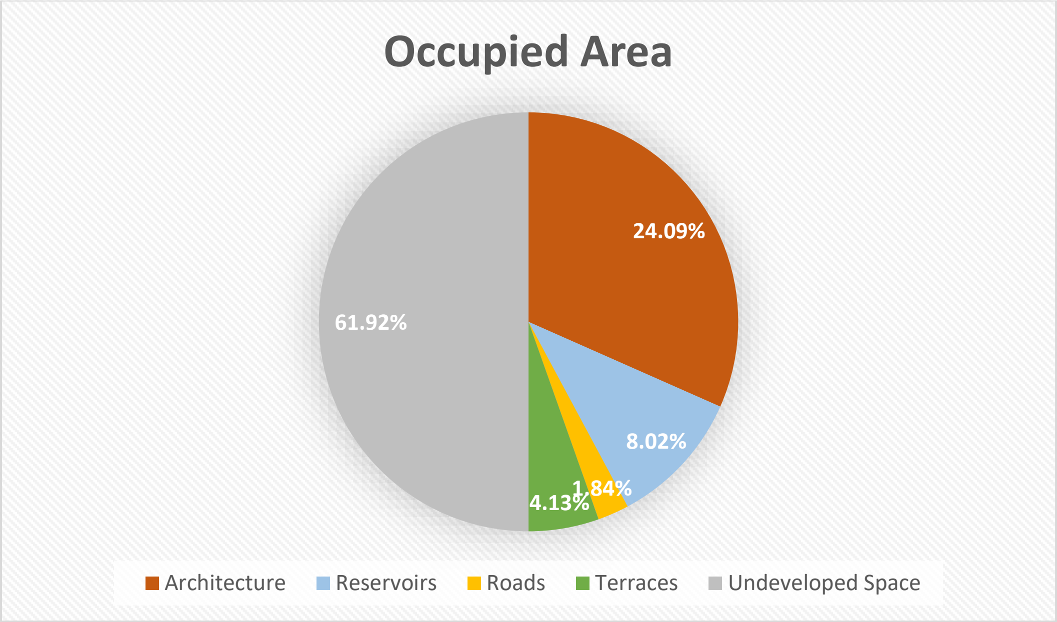


Figure 36: Chart showing the make-up of space in percentages at Angamuco.

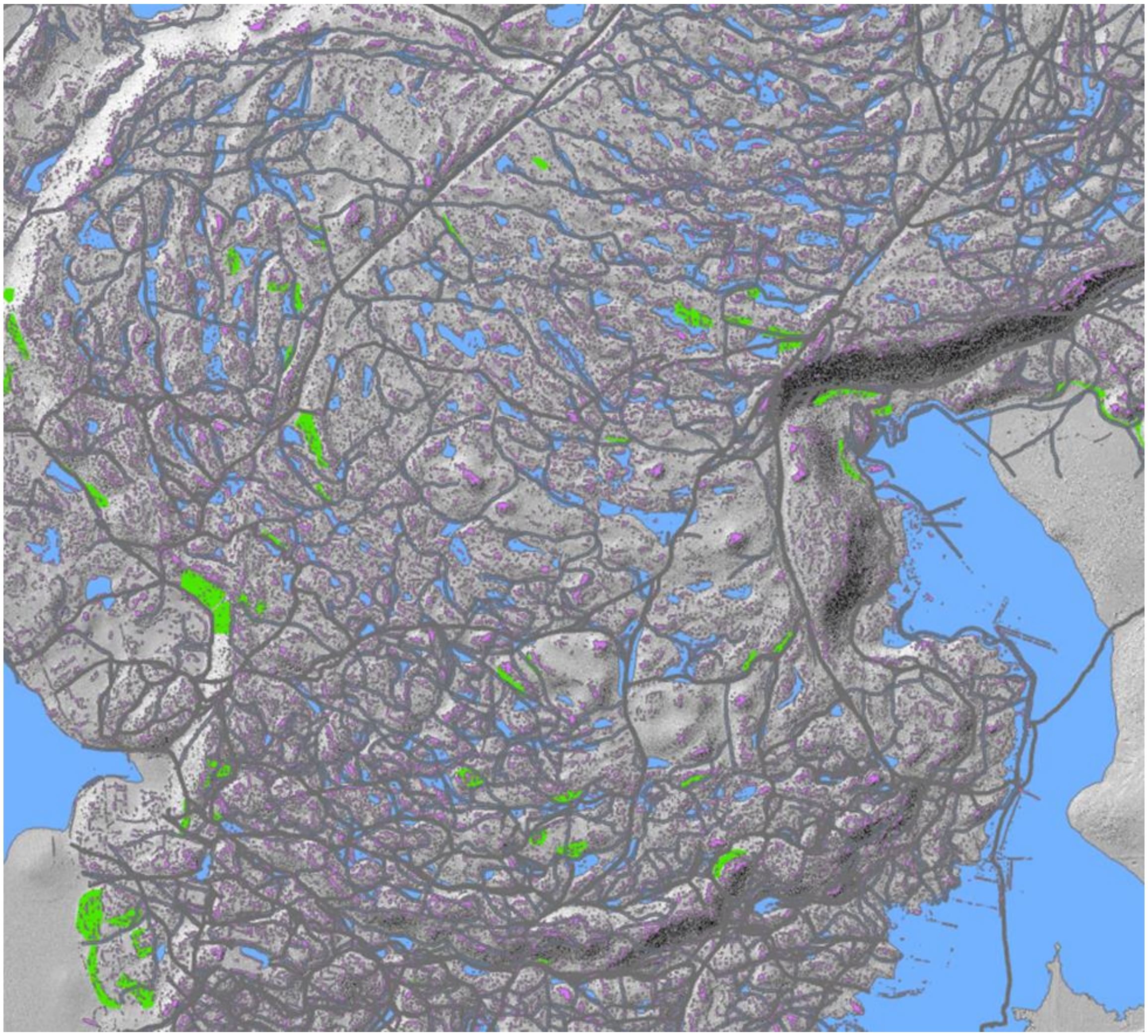


Figure 37: Composite image showing all of the built features at Angamuco. Architecture shapefile by Edwin Harris, roads shapefile by Rodrigo Solinis-Casparius, and reservoirs shapefile by Nick Simpson. See appendix A for geospatial metadata.*

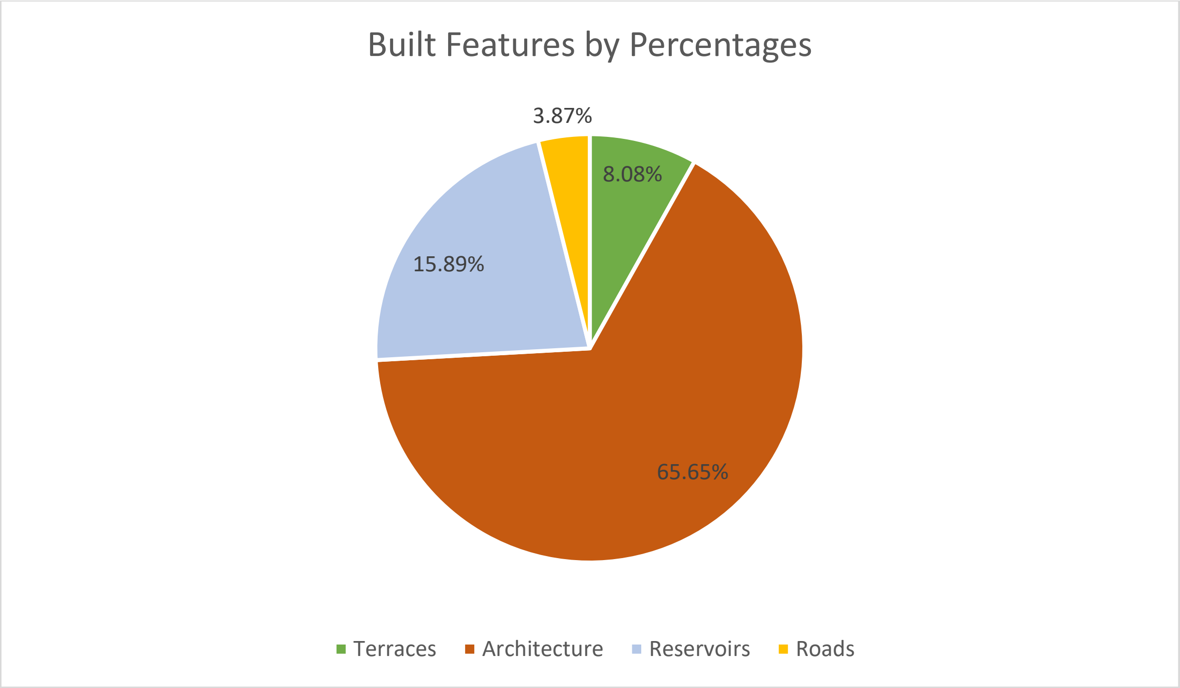


Figure 38: Chart showing the percentages of each type of built feature at Angamuco

5. Qualitative Observations

Examining the numerous different categories of features and city as a whole is necessary for any sort of complete analysis. By overlaying many of the GIS shapefiles created through pedestrian survey and LiDAR analysis I was able to make several important observations about the terraced zones. With very few exceptions, the terraced zones on the malpaís directly border roads (Figure 39). The exceptions include terraces that are directly above reservoirs or line the edges of sunken plazas.

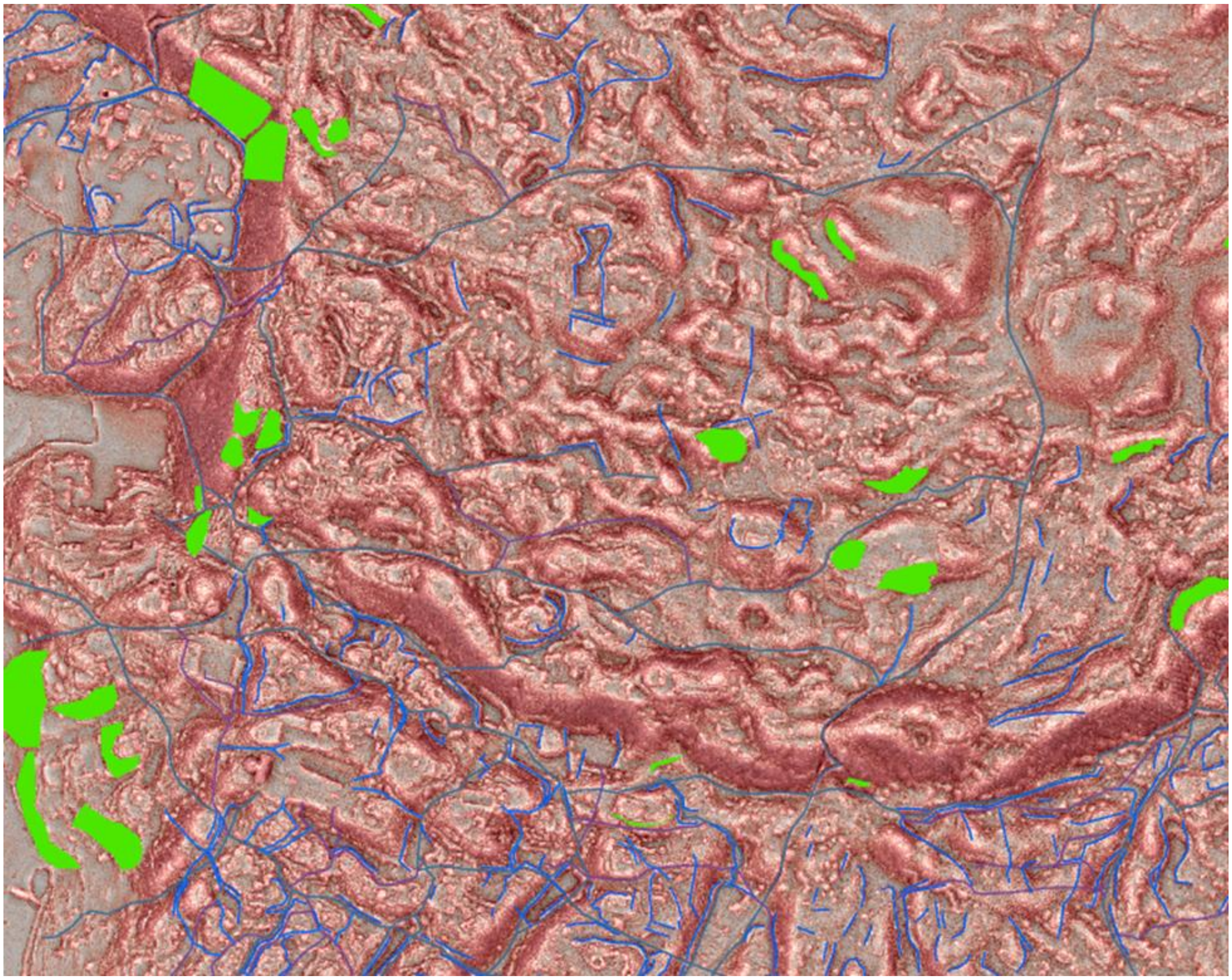


Figure 39: Terraced zones related to roads on the southern portion of the malpaís. Road shapefiles provided by Rodrigo Solinis-Casparius. See appendix A for geospatial metadata and PRRIM visualization information***.*

Terraced zones on the malpaís followed two different patterns; in the upper portion of the site, terraced zones were often not associated with significant architecture. On the lower half of the malpaís the terraced zones were closely correlated with both domestic and monumental architecture. Walled complexes outlined by Steele (2021), were occasionally associated with terraces, though not with regularity. Two individual instances of association with walled complexes will be discussed further in Chapter 7. In addition to association with architecture, terraces varied in form from the upper to lower malpaís. The lower malpaís contained higher numbers of terraced zones, larger zone footprints, and wider benches. The upper malpaís contained less terraced area, the zones were more compact and had narrower benches and less rows. A note on the observations about individual benches made through LiDAR analysis: it is likely that smaller benches, 1-2 meters wide, are not showing up in the LiDAR data, either through resolution issues or because of erosion and deterioration. Larger benches are more likely to have stood the test of time.

6. Hydrology and Canals

The watershed that was created for the entire malpaís shows a complex set of water movement in a general trend towards the southeast. There are some areas of accumulation that likely represent either present or past water catchment areas. On both the east and west edges of the malpaís there are many points of water flowing off of the edges and often into reservoirs.

The three indices that I created: topographic wetness index, sediment transport index and stream power index all modeled similar behavior. The common theme showed hydrologic movement towards the edges of the malpaís. The TWI showed an abundance of moisture on the eastern and western edges of the malpaís in addition to several accumulations underneath high slopes (Figure 40).

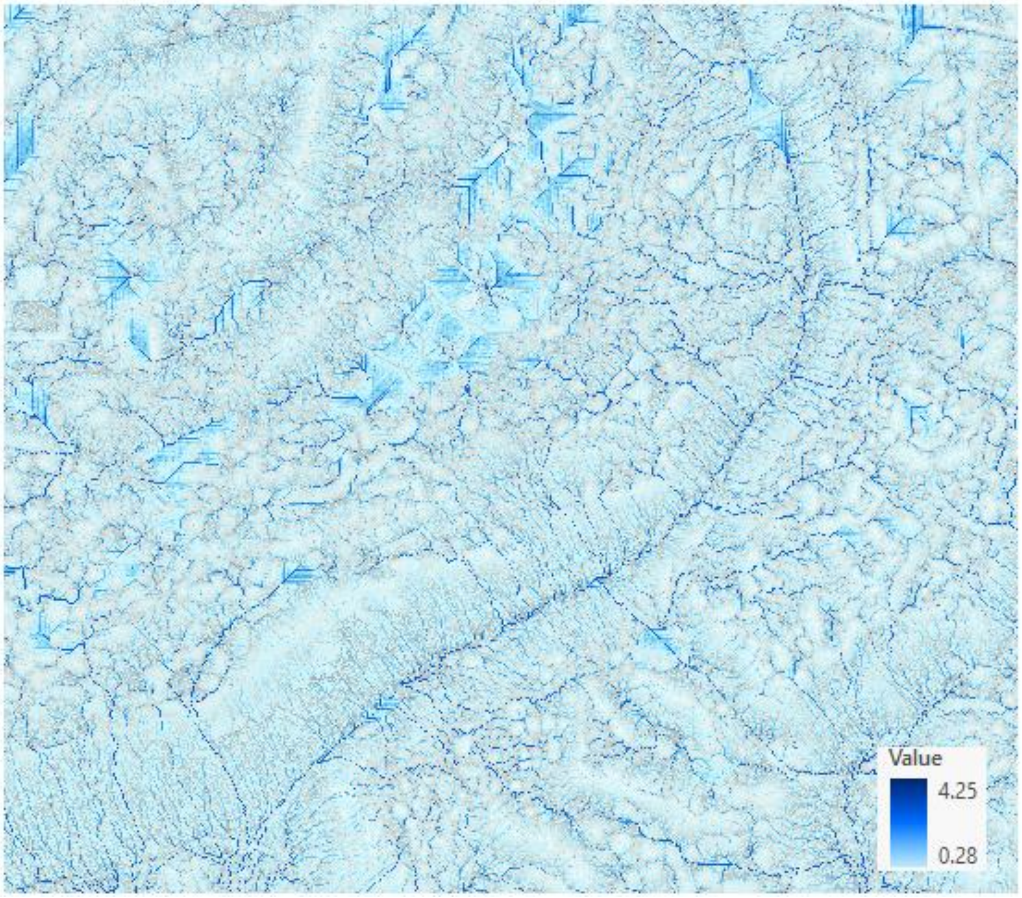


Figure 40: Darker blue showing significant moisture underneath and on slopes on the eastern edge of the malpaís.

The SPI was able to pull out several large canals that were manually identified during my initial terrace analysis (Figure 41). However, there were canals that are visible in both the ifactor and RRIM that were not readily identified in the SPI. In addition to this, several roads identified by Solinis-Casparius (2019) seem to be categorized as possible streams. The STI was the most successful index; while this still modeled some of the same movement as the other indices, it did show that sediment movement along the terraced edges of the malpaís is minimal except for the canal areas (Figure 42). This is precisely one of the main functions of terraces: to prevent soil erosion.

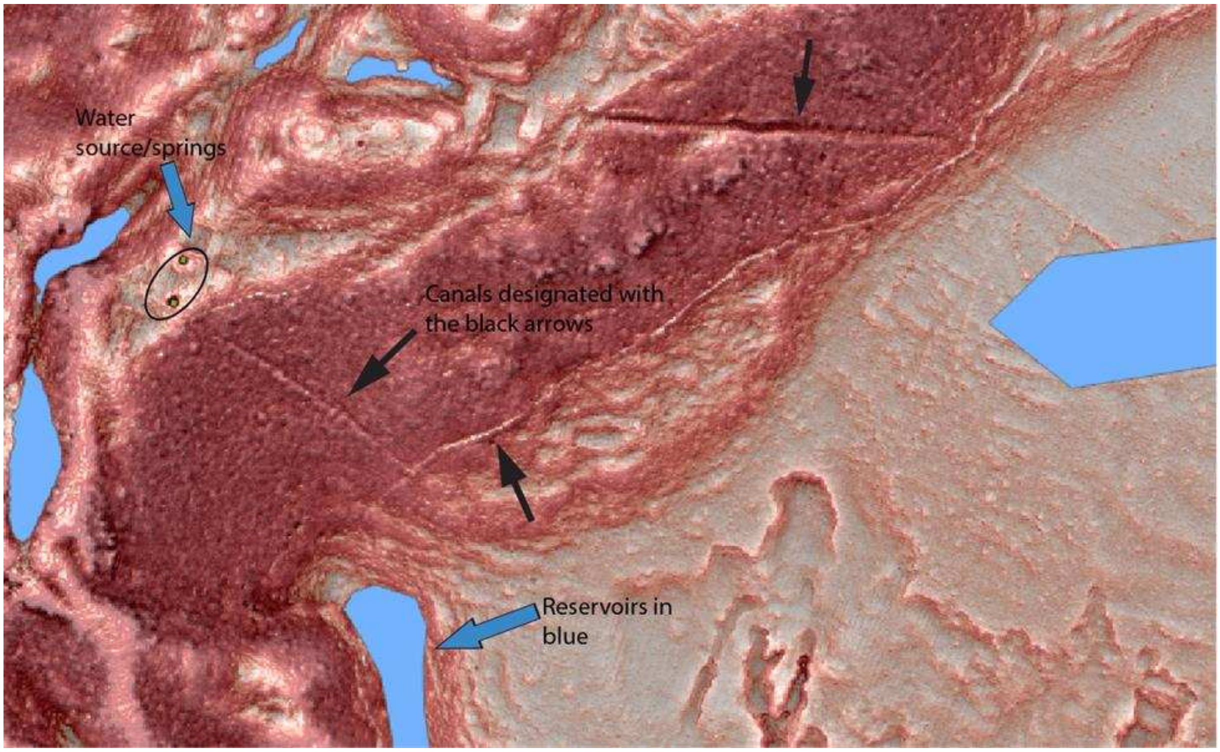


Figure 41: Manually identified canals, suggesting irrigated terraces.

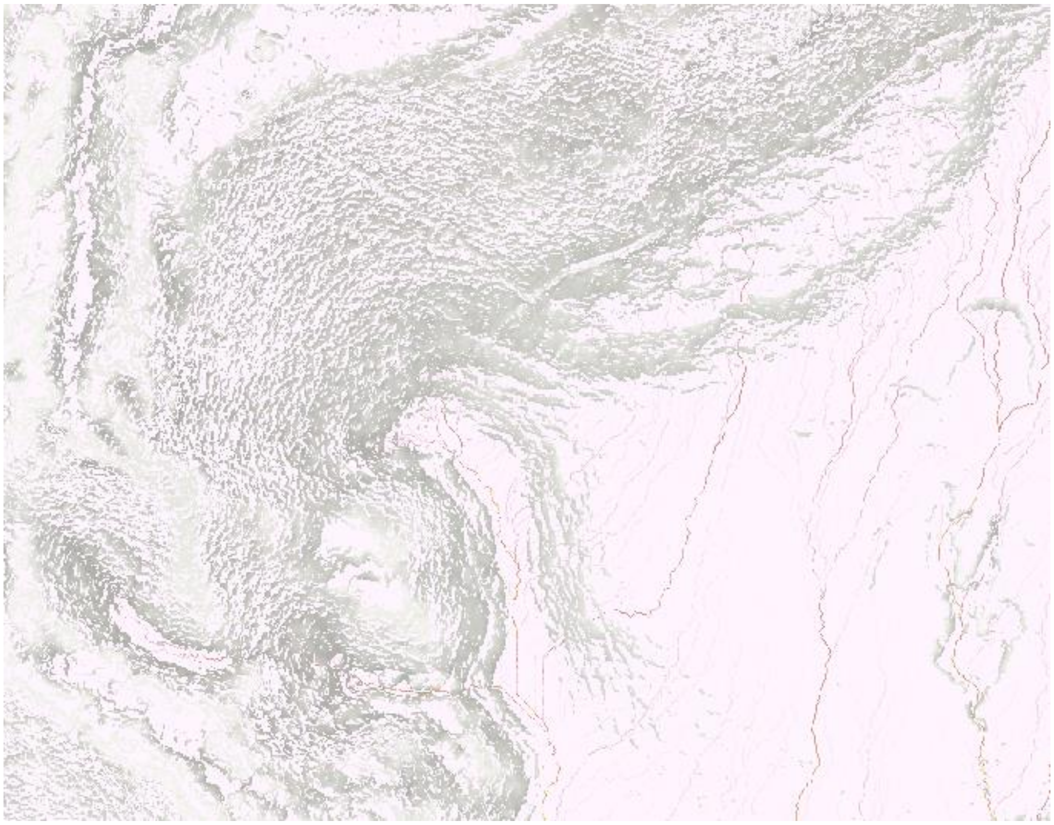
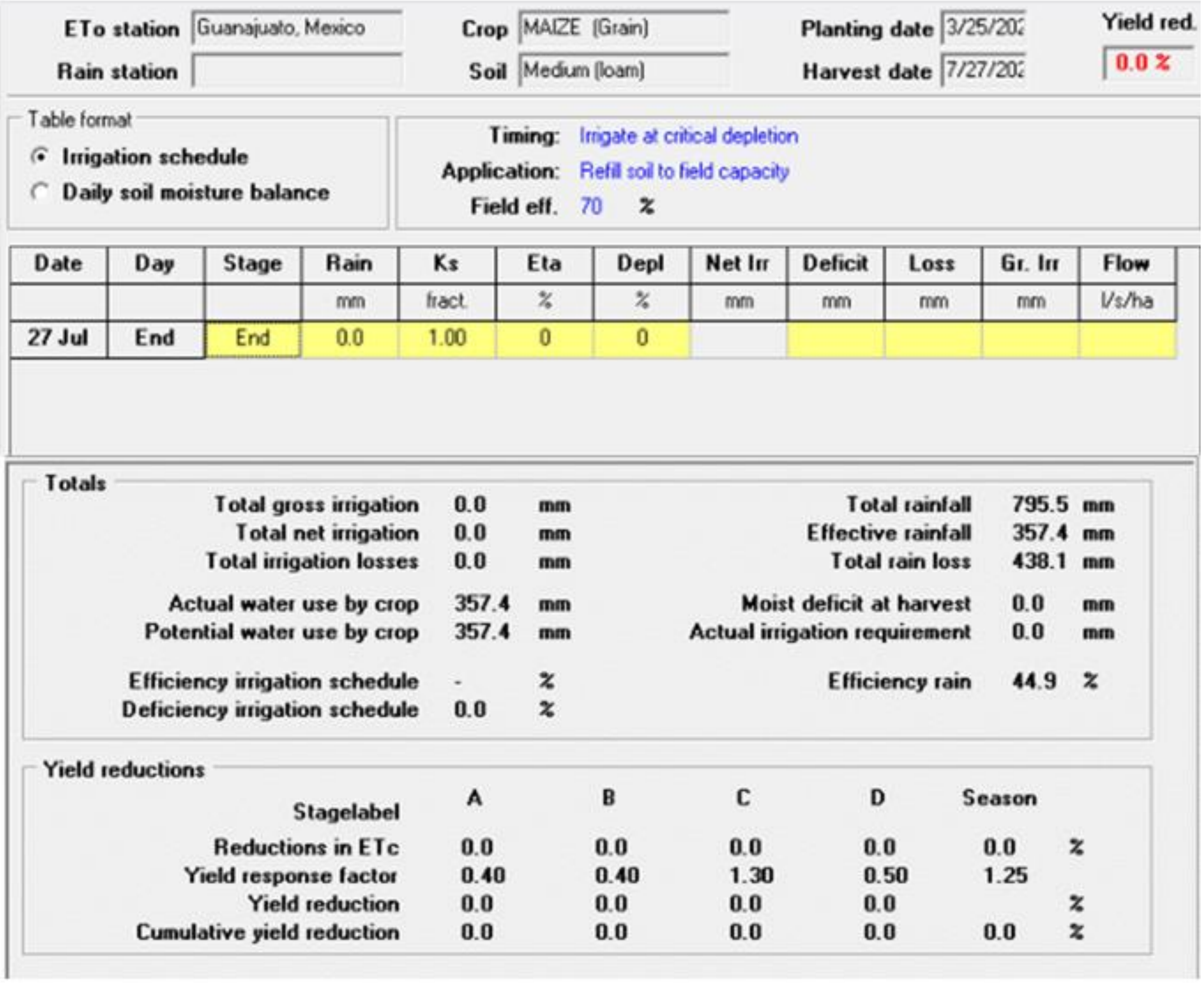


Figure 42: STI showing the stability of sediments on terraces on the eastern edge of the malpaís.

Overall, the hydrological modeling was not exceedingly successful at identifying potential water features such as canals. While some visualizations and indices did successfully identify portions of irrigation features such as canals, others were not able to. Future analysis, pedestrian survey and excavation are needed to further corroborate the existence and function of irrigation features at Angamuco.

7. Crop Productivity Model

CROPWAT 8.0 modeled evapotranspiration and irrigation requirements for spring and fall maize harvests. Both growing seasons required no irrigation and had no yield reduction using just rainfall to provide water use for crops. The fall harvest did have a 5.3 mm moisture deficit by harvest, but this deficit did not affect the total yield at all (Figures 43 and 44).



ETo station: Guanajuato, Mexico
Rain station:
Crop: MAIZE (Grain)
Soil: Medium (loam)
Planting date: 3/25/202
Harvest date: 7/27/202
Yield red.: 0.0 %

Table format
● Irrigation schedule
○ Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff.: 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
27 Jul	End	End	0.0	1.00	0	0					

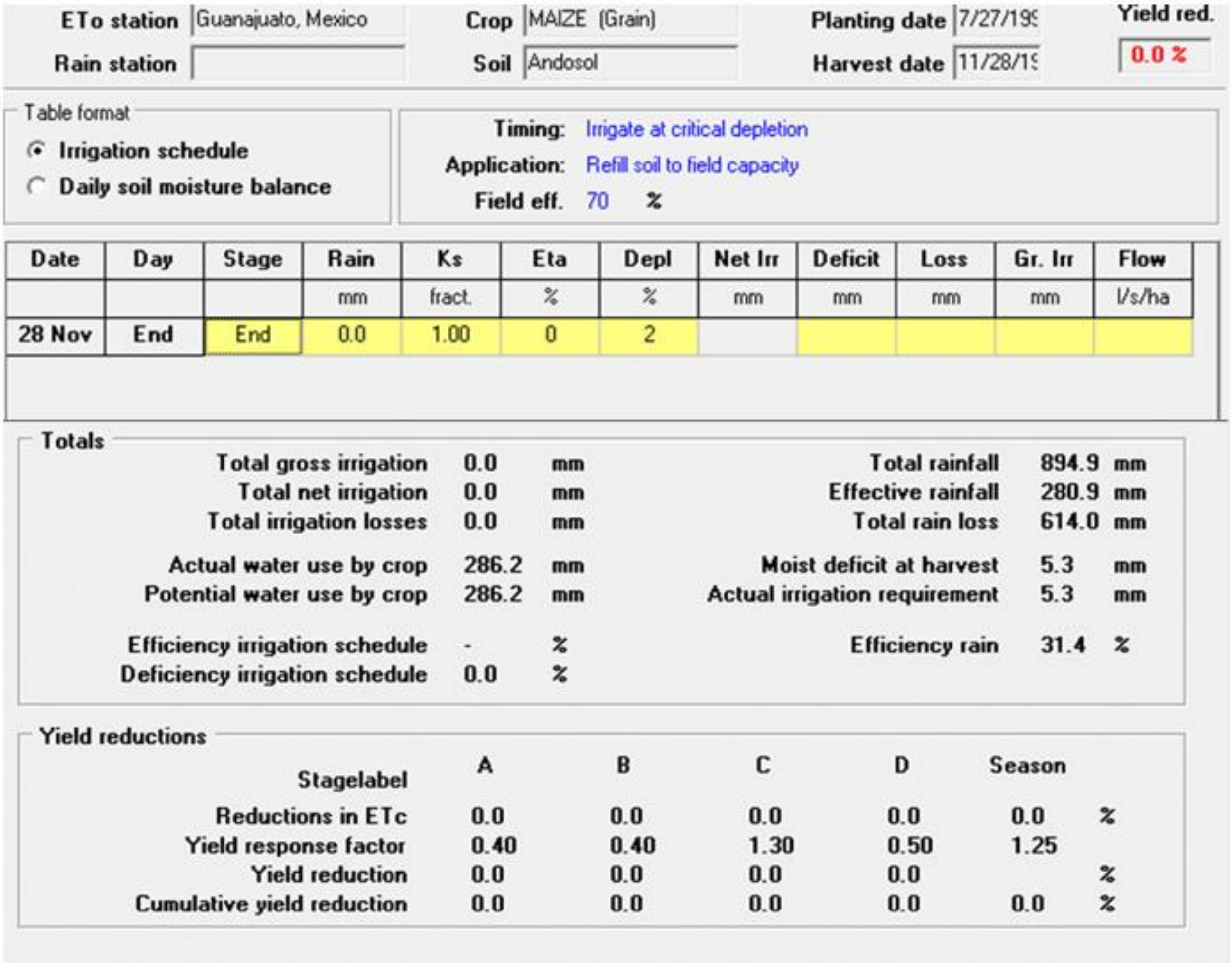
Totals

Total gross irrigation	0.0	mm	Total rainfall	795.5	mm
Total net irrigation	0.0	mm	Effective rainfall	357.4	mm
Total irrigation losses	0.0	mm	Total rain loss	438.1	mm
Actual water use by crop	357.4	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	357.4	mm	Actual irrigation requirement	0.0	mm
Efficiency irrigation schedule	-	%	Efficiency rain	44.9	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.40	0.40	1.30	0.50	1.25	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

Figure 43: Irrigation Requirements Spring Harvest



ETo station: Guanajuato, Mexico
Rain station:
Crop: MAIZE (Grain)
Soil: Andosol
Planting date: 7/27/19
Harvest date: 11/28/1
Yield red.: 0.0 %

Table format
● Irrigation schedule
○ Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
28 Nov	End	End	0.0	1.00	0	2					

Totals
Total gross irrigation 0.0 mm
Total net irrigation 0.0 mm
Total irrigation losses 0.0 mm
Actual water use by crop 286.2 mm
Potential water use by crop 286.2 mm
Efficiency irrigation schedule - %
Deficiency irrigation schedule 0.0 %
Total rainfall 894.9 mm
Effective rainfall 280.9 mm
Total rain loss 614.0 mm
Moist deficit at harvest 5.3 mm
Actual irrigation requirement 5.3 mm
Efficiency rain 31.4 %

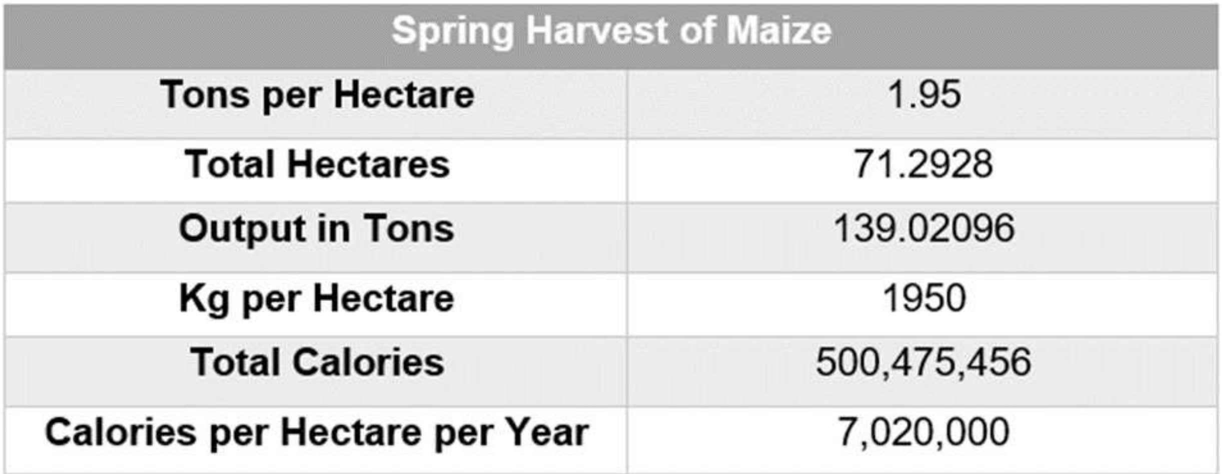
Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.40	0.40	1.30	0.50	1.25	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

Figure 44: Irrigation requirements fall harvest.

The modeled spring harvest of maize at Angamuco was 1.95 metric tons per hectare. Expounded over the total area of terraced zones, 712,926 square meters or 71.2928 hectares, Angamuco would have been able to produce 139.02096 tons or 139,020.96 kg of dried maize during the spring harvest: that is 1950 kg per hectare. Using Wetterstrom's (1986) value of 3,600 calories per kg of dried maize, we see a total 7,020,000 calories per hectare, per spring harvest. In total that is 500,475,456 calories produced from maize crops in the spring (Table 3).

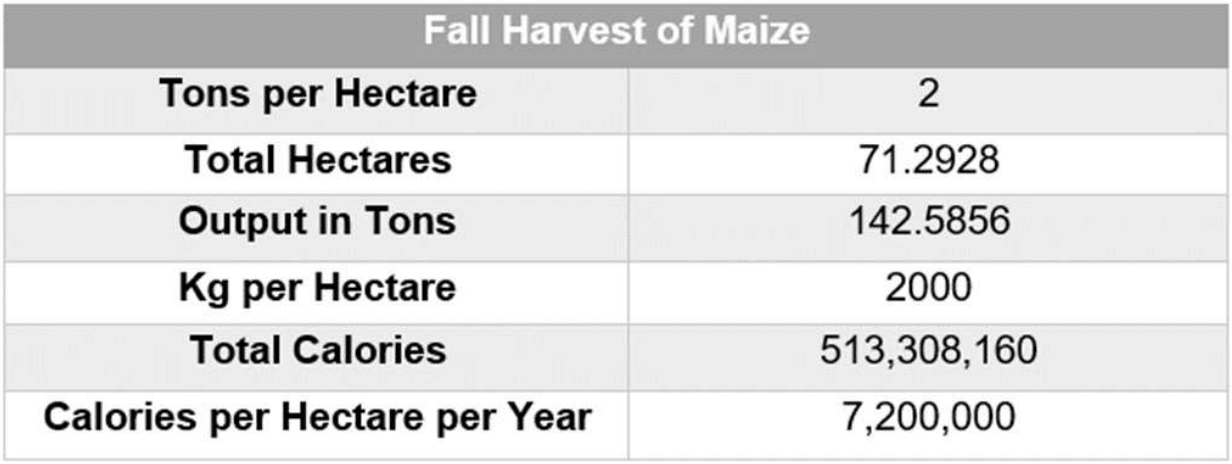
Table 3: Spring harvest of dried maize at Angamuco.



Spring Harvest of Maize	
Tons per Hectare	1.95
Total Hectares	71.2928
Output in Tons	139.02096
Kg per Hectare	1950
Total Calories	500,475,456
Calories per Hectare per Year	7,020,000

The fall harvest that I modeled for Angamuco was quite similar, with 2 metric tons of maize as the input. When computed for the total area of terraces, in the fall the residents of Angamuco would have been able to produce 142.5856 metric tons of dried maize, or 142,585.6 kg. That is 2000 kg per hectare, 7,200,000 calories per hectare per year, and 513,308,160 total calories for the fall harvest (Table 4).

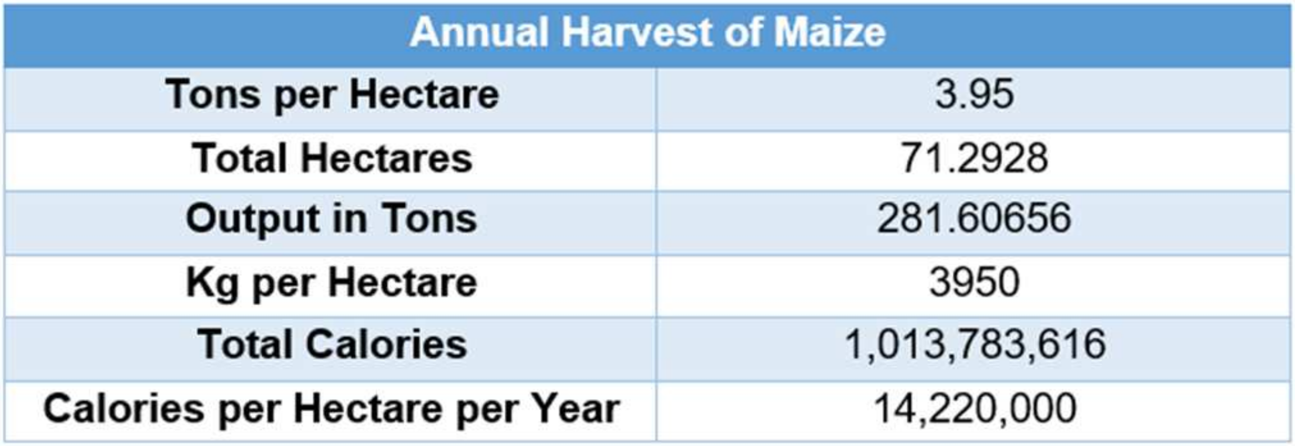
Table 4: Fall harvest of dried maize at Angamuco.



Fall Harvest of Maize	
Tons per Hectare	2
Total Hectares	71.2928
Output in Tons	142.5856
Kg per Hectare	2000
Total Calories	513,308,160
Calories per Hectare per Year	7,200,000

Combining the spring and fall harvests for Angamuco represents the total possible output of maize from the terraces. Collectively, the total expected tons per hectare is 3.95, meaning the terraces would have been able to produce 281.60656 tons or 281606.56kg of dried maize. That is a total of 3950 kg per hectare. For a total of 1,013,783,616 calories, representing 14,220,000 calories per hectare per year (Table 5).

Table 5: Annual harvest of dried maize at Angamuco.



Annual Harvest of Maize	
Tons per Hectare	3.95
Total Hectares	71.2928
Output in Tons	281.60656
Kg per Hectare	3950
Total Calories	1,013,783,616
Calories per Hectare per Year	14,220,000

It should be noted here that while these caloric estimates are based off of maize as the main crop, past people at Angamuco and elsewhere were likely not monocropping maize or any other cereal grain. Instead past people in Mesoamerica used a milpa system. They grew many different crops together that provide both better growing conditions for the crops and better nutrients when consumed.

Chapter 7: Discussion

1. Introduction

While the previous chapter discussed the results in a primarily numerical format, this chapter will serve to elaborate on those numbers and provide more context and description. Furthermore, this chapter will serve to give a more anthropological lens to the spatial data and analysis that was previously established.

2. Terrace Attributes

2.1 General Area

Terraces cover roughly 4.13% of the total area of the archaeological site of Angamuco. Using both modern and past proxies that is a relatively high number considering the urban environment of Angamuco. Another archaeological site in the Lake Pátzcuaro Basin, Apúpato (Figure 45), was comprehensively surveyed for the sole purpose of agricultural research. This agricultural hamlet was extensively terraced and had almost no evidence of residential architecture, suggesting that this island city was used exclusively for agricultural production. The entire site of Apúpato measured 121.26 ha or 1,212,600 meters^2. 90% of this site was terraced during the Late Postclassic Period measuring 109ha or 1,090,000 meters^2 (Pezzutti 2010).

Figure 45: Former island city of Apúpato, outlined in red in the Lake Pátzcuaro Basin. Lake Pátzcuaro Basin. Source: 19°33'31.54" N and 101°34'17.40"W. Google Earth. 2/24/2015.

When compared to Apúpato, Angamuco's terraced zones do not equate to the percentage of coverage at Apúpato; however, in total area of terraces Angamuco comes fairly close to this agricultural center. Of the area that was examined for the purposes of this thesis there was a total of 178,232m^2 of terraces, when extrapolated to the whole of the site the estimated total area of terraces is 712,928m^2. That is 65% of Apúpato terraced area. Angamuco was an urban center thus had many functions including economic and religious, while Apúpato sole purpose was to grow crops for the elite. The terraced area at Angamuco represented a significant role in the city's operation.

2.2 Types of Terraces

There are two types of terraces visible in the LiDAR data at Angamuco. The first type of terraces are commonly referred to as bench terraces (Figure 46). These benches generally contour slopes and are used to create a level planting surface (Whitmore and Turner 2001). This type of construction increases arable land, prevents erosion, and can be used for irrigation purposes. Generally, these types of terraces are built on steep slopes, and the record at Angamuco supports this observation as they are located on both the sides of the malpaís and on the varied topographical landscape across the site. The bench terraces at Angamuco are mostly dry or rain fed, though it seems from initial observation that some of the bench terraces may also have been irrigated, especially those on the edges of the malpaís. These are the most common type of terraces that have been located thus far at Angamuco.

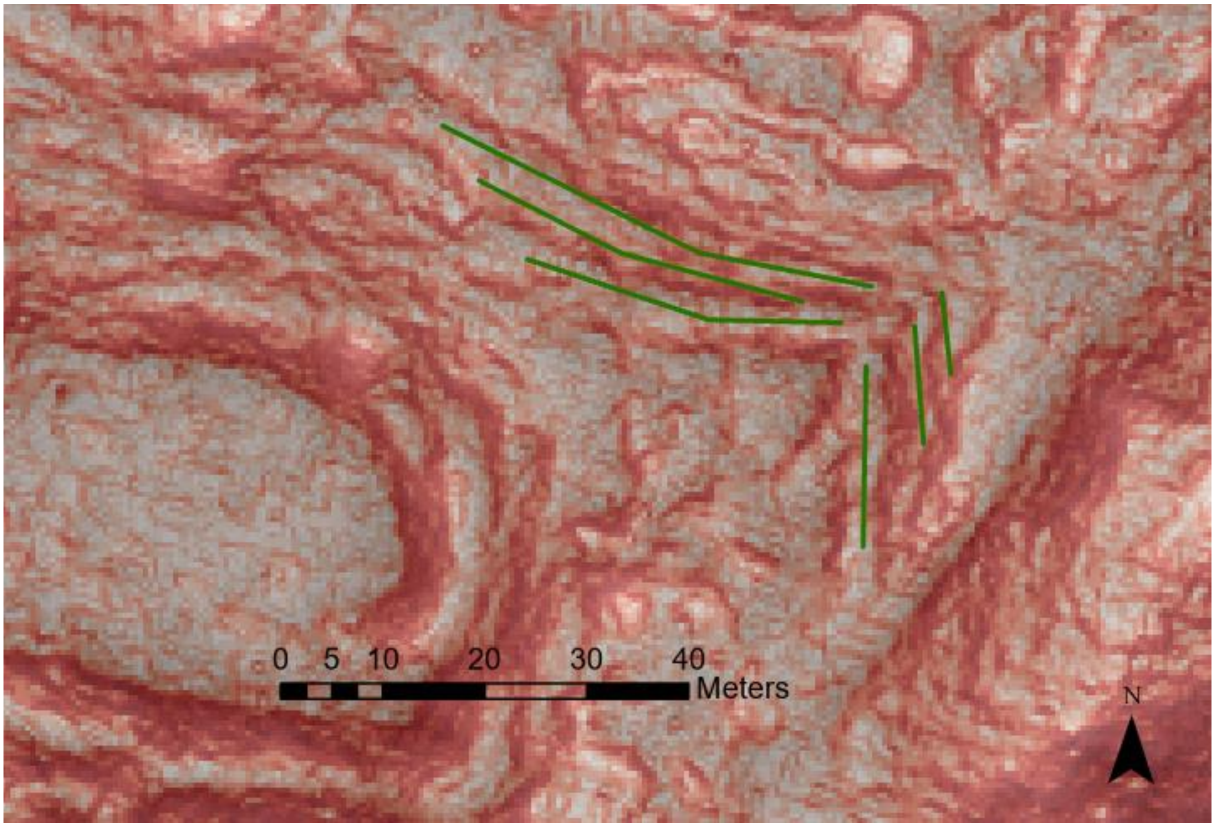


Figure 46: Bench terraces lined in green at Angamuco. See appendix A for geospatial metadata and PRRIM visualization information***.*

The second type of terraces identified at Angamuco form a type of barrier at the base of hills and reservoirs. Because of this perceived function I will call these check dam terraces. The traditional definition of a check dam is a construction built across a channel in order to slow, stop, or control the movement of water or sediments (Figure 47). While these features at Angamuco are not built perpendicular to water flow, I do believe that they did function to control and divert slow water flow. These types of terraces are located both at the base of significant slopes, that often have remnants of bench terraces on them, and at the edge of water reservoirs. They have both a hollowed out portion at the base of the slope and a sizeable ridge on the other side of the depression (Figure 48).

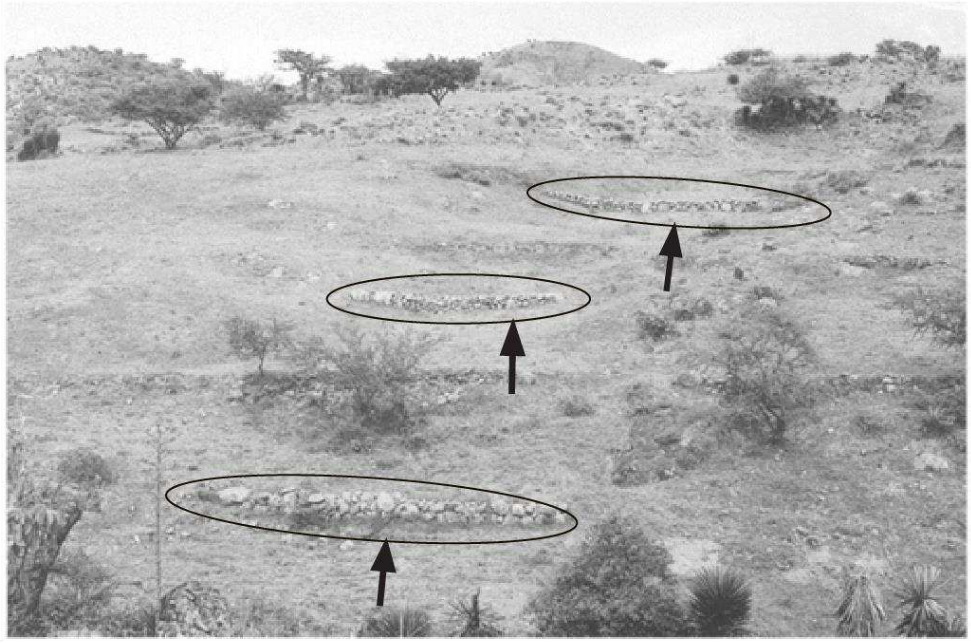


Figure 47: Check dams along a slope in Oaxaca, adapted from (Feinman and Nicholas 2013).

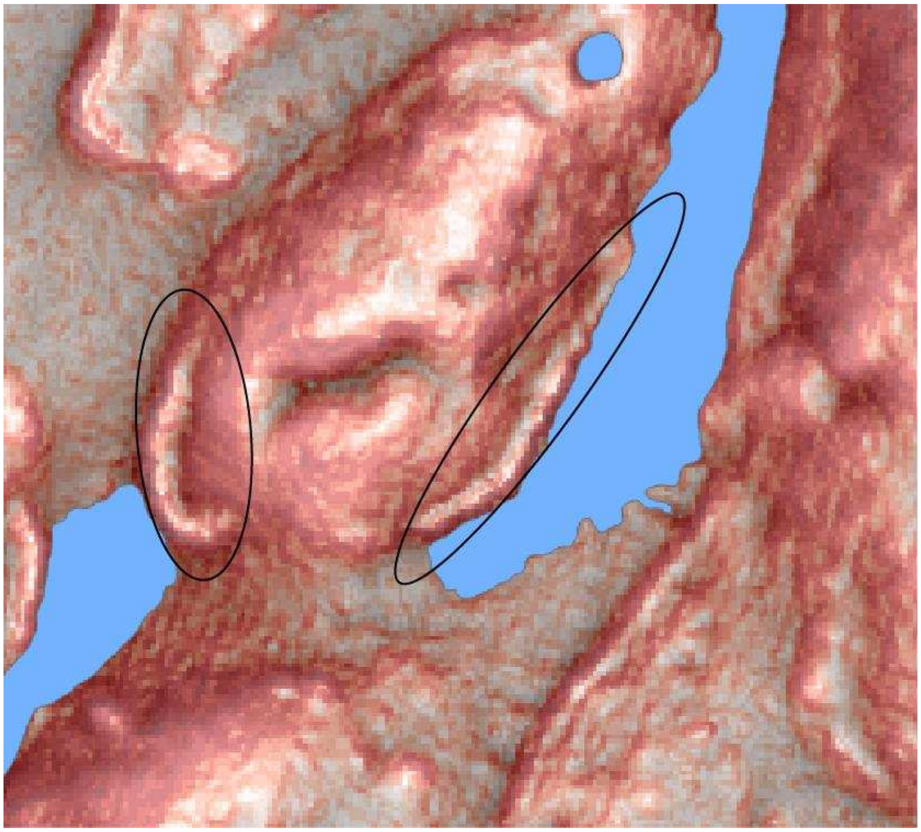


Figure 48: Check dam terraces at Angamuco bordering reservoirs in blue. See appendix A for geospatial metadata* and PRRIM visualization information***.

Considering the significant topographical variation at Angamuco, it is possible, even likely, that there are other types of terraces that are not visible through LiDAR analysis. There is even the possibility that pedestrian survey would not locate these features. Thorough excavation would be the most efficient, and potentially the only, method to locate and identify these features.

2.3 Physical Characteristics

As mentioned previously in Chapter 6, the width of terrace benches varied greatly, with benches less than 1 meter wide, and some upwards of 6+ meters wide. In general, when there were varying sizes in width in the same zone, the wider terraces were near the bottom with more narrow terraces near the top of the zone. This was not the case in every terraced zone, some benches were much more uniform in size throughout the entire area. This lack of uniformity suggests that the terraces were not built all at once, or necessarily by the same group of people, rather they were individually constructed to suit environmental or cultural requirements.

Relief is another variable in terrace form that had great variation. Terraced slopes had an average of 7.06 meters with a range of 1.03 meters ranging up to 26.88 meters. These numbers are likely skewed due to observation bias in the LiDAR data better representing the zones with many platforms versus smaller single or double platforms. Still, this drastic variation in the height of terraced zones produces some interesting observations.

With some zones having a range up to 26.88 meters high, ease of access comes into question. Some terraced zones clearly have roads running through the center of them allowing for unproblematic access to whatever crops may be growing in that region. However, roads do not show up in the LiDAR data through the terraced zones in all cases. This means that some zones would have less access for daily or easy crop maintenance. This could have several implications: first, different crops could be grown in these differing zones. Crops such as maguey do not require daily upkeep and do not reach maturity until 7-25 years (Parsons and Parsons 1990). After that point harvesting is a bit more intensive, however, it would make logical sense to leave plants that need not be attended daily at harder to reach areas such as high relief terraces.

Another possibility for cropping these high relief areas is sloped orchards. Crop trees generally require little maintenance, take several years before they reach maturity, and are harvested only a few times a year. Evidence of this type of agriculture is visible on the malpaís contemporarily. Satellite imagery as well as the LiDAR data show that orchards are being planted on the steep slopes of the edge of the malpaís for at least the past few years (Figure 49).

Figure 49: Google Pro satellite and LiDAR imagery showing sloped orchard planting on the edge of the malpaís. Top image Source: 19°36'52.97" N and 101°29'26.15"W. Google Earth. 12/31/2020. See appendix A for geospatial metadata and PRRIM visualization information***.*

The agricultural terraces that were only a few platforms high, were much easier to access. Thus, crops that needed constant servicing, either in the form of pruning or harvesting were likely planted on these features. These could have included tomatoes, chilies, or beans. Other important crops such as maize and amaranth require harvesting every 2-3 months, thus need mid-range access and could be grown in any terraced location.

3. Location of Terraces

There are three main zones on the malpaís that contain terraces, and they are clearly defined. These include, the upper zone of the malpaís, the lower zone of the malpaís and the edges of the malpaís. The upper zone contained 11 tiles with 19,827.33m^2 of terraces and the lower zone contained 12 tiles with 25,930m^2 of terraces. In terms of area, these zones are very similar. In regard to association with architecture and features, the zones were not analogous, except for one shared trait: almost all of the terraces in the upper and lower zones are located directly on roads (Figure 50). In both cases this speaks to public access. It does not necessarily mean that all of the terraces were public domain, but it does suggest that there was not the need for authoritative restriction to these zones. This data implies that there is likely not political or state control over the agricultural resources located at Angamuco.

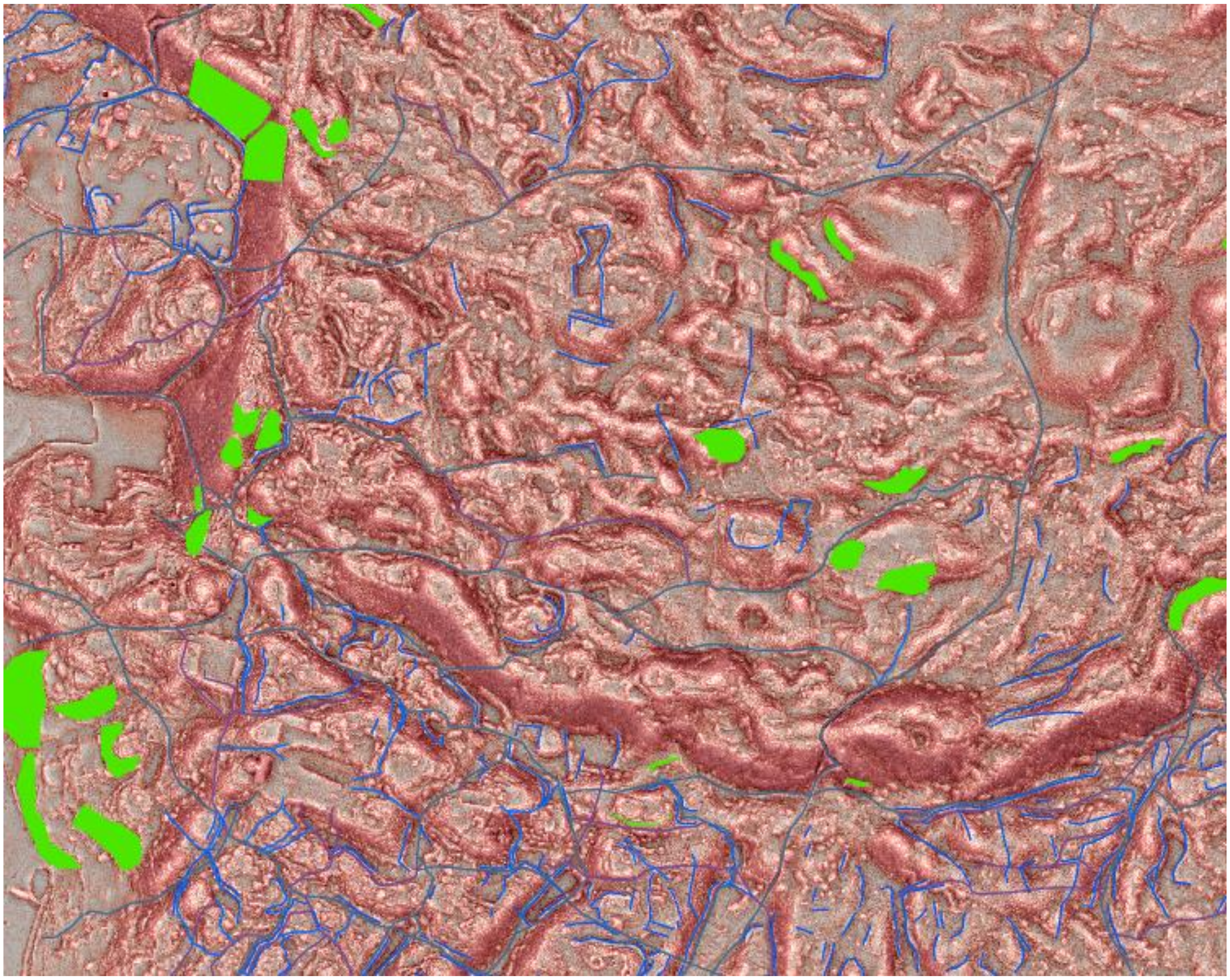


Figure 50: Terraces bordering roads. Road shapefile from Solinis-Casparius. See appendix A for geospatial metadata and PRRIM visualization information***.*

3.1 The Lower Zone

The lower zone had terraces that are directly associated with architecture, both monumental and residential. The cause of this could have two different interpretations. The first, is that because of the density of architecture in this zone terraces are built wherever there is space and proper topographic variation, therefore terraces are forced to have direct association with other features and could still be public. The second interpretation is that terraced zones are directly related to, owned, or maintained by the occupants who live near them. Residential structures such as walled complejos and the residents who lived there could have owned associated terraced zones, making them private. One example of this can be found in tile BZ146. Here you see three walled complex units all very closely associated with terraced zones (Figure 51). It is possible that these units were sharing the responsibility and advantages of the terraces. The same could be true with the monumental architecture: the terraced zones associated with these features could be owned and *operated* by religious officials or administrative elites.

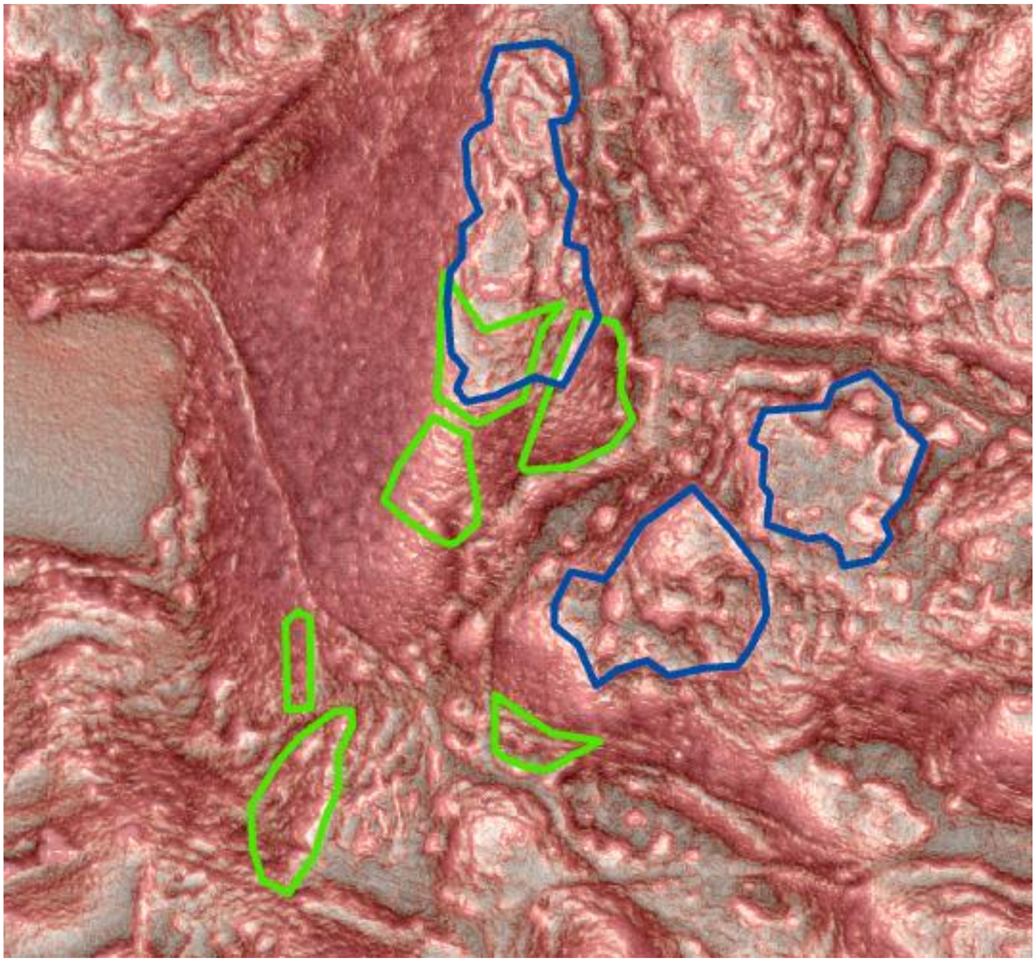


Figure 51: Walled complejos outlined in blue, shapefile provided by Louise Steele, and terraced zones outlined in green. See appendix A for geospatial metadata and PRRIM visualization information***.*

One unique example of association of household architecture, monumental architecture and terraced slopes can be found in square BU147. Located here there is a pyramid located directly off of a main road lined in blue, an attached priests quarters circled in green, with terraces, outlined in black, lining the plaza of the casa de papas (Figure 52). Access was likely tightly controlled to these specific terraces. This demonstrates direct access, ownership and operation of these terraces. Furthermore, the crops grown here were likely some sort of elite or ritual crop due to the direct association with priests and a pyramid, rather than basic subsistence goods.

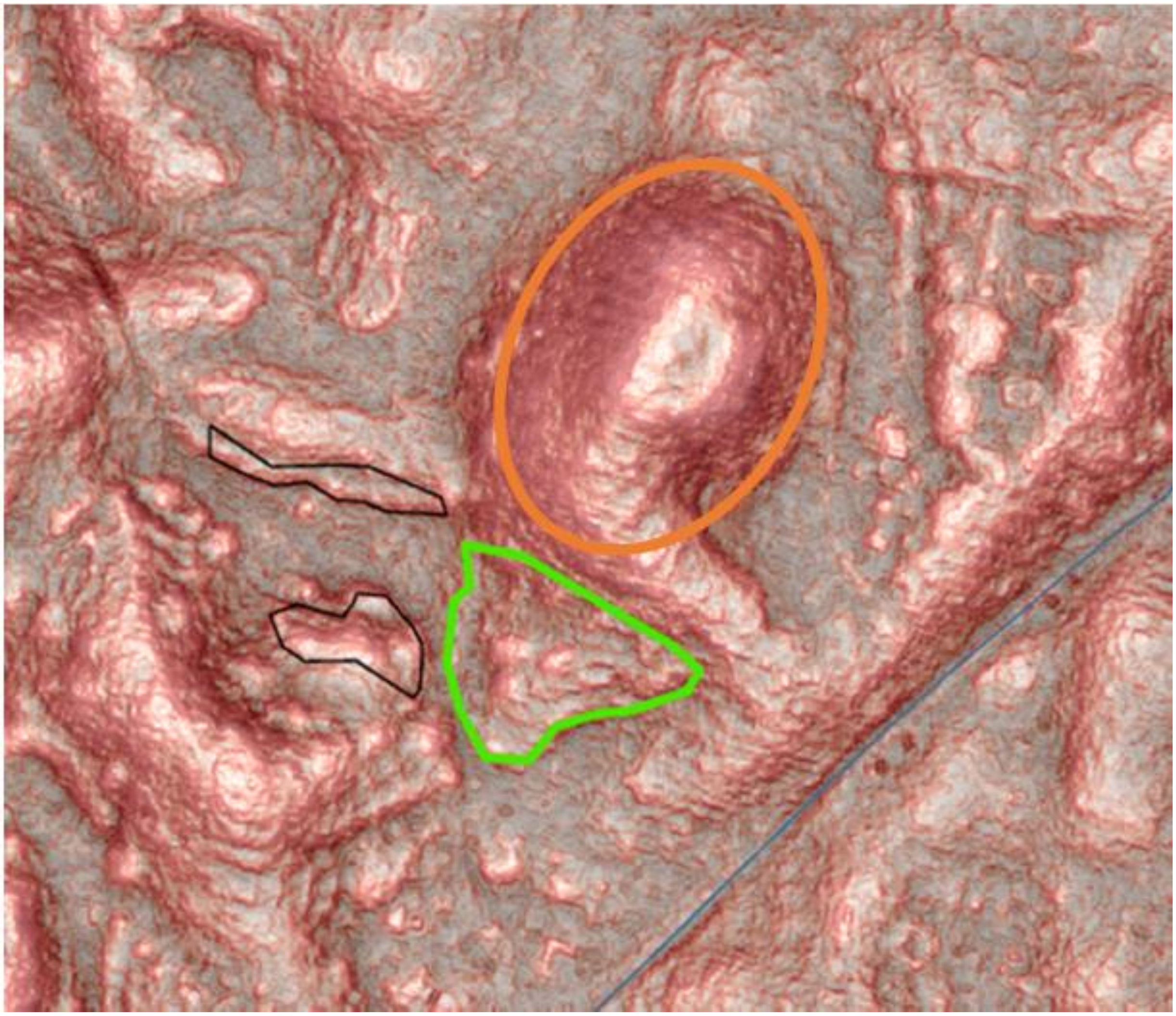


Figure 52: Pyramid (orange circle) off the main road (blue line), associated casa de papas (circled in green), with terrace line plaza (outlined in black). See appendix A for geospatial metadata and PRRIM visualization information***.*

3.2 The Upper Zone

The terraced areas on the upper zone of the malpaís have different spatial orientations and associations. There are some residential structures with associated or nearby terraced areas. These structures are square based edificios. They are ground based features with more than two walls. There are three types: type A has 3 walls and an open side, and type B and C have four walls with a small opening, likely an entrance to the building. These typologies represent residential contexts (Fisher et al. 2019). All three of these types of buildings are located near terraces on the upper zone of the malpaís. In addition to the Edificios, there are a number of circular platforms directly near terraces (Figure 53). The sizes of these range from 1m-6m. The smaller platforms less than 1m-3.5m likely served as granaries or cuexcomates (Ahrens 2013). However, the function is unknown for the larger circular platforms, 5 or more meters in diameter (Fisher et al. 2019). It is possible that these represented a different form of residential homes as well.

Figure 53: Terraces lined in green, circular platforms outlined in black. See appendix A for geospatial metadata and PRRIM visualization information***.*

3.3 The Edge Zones

The edges of the malpaís represent the most substantial differences in terraces from anywhere else on the site. The first difference is the total area; the edges of the malpaís have almost three times as much terraced area as the upper and lower malpaís combined at 132,473.73m^2 in only 23 tiles. This area represents an important contribution to the overall agricultural framework of the city. The entirety of the edges does not seem to have evidence of terraces, but a large majority were likely being exploited due to their advantages of an increase in arable land, nutritional soil, and potential for irrigation.

Natural rainwater runoff will go directly to the edges of the malpaís bringing with it eroded soil and nutrients. This natural process is shown in the watershed pictured in Chapter 5. On top of natural runoff, the residents at Angamuco were certainly manipulating the water landscape through canals and catchments. While much of this built landscape has been degraded through the centuries there is still evidence of these features in some areas, both moving towards the edges of the malpaís and going over the sides (Figure 54).

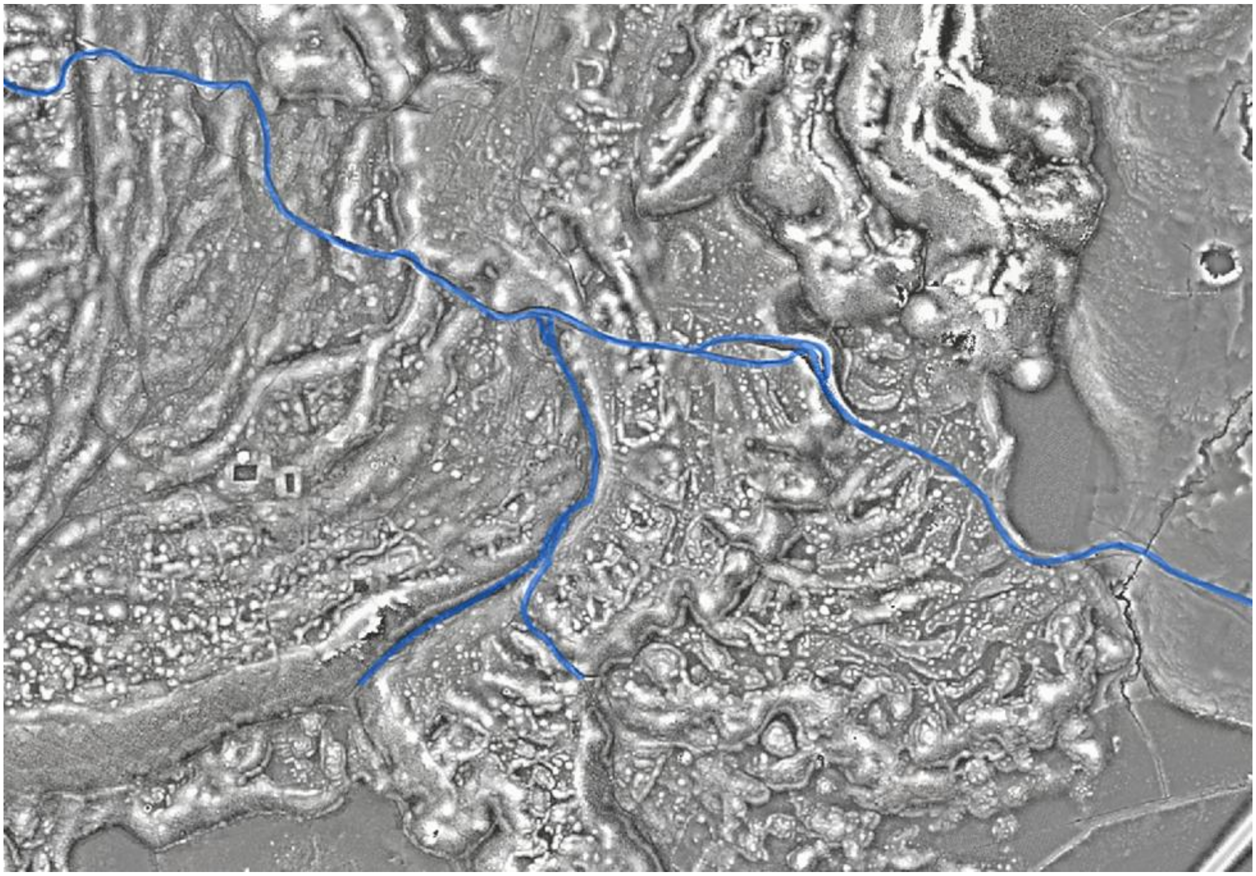


Figure 54: Canal outlined in blue showing the movement of water from the center of the malpaís to the eastern edge. See appendix A for geospatial metadata.*

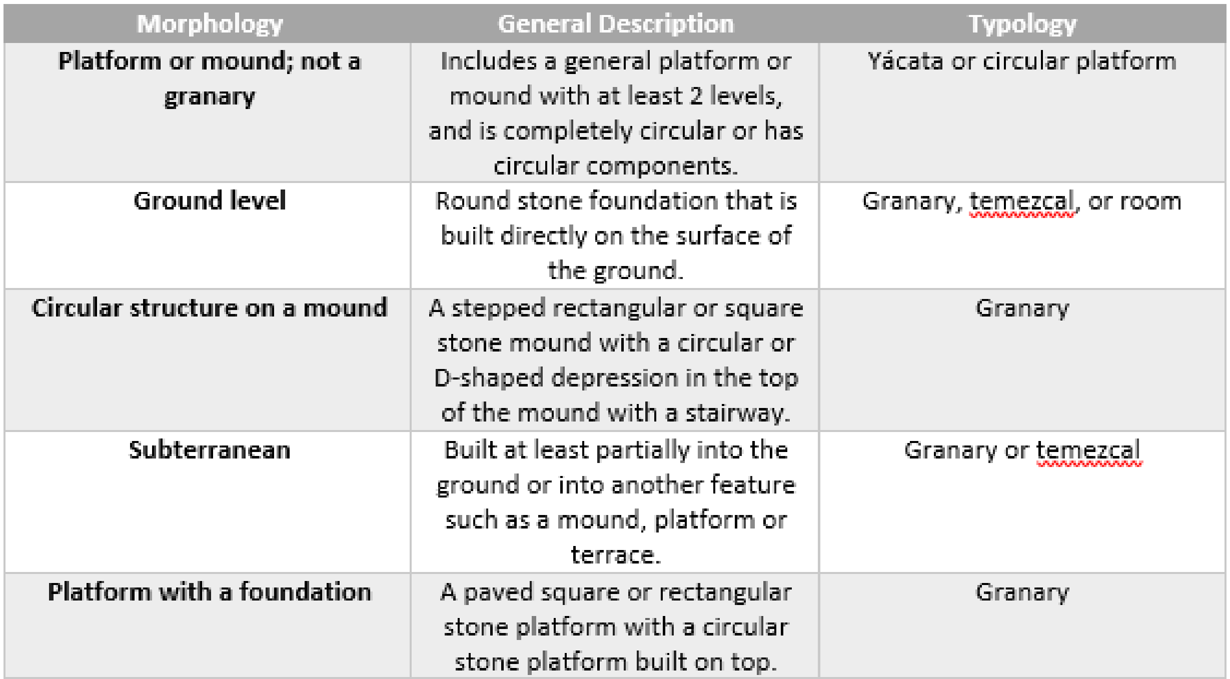
4. Granaries

Granaries or cuexcomates were used in the initial analysis of establishing presence or absence of terraced zones. The methodology for identifying these features was created by Ahrens (2013). Using data gathered from two seasons of survey, 2010 and 2011, in addition to the 2013 excavation season, Ahrens was able to identify 296 circular features, of which 286 were possible granaries measuring between ≤3.5 meters in diameter to ≤ 7.5 meters in diameter. The majority of these features fell in the ≤3.5 meters zone (Figure 55). All of these features are located on the lower portion of the malpaís, as that is currently the only portion of the site that has been surveyed and excavated.

Figure 55: Photo of a granary located during survey. Copyright LORE-LPB Angamuco 2011.

For the purpose of this thesis, I will use Ahrens (2013) definitions of morphology, function, and control to better understand the granaries associated with the terraced zones at Angamuco. The morphologies of these features are summarized in the table below (Table 6).

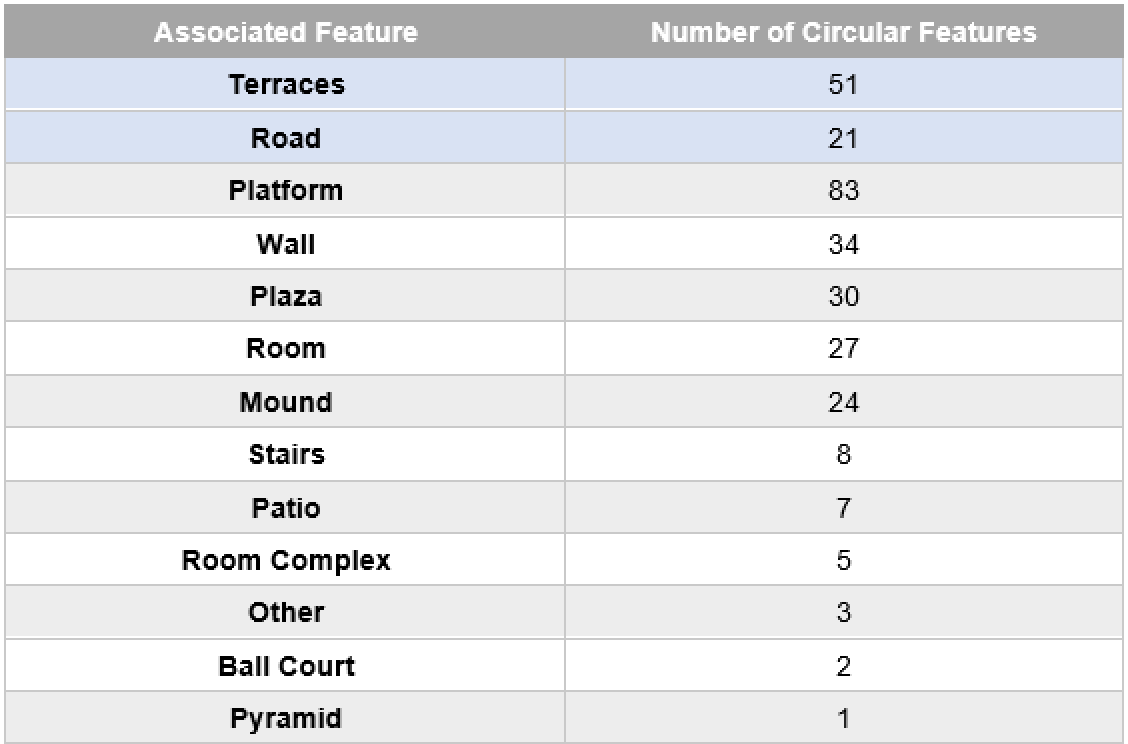
Table 6: Descriptions of circular features at Angamuco, adapted from Ahrens (2013)



Morphology	General Description	Typology
Platform or mound; not a granary	Includes a general platform or mound with at least 2 levels, and is completely circular or has circular components.	Yácata or circular platform
Ground level	Round stone foundation that is built directly on the surface of the ground.	Granary, temezcal, or room
Circular structure on a mound	A stepped rectangular or square stone mound with a circular or D-shaped depression in the top of the mound with a stairway.	Granary
Subterranean	Built at least partially into the ground or into another feature such as a mound, platform or terrace.	Granary or temezcal
Platform with a foundation	A paved square or rectangular stone platform with a circular stone platform built on top.	Granary

Using proxies from other archaeological and ethnographic contexts as well as excavation at Angamuco, function was defined as storage for maize in different contexts including husk on cobs, husked cobs, and shelled maize, each having a different shelf life according to technique and climate (Ahrens 2013, Smyth 1991). Control of these features is largely defined by access and archaeological context. Ahrens (2013) found examples of both publicly and privately accessed granaries, though there were zero examples of dual access granaries. The following table summarizes the contexts and nearest neighbor for each of the granaries that were located during Ahrens (2013) analysis (Table 7).

Table 7: Associated nearest neighbor feature to circular features. Adapted from Ahrens (2013).



Associated Feature	Number of Circular Features
Terraces	51
Road	21
Platform	83
Wall	34
Plaza	30
Room	27
Mound	24
Stairs	8
Patio	7
Room Complex	5
Other	3
Ball Court	2
Pyramid	1

In my analysis of terraces at Angamuco, I located features determined to be granaries in 36 of the 46 terrace positive tiles. The remaining 10 tiles are not necessarily excluded from containing storage features, as granaries such as subterranean types have poor preservation, and often are not recognizable in either LiDAR data or pedestrian survey. The majority of these were in the 3-5-meter range varying slightly from Ahrens (2013) findings, likely due to observational bias in the LiDAR analysis (Figure 56). The direct associations of these granaries also varied from residential contexts, public access, and association with monumental architecture. From the limited information available through remotely sensed spatial data it seems that the majority of these features can be easily or publicly accessed.

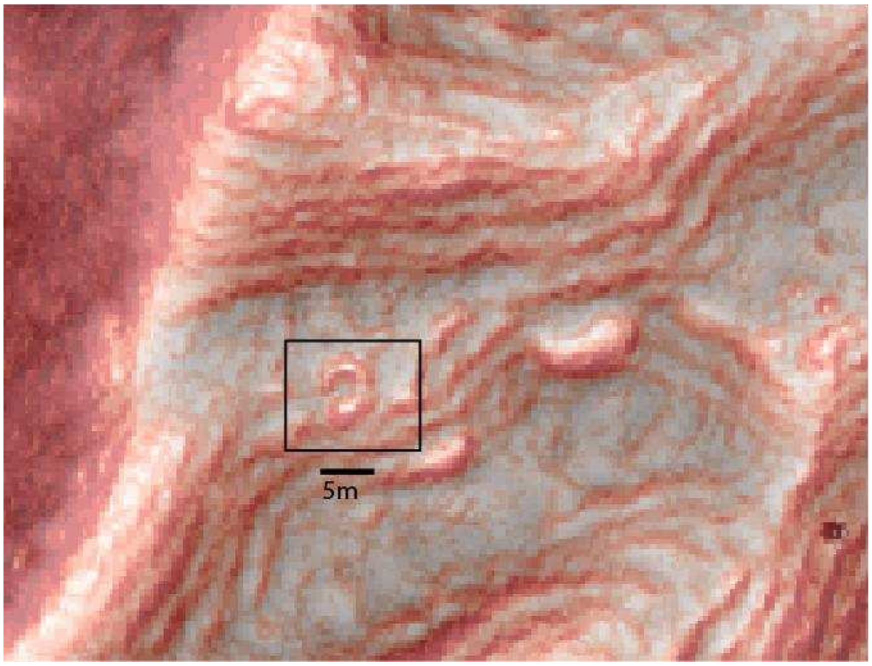


Figure 56: Large granary, 5.62 meters in diameter, clearly visible in the LiDAR data. See appendix A for geospatial metadata and PRRIM visualization information***.*

Cluster analysis of survey data showed that there are significant areas of grouped granaries across the lower portion of the malpaís. One specific example is located on the ridge that separates the Zona Baja and Zona Alta. Here there are 12 granaries all no further than 5 meters apart and have no restricted access (Ahrens 2013). Another example of this type of clustering of granaries can be found in the Zona Alta. Between a group of terraces and potential monumental architecture (Figure 57), lies a line of rounded features all between 3-5 meters and grouped closely together (Figure 58). Both sets of these granaries likely represent public storage facilities.

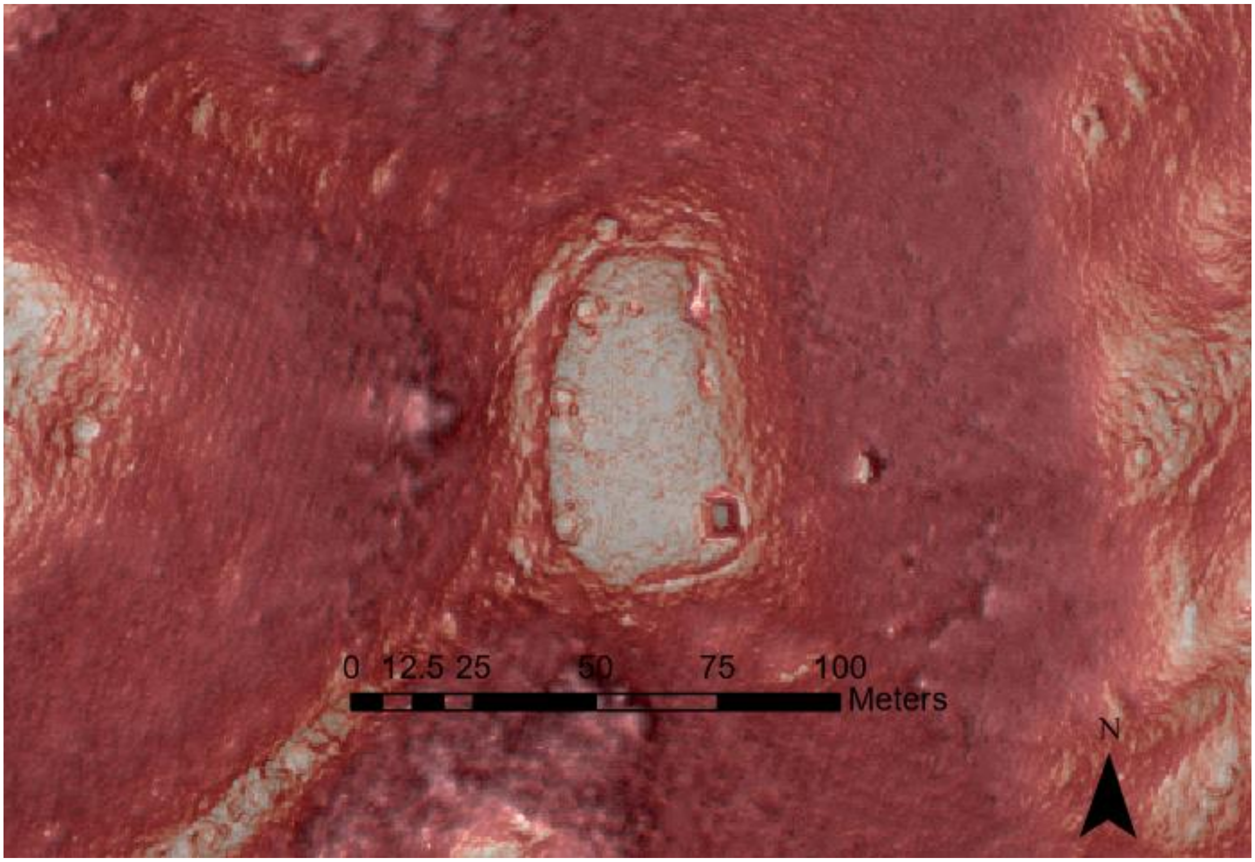


Figure 57: Monumental architecture, large sunken oval plaza, located on the upper malpais. See appendix A for geospatial metadata and PRRIM visualization information***.*

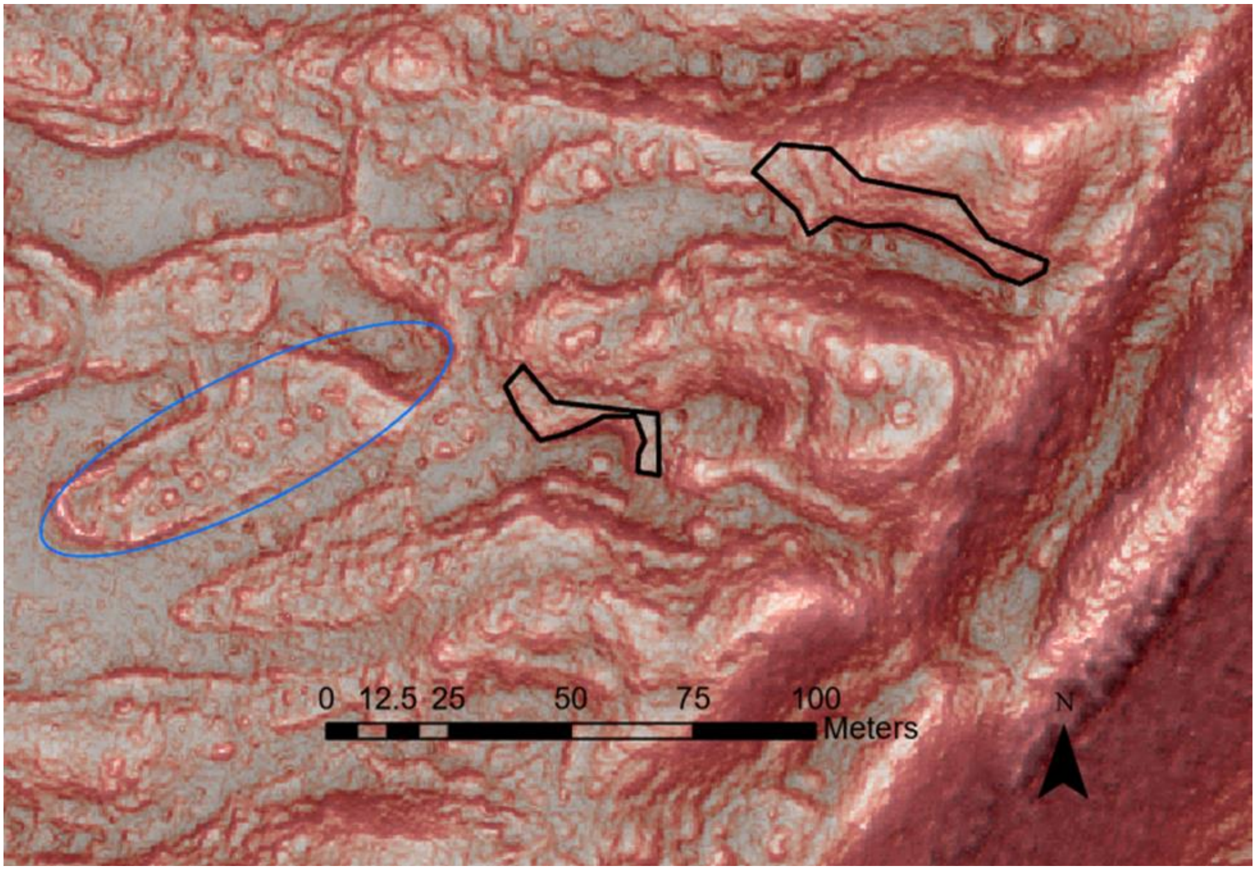


Figure 58: Terraced zones outlined in black with associated clustered granaries on a platform circled in blue. See appendix A for geospatial metadata and PRRIM visualization information***.*

Terraced zones that are directly related to residential architecture also have associated granaries. These are likely privately owned either by individual families or groups of families. It is estimated that one granary could sustain a family for an entire year. These granaries are certainly not the only option for food storage or access and thus can represent substantial surplus or wealth.

5. Productivity Models

5.1 Crop Yields

Productivity models and crop yield estimates offer a compelling look at the lives of past people in an archaeological context. However, using these sorts of models can be problematic in some contexts. Using current proxies such as weather, soil type or even crop genomes are not necessarily representative of the past. Any reproductions such as the one presented in this thesis can provide a baseline of information, but certainly will not tell the whole story.

The challenging variables in this particular study are soil type and productivity increasing methods, such as irrigation and fertilization, as well as crop type. In depth analysis of soil type has not yet been conducted. We do know that the malpaís is an ancient lava flow, thus the soil type is andosol. Generally speaking, these soil types are highly productive, but we do not know the exact physical or chemical properties of the soils at Angamuco, or how these vary from the upper to lower malpaís. In addition to natural soil type, past people had many methods for increasing productivity of the land, including irrigation and fertilization. Evidence of irrigation has been located at Angamuco, and further study could drastically change the models presented here and ethnographic information has detailed the use of fertilizer for crops. There are many distinctions that could alter the productivity of the city.

The specific types of crops that were grown in the past are also unknown. The people of Angamuco certainly weren't mono-cropping maize, however, maize-only productivity models are common in archaeological studies due to the preservation of maize phytoliths and the perseverance of maize culture in many food insecure regions across the globe. It is much more likely that when growing food, a milpa system was being used in addition to many other nutritious and locally domesticated crops. An alternative theory is that urban terraces weren't being used for food crop at all, and instead were being utilized for a crop such as maguey to be used for market or ritual purposes.

As it stands the productivity estimates for the terraces at Angamuco models a two-harvest system, where the yields are very similar for both seasons. While the current model is specifically maize, many other crops follow two or three harvest systems that would likely generate the same evenly dispersed numbers. The maize calories generated from the terraces do not cover a large population, however people were not consuming all of their calories from maize. A number of other resources were being exploited including home gardens, crop trees, market resources, and meat both from hunted game and domesticates such as turkeys.

5.2 Irrigation

This analysis of terraces at Angamuco has also shown evidence of irrigation features across the city. Multiple canal like features are visible both on the malpaís and surrounding the landform. These canals move between various reservoirs and many seemingly move water to the edges of the malpaís. Several steep canals appear to directly feed the terraced edges especially on the eastern edge. While further investigation in the form of ground truthing is needed preliminary results suggest that the residents were irrigating crops at Angamuco, notably on the edges. The results of any future excavation in this area have the potential to exponentially increase productivity estimates.

6. Urban Farming

6.1 Urban Farming in Archaeology

The traditional view of early agricultural systems is that the hinterlands produce and supply cities with food and other resources. However, there is increasing evidence that some cities in Mesoamerica did in fact supply at least some, if not much of, their own agricultural products. Much of this research has come from tropical environments such as the Maya lowlands, where the term ‘garden cities’ was coined. These cities use open areas between residential or public architecture as horticultural zones. These are often comprised of raised bed garden plots and adjacent ponds (Folen et al. 1983, Tourtellot 1993). This has been further elaborated on as ‘green space’ in urban environments that could be used for garden areas or public open-air space. These could function as food sources, medicinal plantings, shade, wind breaks, or other functional uses (Stark and Ossa 2007).

The above contexts are suited well for lowland tropical environments. Rainy seasons and water control features make these garden cities possible. In a similar fashion, the environmental contexts at Angamuco make this city a possible modified ‘garden city’. The topographically varied landscape, plenty of rainfall, and canal irrigation features likely allowed residents to use green space to grow food on features such as terraces and raised bed gardens. Though this thesis focused primarily on the terraces located at Angamuco, it is very likely that past people were also using other agricultural features to their advantage in order to best benefit from their environment. Using the terraced zones alone, the residents at Angamuco could have supplied a decent amount of agricultural provisions for their families. Couple this with other urban farming techniques, families or groups of families could have provided food and market resources for themselves providing a level of economic and subsistence security that did not rely on outside variables.

6.2 Modern Urban Farming

Over the past two decades urban farming has had a resurgence in popularity and necessity. In 2017 over half of the world’s population lived in urban environments (Ritchie and Roser 2018). As more and more of the world’s population moves into urban environments, the need to have food grown and easily available in the urban centers will continue to grow. This is especially true for the global south where income inequality is high, food insecurity is common, and access to nutritious foods, such as fruits and vegetables is not always possible.

Urban farming can be organized in multiple forms including individual family operated, several families grouping together, community based, or city/organization run. This can be compared to archaeological understandings of urban farming as well. Recent studies looking at urban farming in 15 different countries in the global south showed that an average of over 30% of urban dwellers are currently participating in in some sort of urban agriculture accounting for 5-15% of total agricultural production in individual countries (Zezza and Tasciotti 2010). Other studies in individual cities around the world put those numbers as high as 80% in places such as Brazzaville, Congo (Shackleton et al. 2009). While this form of agriculture is largely being consumed within households, according to some data up to 30% of household income is also being derived from urban farming (Zezza and Tascitti 2010). Of the 800 million people worldwide estimated to be currently involved in some sort of urban agriculture, 200 million of those are deriving some sort of income from this activity (Armar-Klemesu 2000).

While the links between modern and ancient urban agriculture may not seem obvious, there are many similarities. First, the security of having readily available food for sustenance that does not rely on market resources cannot be understated in the present or the past. Second, participating in local market economies with home grown goods is a valuable way to generate an income or barter for needed resources. Third, much like current movements to urban environments, there have been many episodes of rural to urban movement in the past. These types of migrations call for reorganization of modes of production, especially agriculture. The hinterlands can be beneficial for providing some food for cities, but for economical, organizational, and plain logical reasons residents within cities will always provide some of their own agricultural resources.

7. Agrarian Smallholder Model

As discussed in Chapter 5, the agrarian smallholder model can be applied to some Mesoamerican archaeological contexts where agriculture predates state formation. Families or groups of families invest in the land where they live and work in order to contribute to generational wealth, agricultural development, and sustainable land intensification (Netting 1993). Applying this theory to urban environments has been accomplished in low-density Maya cities (Chase and Chase 1998, Fisher 2014, Stark 2012). The use of intra-settlement infield agriculture built by multi-generational households is considered one of the characteristics that led to the creation of these dispersed cities in the Maya region (Fisher 2014).

This theory has yet to be applied to different environmental regions. However, considering the spatial associations and other archaeological evidence, I believe that the built agro-urban environment at Angamuco was created through an agrarian smallholder model. The first line of evidence to support this theory is the established chronology of the site: Angamuco was continuously occupied from 250AD, for 1300 years (Solinis-Casparius 2019). The initial significant occupation of the site was at 250AD-600AD and was centered on the lower malpaís giving residents plenty of agricultural opportunities due to access to reservoirs, and fertile soil. Given the lack of a centralized or large political structure during this time (Pollard 1980, Pollard 2004), it is likely that residents would need to grow agricultural products for subsistence and trade, and that this would be accomplished through familial groups rather than managed by political entities. This initial investment would be the foundation of agricultural intensification features that would slowly build the wealth of the residents of the city.

Expansion to the upper malpaís during the Epiclassic could have been due to environmental pressures or a rapidly expanding population. Either of these would increase the need for productive and sustainable agricultural intensification features such as terraces. Again, the lack of a centralized political entity suggests that these features would be built and maintained by familial groups, for their own benefit.

The Postclassic period at Angamuco represents the most substantial occupation phase. Elite occupation is clear on the lower malpaís during this time through both monumental architecture and walled residential complexes. Associated with all of these features are terraced zones. The terraces in the most elite zones are larger in both bench width and individual zone area. They often demonstrate both architectural and agricultural capacities. Any residential architectural evidence located on terraces directly suggests familial ownership, and to a lesser degree close association of architecture does as well. The upper malpaís terraced zones are also closely associated with groups of residential structures, suggesting multiple household management of the terraces.

The second line of evidence to support the agrarian smallholder model is the fact that the terraces throughout the site of Angamuco are not uniform in size or shape. This suggests that they were built at varying times, by different groups of people, and possibly for varying functions. More uniformity in design suggests a top-down model of intensification which is not visible in the features located on the malpaís.

The initial labor investment to build terraces is high. However, if this process is undertaken by multiple families and is expanded upon throughout many generations this labor and time investment is more evenly distributed. Modern ethnographic accounts around Mexico show that multiple familial groups will trade labor investments in order to accomplish difficult construction projects in a more efficient manner (Smith and Price 1994). This could certainly be a model passed down through Purépecha tradition leading back to settlement of cities. Taken together, multiple households and several generations of families were certainly capable of building and maintaining agricultural intensification features such as terraces, and as a result would build generational wealth.

The Purépecha State formation in the Late Postclassic certainly had an effect on the city of Angamuco. Reformation of power and wealth are always associated with state formation and changes in leadership. However, it is highly unlikely that the Purépecha Empire imposed the construction of agricultural features such as terraces in a city that was already densely built and populated. The mechanics of such a feat would hardly be worth the investment, nor would the potential economic gain. It is much more likely that the Empire capitalized off of the existing agricultural features by demanding tribute in the form of agricultural products from the owners of the said cultivated landscapes.

8. Conclusion

In this chapter I have discussed the implications of the analysis completed for this thesis. There are several important points that were discussed previously that should be concisely summarized here. The first is that the physical properties of the terraces are varied and have spatial patterns relating to the location on the malpaís itself suggesting differing patterns of construction. The second point is that the terraces represent a substantial proportion of the built environment at Angamuco, including 4.13% of total area and 8.08% of the total built features, and they were all located directly on or very near roads signifying that they were a regular and omnipresent facet of day-to-day life in the past. The terraces were not necessarily all used in the same way contemporarily or even throughout time. At any point they could have been used to grow maize, a milpa crop system, or maguey, either way they contributed significantly to the culture of the city.

Chapter 8: Conclusions

1. Summary

In this thesis I have identified terraces at Angamuco, run productivity models, and discovered irrigation features across the site. These analyses have helped to provide a clearer picture of agricultural systems in this city. Agricultural systems are deeply linked with socio-political organization, and by better understanding the urban agriculture within Angamuco, I have presented models for early socio-economic patterns. Each of these analyses contribute to the larger cultural dynamics that made up the city of Angamuco.

Angamuco was a Postclassic city located in Lake Pátzcuaro Basin. The malpaís consisting of volcanic soils that the city sat on made it highly productive for potential agricultural practices. In addition to the nutrient rich soils the varied topographic nature of the city made it ripe for terracing, a form of agriculture used to increase arable land, retain moisture and prevent erosion.

While agricultural research in this region has been limited, there is evidence of extensively terraced landforms and raised field features have been documented (Fisher et al. 1999, Pezzutti 2010). These agricultural features range from as early as the Late Preclassic period to the contact period. While Angamuco's peak was during the Middle Postclassic period there is evidence of occupations much earlier than the Postclassic, as early as the Preclassic period. It is logical to assume that early inhabitants were using intensification features to grow food near their homes, just as others in the LPB were doing at the same time. The continual occupation of Angamuco for centuries and resulting accumulation of built features suggests that residents were using and building upon previous generation's landscapes, including agricultural features such as terraces.

Agricultural intensification features such as terraces take massive amounts of labor to construct initially, but take minimal upkeep once constructed. However, if a theoretical model such as the agrarian small holder model (Netting 1993) were to be adopted, multiple generations of families, or groups of families, could continually invest time and labor into constructing their own agricultural intensification features, thus cultivating the productivity of the land through sustainable practices and growing the wealth of the families.

The spatial analysis that I conducted at Angamuco found at least 712,928m^2 of terraced zones. The variability in size, shape, and location suggests that these terraces were not all built at the same time or by the same group of people. In addition to variability in size and shape, many of the terraces are located near multiple residential structures, with groupings of granaries. Furthermore, almost without exception, the terraced zones are located directly near roads, suggesting ease of access rather than political restriction to these areas. These discoveries support the agrarian small holder model for construction and ownership, at least in the early stages for these terraces.

Productivity models for the terraces at Angamuco support the idea that smaller groups of people were invested in agriculture, rather than a large power structure. With caloric estimates of 3950kg per hectare of dried maize per year, the population estimate for this number is only 1543 people. This implies that the entire population was not being sustained off of these agricultural features alone, and instead either groups of families were supplying their own food resources or creating a surplus for market goods. Another possibility is that instead of using these terraces to grow food, families were growing elite crops such as maguey for ritual or market purposes.

2. Research Questions

There were four main research questions that guided the analysis for this thesis. After much investigation I am able to answer each of these questions with some clarity:

Question One: How can we identify and quantify terraces at Angamuco?

LiDAR scans of Angamuco have provided us with an invaluable dataset in which we can methodically survey the entire landscape of the city. Using GIS software and spatial analysis I was able to identify and quantify terraces across the entire site. This was of course aided by previously ground verified terraces at Angamuco. Using the parameters of these ground verified features such as area, bench width, and location I extrapolated these measurements onto other features to accurately identify terraced areas. Measurements such as total area, bench width, relief and location were all recorded and combined into a comprehensive dataset about terraces and the agricultural landscape at Angamuco.

Question Two: What is the function (what were they growing) of the terraces at Angamuco?

This cannot yet be definitively answered solely from the spatial analysis alone. Nonetheless, using spatial analysis, ethnographic records and archaeological evidence from other sites I have reached two likely possibilities. First, I created productivity models for maize because maize is a staple in the diets of many in Mesoamerica in the past and present. There is much ethnographic and archaeological evidence to support the idea that maize is an important crop for past people in LPB. However, it is much more likely that any tended agricultural fields at Angamuco or elsewhere in LPB, including terraces, grew milpa crops. Milpas can be a mix of many different types of crops that are often mutually beneficial both for growing processes and nutritionally complimentary.

The other likely candidate for terrace crops at Angamuco is maguey. Maguey was an important elite good used for many purposes in the LPB. Ethnographic evidence discusses the extensive use of pulque by elites. In addition to pulque or aguamiel, maguey can also be used for fiber making it a valuable, multiuse crop. Maguey does take many years to mature, and while it is growing needs little maintenance. This makes it an ideal crop to be tended to over multiple generations, again supporting the agrarian smallholder model.

Question Three: When were the terraces built? Is there evidence of multiple stages of construction or were they built at the same time?

Both the spatial patterning and the structure of the terraces suggest that they were not built in one successive stage. Instead it is more likely that they were built either at varying times or by different groups of people. It is possible that the variation in size and structure of terraces is somewhat influenced by environmental factors; however, there is variation in size and structure in similar environmental contexts, such as the upper and lower malpaís. The differences in the terraces suggests that there was not a top down approach to building these features, and instead was a bottom up process, led by individual circumstances.

Question Four: Who is responsible for the construction, maintenance, and economic gain of the agricultural features at Angamuco?

The first two research questions offer part of the answer to this question. As previously stated, the evidence points to a bottom up strategy for the initial construction of the terraces at Angamuco. The maintenance and control of these features was presumed to remain in the hands of smallholder groups, at least for early occupation of the city. These could have been used to provide food for families or provide market resources. The peak of occupation of Angamuco was during the Middle Postclassic, at which time the city was densely built and occupied. The density of occupation, public access to terraced zones on roads, and grouping of storage features still suggests a lack of political control over these resources.

With the formation of the Purépecha Empire in the Late Postclassic, there was certainly the possibility that the organization and control of agricultural resources at Angamuco was rearranged. With state formation, taxation or tribute must be paid to the ruling class, and in this case that seat was the imperial capital of Tzintzuntzan. The shift in leadership can be seen in the architecture at Angamuco, and control of many resources including agriculture likely changed hands at this point. With such a massive change in political structure in LPB, domestic and economic changes are to be expected.

3. Future Work

The work I have established here can benefit greatly from future work. First and most importantly, while geospatial work can greatly enhance archaeological understanding, it must be ground verified. Much of the site of Angamuco that I analyzed for this thesis has not yet been surveyed or even accessed by the LORE LPB team. Boots on the ground are necessary to verify many of the findings of this and other LiDAR analyses. This especially applies to the irrigation features that were detected by this analysis for the first time at the site. These must be minimally ground verified, and furthermore should be excavated.

Further excavation at Angamuco is necessary for a number of reasons, but specifically terraced zones need to be further examined. In past excavation seasons at the site, very little attention has been given to the terraced zones. Excavation can give us clues to what was being grown, the processes pre- and post-harvest, as well as who had access to these zones. Detailed information can be derived from these excavations such as soil profiles and compositions, phytolithic and palynological data, as well as radiocarbon dates. Soil documentation can provide better data for future productivity models. Plant particulates can offer direct evidence of exactly what was being grown on the terraces, and radiocarbon dates can provide chronologies for construction and use of the terraces.

In addition to groundwork at Angamuco, further hydrological modeling of the entire malpaís could prove to be useful. The preliminary hydrological work initiated for this thesis can be used to establish a baseline of water movement around the site. In depth analysis of canals and water movement over terraces is outside of the scope of this work. Results of future hydrologic modeling could drastically alter the results of productivity models at Angamuco.

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Appendix A

* Lidar Metadata:

The first LiDAR flight for Angamuco was not projected using WGS-84. This means that the first and second flights (Merrick vs NCALM) have z-values that differ by roughly five meters.

Juan Carlos Fernandez-Diaz (University of Houston/NCALM) re-projected the original Merrick data in late 2016 and merged the two point cloud datasets so the z-values match. This was not a minor effort on Juan's part.

Projection Standards

Version 1.0 04/09/17

Projection - UTM Zone 14 North

Units - Meters

Horizontal - WGS-84

Vertical Datum – WGS ellipsoidal heights

Data Collection and Processing Summary for the 2015 Mapping Project of Corrales, Michoacan

PI: Christopher Fisher

Data Collection Summary:

Collection dates, # of flights: 1 flight on March 29, 2015

Airplane and Equipment: Piper Navajo PA-31-350, N154WW, Optech Titan s/n 14SEN340

Equipment Specs: http://www.teledyneoptech.com/index.php/products/airbornesurvey/

Flight Plan Parameters: Flying height 900 m AGL (2 PIA), swath1000 m, 50% Overlap, line spacing 500 m.

Equipment Parameters: PRF: 250 kHz x 3 main, 30° x 20 Hz

GPS Reference Stations: Morelia Airport: 19.84606792 W, 1830.098 m Ellip

Requested / Collected Area:16.595 km² / 50.571 km²

Data Processing Summary:

Horizontal / Vertical Datum: WGS-84 / WGS-84 ellipsoidal heights

Projection / Units: UTM Zone 14 North / Meters

Point Cloud Tiles: 500 m x 500m tiles, 233 total in the LAS 1.2 format classified as ground and not-ground returns.

First Surface Elevation Model: ArcGIS FLT @ 2 meter resolution. Anga2_GEF20.flt

First Surface Hillshade: ArcGIS ADF @ 2 meter resolution. Anga2_HEF20

Bare-earth Elevation Model: ArcGIS FLT @ 2 meter resolution: Anga2_GEG20.flt

Bare-earth Hillshade: ArcGIS ADF @ 2 meter resolution. Anga2_HEG20

Conventions Followed:

Flight Line Numbering: The flight number assigned to each of the returns contained on the .LAS tiles has been encoded with four digits #### (i.e. 1012). Where the first digit corresponds to the Titan Channel (1: 1550, 2: 1064, 3: 532 nm) and the next three digits correspond to the sequential order of each flight strip ranging from 037 to 049.

PC Tile Naming: The 500 m tiles follow a naming convention using the lower left coordinate (minimum X, Y) as the seed for the file name as follows: XXXXXX_YYYYYYY. For example if the tile bounds coordinate values from easting equals 556000 through 556500, and northing equals 3769000 through 3769500 then the tile filename incorporates 556000_3769000.

ArcGIS Products Naming: Due to the limited number of characters that can be used for ArcGIS data products the following format was followed: NNNNN-TWR##. Where “NNNNN” correspond to the 5 letter identifier for the project area; the seventh character “T” represent the type of raster and it can be an “G” for a grid or “H” for a hillshade; the eight character “W” represent what kind of data was used to create the raster and it can be an “E” for elevation or an “I” for intensity; the ninth character “R” represents the type of return that was used for creating the raster and could be a “F” for First return or “G” for ground return, the last two characters “##” represent the raster resolution in decimeters.

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Digital Elevation Model of Angamuco for this thesis created using LiDAR base files (see above) processed from the .las files and projected into UTM Zone 14N using Global Mapper by Blue Marble. The .las point cloud data was cleaned to include only last returns/ground returns. A triangulated irregular network with a .25m grid was built from these returns and then exported as a float/grid file to be used as the DEM in other geospatial software.

** Patzcuaro Basin Wide DEM

Digital Elevation Model Creation:

ALOS PRISM data, with pixel size of 2.5 meters, was used to develop a high-resolution digital elevation model for the Lake Patzcuaro lake basin using photogrammetric methods. The scenes used were ALPSMB20431(frame 3255, 3260, and 3265), collected on November 24, 2009. The scenes are oriented in the fore, aft, and nadir look position, so that maximal overlap of the scenes was achieved. 60 well distributed ground control points were collected using Differential GPS (horizontal accuracy +/- ½ m, vertical accuracy +/- 1m) units. 11 were used as ground control points in the digital elevation model (DEM) development process and 49 were held back and used to assess the accuracy of the DEM. Leica Photogrammetry System (within ERDAS Imagine) was used to generate the DEM. The DEM was generated to a pixel size of 2.5 m by 2.5 m, the pixel size of the original ALOS PRISM data. At the suggestion of the Space Archaeology Program Manager we requested that the Alaska Satellite Facility (ASF) create a DEM for the same area using similar ALOS PRISM data. ASF uses state of the art software and creates DEMs for production purposes and for use by other scientists and organizations. We then compared our results to the ASF produced DEM. The average vertical error of our DEM is +/- 2.4 m, the ground truth point with the least error has an error of +0.06 m and the largest error is -12 m. The ASF DEM's average error is 11.31 m, the ground truth point with the least error has an error of 0 m and the largest error is 16.83 m. Overall the DEM that we were able to produce appears to be more accurate and have less vertical error than the ASF produced DEM. The DEM is registered to the WGS 84 Datum.

***Pseudo-Red Relief Image Map (PRRIM)

Pseudo-Red Relief Image Map created using LiDAR base files (see * above) and methodology developed in Harris (2019).

****Hillshade Raster

Hillshade raster created using the LiDAR base files (see * above) and 3D Analyst toolbox in ArcGIS Pro from ESRI.