I, Ezgi Akpınar, hereby submit this original work as part of the requirements for the degree of Doctor of Philosophy in Geography.

It is entitled:
**Aguadas: A Significant Aspect of the Southern Maya Lowlands Water Management Systems**

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AGUADAS: A SIGNIFICANT ASPECT OF THE SOUTHERN MAYA LOWLANDS WATER MANAGEMENT SYSTEMS

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Abstract
The studies of water management in Maya cultural regions constitute an integral part of our understanding of ancient Maya Civilization. Aguadas, as ancient Maya water management features have been an understudied aspect of Maya water management systems. In this dissertation, it is proposed that recognizing the origins and the function of aguadas will help us obtain a more complete picture of ancient Maya water management strategies. Overall, the dissertation aims to synthesize the available archaeological and environmental investigations of aguadas, in addition to adding my own original work.
The three research articles presented here seek to understand varied uses of aguadas. Articles 1 and 2 focus on my own paleoenvironmental aguada investigations done under the supervision of Dr. Nicholas Dunning in Guatemala and Belize. Article 3 brings forward a synthesis of Maya Lowland aguada studies that took place between 1930s and the present. The research articles contribute to the advancement of Maya archaeology by: 1) providing a better understanding of aguadas within ancient Maya water management systems; and 2) placing aguadas in the broader framework of the cultural ecology and geography of the southern Maya Lowlands.
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1. Introduction

1.1 Statement of Problem

The study of water management in the Maya cultural region constitutes an integral part of our understanding of ancient Maya civilization. My focus area, the southern Maya Lowlands, covers an area of about 68,000 km² including Belize, central and northern Guatemala, and the neighboring areas of Mexico and Honduras (Scarborough, 1993). Sometimes, the southern Maya Lowlands are divided into two areas by Maya scholars, namely Central Lowlands and Southern Lowlands (e.g. Sharer, 1994, Beach et al., 2008). In this dissertation they will be treated as one territory.

The southern Maya Lowlands was home to some of the most important Preclassic and Classic Maya sites, such as Calakmul, El Mirador, Nakbe, Tikal, Caracol, Seibal, and Copan. Much of the region is characterized by a widespread deficiency of surface water due to its karst landscape and a dry-wet climatic regime (Scarborough, 1993). As a result of its unique environmental parameters, the southern Maya Lowlands necessitated a variety of ancient Maya water management adaptation strategies. Among the site specific water management adaptations, man-made or natural aguadas have been observed in addition to also being ubiquitously present in other Maya regions (e.g., northern Maya Lowlands). The word *aguada* in Spanish denotes a “watering place.” The Yukatek Maya term *akal* can also refer to aguadas. The words *tz’onen* or *dzonot* or the Spanish word *cenote* stands for steep-walled exposed water feature that reaches below the water table. Cenotes should not be confused with aguadas.

In general, studies of the Maya Lowlands provide a variety of descriptions for aguadas. They range from “less permanent pools that are ancient cenotes with sloping sides” (Cole, 1910) and “broad shallow depressions” (Flores-Nava, 1994; Monroe, 1970; Matheny, 1976) to “small dissolution dolines” (Beach et al., 2008), etc. However, it should be noted that the origins of aguadas are usually difficult to discern without an excavation and using a blanket statement to describe them may be inaccurate.

It is proposed in this dissertation that recognizing the origins and the function of aguadas will help us obtain a more complete picture of the ancient Maya water management strategies, as aguadas have been an understudied aspect of these systems. In this dissertation, I aim to bring
forth a synthesis of the available archaeological and environmental aguada investigations, in addition to adding my own original work on aguadas, in order to help develop a better understanding of aguadas as water resources. However, it should be pointed out that large areas of the southern Lowlands have remained unsurveyed at the onset of the twenty-first century (Johnston et al., 2001). As a result, many aguadas continue to be unstudied to this day.

The three research articles presented as a part of this dissertation concentrate on different functions of aguadas. Article 1 specifically discusses paleoenvironmental research conducted at four aguadas around two adjacent Maya sites, San Bartolo and Xultun in Petén, Guatemala. Both San Bartolo and Xultun were established during the Preclassic period. However, the fates of the two sites differed, as Xultun continued to prosper while the city of San Bartolo was abandoned near the close of the Late Preclassic period. In Article 1, we show that the study of aguadas can provide important clues for understanding the fate of ancient sites, such as San Bartolo and Xultun, and likely many others in the Maya Lowlands.

Article 2 focuses on Aguada Elusiva, a small aguada close to the ancient Maya site of La Milpa. The aguada was investigated initially by Dr. Nicholas Dunning’s research team in 2003, with continued interdisciplinary research in 2008, 2009 and 2010. The article presents the results of this cumulative work. The methodology involved the excavation of the interior and the periphery areas of the aguada, as well as a core sample taken from the aguada’s floor for pollen and sediment analysis. Article 2 reveals that Aguada Elusiva was an important water source for the local Ancient Maya population based on its multiple-resource use.

In the final article, Article 3, a list of the available aguada investigations starting with studies from 1930s was compiled, focusing particularly on the southern Maya Lowlands. The sample studies were analyzed and synthesized in order to develop a comparative framework for understanding aguadas as vital ancient water resources in Maya Lowlands. Our results show that a great variation exists among aguadas, including wide ranges in size, shape, and location. Yet, we find that aguadas were clearly of great importance to the ancient Maya and focused investigation of these features is called for. Aguada studies are also important for scientists for the paleoenvironmental information still locked in the aguada sediments.
In summary, Articles 1 and 2 focus on my own paleoenvironmental aguada investigations done under the supervision of Dr. Nicholas Dunning with an interdisciplinary team of researchers. Article 3 brings forward a synthesis of aguada studies that took place between 1930s and the present. With the findings presented from these research articles, this dissertation hopes to contribute to the advancement of Maya archaeology by: 1) providing a better understanding of aguadas within ancient Maya water management systems; and 2) recognizing aguadas in the broader framework of cultural ecology and geography of the southern Maya Lowlands.
2. Literature Review

2.1 Study Area

The southern Maya Lowlands extend from parts of the Yucatan Peninsula into the lower elevation areas of Central America. The corresponding latitude and longitude for the region is roughly from 15 to 19° N latitude, 88 to 92° W longitude (Harrison, 1993; Beach et al., 2008) (figure 1).

Figure 1. Southern Maya Lowlands with some of the major Maya sites.
The Yucatan Peninsula, where Southern Maya Lowlands is situated, was subjected to two geologic forces events of profound significance—an asteroid crash at Chicxulub (Cretaceous, 65 Mya), and the position, placement, and movement of two crustal blocks (Maya and Chortis) - impacting the sedimentary history, landscape morphology, and the groundwater flow in the region (Dunning et al., 1998a; Graham, 2003). Differential solution in the area surrounding the Chicxulub crater, for instance, has resulted in numerous small sinkhole lakes (cenotes and aguadas), locally known as the “ring of cenotes” (Hodell et al., 2005).

The Maya Block, where much of the southern Maya Lowlands is situated, was a shallow marine platform through most of its history. The carbonate sediments and coral reefs in this depositional environment formed the limestone matrix which was later shaped and weathered into the karst topography that characterizes the region today (Graham, 2003). It is estimated that 40% of Central America’s karst is found in the Petén Department of Guatemala, and neighboring parts of Belize and Honduras (ie. much of the southern Maya Lowlands). The karst found in the region is heterogeneous, shaped by distinct environmental factors (Day, 2007). Some of these factors have been tectonic movement leading to folding and faulting, periodic climate and sea-level changes, and human impacts (Dunning and Beach, 1994; Dunning et al., 1998a; Kueny and Day, 2002; Day, 2007).

The karst landscapes had significant implications for the Ancient Maya. Due to longterm weathering, karst landscapes have been transformed into a rugged territory defined by ridges, conical hills, and uneven depressions—called bajos (also known as poljes in karst terminology) (Dunning et al., 2003). Further, the solution of calcium in the sedimentary rocks of the region through rainwater or groundwater led to the development of hollows, openings and depressions (Wilson, 1980). Naturally occurring aguadas in the Southern Maya Lowlands are attributed to this geomorphic transformation. Topographically, the Sierrita de Ticul range forms a border between the flat pitted karst terrain of the northern Yucatan Peninsula and the hilly karst terrain towards the south (Marshall, 2007). Elevation, soil depths, and precipitation, as well as broad and shallow depressions filled with water (aguadas) increase as one moves towards south of the Sierrita de Ticul (Flores-Nava, 1994).

The carbonate rocks of the Maya Lowlands vary from “older pure, dense, hard, fractured, crystalline limestones to different types that are altered from their original formations, to young
impure, powdery, soft, porous and amorphous carbonates” (Day, 2007). Geologically, limestone forms the majority of the southern Maya Lowlands (Middleton and Waltham, 1986). The oldest rocks are found in the southern and the central parts of the Yucatan Peninsula and date back to the Paleocene-Eocene periods. They compose a tectonically stable matrix despite the plates and faults of the Cretaceous to early Tertiary eras. The limestone found in the region is also observed to be highly fractured, permitting the storage and flow of underground water between the open areas of the rock’s formation, leading to few available surface water resources (Villasuso and Ramos, 2000). Some of these geological discontinuities also control the distribution of springs in the Maya Lowlands. The ancient Maya took advantage of them wherever they were available (Johnston, 2004).

Climatically, the Maya Lowlands have a wet and dry seasonal pattern and fall into Köppen Am (Tropical Monsoon) and Aw (Tropical Wet and Dry) classifications depending on location. The major difference between the two regimes is the length of the dry season, which is more prominent towards north of the Yucatan Peninsula (Foster and Turner, 2004). Rainfall in the Maya Lowlands varies spatially as a result of latitude, elevation and rain shadow (Beach et al., 2008), and interannually due to regional and global climatic dynamics (Hodell et al., 2001; Brenner et al., 2003; Mueller et al., 2009). In the Petén, for example, precipitation shifts from 900 to 2500mm, with a regional annual mean of 1600mm (Rosenmeier, 2002). Furthermore, annual precipitation is largely affected by shifting atmospheric pressure belts, and prevailing winds (Piperno and Pearsall, 1998; Kueny and Day, 2002). The northward migration of the Inter Tropical Convergence Zone (ITCZ) and the Azores-Bermuda high pressure stimulates heavy rains in the lowlands between the months of June and October. During November and December, the low-sun season, dry weather conditions are displayed as ITCZ, and Azores-Bermuda move toward the Equator with strong trade winds becoming predominant. A distinct dry season is established from the months of January to May in the region (Rosenmeier et al., 2002; Encyclopedia Britannica, 2010).

Hydrologically, the region is defined as an “open basin” (Villaruso and Ramos, 2000). Surface and spring-fed rivers drain the margins of the southern half of the peninsula, while perennial surface water is nearly absent, and the groundwater is largely inaccessible due to increasing underground water depth in the elevated karst interior of the southern Maya Lowlands
Groundwater discharge along the margins of the elevated interior parts feed coastal river systems. The main rivers in the region are the Rio Hondo and Belize River in the east, and the Usumacinta and San Pedro Rivers in the west. Besides these few important river systems, lakes and small depressions make up some of the most important surface water formations available to the local populations (Leyden, 2002). Ponors (swallow holes) and perforations on bajos’ lower margins also help drain the water out from the lowlands during the rainy seasons (Siemens, 1978). For the most part, bajo hydrology remains “little understood” (Wahl et al., 2007). In order to understand the hydrology of the ancient Maya period, Dunning et al. (1998a) maintain that better modeling of past climate and sea-level changes, as well as understanding the regional and the hydrogeology of the region is necessary.

Soils in the southern Maya Lowlands reflect the limestone parent material, drainage characteristics of the area, and “panregional” climatic factors (Dunning et al., 1998a; Dunning and Beach, 2000). In the southern Maya Lowlands, soils are generally deeper than in the northern Lowlands (Dunning et al., 1998a). In the bajos, weathering of the bedrock results in the deposition of montmorillonitic clays that produce an impermeable layer seen ubiquitously in the formation of Vertisols (Wahl, 2005). Besides Vertisols, Mollisols and Histosols (organic mucks) additionally exist. These deeper soils, often fertile, are exposed to argilliturbation (shrink-swell) and considerable drainage limitations. In the limestone uplands, soils consist of fertile, but shallow clayey Mollisols or Rendzinas. These soils are prone to erosion due to their general location on sloping surfaces (Siemens, 1978; Dunning et al., 1998a). Soils found around and associated with aguadas range from thin, highly erodible, arable soils to heavy, impervious clays (Lundell, 1937; Higbee, 1948; Dunning and Beach, 1994; Chmilar, 2005; Dunning et al., 2007; Akpinar-Ferrand et al. in review).

Additionally, deeper depressions lead to wetter conditions with hydromorphic clay and the formation of organic soils (Dunning et al., 1998a). Dense layers of anthropogenic sedimentary clays within basins have been collectively referred to by scholars as “the Maya Clay.” Deforestation and agricultural practices leading to accelerated soil erosion are believed to have generated this deposition (Rosenmeier et al., 2002). Many of the perennially wet bajo systems are assumed by some scholars to have turned into seasonal swamps through erosion and
deposition associated with human disturbance (Dunning and Beach, 1994; Dunning et al., 1998a; Dunning et al. 2006).

In the Maya Lowlands, sedimentation and erosion rates have been revealed through the study of lakes, bajos and aguadas. Studies of central Petén lakes have so far demonstrated that sedimentation rates increased in the Late Preclassic and in general through the Late Classic period. The significant decline in the rates of sedimentation observed after the Classic Era Maya Collapse is a likely result of reforestation (Dunning and Beach 1994). Many years of geoarchaeological work has shown 0.5 to 2 m of soil deposition above paleosols in the ancient Maya regions. Additionally, investigation of a natural aguada in the site of Cancuén revealed a 1.1 m sediment accumulation above an AMS ¹⁴C date of 1420-1270 BP (580-730 AD). The higher sedimentation rates during the Maya period pointed to the likely removal of the adjacent vegetation cover during the use of this aguada (Beach et al., 2008).

The vegetation of the southern Maya Lowlands is influenced by rainfall patterns, as well as by the soil drainage properties of the region (Dunning et al., 1998a). Dominant local vegetation has been referred to as ‘quasi-rain-forest’ by Lundell’s influential 1937 study. Overall, the upland forests can be described as lowland humid tropical mesophytic semi-deciduous forests, and the low-lying bajo swamp forests as stunted forests that include twisted and thorny tree growth. Trees in bajos are no more than 11 m in height resulting from the annual argilliturbation processes (Wahl et al., 2007). The southern parts of the southern Maya Lowlands include grass savannas covering large areas of land (Lundell, 1937; Cowgill and Hutchinson, 1966; Brenner et al., 1990).

Aguadas, having higher moisture contents have plant species similar to transitional uplands with larger tree species and hardwood (Lohse, 2004; Wahl et al., 2007). In the Edzna region to the north of southern Maya Lowlands, aguada studies describe the presence of water loving species of Nymphaea (water lilies), Hyacinth, *Pistia stratiotes* (water lettuce), and Graminae (grasses) (Matheny et al., 1983). These species are also commonly observed in aguadas of the southern Maya Lowlands. However, one should note here that *Pistia stratiotes* (“lechuga de agua”) seen in many aguadas today is not believed to be endemic to the region (Cilliers, 1987), and probably was not present in aguadas during the ancient Maya period. Wahl et al., (2007) in a detailed analysis of the plants around an aguada lists numerous aquatic species,
herbs, cultigens and arboreal species. In the Petén savannas, Brenner et al. describe a vegetation cover characterized by “interdigitating” species of low height dry tropical forest to savanna grasses around aguadas (1990). A similar description was given to Aguada Santa Ana Vieja by Cowgill and Hutchinson in the Petén savannas (1966).

Aguadas as freshwater ecosystems are also important habitats for a variety of animal species and limnetic fauna such as mammalian, avifauna, fish, gastropods and zooplankton in the Maya Lowlands (Goulden, 1966; Moholy-Nagy, 1978; Matheny et al., 1983). Goulden’s 1966 study gives a detailed list of the variety of the species found in reservoirs and in aguadas investigated during a Tikal project. Other studies have also investigated the zoology of aguadas in the Maya Lowlands (Hubbs, 1935; Murie, 1935; Flores-Nava, 1994, etc.) Lastly, Moholy-Nagy’s 1978 study identified certain types of Pomacea shells associated with aguadas.

2.2 What are Aguadas?

Aguadas are common features in the southern Maya Lowlands, as well as in other Maya cultural regions. During a Pan American Airways and Carnegie Institution of Washington collaborative exploration in 1929, expedition members were surprised to see most of what was recorded in earlier maps as lakes were in actuality aguadas, pointing to the widespread occurrence of aguadas in the Maya Lowlands (Ricketson and Kidder, 1930).

Aguadas, as ancient Maya water management hubs, result from both cultural and natural processes. Geologically, tectonic activity has had a significant role in aguadas’ spatial distribution. It has been observed that horst/graben and syncline/antisyncline features largely control the dispersion of natural aguadas in the southern Maya Lowlands, because limestone dissolution and sinkhole formation concentrates along fractures created by these processes (Beach et al., 2003, Ramos et al., 2004). In Alta Verapaz, to the south of the southern Maya Lowlands, remote sensing studies have shown that synclines direct the spatial distribution of bajos, and dissolution features, such as sinkholes, typically form along their main anticline axes (Ramos et al., 2004). In the Petexbatun region, horst and graben faulting formations also control the dispersion of aguadas in a similar pattern (Dunning and Beach, 1994). In the absence of fractures, limestone dissolution still takes place yielding a more random and less concentrated distribution (N. Dunning, personal communication).
The word *aguada* in Spanish denotes a “watering place.” The Yukatek Maya words *tz’onet* or *dzonot* or the Spanish word *cenote* stands for steep-walled exposed water feature that reaches below the water table (Monroe, 1970). Cenotes should not be confused with aguadas. The words *tz’onet, dzonot* or a *cenote* imply connections to an underlying water table and form a different geologic feature from the closed-system of an aguada. In Yukatek, the term *akal* can refer to aguadas specifically, but can also refer to any low-lying area subject to seasonal flooding.

Studies of the Maya Lowlands provide a variety of descriptions for aguadas. They range from “less permanent pools that are ancient cenotes with sloping sides” (Cole, 1910); “surface water pools” (Higbee, 1948); “broad shallow depressions” (Flores-Nava, 1994; Monroe, 1970; Matheny, 1976); “sinkholes and shallow water deposits” (Lundell, 1937; Cervantes-Martinez et al., 2002; Acuña, 2008); “a water body that is isolated from the underlying aquifer by an organic or clay basin seal” (Schmitter-Soto et al., 2002; Hodell et al., 2005); “small ponds associated with topographic depressions” (Wahl et al., 2007); and “small dissolution dolines” (Beach et al., 2008), etc.

Over the years, descriptions of aguadas have mostly identified aguadas as either collapse, solution sinkhole (doline) features or as small ponds that accumulated in shallow depressions. It is proposed here that the origins of aguadas are usually difficult to discern without an excavation, and using a blanket statement to describe them may be inaccurate. It should be noted that while most aguadas are modified versions of natural karst features, they may also result from quarrying activities of the ancient Maya. These tanks are often called reservoirs with plaster or clay lining if found in site centers, or aguadas if found in the hinterlands (typically with no plaster lining).

In this dissertation, I classify aguadas by and large under three categories—permanent sinkhole aguadas (less frequent than the next two types in the southern Maya Lowlands); seasonal shallow basin aguadas (dissolution dolines); and quarry aguadas after Arredondo-Figueroa and Flores-Nava (1992) and Flores-Nava (1994).
Permanent Sinkhole Aguadas

Dissolution of the carbonate rock comprising the Yucatan Peninsula has led to underground caves, and also epigean or exposed systems (Cervantes-Martínez et al., 2002). The exposed systems include cenotes, in addition to the permanent sinkholes and seasonal shallow basins that are both locally known as aguadas. Sinkholes (European name dolines) usually result from sinking or collapse of the land surface due to the removal of the underlying rock layers by continuous dissolution by water (Flores-Nava, 1994). A distinction must be made between these types of sinkholes and dissolution ones, where the latter formation takes place by direct solution of the surface rock, leading to seasonal shallow basin aguadas or dissolution sinkholes/dolines (Monroe, 1970).

The sinkholes that are locally known as “cenotes” on the Yucatan Peninsula will usually be open systems, meaning the bottom of the sinkhole is still connected to an aquifer. The closed types of collapse sinkholes identified as aguadas or permanent sinkhole aguadas have been cut-off from the underlying water table by sedimentary and organic matter accumulation over time and may display steep walls as former cenotes (figure 2).

Cenotes and permanent sinkholes as water resources have distinct characteristics and differences in terms of their pH, thermal and chemical stratifications, nutrient levels and water quality. The permanent sinkhole aguadas are only fed by rainfall and water-run off as a means for water accumulation, in contrast to cenotes (Flores-Nava, 1994; Cervantes-Martínez et al., 2002; Schmitter-Soto et al., 2002). Overall, permanent sinkhole aguadas will display depth ranges of up to 15 m and the areas of these types of aguadas can extend from less than a hectare to several hectares (Monroe, 1970; Schmitter-Soto et al., 2002). Permanent sinkhole aguadas rarely go dry mostly because of their depth.

Additionally, there are water features in the Maya Lowlands that are called “lagunas.” Foster and Turner (2004) define them as “solution features that retain water in their deeper parts throughout the year.” In their identification of lagunas, perhaps what they are actually referring to is permanent sinkhole types of aguadas that we describe here. Since there is no uniform way of identifying aguadas, it is hard to tell whether certain lagunas stand for one type of water body.
or another. However, we suspect most investigated lagunas in the Maya Lowlands based on their description indicate permanent sinkhole type of aguada formation.

![Image of a Permanent Sinkhole aguada](image)

**Figure 2.** Illustration of a Permanent Sinkhole aguada (adapted from Gaona-Vizcayno et al., 1980).

### Seasonal Shallow Basin Aguadas

The solution depressions that pit and scar the surface rock layers in the karstic Maya Lowlands result in the second types of aguadas—seasonal shallow basin aguadas. These formations, sometimes also referred to as dissolution dolines, are a typical feature of karst landscapes in humid locations (Ford and Williams, 1989). As the land elevation, precipitation and soil depth further rises as one moves towards south on the Yucatan Peninsula (south of Sierrita de Ticul), deep permanent sinkhole aguadas become less common, and give way to broad and shallow seasonal basin aguadas (Flores-Nava, 1994).

Water in shallow depression basin aguadas originates from precipitation and run-off. These features are usually made impervious by the organically rich and less permeable clayey sediments that are deposited in their floor, a process similar to what takes place in permanent sinkhole aguadas (Flores-Nava, 1994). The seasonal shallow depression aguadas exhibit two ecological phases—dilution and concentration (Arredondo-Figueroa et al., 1992; Flores-Nava, 1994).
In the early dilution phase, when the rains begin during the wet season, nutrients such as phosphorus and nitrogen are suddenly released into the water setting off a high primary productivity and successive links of the trophic chain (limnetic fauna, zooplankton, etc). In the concentration phase during the dry season, nutrients supplement the dry aguada sediments in the floor of the aguada, leading to vegetation cover that retains the nutrients until the following wet season. It has been pointed out that the nutrient rich soils from the floor of the seasonal aguadas during dry seasons have been utilized by the rural Maya population to grow fast maturing crops such as beans, and chili, in addition to high-nutrient-demand crops, such as corn. Rural Maya have also been known to apply the fertile bottom soils of these types of seasonal aguadas to improve the soils of less fertile areas (Flores-Nava, 1994). Corroborating modern observations, a study in the Petexbatun region has also shown that karstic sinkholes have been very attractive locations for the ancient Maya as they are surrounded by remains of settlements and agricultural terraces. The same study tied the interest of the Maya to the presence of fertile but largely erodible soils in the upper slopes around sinkhole formations, and also for the deep, cumulic soils that accumulated on their floors (Dunning and Beach, 1994).

**Quarry Aguadas**

Contemporary human activities such as excavations by construction have led to the creation of man-made ponds (Flores-Nava, 1994). This was also the case for the ancient Maya. The Maya created anthropogenic depressions from quarrying activities for building materials resulting in our third type of aguadas, namely, quarry aguadas (Hester and Shafer, 1984; Dunning et al., 2007; Beach et al., 2008). In order to be used as reservoirs, quarries of the ancient Maya were usually lined with an impermeable layer. This was due to the fact that fractured limestone surfaces would not be conducive for water storage. Flores-Nava’s (1994) study observed the modern man-made quarry ponds to be of irregular shape.

### 2.3 Paleoclimate Studies of the Maya Region

**Isotope Analysis**

Maya civilization had to rely on available precipitation in the absence of abundant surface water. As a result, the climate history of the region following the Early Holocene is an important factor for our understanding of Maya water management systems. Until presently,
isotope-based climatic reconstruction rather than palynology provided the useful insights for the past climate of Central America. Although, dendrochronology studies also show promise (e.g. Stahle et al., 2011). The earliest effort in extracting isotopic values took place by Covich and Stuiver at Lake Chichancanab in 1974. Subsequent improvements in mass spectrometry allow for higher resolution in the isotopic values today (Brenner et al., 2003).

Studies have so far shown that the Maya not only had to concern themselves with interannual disparities in the timing and amount of rainfall, but also with decade-to-century shifts in available moisture (Hodell et al., 2001; Brenner et al., 2003; Mueller et al., 2009). During the Late Holocene, climatic drying intensified in the late Middle Preclassic (475 to 250 B.C.), Late Preclassic (125-210 AD), and Late to Terminal Classic eras (800-1000 AD) (Curtis et al., 1998; Hodell et al., 2001; Brenner et al., 2003; Wahl et al., 2007; Mueller et al., 2009). Corroborating isotope studies, latest dendrochronology study from Central Mexico demonstrate that the Terminal Classic drought reached to central Mexican altiplano, as one of the worst megadroughts experienced in the last 1200 years (Stahle et al., 2011).

The time periods of 125-210 AD and 800-1000 AD correspond with the widespread abandonment of Preclassic and Terminal Classic Maya sites in the Southern Maya Lowlands. Climate histories of the region provide evidence that the Terminal Classic climatic drying was not a local phenomenon, as evidence of drier climate and discrete rainfall phenomena is known to exist in other areas of Mexico, Central America, South America and Sahel, contemporaneously (Hodell et al., 2001; Beach et al., 2008; Stahle et al., 2011).

In treatment of climate history in Central America, another promising area of inquiry is the El Niño-Southern Oscillation events (ENSO). During El Niño events, weak northeast trade winds and few hurricanes are observed in the Gulf of Mexico and Caribbean Sea. In non-El Niño years, hurricanes are detected to be increasing by ten-fold, bringing massive destruction to the region (Graham, 2003). Holocene frequency of ENSO fluctuated largely with little El Niño impact observed between the early Holocene with an increase after 5-6000 BP (Beach et al., 2008). It is known that Maya survival depended on how much water the annual rains would bring to their mostly karst and water poor environment. Thus, the chronology of the El Niño events holds promising insights concerning the human-climate relationship during pre-Hispanic era.
Pollen Analyses

At the onset of 21st century, the Holocene vegetation history of the Maya landscapes was still inadequately documented and only general paleoecological facts were made available through studies involving palynology (Islebe and Sanchez, 2002). The first pollen diagrams came from Lake Petenxil, south of Lake Petén from Tsukada’s study in 1966 (Wiseman, 1985). Pollen studies done in the Maya Lowlands reflect for the most part the anthropogenic modification of the environment rather than natural events, such as climate change. This is a direct result of vegetation disturbance by the early and subsequent Maya activities (Rosenmeier et al, 2002; Leyden, 2002; Brenner et al., 2003; Beach et al., 2008).

To date, pollen studies indicate that Petén and Yucatan regions hosted tropical forests starting around 8600 BP after the drying trend of the Early Holocene, with many ‘matching common floral elements’ across both regions. The mid-Holocene is marked by more open vegetation, which signals the beginning of the anthropogenic impact. Subsequent Late Holocene vegetation has been observed to be greatly impacted with the increased activities of the Maya (Curtis et al., 1998; Leyden et al., 1998; Leyden, 2002; Islebe & Sanchez, 2002).

Over the years, aguadas and larger-bodied lagunas have formed ideal locations for scientists to collect environmental proxy data. However, for pollen to be preserved successfully, the deposit has to be either anaerobic or permanently dry (Leyden, 2002). Seasonally drying aguadas and post-depositional disturbances may pose some problems in collecting pollen. Nevertheless, many aguada investigations have proved valuable.

In the following paragraphs, we look at certain aguada and laguna pollen studies from different parts of the southern Maya Lowlands. These water bodies show us pollen histories to be similar as far as ancient Maya disturbance indicators are concerned. Pollen extracted from lake, aguada and laguna cores over the years and what they represent in the Maya Lowlands are further summarized in Appendix A.

Aguada Elusiva

Aguada Elusiva is situated near the site of La Milpa, Belize. Samples from a core at 50-70 cm encompassing the Maya Late Classic period reveals a strong human disturbance signal with high percentages of Poaceae, Asteraceae, and Zea mays (maize pollen) (figure 3). Zea
*maize* percentages are as much as 5-6%, conveying maize cultivation close to the aguada. Around 50 cm (~800-900 AD), a large decrease in cultigens with a large increase in fern spores and higher numbers of high forest arboreal species is apparent (e.g. Combretaceae). The fern spike may indicate presence of bracken fern (*Pteridium aquilinium*), “an aggressive species that thrives in nutrient poor soil and is noted for invading over-cropped fields in the Southern Maya Lowlands.” By 900 AD, the area around the aguada was mostly abandoned and succeeded by upland forests. These findings agree with the archaeological record that shows that urban site of La Milpa center was hastily abandoned around AD 830 (Dunning, 2003).

Figure 3. Aguada Elusiva pollen profile.

**Laguna Las Pozas**

Laguna Las Pozas is a large laguna situated south of Petén, Guatemala. The pollen analysis here shows significant changes in vegetation in the Rio de la Pasion basin during the last 3000 years (figure 4). Three pollen zones from the core were analyzed. The bottom and the lower zone starting at 235 cm (2470-2130 cal B.C. and 2080-2050 cal B.C.) were dominated by arboreal Urticales pollen, primarily of Moraceae. Pollen of savanna species or disturbance and agricultural plants were nearly missing. The middle pollen zone 195-115cm (1690 cal. B.C. to
1040 cal. AD) was mostly of Poaceae, Tubuliflorae, and Byrsonima, species commonly seen in the savanna landscapes. However, rapidly declining semi-deciduous species (e.g. Moraceae, etc.) was noted. The expansion of the savanna species may either point to agricultural clearance or climatic aridity according to Johnston et al. (2001). One grain of maize was found further indicating cultivation around the lake. The middle pollen zone also included high concentrations of charcoal fragments, which was interpreted as a possible sign of slash-and-burn agriculture or, alternatively of increasing natural fires in the area (Johnston et al, 2001).

Figure 4. Laguna Las Pozas sediment characteristics (after Johnston et al. 2001).

Aguada Petapilla

Aguada Petapilla is in the Copan region in Honduras. Scientists have come across Zea mays pollen dating back as early as 2300 B.C., which correspond to early cultivation of maize elsewhere in the Maya world (figure 5). This study corroborates the idea that aguadas may have been important locations for corn production, since maize pollen is rather large and does not travel long distances. In the Aguada Petapilla core, charcoal peaked at 900 B.C., 400 B.C. and 700 AD The sequence shows that cultivation and associated deforestation continued several
centuries after what had been believed to be the Maya abandonment of the region after 9th c. AD (Rue, 2002; Webster et al., 2005).

Figure 5. Aguada Petapilla pollen profile (after Rue et al. 2002).

Discussion on Paleoclimate Studies of the Ancient Maya

In the context of climate and vegetation changes in the Maya landscapes, an additional explanation of the major changes to the ancient society is the human-induced environmental impact in the form of forest clearance and soil erosion (Dunning et al., 2002; Wahl et al., 2007). Lower lake levels found in various Maya landscapes during the Late Classic Maya is linked with strong evidence of lower forest cover, and as well as, higher aridity (Beach et al., 2008). It is a possibility that extensive deforestation may have led to microclimatic changes in numerous Maya sites, exacerbated by the regional climatic drying events. A parallel example to this phenomenon is the aridification of many parts of the Mediterranean, which was in some measure attributed to human intervention with regional environments. For instance, Theophrastus, a 4th c. B.C. Greek philosopher, described clear changes to local climates after trees around the ancient city of Philippi were removed (Hughes, 1994).
2.4 Aguadas as a Part of Ancient Maya Water Management: A Review

Karst topography and the tropical wet-dry climate of the southern Maya Lowlands had significant implications for ancient Maya civilization. In particular, the distribution of the natural resources, such as agricultural soils and availability of water sources, have been observed to impact Maya settlement patterns (Dunning et al., 1998; Lucero 2002; Scarborough et al., 2003; Lohse, 2004). As a significant natural resource, good soils were needed by the Maya to optimize their agricultural output. Maya also incorporated irrigation and soil improvement methods through drainage works, dams, canals, raised fields and terraces (Dunning et al., 1998a; Lucero 2002; Gunn et al., 2002). Non-agricultural Maya water management features included the areas of transportation, defense, drainage, flood control and ritual (Scarborough, 2003).

Besides the limiting factors of absence of abundant surface water and the dry/wet climatic regime of the region, one other important aspect was the unique bajo wetland ecology of the Lowland Maya landscapes (Dunning et al., 2002). Many ancient Maya cities in the southern Lowlands were founded next to bajos, such as Calakmul, Tikal, Naachtun, Naranjo, Kinal, Nakum, Nakbe, and El Mirador. Advantages of settling adjacent to bajos included access to seasonal sources of water and the locally available chert supplies (Folan et al., 1995). In fact, some bajos likely contained perennial water when the Maya first settled on their margins (Dunning et al., 2002; 2006). Aguadas are also observed in close spatial association with bajos. Puleston noted that the natural aguadas at the margins of bajos were suitable for modification, resulting as important water resources for the ancient Maya (1973).

Due to the unique geologic and climatic characteristics of the southern Maya Lowlands, water conservation was a significant factor for ancient Maya’s survival (Matthewson, 1977; Scarborough and Gallopin, 1991; Folan et al., 1995; Gunn et al., 2002; Acuña, 2008; Crandall, 2009). Water management strategies have been observed to be site-specific and diverse. Ancient Maya focused largely on solving common problems, such as water accessibility and drainage. In non-riverine locations, the principal aim of water management was retention. For sites located on flood plains, the emphasis was seen on diverting water away from settlement surfaces (Crandall, 2009).
Since sufficient surface water did not exist, the use of classic irrigation water management was not prevalent in most Maya habitats. Nevertheless, subsequent management of land surfaces under unique environmental conditions morphed the landscape into one with much higher carrying capacity than what is currently being observed today (Scarborough, 1995).

The water supply of Maya settlements also differed based on the ease of access to underground water. Northern Lowlands are known for near surface groundwater, which is considerably more difficult to reach in the southern Maya Lowlands (Wilson, 1980; Siemens, 1978). In certain locations benefiting from distinct geologic attributes, the Maya certainly used fault springs, such as in the Itzan escarpment, in the southern Maya Lowlands (Johnston, 2004). Wells have also been observed in some Lowland Maya communities. Albeit, the general understanding is that the practice does not constitute a reliable means of gathering water in the region (Scarborough, 1993). For example at Tikal, a modern constructed well of 180 m depth failed to reach groundwater, while in not far distant city of Uaxactun, a well of about 7 m depth exposed water below the surface, reflecting the presence of a local perched aquifer (Siemens, 1978; Johnston, 2004).

Concerning the evolution of Maya water management in non-riverine areas, Scarborough views the relatively isolated natural aguadas and man-made reservoirs to be early nodes for household and small community growth, but inadequate for expansion of ancient Maya urbanism (1996). According to him, due to the intense rainfall eight months out of a year, earlier Maya settlers were able to move away from riverine locations, and settle next to the margins of bajos with aguadas with no connection to perennial water systems. If the water storage characteristics of aguadas were improved, longer settlement periods were possible. Settlement growth around these landscapes subsequently led to nucleated city-center development and urban reservoirs (Scarborough, 1993).

Based on Scarborough’s identification, nucleated city-centers can be divided into two types of micro-watersheds according to the period in which they were built in—concave and convex (1993). Analysis of Late Preclassic sites such as Cerros and El Mirador conveys a concave micro-watershed design. These centers were constructed near the bottom of shallow natural depressions to store the water flowing into them. This Late Preclassic strategy is identified as “passive form of water management” (Scarborough, 1998).
By the Classic Maya period, cities were observed to utilize the gravity flow of water into the built-in reservoir systems constructed at the high point of ‘natural hillocks and ridges’, in what Scarborough defines as the ‘convex micro-watershed’. During this period, a change in the Maya water management design can be observed in several significant nucleated Maya sites, as certain major capitals moved away from immediate and expected water sources, while building sizable reservoirs as alternatives. One important example to these types of cities was Tikal (Scarborough and Gallopin, 1991; Scarborough, 1998). The large quarries found in these cities were modified into “central precinct reservoirs” linked by paved surfaces to form a complex water management system (Scarborough, 1996).

Scarborough’s influential work has shown that the Classic Maya centers were overall in more control of their water resources, relative to the ‘passive’ system adapted by the earlier Late Preclassic centers. It is possible that the changes in the site designs from one period to the next may in fact correlate with the climatic drying faced by the Maya during the Late Preclassic (125 to 210 AD). Late Preclassic was a period where a number of southern Maya Lowland sites were abandoned (Brenner et al., 2003; Akpinar et al., 2008). Gunn et al. (2002) maintain that bajo edges had to be modified to ensure the continued success of Preclassic sites, such as Calakmul, which were built away from perennial water resources. Nakbe and other Preclassic centers failing to make such a modification were abandoned. Additional studies concerning the changes to bajo hydrologies may prove essential to understand some of these site abandonments (Dunning et al., 2002).

2.5 Introduction to Aguadas as a Part of Ancient Maya Water Management

In 1957, Karl Wittfogel stated that the Maya adapted certain hydraulic systems, including construction of cistern chultuns, cenotes and aguadas, as equivalent practices common to hydraulic societies in arid zones (Mathewson, 1977). In archaeological studies, the “ease of access” to water is associated with a location, and the amount available (the volume) is factored into a settlement’s population density (Veni, 1990; Gunn and Folan, 2000). For the ancient Maya, water was most likely considered a key determining factor for the habitability of an area as a significant natural resource. Centuries later, “splendid mosaic of aguadas” was relevantly viewed to be important nodes of life, as they allowed for habitation around them (Higbee, 1948).
As the geologic and climatic factors largely impeded the water availability in the southern Maya Lowlands, effective exploitation of aguadas indisputably formed an important aspect of the Maya adaptive strategies. Historically, traveling in the southern Maya Lowlands during the dry season, a day’s journey was described as twelve to fifteen miles, or the distance between larger aguadas, as streams and springs were not present or were unknown (Ricketson, 1933). During his survey in Petén, Bullard noted that the likely maximum distance between aguadas and ancient Maya remains to be less than two kilometers (1960). Corroborating Bullard’s observations, the presence of aguadas in relation with ancient Maya settlements was continuously observed in archaeological surveys during the twentieth and the early twenty-first centuries (e.g. Maler, 1908; Cole, 1910; Ricketson and Kidder, 1930; Lundell, 1933; Bullard, 1960; Culbert et al., 1990; Lohse, 2004).

Higbee observed the “ancient relationship” being restored between men and aguadas as the chicle tappers returned to the largely uninhabited Maya Lowlands to gather gum extract and needing the water supply provided by aguadas (1948). Scholars continued reporting on certain aguadas still acting as attractive resources for modern human settlements in parts of the southern Maya Lowlands (Scholes and Roys, 1948; Cowgill and Hutchinson, 1966, Dahlin et al., 1980). Parallel to these observations, aguadas and reservoirs began to be of interest to Maya specialists. However, archaeological studies of aguadas themselves did not really become prevalent until the development of interest in collecting environmental proxy data for various analyses (e.g. Dahlin et al., 1980, Culbert et al., 1990, etc). Cowgill and Hutchinson’s 1966 study of Aguada de Santa Ana Vieja and other studies of aguadas in Tikal (Goulden, 1966) make some early exceptions.

In this section, we hope to provide a review of the available aguada studies that are relevant to what is known about ancient Maya water management as a way of fitting them into the picture. Some examples that will be treated in this review from north to south are: Edzna (Matheny, 1978; Scarborough, 1993; Gunn et al., 2002); Calakmul (Folan et al., 1990, 1995; Dominguez and Folan, 1996; Gunn et al., 2002); Colha (Haster and Shafer, 1984); La Milpa (Scarborough, 1993, Scarborough et al., 1995, Dunning et al., 1999; Krejci-Weiss and Sabbas, 2002); Kinal (Scarborough, 1994, 1996); Caracol (Crandall, 2009); Tikal (Goulden, 1966; Scarborough and Gallopin, 1991; Dunning et al., 2010); Dos Hombres, (Lohse, 2004); San
Bartolo and Xultun (Akpinar et al., 2008, Akpinar-Ferrand et al. in review); and Petexbatun (Dunning and Beach, 1994).

**Edzna**

The Late Preclassic site Edzna, found in the northwestern Yucatan, provides us with a good example of large scale modification of the landscape around a Maya city and the significance of aguadas in it. Edzna is situated in the northern Lowlands and receives 1000 mm of rainfall. Despite its low rainfall and location, Edzna is discussed here, as it displays similar water management characteristics to the southern Maya Lowlands (Scarborough, 1993).

Edzna was established near the head of a valley and had numerous aguadas (Matheny, 1978, 1983; Scarborough, 1993, Gunn et al., 2002). Aguadas as the only observed natural surface water formations were surely important and their presence is believed to have made the location attractive to the early Maya settlers (Matheny, 1983). Aguadas at Edzna had the capacity to hold a substantial amount of water. Yet, they probably had to be modified to increase their potential for water storage to ensure water availability for the city’s growing populations.

During the Middle Preclassic (1000-400 BC), settlers in Edzna likely utilized the capacity of the water retention of the clay lined floor of the valley. In his further analysis of the clay-lined aguadas, Matheny did not identify wells or chultuns in them. Moreover, Matheny observed close to twenty-five large water storage features in the northeast and northwest of the city, which were associated with mound groups (Matheny, 1976; 1978; 1983). During the Late Preclassic (400 BC to 250 AD) canals and additional reservoirs were built, increasing the water holding capacity of the city. The built canals themselves were estimated to capture 88% of the rainfall in the valley and its surrounding walls. It has been observed that numerous reservoirs and a combined canal system with a total of 20 km created an immense hydraulic system in Edzna (Gunn et al., 2002).

Others, nonetheless, (Doolittle, 1990) have noted that large portions of the canal system on the north side of Edzna may in fact be natural, geologic depressions, albeit water-filled. Scarborough (1993) estimated the entire storage for the canal basin to be 2,000,000 m³ and concluded that Edzna’s reservoirs were placed higher than its canals showing a precedent of water management of controlling water distribution away from the site center, as also witnessed in the Late Classic settlements (600-900 AD). Evapotranspiration studies at Edzna showed water
lilly or hyacinth plant species may have been used to reduce the evaporation rates in the canals (Matheny, 1978).

Calakmul

In Calakmul, interconnected hydraulic features range from bajos, aguadas, arroyos and canals that surround 22 km² of the city. Calakmul was built on higher ground during the Preclassic period to collect water in reservoirs and aguadas on the flanks of its bajos. Calakmul with its early establishment period and water management system varies from Scarborough’s concave model attributed to the Preclassic Period. Surveys around Calakmul have identified secondary and tertiary centers around the city, all with water sources of varying types including aguadas, springs and others. Many of these centers also had stelae. Folan and colleagues believe these centers were acting as part of a multi-level regional state rather than consisting of smaller independent polities (Folan et al., 1990, 1995; Dominguez and Folan, 1996). The city of Calakmul had estimated water storage of about 228,000 m³, a much lower capacity than that of Edzna. Further, modularization of Calakmul’s water management system (in contrast to Edzna’s) is a seeming adaptation to its interior upland environment lacking permanent water sources (Gunn et al., 2002).

A number of aguadas was studied by Dominguez and Folan in the region of Calakmul. The scholars identified thirteen prototype aguadas and divided them into four categories as described below (Dominguez and Folan, 1996):

1. **Large Aguadas of Public Type**-Two aguadas analyzed of this type were located to the northwest of city nucleus. They were supplied partly through a stream called Tomatillo. The stream was linked to the aguadas by small channels via entrances and exits for water. Aguada # 1 was estimated to have 105,000 liters of storage capacity when full, and when overflowing, the water was believed to return to the main stream to supply Aguada # 2, which had a capacity of 33,000 liters.

2. **Aguadas of Medium Size/Public Type**- Two of these types of aguadas were found north of the city nucleus. Both aguadas were united through a channel 250 m long and had 80 cm of depth on average. One of the aguadas had a 13,500 liter capacity and the other one 19,000 liters.
3. **Aguadas of Small Public Type** - Six of this type varying in capacity from approximately 2,050 liters to 9,800 liters was looked at. Some of the aguadas were located at the edge of the Bajo El Laberinto, and four were located at the mouth of a stream.

4. **Aguadas in the Surroundings** - Two aguadas were identified of this type with 1,250 and 5,000 liters of water capacity. Both aguadas were situated in the housing areas of the outskirts of nucleus of the city.

Dominguez and Folan’s observations on aguadas at Calakmul indicate that aguadas were chiefly utilized to satisfy domestic ends, as well as probably for the cultivation of certain agricultural products. In a contemporary farming cooperative found near the limits of Calakmul Biosphere Reserve, the team further learned that none of the aguadas could be utilized to create irrigation channels. The aguadas they found located within the interior of the bajos with scarce water availability would have had the same issue based on their opinion. For the corn growers today, they observed the most favorable place for agriculture was areas at the margins of the bajos. Thus, they implied modern milpa practices could reflect the practices of the ancient Maya. As for the potability of the water, Dominguez et al. imagine a certain degree of contamination due to the constant use of these aguadas. They alternatively proposed chultuns and pitcher cisterns for water collection and storage.

**Colha**

In Colha, archaeologists identified at least five aguadas throughout the site believed to have originated artificially from quarrying activities of the Maya. Their creation was attributed to the needs of the ancient inhabitants for building material and marl. Subsequently, these aguadas were also believed to serve as chert-processing locations based on the gathered archaeological evidence (Hester and Shafer, 1984). In the context of quarry aguadas, the presence of chert may not be surprising. Chert forms in limestone and when weathered or exposed appears in the form of chert cobbles. Chert was an important material in tool manufacturing for the ancient Maya and lithic debitage is associated with the testing of chert cobbles (Kunen, 2004; Chmilar, 2005).

**La Milpa**
La Milpa was established on the summit of a small hill and forms a convex micro-watershed. The site has a “reservoir-based water system” that dates mostly to the Late Classic period. La Milpa does not have a permanent water source known close by and a survey across seventy-five hectares in the city has shown a population density of 250 to 410 per sq km, comparable to other ancient Maya sites in northeast Petén (Scarborough et al., 1995; Dunning et al., 1999). It was observed that the upper areas of the watersheds draining the site core of La Milpa were dammed to create reservoirs. These reservoirs may have possessed sluice gates to control the distribution of water, and also one possible purpose of this activity could have been to regulate the soil moisture (Dunning et al., 1999).

There are numerous aguadas, reservoirs and small depressions present in and around La Milpa (Krejci-Weiss and Sabbas, 2002; Beach et al., 2003; Chmilar, 2005; Johnston, 2004; Dunning et al., 2005; Brewer, 2007; Beach et al., 2008). In the La Milpa Aguada, Dunning found a well inside the feature, known as a “bukte.” Around Aguada Elusiva close to La Milpa, box terraces and agricultural lithics were discovered (Dunning et al., 2005; Akpinar et al., 2008). Similarly agricultural lithics were also discovered in excavations at Turtle Pond, another aguada on the outskirts of La Milpa (Chmilar, 2005). Additional aguada investigation in the vicinity of La Milpa at Mahogany Ridge showed a high C₄ vegetation signature (indication of maize) dating to Classic Period (Beach et al., 2008). Other water sources besides water storage basins in La Milpa may have been the wells dug by ancient Maya to uncover fault springs (Johnston, 2004). In dissertation article # 2, we will present our own findings from the Aguada Elusiva investigation.

**Kinal**

The site of Kinal is 25 km southwest of La Milpa. Kinal is set in a similar environment to Tikal. However, Scarborough and colleagues concluded that Kinal’s water management system lacks the ‘centralized feeder reservoirs’ of Tikal. Yet comparable to Tikal, water was captured from numerous paved surfaces and directed into residential/bajo-margin reservoirs in the city (1994). Overall, Kinal has fifteen aguadas with 16.71 ha catchment area and a reservoir capacity of 1450 to 4959 m³ (Scarborough, 1996).
Scarborough et al. (1994) investigated the presence of several diversion weirs and possible naturally formed watersheds in Kinal. A silting tank was further identified next to a big reservoir in the city (60m in diameter, 2 meter deep). Near the lowest elevation of the reservoir, a V-shaped down slope outlet was also reported. Overall, it was found that the Kinal water system appeared very similar to the Perdido Reservoir at Tikal (Scarborough et al., 1994; Scarborough, 1996).

**Dos Hombres**

Dos Hombres is a site dating chiefly to the Late Classic (600-850 AD) and is situated near the Rio Bravo in northwestern Belize. There are two aguadas, 1.4 km east of Dos Hombres, which were investigated by Beach et al., (2003) and Lohse (2004). Both aguadas were described as natural, irregularly shaped depressions, 200 to 300 m across and located on an elevated ground (Lohse, 2004). As an indication of the significance of the ‘environmental niche’ found around these aguadas, Lohse reported some of the highest ancient Maya settlement densities around the two aguadas observed in the northwestern Belize. He also recorded several large dry-slope terraces between the Escoba Bajo and the aguada margins in association with residential groups. Based on the scale of the terracing, Lohse observed, agriculture was practiced at a community level since the terraces were much larger than house gardening lots. A boxed terrace was also observed next to one aguada, which may have acted as a seedbed (allowing farmers a better control of their area of cultivation by easier management of moisture, pests and fertilization) (Lohse, 2004).

**El Mirador**

El Mirador is the largest Preclassic urban center in the Maya Lowlands. In 1979 field work at El Mirador showed the availability of water to be a “strong determinant” of settlement patterns (Matheny, 1980). Matheny believed that a large natural aguada found at the base of an escarpment was an early factor drawing in inhabitants. By the Late Preclassic, the Maya started creating reservoirs throughout the site. El Mirador has several large reservoirs that catch considerable amount of water during the rainy season in addition to the several aguadas found below the limestone ridges. At least four aguadas have been identified to retain water during most of the dry seasons, excluding the extremely dry years (Matheny, 1980; Nielsen, 1980). Two
of the site’s reservoirs, one of which is called Aguada Limon, were used as the field camp’s water source during the 1979 season, though filtration was needed to make the water potable (Matheny et al. 1980). Overall, three decades of studies in El Mirador have presented a clear picture of aguadas and water management of the city. In a map area of 7.3 km², investigators found numerous canals, dikes, arroyos and a total of eighteen aguadas (Hansen et al., 2006).

Nakbe

Nakbe is located 12 km southeast of El Mirador and is one of the earliest urban sites in the Maya Lowlands. Based on the channels, dams, reservoirs, chultuns, plazas and architectural terraces, one can easily deduce the importance of water management for the Nakbe denizens. The city of Nakbe presents us with examples of reservoirs and chultuns that were used for water collection (Brewer, 2007). Aguada Zacatal situated on the eastern edge of the Narros bajo and still acts as a primary water source during the dry season for the site (Wahl et al., 2007). The city of Nakbe was abandoned during the Late Preclassic (Gunn et al., 2002).

Tikal

Very similar to Calakmul, Tikal was built on a promontory, and exhibits a combination of modified watersheds, bajo-edge reservoirs, and neighborhood reservoirs (Gunn et al., 2002). The central precinct reservoirs, situated above household tanks and the four large flanking reservoirs at the margins of bajos of the city are highly interconnected, forming a complex water collection and distribution system for Tikal. The four bajo margin reservoirs collected ‘grey water’ and the water was probably used for agriculture (Scarborough and Gallopin, 1991; Scarborough, 1996). Tikal was found to have about three times as much water storage capacity per square km as Calakmul. Tikal also displayed a good balance between intense centralization and dissemination of settlements in its hinterlands (Gunn et al., 2002). The hinterlands of Tikal also host numerous aguadas. Some of these aguadas have been reported and studied in detail (Goulden, 1966; Puleston, 1973, Dunning et al., 2009, 2010). The information gathered from these studies will be used in our overall analysis of the function of aguadas among Maya water management systems in article # 3 of this dissertation.
San Bartolo and Xultun

San Bartolo and Xultun were two Maya cities that are situated 8 km distant from one another in northeast Petén. Both were significant Preclassic centers. San Bartolo was abandoned like many other Preclassic cities at the end of the Late Preclassic period, whereas Xultun flourished into one of the largest Classic period centers in the region. Surveys around the two cities revealed a number of aguadas (Garrison, 2007; Dunning et al., 2007). Only one reservoir in San Bartolo was identified whereas at least six were in Xultun, suggesting possibly an effective water management system in one of the cities in the face of climatic drying possibly towards the end of Late Preclassic period (Akpinar et al., 2008). Aguada explorations in and around these two cities will be presented in dissertation article # 1.

Cancuen

In Cancuen, archaeologists identified several canals with the purpose of diverting water away from constructed aguadas in the site center and into the Rio Pasion. The water would be carried away from the elevated ground surface of the settlement structures during the Classic Period (Crandall, 2009). Beach et al. (2008) investigated two aguadas in the vicinity of the site and found one of them to be of artificial origin (8th c. AD). The second aguada was of natural origin. The research team further identified sedimentation rates to be higher during the occupation period than the post-occupation, most likely as a result of the removal of surface vegetation followed by reforestation. Carbon isotopic data from the aguada investigations also showed high input of C₄ species (such as maize) during the Late Classic period (Beach et al., 2008).

Caracol

Caracol, situated at high elevation on the Vaca Plateau in Cayo district of Belize, lacks immediate access to perennial water sources. Thus, water storage systems proved necessary and essential. In the city of Caracol, two major reservoir types were observed—small constructed ones connected to terrace field systems, and a second type associated with residential groups. Moreover, numerous aguadas were seen spread throughout the landscape (Crandall, 2009). Water storage features of artificial reservoirs were found 5 per sq kilometer. Naturally occurring aguadas were described by being surrounded with terraces during Classic Period.
Crandall’s study measured one natural aguada situated at the site center. The aguada retained water throughout the year and could hold 131,100 liters of potable water during the dry season alone (2009).

The small constructed reservoirs found outside of the site center are believed to be for residential groups and are found widely distributed across the terraced terrain of Caracol. Caracol’s water management system based on its terrace and reservoir system was more similar to Kinal’s rather than to Tikal’s. However, Caracol was observed not to use specialized weirs or check dams that were present in Kinal. The Caracol Maya diverted water through terraces and into gullies, and placed small reservoirs below those control systems. In further comparison, Caracol’s water management system was not as interconnected as that of the city of Tikal (Crandall, 2009).

**Petexbatun**

Analysis of ancient Maya agriculture and settlement in Petexbatun showed the Maya’s interest in karstic sinkholes (freely drained rejolladas and aguadas). Maya cultivation was focused on erodible, but rich soils on sinkhole’s upper slopes and on thickened top soil layers on their floors. The surveyed aguadas also had many surrounding relict agricultural terraces. One important aguada, the Aguada Catolina, is believed to be created around 1000 B.C. by a considerable clay buildup plugging the karst swallow hole inside the feature (Dunning and Beach, 1994).

**Discussion**

In her writing, Lucero pointed out that hinterland aguadas could not have the necessary potential to support large populations throughout the dry seasons (2002). Particular issues, according to her, included potability and also higher evaporation rates in hinterland aguadas rather than in larger reservoirs maintained in the city-centers. Lucero indicated that standing water would become stagnant, requiring a considerable amount of effort to keep clean. Because of this reason, she implied that the Maya communities around aguadas may not have constructed water catchment systems, enlarged or upkept aguadas. Lucero also stated that the Maya farmers in the southern Lowlands were quite mobile and would move toward stable water sources in the large city centers when it was necessary (Lucero, 2002). We will return to Lucero’s views in our
analysis of aguadas’ function among Maya water management features in research article # 3 of this dissertation.

2.6 Archaeological Evidence on Engineering and Modification of Aguadas

Investigation of aguadas over the years demonstrated a variety of ancient Maya modification strategies aimed to make them more functional. The following list summarizes some of the observations made by investigators over the years:

1. Stephens mentioned that “Indians” frequently dug holes in the floors of aguadas for collecting water that would filter through clay sediments. He mentioned the presence of wells (casimbas) in some aguadas, providing us with the initial account of the Maya’s modification of these features (1860). The same process was described later by Brasseur de Bourbourg (1865) and in Ancona’s book on the history of Yucatan (1889). Wells found inside aguadas are known in Yucatec Maya as a Buk’te. Buk’teob are lined with stones and are placed inside an aguada to maintain water throughout the dry seasons (Johnston, 2004). These types of wells found in certain aguadas have been investigated over the years (Huchim Herrera, 1991; Dunning, 1992, Johnston, 2004).

2. Scarborough describes wells that emerge in proximity of aguadas or reservoirs, which may indicate an elevated or perched water table and the ancient Maya’s attempts to filter water (1993).

3. Puleston observed the management of swallow holes (ponors) in association with aguadas, while he was surveying the Tikal region. He also discussed the origins of Aguada Naranjal at Tikal as a possible result of a dam that was built in the “impermeable sections of an intermittent stream bed” to collect water (1973).

4. Culbert et al. (1990) observed an aguada 3km east of Ixcan Rio at the foot of an upland location with two walls descending down possibly for the purpose of directing run-off into the aguada. This particular aguada also had two drainage channels and a berm. The berm was believed to stop the flow of water into and out of the catchment area of the aguada. Ceramics were also found in association with the construction fill of the berm.
Berms are typical features around aguadas. Wahl et al., found the existence of an S-shaped berm in Aguada Zacatal, which was believed to let water in and out of the aguada (2007). Other function attributed to berms by Beach et al. (2008) describes berms possibly being used for drainage modification and for agricultural purposes. Berms may have also acted to counter against high velocity water entering aguadas, and to help contain the water within them (Chmilar, 2005).

5. According to Wahl et al. (2007), Aguada Zacatal also possessed a limestone and stucco pavement to avoid desiccation during the dry periods. Limestone pavement found in aguadas is a modification technique frequently mentioned in the Maya Lowlands (Ancona, 1889; Matheny et al., 1980; Dominguez and Folan, 1996; Akpinar et al., 2008). Plastering an aguada floor is another technique, which may have ensured cleaner drinking water for the ancient Maya. Modern studies show that lime in stucco/plaster kills pathogens in freshwater bodies (Ganguly et al., 1999). However undeliberate, it is a possibility that the dissolving plaster-lining in aguadas/reservoirs released lime into the water that resulted in the reduction of water-borne diseases. Yet as a side-effect, this practice may have also led to hard water formation in ancient Maya’s drinking water.

6. Siltation tanks have also been identified in association with aguadas. These features possibly acted to remove debris entering the aguada and also filtered the water (Matheny et al., 1980; Scarborough et al., 1994; Akpinar et al., 2008; Akpinar-Ferrand et al. in review). Silting tanks next to aguadas could be identified by the presence of coarser textured sediments during geoarchaeological investigations (Chmilar, 2005).

2.7 Function of Aguadas: Defined and Discussed

In the sections above, we discussed how aguadas are seen closely correlated with ancient Maya settlements ranging in size and specific activities. It is clear that recognizing links between settlement patterns in relation to the aguada locations is important. Interestingly, modern settlement patterns in places like Uaxactun and Tikal in the late 1970s still showed an inclination for settlement around ancient reservoirs (Dahlin et al., 1980).
In his doctoral dissertation, Garrison (2007) defined a four-tier settlement hierarchy in the Maya lowlands: “temporary settlements (field houses/ temporary residence types); extended family groups (multiple courtyard and single courtyard types); minor centers (secondary center and tertiary center types); and capitals (major and minor capital types).” Bullard while surveying in the southern Lowlands talked about the numerous aguadas in the immediate area of household plots or house mounds (1960). Scarborough also explained that isolated locations of resources available to Maya resulted in a somewhat scattered settlement pattern of households (1996).

Nucleated major site-centers showed two important settlement strategies of the Maya as far as aguadas were concerned. Late Preclassic sites such as Edzna and El Mirador were constructed near the base of shallow natural depressions to collect run-off water in them (Scarborough, 1998). On the other hand, Classic Maya period cities chose to utilize the gravity flow of water into urban reservoirs and then outward into the aguadas/reservoirs situated away from the site cores as seen in the city of Tikal and elsewhere (Scarborough, 1998).

Interestingly, a thorough survey around two large Dos Hombres aguadas displayed some of the highest settlement density observed in northwestern Belize, namely, three times more settlement density per area around the aguada margins than those of the transitional uplands (Lohse, 2004). Based on the scale of the terracing associated with the aguadas, Lohse felt that agriculture was practiced at a community level (Lohse, 2004). Among Maya cities, an agricultural function is usually suggested in connection with aguadas based on evidence that accumulated over the years (Dunning, and Beach, 1994; Lohse, 2004; Lucero, 2002; Scarborough et al., 2003; Dunning et al., 2007; Akpinar-Ferrand et al. in review).

The likely use of aguadas for specific resource-based economies is further apparent. For example, chert working is a typical activity that surfaces in connection with aguadas (Hester and Shafer, 1984; Akpinar-Ferrand et al. in review).

One particular issue that surrounds aguadas is the availability of drinking water in them. In this review, we mentioned examples of aguada water being used for drinking by chicleros, small modern settlements, and archaeological camps. However, aguadas as shallow depressions are subject to a cyclic pattern (dilution and concentration) based on the seasonal availability of precipitation. Often, aguadas are also exposed to a certain amount of contamination from
surrounding areas. Examples of aguadas becoming contaminated because of water being reduced to low and polluted levels were recorded in the past decades (Adams, 1981).

Belcher (1982) describes the uses of water in tropical areas that are subject to seasonal rains in the modern developing countries. He explains the collection of rain water in barrels and water pots, and utilization of low surface ponds when the former collected water is expended by the end of the dry season. He cautions against the use of ponds when the water level is too low for health reasons. It appears that the ancient Maya likely used different means of water collection during the rainy season, and used their aguadas for drinking only when it was necessary for them to do so, unless the aguada was modified with the specific intention of storing drinking water (i.e. the use plaster lining). An interesting case of a plastered aguada comes from a hinterland aguada in the nearby city of Xultun. Our research team found the rather large aguada of Aguada Los Tambos with a plaster lining in parts most likely to ensure drinking water for the local population (Akpinar-Ferrand et al. in review).

Aguadas may have also served religious purposes. However evidence remains scarce. In an isolated finding, Me-Bar indicated the existence of an artificial cave at the eastern margin of an aguada at Dos Hombres, believing the feature to have served a ritualistic purpose (Brewer, 2007).

It is known in the Maya belief system, water was a ‘central metaphor’. Additional sacred entities were wind, forest, and corn that were deemed vital to survive in the Maya environment (Faust and Bilsborrow, 2000). The authors describe the possible relationship between aguadas and Maya belief systems as follows (2000:84):

“Human reproduction is seen as participation in the processes of life that are continually reconstructing the universe: as male rain collects in female aguadas, cenotes, and wells, making life possible in the dry season, so semen is transformed into new life in a watery female environment. These ceremonies are reminders of the dependence of the Maya on corn and water. There is no water for dry-season needs unless people “call the rains” with a rain ceremony and (in the southern areas) maintain the aguadas and wells and canals; and there is no corn without human work in planting.”
Back further asserts that the Maya religion and much of the culture was ‘water oriented’ (Back, 1995: 242):

The Mayan priests prayed and performed rituals and sacrificed to Chac, the water god, for assistance in water management—primarily to decrease the severity of droughts. In the Dresden Codex, Chac is seated on a coiled snake enclosing a deposit or reservoir of water from which he dips water to sprinkle on the earth in the form of a rain.

Scarborough adds (Scarborough, 1998: 155):

Bajo margin reservoirs were designed to extend the agricultural productivity of the area, high ritual conducted in the context of a water cosmogram of the site was a transparent way of appropriating the mundane activities.

Perhaps, religious significance of aguadas could further be found in the presence of water lilies. Based on pollen evidence, we know that the water lily species grew on aguadas (Wahl et al., 2007; Akpinar et al., in review). They were also likely encouraged to grow in site-center reservoirs and canals because of their water filtering and shading properties to prevent evaporation. Water lilies were also a symbol for Maya royalty that often appeared in royal headdresses and in association with royal houses. The plant was a symbolic claim of royal authority over clean water (Lucero, 2002; Sharer and Traxler, 2006). Glyphic evidence from the site of Yo’okop in the northern Lowlands has shown that the “ajaw nal imix (lordly person of the waters)” title was in part referencing the site’s large aguada in close proximity of the architectural structure that the glyph was found on (Nygard and Wren, 2008).

Besides possible religious function, additional evidence points to aguadas possibly serving as locations to gather edible food sources, such as Pomacea shells and fish. Moholy-Nagy’s article on Tikal’s *Pomacea Flagellata* (Pomacea species associated with aguadas and reservoirs) indicate that these species were eaten by the ancient inhabitants of Tikal. However, they were unlikely a major source of protein and calories, but were possibly important in the marginal diet of the ancient population. Pomacea shells (*Pomacea Flagellata* along with other Pomacea species) were further found deposited in ceremonial contexts mostly during the Early Classic period in Tikal (Moholy-Nagy, 1978). The modern uses of Pomacea as a food source was similarly discussed by Matheny et al. (1983), as also observed by Moholy-Nagy in modern Petén (1978).
In addition to gastropod mollusca species, aguadas could also host various fish species. Some aguadas were observed to be teeming with several species of fish that die as soon as the water evaporates during the dry season (Murie, 1935). It is a possibility that aguadas may have been exploited by the ancient Maya for aquaculture. Similarly, canals and raised fields are believed to perform as an “agro-aquacultural complex” by yielding fish and food crops interchangeably for the ancient Maya (Mathewson, 1977). A comparable function for certain aguadas would not be surprising given the evidence of agriculture practiced around them and the naturally present fish species found in them during the wet season. Additionally, as observed by Cole (1910), the fish present in aguadas would help reduce, and possibly exterminate the mosquitoes breeding in them. Standing water is the necessary condition for mosquitoes to breed, and the presence of fish in aguadas would help fight the problem for the ancient Maya.

Interestingly, scholars studying aguadas in the modern-day state of Yucatan, Mexico found seasonal shallow depression and quarry type aguadas to be attractive locations for aquaculture. In the case of seasonal shallow depression aguadas, adaptation of rotational management combining agriculture and aquaculture was suggested (Flores-Nava, 1994). Arredondo et al.’s (1982) study describes the placement of 18 gr of tilapia in a seasonal shallow depression aguada in central Mexico (0.8 fish/m²) with a resultant 450 kg/ha tilapia yield that required no additional feeding. Flores-Nava (1994), accordingly, suggested the introduction of endogenous fish species in early June subsequent to the dry season when the oxygen levels are stable to seasonal depression aguadas, and finally harvesting them in December. The author believes this as an ideal rotational management technique for aguadas when agriculture is practiced in tandem (figure 6).

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1 I have experienced this problem first hand while excavating Aguada Elusiva after heavy rains that filled the seasonal aguada in a matter of couple of days. Working next to the aguada, I had acquired about forty-bites according to official counts.
2.8 Aguadas as Paleoenvironmental Proxy Data Sources

Aguadas are some of the few standing water resources available to scientists who want to study climate, environment and human impact in the southern Maya Lowlands. It is known that standing water sources or anaerobic environments make excellent locations for obtaining paleoenvironmental proxy data. One cannot quantify past climatic variables or evaluate human environmental impact directly. Consequently, it is necessary to obtain indirect information from “natural materials” that act as proxies to record environmental change over time (Curtis et al., 1998). In this section, we discuss the value of aguadas as features from which to obtain paleoenvironmental proxy data.

Scientists have been collecting proxy data from aguadas since the 1960s (Cowgill & Hutchinson, 1966; Brenner et al., 1990; Hodell et al., 2005; Dunning et al., 2007; Beach et al., 2008). Aguadas allow for localized, site-specific data collection and sometimes are preferred to other water bodies (i.e. large lakes) depending on the purpose of one’s study (e.g. Johnston et al. 2001; Hodell et al., 2005). The following list discusses the most common analyses that can be done in aguadas and the information one can obtain about the function of aguadas and on other past environmental variables.

1. Water chemistry can be analyzed to understand the nature of the water found in aguadas (Brenner et al., 1990). Some scholars could also be interested in the suitability of aguadas for aquaculture (Flores-Nava, 1994) and even for potability.
2. Oxygen and Carbon isotopes can be measured on samples consisting of single species of gastropods. A permanent sinkhole aguada type may be a good place to get this kind of data. In contrast to a completely open aquatic system with no evaporative loss, in which the O$^{18}$ will be small and equivalent to the ‘isotope ratio of mean annual precipitation and regional groundwater’; in a closed system of a permanent sinkhole aguada, O$^{18}$ values will be high and responsive to the balance between evaporation and precipitation, where water is lost simply to evaporation. Increase in O$^{18}$ ultimately means climatic drying (Hodell et al., 2005; Mueller et al., 2009). For example, due to its small volume, the O$^{18}$ of the Aguada X’caamal in Yucatan responded sensitively and rapidly to changes in local and regional conditions according to Hodell et al. (2005).

3. Pollen histories for local vegetation can be obtained from aguadas (Johnston et al., 2001; Wahl et al., 2007, Dunning et al., 2007). Overall, pollen records will document environmental changes at differing spatial scales based on the areal extent of a water body. In lake sizes greater than 1 km sq, pollen records mostly inform us of the changes at the regional level (Johnston et al., 2001). Pollen profiles obtained from aguadas will provide information on local activities such as agriculture or land clearance. Sometimes, seasonal drying experienced in many aguadas will not be conducive to preserving pollen. However, the presence of berms, limestone and stucco pavements that are found in certain aguadas may help prevent dry season dessication. These typical modification techniques adapted by the ancient Maya could further result in micro fossil preservation (Wahl et al., 2007).

4. Faunal and plant evidence can prove useful for interpreting other data obtained from aguadas. For instance, the presence of the specie *Ammonia Beccarii Parkinsoniana* may point to increased salinity in water, and when coinciding with an increase in O$^{18}$ levels could be interpreted as evidence of climatic drying (Hodell et al., 2005). Studying other species in aguadas could also add considerably to paleolimnological investigations of aguadas. The dominance of Chydorus is an indication of greater weedy littoral zone, while the presence of Diaphanosoma conveys a larger open water zone for the launching of plankton. The presence of certain species in parts of the sediment column obtained from aguadas may also indicate probable low/high productivity during parts of aguadas’ history (Goulden, 1966).
5. Radiocarbon dates using AMS and bulk humates can be obtained on samples from aguada cores and excavations. However, one may want to choose terrestrial charcoal to avoid potential problems associated with hard-water lake error (Hodell et al., 2005; Webster et al., 2005; Wahl et al., 2007; Dunning et al., 2007; Beach et al., 2008).

6. Bulk sedimentary acquisition rates using Pb$^{210}$ dating can be measured in aguadas. Estimates of the sedimentary accumulation can help understand environmental processes around aguadas better. Most sediments deposited in places like aguadas will be of local origin except for the wind-borne pollen. Increased sedimentation rates could be an indication of settlement and stripping of surrounding vegetation cover (Brenner et al. 1990; Curtis et al., 1998; Webster et al., 2005).

7. Analyses of soils for physical and chemical traits will also be revealing in terms of geomorphic change and human impact around aguadas. Some tests: pH, available and total P, exchangeable K$^+$, Ca$^{2+}$, Mg$^{2+}$, and Na$^+$, particle size analyses, total carbon, total organic content and clay minerals, can provide clues to both the history of the aguada and the ambient or changing environmental conditions. Other studies may incorporate magnetic and geochemical analyses of sediment cores (Johnston et al., 2001; Ariztegui et al., 2001; Brenner et al., 1990; Beach et al., 2008).

8. Soil carbon isotope ratio studies ($^{13}$C) can be performed to indicate maize agriculture and other species growing around aguadas. The C$_4$ plant (e.g. maize) is known to be cultivated by the ancient Maya. So high levels of this signature versus C$_3$ (native forest species) in soils around aguadas will denote agricultural activities of the ancient Maya (Webb et al., 2007; Beach et al., 2008).

9. Lastly, flotation analysis can be done on sediments acquired from aguada excavations (Akpinar et al., 2008). Macrophyte findings from flotation samples could be analyzed to shed light into May activities and vegetation found around aguadas during the feature’s use (Hegeman and Goldstein, 2009; Akpinar-Ferrand et al., in review).

It has been observed that aguadas make excellent locations for paleoenvironmental proxy data collection. However, since aguadas functioned as valuable water sources for the Maya, their periodic dredging to maintain their water holding capacities may prove problematic for the modern scholar (Beach et al., 2008; Dunning et al., 2009). In addition, shallow aguadas may dry up during certain years destroying certain proxy data, such as pollen. Nonetheless, aguadas
provide variety of useful information about the nature of past human activities and local environmental variables across different scales. Their archaeological and paleoenvironmental investigation is certainly valuable when coupled with other investigations in the cultural area in which they are situated.

2.9 Literature Review Conclusion

In the literature review section of this dissertation, we examined aguadas in the context of the southern Maya Lowlands’ climate and environment, Maya water management systems, settlement patterns, and the availability of paleoenvironmental proxy data. We additionally explored aguadas’ origins in terms of their geology and anthropogenic modification. Aguadas as an understudied aspect of Maya water management systems have clearly the capacity to provide many useful insights to Maya scholars about ancient Maya’s relationship to water. It is therefore the aim of this dissertation to present the results of our own original work on aguadas, in addition to presenting a synthesis of decades worth of aguada investigations in the following dissertation articles.
USE OF AGUADAS AS WATER MANAGEMENT SOURCES IN TWO SOUTHERN MAYA LOWLAND SITES

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Abstract

Aguadas, either natural or man-made ponds, were significant sources of water for the ancient Maya. Aguadas are common features in the Maya Lowlands and make valuable locations for collecting archaeological and paleoenvironmental data. This article discusses research conducted at four aguadas around two adjacent Maya sites, San Bartolo and Xultun in Petén, Guatemala. Both San Bartolo and Xultun were established during the Preclassic period. However, the fates of the two sites differed, as Xultun continued to prosper while the city of San Bartolo was abandoned near the close of the Late Preclassic period. We argue that aguadas provide important clues for understanding the fate of these two ancient communities and many others in the Maya Lowlands.

INTRODUCTION

Aguadas are the most common water resource in the southern Maya Lowlands. Naturally occurring aguadas originate from collapse or dissolution sinkholes (Monroe, 1970). They are usually found at the margins of bajos (larger karst depressions) and along the fractured bedrock of karst uplands (Siemens, 1978). Most of the naturally occurring aguadas were later lined by the Maya with clay, plaster and/or stone-facing to improve their ability to hold water (Ancona, 1889; Adams, 1981; Wahl et al. 2007). However, aguadas could also be man-made depressions, such as ancient quarries that were later transformed to store water (Bullard, 1960; Hester and Shafer, 1984; Krejci-Weiss and Sabbas, 2002; Dunning et al. 2007). Aguadas were a significant aspect of the ancient Maya daily life, given the seasonality of available precipitation and the porous nature of the karst landscape of the southern Maya Lowlands.

Historically, numerous aguadas have been identified, and a few have been studied in the Maya Lowlands as valuable sources for paleoenvironmental and archaeological data (e.g. Dunning et al. 2003; Wahl et al. 2006). In March and April of 2005 and 2007, we undertook archaeological and paleoenvironmental investigations in several aguadas near the ancient Maya sites of San Bartolo and Xultun in northeast Petén, Guatemala in order to gain insight into the histories of these communities within the context of environmental change and adaptation (Dunning et al. 2005, 2007).
STUDY AREA

The Petén makes an attractive study area for archaeological and paleoenvironmental investigations since its physical environment remained considerably intact after the 1697 Spanish seizure of Tayasal until 1970, though rapid change has occurred since then (Schwartz, 1990). San Bartolo and Xultun are situated in the Three Rivers physiographic region along the fractured eastern edge of the central Petén Karst Plateau, consisting of stepped escarpments dividing karst uplands and lowland bajos (Dunning et al. 1998). Both San Bartolo and Xultun are located to the south of sprawling Bajo de Azúcar and by Bajo Itz’ul to the west and northwest. Seasonal swamps and Vertisol soils dominate within these bajos. Ixcan Río is the only river close to San Bartolo and Xultun, connecting several small bajos east of the two sites before draining into the Bajo de Azúcar. The river largely desiccates during the dry season (Garrison, 2007; Garrison and Dunning 2009).

The climate of the northeast Petén is classified as Köppen Am with a tropical wet/dry climatic regime. The majority of the rainfall in the region occurs during late May to December, and the dry period is experienced between January and May (Dunning et al. 2003; Wahl et al. 2007). In Petén, the annual rainfall varies between 900 to 2500mm with a regional average of 1600mm. Additionally, the inter-annual variation in rainfall is unpredictable, as the seasonal migration of Inter Tropical Convergence Zone and the Azores-Bermuda high pressure system varies on both short and long-term temporal scales (Rosenmeier et al. 2002; Mueller et al. 2009).

The biodiversity in the Petén forests is not as rich as the tropical forests of Costa Rica or rain forests of the Amazon. Nonetheless, Petén still enjoys substantial species diversity (Reining and Heinzman, 1992). The modern vegetation around and between the sites of San Bartolo and Xultun include upland, transitional and bajo forests (Table 1). Perennially or seasonally wet depressions of aguadas typically include sedges, ferns and grasses, and arboreal species that are common to transitional upland forests. Additionally, as freshwater ecosystems, aguadas act as important habitats to a number of mammals, avifauna, fish, gastropods and zooplankton (Goulden, 1966; Moholy-Nagy, 1978; Lohse, 2004; Reyes 2004).
AGUADAS OF SAN BARTOLO AND XULTUN

San Bartolo (16 Q 245036 E, 1940939 N) and Xultun (16 Q 243368 E, 1934323 N) are two ancient Maya sites that are eight kilometers distant from one another in northeast Petén. Both were significant Preclassic period centers. San Bartolo is a mid-sized polity that occupies an area of four km², whereas Xultun is comprised of a very large settlement area that covers at least sixteen km² (Garrison, 2007; Garrison and Dunning 2009). San Bartolo is particularly well known due to the existence of the earliest known examples of Maya writing and mural paintings dating to the 3rd and 2nd centuries B.C. (Saturno et al. 2006). San Bartolo, abandoned at the end of the Late Preclassic period, was re-settled briefly during the Late Classic period, probably as settlement pushed outward from Xultun. The city of Xultun developed into one of the largest Classic period Maya centers in the region, becoming an important territorial center (Garrison, 2007; Garrison and Dunning 2009).

Interestingly, only one aguada (Aguada San Bartolo) occurs in the urban heart of San Bartolo, and six aguadas are known to exist in the sprawling urban zone of Xultun. The aguadas reported in this article are situated in either the urban settlement zone or hinterlands of the two polities. They are locally known as Aguada Los Loros (16 Q 248318 1942780), Aguada Chintiko (16 Q 247949 1941025), Aguada Delirio (16 Q 243681 1936336) and Aguada Los Tambos (16 Q 244037 1932227) (figure 1). Investigations conducted at Aguada San Bartolo, Aguada Tintal, and Aguada Hormiguero are briefly summarized in separate later in this article.

Aguadas Los Loros and Chintiko are located in the hinterlands of San Bartolo. In comparison to urban San Bartolo, the settlement density around these aguadas appears less dense. Aguada Los Loros is situated 3.6 km northeast of San Bartolo on the border of a small upland bajo. Aguada Chintiko is found in a rural upland location with small bajos nearby, 3.2 km southeast of San Bartolo. Aguada Delirio is located within the urban settlement zone two km to the north of Xultun site center. This aguada gets its name from chicleros (gum tappers) who become ‘delirious’ when they find the aguada dry. Lastly, Aguada Los Tambos is situated 2.2 km south of Xultun within the site’s sprawling urban settlement zone (Dunning et al. 2007).
METHODOLOGY

As a part of the archaeological and paleoenvironmental investigation of the aguadas, we retrieved sediment cores from the interior of the aguadas. Also, excavations were performed to further clarify their function and to acquire soil samples for further analysis. We obtained Accelerator Mass Spectrometer (AMS) dates to establish sediment core chronologies and analyzed pollen from core samples. We also examined sediment texture and chemistry, organic content, X-Ray Diffraction (XRD) and Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS) images, and micro and macro paleobotanical remains from core and soil samples.

We extracted sediment cores from Aguada Los Tambos in 2005 and from Aguadas Los Loros and Chintiko with a Livingstone Piston Corer during the 2007 season. Aguada Delirio was not cored because there was a large quantity of chert on the aguada floor surface making it impossible to penetrate. The sediment within the bottoms of the other aguadas was extremely soft except for dense, packed clay at the base. Hence, the sediments were severely compressed during the coring process and extrusion.

The core from Aguada Los Tambos was initially about 110 cm long, compressing to 41 cm; carbon was extracted at 20 cm and pollen examined from samples at 15 and 25 cm. The core from Los Loros was about 70 cm long but compressed to 22 cm after coring and extrusion with pollen samples taken from 0, 5, 10, 15, and 20 cm. One sample of carbon was also taken from the aguada’s core at the 23 cm point (coring boot sample) and another at about 12.5 cm for AMS dating. The core from Aguada Chintiko was about 85 cm long and compressed to 36 cm after extrusion; we analyzed six samples from at 5, 10, 15, 25, 30 and 35 cm for pollen analysis, with a carbon sample taken at 31 cm for AMS dating. Carbon samples were sent to Beta Analytic Inc. for AMS dating, and pollen was analyzed in the Pollen Laboratory of the Department of Anthropology, Washington State University.

During pollen analysis, recognizing that microfossils could be poorly preserved in the samples, a conservative extraction technique was utilized. After adding Lycopodium spp. spores to each sample, carbonates were removed with 10% HCl, silicates with 50% HF, and humates with 2-5% KOH. An acetolysis procedure (Erdtman, 1960) eliminated unwanted organics; pollen
and charcoal was isolated from the remaining minerals with heavy density separation using ZnCl (Sp.G. 2.00). Pollen identification took place on a Jenaval compound stereomicroscope at 400-1250x magnification and identifications were confirmed by using the Palynology Laboratory’s extensive pollen reference collection. Minumum 200-grain counts were made for each sample.

We also opened eleven excavation units of 1x1.5 to 2 m in extent, with varying depths for archaeological and additional environmental analysis. We took soil and flotation samples from selected units for basic soil characterization, texture, chemistry and organic content, SEM/EDS, XRD analysis, and identification of micro and macro remains. Soil characterization, texture and SEM/EDS, XRD analysis, in addition to identification of micro and macro remains, were completed in laboratories of University of Cincinnati’s Biology, Engineering and Geology Departments.

We sent soil samples for Mehlich 3 extraction and ICP determination of Phosphorus (P), Potassium (K), Magnesium (Mg), and Calcium (Ca), analysis of organic matter content (LOI), and pH levels to the Spectrum Analytic Inc. We also took samples for soil texture analysis from chosen excavation units to determine sediment sizes larger than 250μm, measuring dry-weight of the samples after removing moisture from the samples in a laboratory oven. Additionally, calcium carbonate nodules found in Aguada Los Tambos excavation unit soil were analyzed for structure and chemical composition using XRD and SEM/EDS to determine their origin.

We also floated the soil samples from the aguada excavations for micro and macro plant remains using a field flotation device designed and set up by our team next to Ixcan Río. After the samples were air dried, they were sieved with soil sieve numbers 10 to 30 (mesh size). The samples were further examined with light microscopy for preliminary identification. The identified seeds were then photographed using a Scanning Electron Microscope (SEM) or a light microscope with a digital camera attached.

Lastly, we estimated the water storage capacity for the aguadas from the modified elliptical cone volume formula adopted from Brewer (2007):

\[
Volume = \frac{H}{2} \times \pi \times \left(\frac{L}{2}\right) \times \left(\frac{W}{2}\right)
\]

Where \(H\), \(\pi\), \(L\), \(W\) defined as:
**RESULTS**

*Aguada Los Loros*

Aguada Los Loros is an irregularly shaped aguada with approximate dimensions of 30 x 40 m. In 2007, it held ~1 m of water. We also observed berms around the aguada, which is an indication that the aguada was modified and most likely dredged to increase its volume. During its use, we believe Aguada Los Loros had close to ~3 m in water depth, accounting also for nearly 1 m of accumulated sediment in its floor and another 1m when its berms were intact. When we used the volume formula for Los Loros to estimate its full capacity, we found the aguada to be capable of holding ~1414 m³ or about ~373,539 gallons of water.

The sediment core taken from Aguada Los Loros revealed a basal measured radiocarbon date of 1890 +/- 40 BP or 30-230 cal A.D. (p = .95, 2σ) at 23 cm (dense, sterile clay). A second AMS date of 780 +/- 40 BP or 1210-1290 cal A.D. (p = .95, 2σ) was determined for a charcoal sample at a depth of 12.5 cm. We observed mottling in the sediment core starting from 8 cm until its final section at 23 cm. Based on these dates and pollen evidence (discussed below), we believe the use of this aguada ended after the Late or Terminal Classic period (ca. AD 900). The core is divided into zones for detailed examination below *(figure 2).*

**Zone 3.** Zone 3 shows the nature of vegetation surrounding the aguada sometime after A.D. 30-230. Pollen in zone 3 is characterized by higher percentages of herbs and cultigens and lower percentages of arboreal taxa, indicative of considerable human disturbance. A single *Zea mays* (maize) pollen grain and arboreal pollen types pointing to possible economic tree species such as Arecaceae, *Coccoloba sp.*, Sapotaceae and *Spondias sp.* are also present. The *Zea mays* pollen found in the pollen sequence is particularly significant because this specie is insect pollinated and its pollen does not travel far (Leyden, 2002). This demonstrates cultivation taking place in close proximity to the aguada. Additionally in zone 3, disturbance taxa such as Asteraceae, *Borreria*, Chenopodiaceae and *Amaranthus* (Cheno-Am) and Solanaceae are present, corroborating our finding of agricultural practices taking place in the vicinity of the aguada.
Zone 2. The higher levels of disturbance taxa in zone 3 peak at the outset of Zone 2, then decrease steadily in conjunction with an increase in tropical forest taxa from the beginning of zone 2 toward zone 1. These changes can be interpreted as a decline in human activity in the area. In the beginning of zone 2, we again see a single grain of *Zea mays* pollen in addition to a single grain of *Gossypium* (cotton) that is accompanied by disturbance indicators of Cheno-Am, Asteraceae, and secondary taxa of *Borreria*. The marginal forest taxon *Cecropia* also appears. Arboreal pollen of Myrtaceae increases rapidly to up to 50% of the total pollen sum toward the end of zone 2, where we also obtained a calibrated date range of A.D. 1210-1290 at 12.5 cm point of the core. High forest taxon of Moraceae further begins to increase, but not as dramatically as Myrtaceae. Zone 2 marks the transition between Maya occupation and the abandonment of the area afterwards.

Zone 1. The boundary between zone 2 and zone 1 displays a sharp break in the pollen diagram. Zone 1 represents a post-Maya reforestation period with particular drop to near zero values in disturbance indicators.

Excavations. During 2007 field work, we did not observe any modern settlements near Aguada Los Loros. Yet, based on the litter around it, we believe the aguada was frequented by *chicleros* and other sporadic visitors. We opened our first unit, 23SB-D1, on the sloping surface in the eastern edge of Aguada Los Loros. We unearthed cherty lithic debitage between 10 and 25 cm above a gleyed clay layer with orange mottling among much larger rocks (figure 3a).

On the western side of the aguada, a second excavation unit, 23SB-D2, was opened in a depression next to a well-defined berm, but we had to stop the unit at 50 cm below the surface due to water seepage. The form and position of this depression and berm suggested that it may have served as a siltation tank at the end of a low gradient drainage leading into the aguada. Between 4 and 25 cm, we identified several chert fragments found among stones placed in a somewhat regular interval. In the levels below, we found additional large stones of various sizes with several pieces of chert. Overall, the levels below the 25 cm depth displayed orange mottling initially in a reduced dark gray gley layer then in the light gray gleyed clay starting at 40cm. Below the 40cm depth, we did not find any other cultural material, but only smaller stones and additional orange mottling within the clay matrix.
The apparent mottling/oxidation seen between the reduced gley soil layers in both the 23SBD1 and D2 units and in the sediment core that corresponds to a calibrated date range of A.D. 30-230, potentially point to a climatic drying episode experienced in the region towards the end of the Late Preclassic period, a phenomenon documented in other parts of the Maya Lowlands (Wahl et al. 2006; Dunning et al. 2011).

Also, the particular arrangement of the large boulders connected to the berm near unit 23SBD2 may signify an effort to control water movement in and out of the aguada to allow for filtering in the silting tank. One diagnostic characteristic noted for silting tanks is the presence of coarser textured sediments with the bottom of the tank (Scarborough, 1994; Chmilar, 2005). When sediment texture analysis was done on samples from between 25 and 40 cm, 6% of the dry-weight was shown to consist of grain sizes larger than 250 μm. For comparative purposes, control samples from similar excavation unit levels with various sizes of stones in Aguadas Delirio and Los Tambos were measured for grain sizes larger than 250 μm. The results were: Aguada Chintiko 23SBE2 at 4-25 cm (3.7%); Aguadas Delirio 23SBF2 at 10-35 cm (3.3 %); and Los Tambos; 23SBG2 at 70-110 cm (% 1.3). Thus, while the overall percentage of coarse grains in the Los Loros tank feature is not high, it is considerably higher than that found in other near-aguada contexts (noting also that the region is a sand-poor environment as a whole), offering support to the identification of this feature as a silting tank.

The soil samples from 23SBD2 were also analyzed for micro and macro plant evidence. We were able to identify seeds of Vitaceae, Poaceae, Lauraceae and Cleome spinosa (figure 4). Particularly, the identification of Cleome spinosa supports that this unit may have acted as a silting tank based on the described habitat of the species as a: “spiny herb of open slopes, sandy thickets and found along streams” (Lentz and Dickau, 2005). Additionally, the evidence of Poaceae indicates grass vegetation around the aguada, which is a common disturbance indicator.

Aguada Chintiko

Aguada Chintiko is +/- 50m in diameter and has a roughly circular shape. The aguada held ~1.5 m of water in 2007. We believe Aguada Chintiko originally held water to a height of about 3.5 m, considering a ~1 m of accumulated sediment from our sediment core, and also ~1 m for the berms when they were intact. When we used the volume formula for Aguada Chintiko,
we found the aguada to be capable of holding approximately 3436 m$^3$ or about 907,695 gallons of water. Visual inspections around the aguada also revealed that a stone lining may have been used on the interior slope of the berm. However, no dates were determined for this construction, nor could the interior slope be excavated because of the standing water.

The sediment core taken from Aguada Chintiko produced an AMS date of 1300 +/- 40 BP or 650-780 cal A.D. (p = .95, 2$\sigma$) from a charcoal sample at 31cm. The late date is likely an indication of the dredging of sediments from the aguada at some point during its use considering the much denser occupation of San Bartolo area during the Preclassic period (Garrison, 2007). On the other hand, the carbon date when coupled with the pollen evidence further presents verification of human presence in the Late Classic period around San Bartolo, as also suggested by Garrison’s surveys of the area (2007). The pollen in the core is divided into three zones as outlined below (figure 2).

**Zone 3.** Zone 3 represents the time period before A.D. 650-780 with clear evidence of human disturbance around Aguada Chintiko. In this zone, herbs and cultigens account for about 20% of the total pollen count, yet there is no *Zea mays* pollen. However, this absence is probably not significant considering that *Zea mays* is insect pollinated and often poorly represented in pollen assemblages. Moreover, *Gossypium* pollen is found along with other possible economically valuable species such as *Arecaceae, Coccoloba* and *Sapotaceae*. In addition, we came across *Cyperaceae* and *Nymphaea* pollen that both diminish toward zone 2. Lowering of these two aquatic species may be interpreted as a clearing of the aguada, or a change in aguada’s hydrology (Wahl et al. 2007). Furthermore in zone 3, there is the appearance and sudden disappearance of *Borreria*, a weed common in cultivated areas (Lohse, 2004). Lastly, pollen of *Pinus* and *Quercus*, which are extra-local species, show some of their highest levels throughout zone 3. Their presence is a likely sign of forest clearance around the aguada allowing for the capture of pollen traveling from greater distances (Mueller et al. 2009). Land clearance is also indicated by the high count of disturbance species such as *Asteraceae, Bursera, Cecropia* and *Poaceae* pollen.

**Zone 2.** In zone 2, while certain aquatics increase slightly, herbs and cultigens begin to show a decline, and the arboreal species gradually reemerge. Aquatics such as *Cyperaceae* increase close to 10% and *Nymphaea* re-emerges at the end of zone 2, after a disappearance from the middle of zone 3. *Bursera*, an abundant specie in the secondary forests (Wahl et al. 2007), shows
an increasing trend from the beginning of zone 3 until the end of zone 2. The specie diminishes gradually toward zone 1.

**Zone 1.** Overall, zone 1 shows a dominance of the tropical forest taxa of Moraceae and Combretaceae and a decline in herbs and cultigens. This zone clearly marks the end of the anthropogenic disturbance and a return of tropical forest taxa in a post-Maya period.

**Excavations.** We opened three excavation units in Aguada Chintiko: 23SBE1, 23SBE2 and 23SBE3 (*figure 3a*). We began our excavations initially on a berm next to the aguada in unit 23SBE1, a 1 x 1m and 1.30 m deep pit. Soil texture is dominated by clay with a slight color variation throughout the profile, but with orange mottling starting at 1.10 m. The lack of variation in the unit’s sediment profile likely indicates that the berm was largely created with the sediments dredged from the aguada. In addition, what we initially thought were carbonized seeds recovered from a depth of 1.10 m through flotation process, were in actuality determined to be aggregates of manganese oxide during our laboratory analysis (*figure 4-e*). Easily mistaken for carbonized seeds, these aggregates are common products of weathering in soils, as manganese and iron tend to form oxides where there has been extensive chemical weathering (Essington, 2003).

Unit 23SB-E2 was opened in a flat, lower area immediately outside of the aguada berm to the east of unit 23SBE1. The 1 x 1 m pit reached a 70 cm depth. We found a concentration of 6-8 cm long stones between 4 cm and 40 cm below the surface. At 40 cm, a number of large stones were uncovered with further evidence of orange mottling before the regolith layer at 70 cm. Overall, we found unit 23SBE2 to be very similar to unit 23SB-D2 from the Aguada Los Loros, with both units exhibiting regularly aligned stones adjacent to clay berms.

Unit 23SB-E3 was excavated on another flat surface 3 m away from the edge of the aguada. Between depths of 15 and 35 cm, we unearthed a number of stones of varying sizes. However, the placement of the stones seemed random compared to those in units 23SBD2 and 23SBE2. We recovered two pottery sherds at 20cm and 36cm that could not be dated due to extensive weathering. There was only a thick layer of gleyed clay with orange mottling between 40 and 60 cm (with no further cultural material), at which point we reached weathered bedrock. We subjected unit 23SBE3 for soil chemical analysis due to our observations of variation in the
soil characteristics in the profile. In this mostly pH neutral unit, we found an increase in Mg with unit depth, reflecting chelation (e.g. mineral aggregates), while the Ca decreased in parallel. We did not find P levels high enough to suggest pronounced human input to 23SB-E3 sediments (Table 2).

**Aguada Delirio**

Aguada Delirio is situated within the urban zone of the city of Xultun and has a somewhat oval shape with dimensions of about 20 x 30 m. The aguada could not be cored in 2007 due to abundance of chert on the aguada’s floor. Lacking information on sediment depth further made it impossible to accurately estimate the volume of Aguada Delirio. With no core, we were also not able to recover pollen from this aguada.

**Excavations.** Three excavation units opened around the aguada found evidence of extensive chert processing (figure 3b). Two of the excavation units were placed roughly 10 m away from the aguada on lower areas next to the berms on the eastern side of the aguada: 23 SB F1 and F2. The third unit, 23SBF3, was opened on a berm on the same side of the aguada.

In 23SBF1, we found an abundance of worked chert and numerous pieces of stone. Sediments in the unit, similar to other units in Aguadas Los Loros and Chintiko, exhibited mottling starting 20 cm below the surface until a final depth of 1 m. Unit 23SBF2 showed more far-reaching mottling starting at 10 cm until 85 cm depth, lithic debitage, several large rocks and broken pieces of badly weathered ceramic. Sherds at 40 to 50 cm and chert at different levels starting at 10 cm until 85 cm in unit 23SBF2, suggest that this aguada was in use for a considerable period of time.

The third unit 23SBF3 was opened on the berm itself close to excavation 23SBF2. The berm exposed in unit 23SBF3 was likely built from material dredged from the aguada, suggested by a lack of variation in soil throughout its profile. The unit produced some lithic debitage but no additional cultural material. Starting at 60 cm and more abundant at 120 cm depth of the unit, we encountered gypsum crystals, a common precipitate in wetting and drying soils in the Maya Lowlands. Interestingly, later lab analysis showed variability in basic soil chemistry within the pit. A high level of P occurred in unit 23SBF3, a clear indication of large human input in the berm of the Aguada Delirio (Table 2).
**Aguada Los Tambos**

Aguada Los Tambos lies along the southern margin of urban Xultun. This aguada is large and irregularly shaped with an approximate diameter of +/- 80 m. It is reported to hold water year-round. When the aguada was cored in 2005, the deeper parts of the aguada held up to 2 m of water, and the longer sediment core taken from the aguada reached a depth of 1.10 m. If we consider ~1m for sedimentary accumulation and another ~1m for the water holding capacity with intact berms, in addition to the present day water level, we estimate a total water height of 4 m when Aguada Los Tambos was at its full capacity. This would result in an approximate volume of 10,053 m³ or 2,655,722 gallons of water for the aguada.

In the sediment core extracted from the aguada in 2005, we observed dark orange/red mottling and gypsum precipitates within dense, light gray clay in the lower section of the core between 22 and 41 cm, an additional sign of past oxidation and drying in San Bartolo and Xultun region. A charcoal sample taken at 20 cm in the core produced an AMS date of 990 +/- 40 BP or 980-1080 cal A.D. (p = .95, 2σ). We find that the oxidation layer several centimeters below the A.D. 980-1080 calibrated date possibly signifies a drying period in the region during the Terminal Classic period (Dunning et al. 2005, 2011; Garrison and Dunning 2009). Above 22 cm, core sediments changed abruptly into organic muck.

Similar to Aguada Chintiko, the late AMS date from Aguada Los Tambos suggests dredging of the aguada during its use, which also led to the removal of pollen evidence corresponding to the Maya settlement period. Pollen was not preserved in the core below 20 cm; above 20 cm pollen identified in the core belonged to the post-Maya reforestation period. Inscriptions on the dynastic stelae at Xultun indicate that it was one of the last Maya centers to be abandoned in the Terminal Classic period (Garrison 2007).

**Excavations.** During the 2007 field season, we opened three excavation units around the aguada: 23SBG1, 23SBG2 and 23SBG3 (figure 3b). The first excavation unit, 23SBG1 was located in a depression 10 m away to the east of the aguada. Based on our observations, this unit was likely a part of the aguada, even though there was no water due to the dry season. In the unit, we observed cultural material such as pot sherds that belong to the Classic period, worked chert and material that resembled plaster or stucco between 50 cm and 70 cm below the surface. In one
section of the pit, a small portion of apparent plaster lining was also preserved in the eastern wall of the unit (**figure 5**). Additionally we continued to find pottery sherds and carbon specks until 1.60 m below the surface. Later analysis of the recovered sherds by San Bartolo Project ceramicist identified exclusively Preclassic ceramics below the apparent plaster-lining level (Rivera Castillo, 2007). Encountering small-round formations that looked like carbonized seeds between 15 cm and 70 cm, we also took flotation samples. However, what we believed to be carbonized seeds were again determined to be metal oxide nodules during our laboratory analysis.

In unit 23SBG2, located 15 m north of the aguada on a raised surface, we similarly unearthed cultural material such as pottery sherds, chert, and again plaster-looking material that was diffused vertically in an irregular manner, starting at 20 cm all the way down to 1.10 m. The diffusion of the calcareous material throughout the profile likely resulted from severe argilloturbation since the clay sediments have been subjected to a dry/wet climate cycle over time. Additionally, San Bartolo Project archaeologists identified the sherds found in unit 23SBG2 to range from Preclassic to Classic period types but with little surviving vertical stratigraphy, an indication of the long use of Aguada Los Tambos, also with considerable post-depositional movement due to argilloturbation. In unit 23SBG3, located inside a dry interior in the western part of the aguada, we similarly found pockets of the plaster-like calcareous material interspersed within the gleyed clay soil, but did not find any cultural material; metal oxide nodules and orange mottling were pronounced within the gleyed clay sediments.

In all of the excavation units in Aguada Los Tambos, we observed high amounts of calcareous material. Soil sample chemistry analysis confirmed the presence of much larger amounts of Ca in this aguada’s samples in comparison to the other aguadas that were tested. We also found elevated P, K, and Mg levels near the surface in unit 23 SBG1, indicative of human activity (Table2).

**Identification of Calcereous Material in Aguada Los Tambos**

The *prima facie* examples of plaster-like material made us question whether there had been a plaster-lining inside Aguada Los Tambos. We were particularly surprised to see possible evidence of plaster-lining inside Aguada Los Tambos given its large size and also its distance
from the city-center, since most known examples of plastered reservoirs in the Maya Lowlands occur in site centers. In order to determine the origin of the plaster-like calcareous material, we employed XRD and SEM/EDS techniques to the samples from Aguada Los Tambos. We also compared the samples to a known plaster sample from the Middle Preclassic period plaster-lining from Aguada San Bartolo.

XRD and SEM/EDS testing showed that the samples from Aguada Los Tambos were largely composed of CaCO₃ (calcium carbonate) as well as the following: Si (silicon) aggregates, small amounts of Mg-calcite, and a few specks of MnO (figure 6). The powder X-ray diffraction scan of an Aguada Los Tambos sample clearly showed definitive calcite (CaCO₃) peaks at 3.85 angstroms, 3.03 angstroms and 2.84 angstroms. Also, the inclusion of Si aggregates in the plaster identified through SEM/EDS, reminded us that the Maya perhaps included the quartz (SiO₂) sand or volcanic ash within the plaster. Additionally, comparative SEM/EDS analysis of the samples from Aguadas Los Tambos and from San Bartolo demonstrated very similar characteristics between the materials from the two aguadas. We found that while the intensity scale (Y-axis) varies slightly between the two, the high calcium peak for the Aguada Los Tambos samples was not very different from the peak for the Aguada San Bartolo sample (figure 7).

Calcium carbonate (CaCO₃) is the principal component used in making plaster (Villaseñor Alonso, 2009). However, the calcium carbonate found in our samples could represent calcium carbonate rich material that naturally exists ubiquitously in the Maya environment. One of the inherent problems in distinguishing man-made lime from naturally occurring calcium carbonate rests in the fact that slaked lime absorbs atmospheric carbon dioxide over time and becomes calcium carbonate again (Wernecke, 2008). Nonetheless, the very similar characteristics of the samples from Aguada Los Tambos in comparison to the sample from the Aguada San Bartolo lining (i.e. that of known Maya plaster), the photograph evidence of intact plaster-lining in a small area of unit 23 SBG1, and the occurrence of the CaCO₃ pockets combined with different minerals throughout the stratigraphy such as Si aggregates, lead us to believe that the samples from Aguada Los Tambos were not natural CaCO₃, but the weathered and broken (by argilloturbation) remains of a man-made plaster lining.

To date, the Aguada San Bartolo (discussed further below) is the only other aguada known at the study sites with a plaster lining. In recent excavations at the Petén site of Tikal and
the Puuc region site of Xcoch, Nicholas Dunning has observed that plaster-lining were used in some site center reservoirs whereas clay lining was more typical for aguadas on the urban fringe.

We know from archaeological studies and surveys in the region that plaster was used and produced by the Maya around San Bartolo and Xultun (Dunning et al. 2005; Garrison, 2007). Garrison mentions that the decrease of plaster thickness in floors seen in San Bartolo was possibly due to deforestation and the necessity of burning large amounts of wood to make Maya plaster (2007). Deforestation was also a likely problem around Xultun. As a result, we are surprised at the evidence of plaster-lining in a rather large aguada away from the Xultun site-center. On the other hand, the creation of a large plastered aguada with high water storage capacity could help provide the necessary drinking water for the inhabitants of Xultun, which was probably necessitated facing episodes of climatic drying. Excavation evidence supporting this finding also shows that the Xultun inhabitants plastered Aguada Los Tambos sometime no earlier than late in the Late Preclassic.

*Aguada San Bartolo, Aguada Tintal, and Aguada Hormiguero*

Archaeological and paleoenvironmental investigations have been carried out at three other aguadas in the San Bartolo – Xultun region: Aguada San Bartolo (in the San Bartolo site center), Aguada Tintal (in a rural settlement area several km NE of San Bartolo, and Aguada Hormiguero (on the northwestern urban fringe of Xultun). These investigations have been reported on elsewhere, but are summarized here.

Aguada San Bartolo is roughly circular with a radius of 8-10 m and situated immediately adjacent to the monumental architecture of the Ventanas Group. In 2005, a 1.0 x 1.5 m trench was excavated in the aguada center reaching a depth of 330 cm (Dunning et al. 2005; Garrison and Dunning 2009). The excavation revealed that the aguada likely originated as a stone quarry, which was sealed with a thick plaster lining; AMS dating of charcoal within the plaster, 780-410 cal B.C. (p = .95, 2σ), indicates that the creation of this reservoir dates to the Middle Preclassic period, contemporaneous with the first monumental architecture known at the site (Saturno et al. 2006). The aguada filled with a large volume of sediment later in the Preclassic period and after site abandonment around A.D. 150, but was partly dredged of sediment and relined with plaster.
around A.D. 700 when the site was briefly reoccupied. Sediments in the aguada did not preserve pollen.

Aguada Tintal is roughly circular in shape with a diameter of about 30 m and is surrounded by a low berm. In 2005, two sediment cores were extracted from near the center of the aguada (Dunning et al. 2005). The longer core reached a depth of 80 cm, but compressed to 24 cm in length and was subsampled and analyzed. The core contained three zones (Dunning et al. 2011). The lowest level corresponded with the Maya Middle Preclassic period and bore pollen including maize, cotton, and manioc. The middle zone was undated oxidized and gypsic clay. The uppermost zone was organic sediments bearing high forest pollen and radiocarbon dated to the Postclassic period after regional abandonment. We interpreted the oxidized zone as most likely corresponding to a severe Late Preclassic desiccation episode (Dunning et al. 2011). Classic period sediments appear to have been removed by dredging. Excavation on and near the western berm of the aguada in 2007 revealed a stone retaining wall supporting a clay berm and covering a buried soil dating to the Middle Classic period (ca. 700 B.C.), suggesting that the aguada was excavated at that time (Dunning et al. 2007). The aguada most likely originated as a chert quarry as evidenced by extensive chert processing deposits in surrounding areas.

Aguada Hormiguero lies on the northern fringe of urban settlement at Xultun and on the flank of the large Bajo Itz’ul. In 2008, Michael Storozum excavated two 1 x 1 m test pits in the aguada and collected sediment samples that were analyzed by Nicholas Dunning (Storozum 2009). The excavations revealed that this aguada likely originated as a natural bajo-margin karst depression that was modified by quarrying beginning early in the Preclassic. The aguada appears to have been in continuous use through the Classic period, including periodic dredging, until its final abandonment in the Terminal Classic. No pollen was recoverable from the aguada sediments.

DISCUSSION

Investigations of Aguadas Los Loros, Chintiko, Delirio and Los Tambos have revealed that these aguadas served various purposes around the ancient cities of San Bartolo and Xultun. Our investigations not only demonstrate that the aguadas around San Bartolo and Xultun were used in activities such as agriculture and chert processing, but also display evidence of ancient
Maya low-technology engineering solutions to help store water in a water poor area that includes the use of berms, silting tanks, stone-pavement, and plaster-lining.

In a region with no lakes, aguadas were particularly useful in the amount of paleoenvironmental data they preserved, including past pollen, charcoal, and sedimentary evidence of past climatic drying. We also observed the ancient Maya’s habit of dredging aguadas to increase or maintain their capacity, which, from the perspective of modern investigators, had the unfortunate effect of removing paleoenvironmental data. We found that the pollen sequences gathered from the aguadas mostly reflected the local vegetation. Aguadas, as small bodies of water capable of providing valuable pollen evidence, also included the pollen of less common insect-pollinated plant species that do not travel far (e.g. Zea mays). As a result, the pollen extracted from aguadas was further valuable in revealing aguadas’ function within ancient Maya agricultural practices.

Through the sediment cores and archaeological excavations in all of the aguadas investigated, we were also able to detect evidence of climatic drying episodes in the Late Preclassic and Terminal Classic periods in the San Bartolo-Xultun region based on the evidence of oxidation and gypsum precipitation. Our findings support various paleoenvironmental studies in the Maya Lowlands indicating climatic drying intensifying during the later Late Preclassic period between A.D. 125-210, and in the Terminal Classic period between A.D. 800-1000 (e.g., Curtis et al. 1998; Hodell et al. 2001; Brenner et al. 2003).

Additionally, our archaeological investigations showed that several of the aguadas seem to have originated as quarries. Aguada San Bartolo began as a stone quarry, whereas Aguada Tintal appears to have functioned for a time as a chert mine. Near Xultun, Aguada Delirio similarly showed strong evidence for originating as a chert mine, and this activity may also have contributed to the formation of Aguada Homiguero. Intriguingly, the emblem glyph used by the Xultun royal dynasty includes the toponym “chert mountain” indicating the importance of this resource at the site (Garrison and Dunning 2009). We find that Aguada Delirio and other similar aguadas in the research area may represent a type of aguada that could be characterized by their resource-based use, and also possibly by their creation from stone quarries or chert mines. Further evidence of working of chert into cores and tools near aguadas apparently during the
period of their use, such as in Aguada Los Loros with confirmed agricultural practices around it, was also informative about an aguada’s function as a multi-purpose area.

Furthermore, the discovery of a plaster-lining in a large aguada such as Aguada Los Tambos shows that the aguada’s water was in all probability intended, among other uses, for drinking by Xultun’s sprawling urban population. Other evidence that the region’s aguadas may have provided potable water is the Nymphaea pollen identified in the Aguada Chintiko core. The presence of Nymphaea is an indication of good water quality since these species are known to grow in clean and still water (Lucero, 2002). These species were likely also useful in preventing excess evaporation from aguadas, while reducing organic waste in the aguada water (Davis-Salazar, 2003).

The water capacities calculated for the aguadas provided additional information on their likely contribution to per capita water availability for the residents of San Bartolo-Xultun area. The current standard of water per day per person is 64 oz. (1/2 gallon) (Brewer, 2007). Thus for the largest aguada we investigated, Aguada Los Tambos with a volume of 2,655,722 gallons, at full capacity with no evaporation, could provide ~14,550 people each day with water for one year, excluding the water need for agricultural production. Garrison calculated ~8260 population or 481-513 people/km² in the San Bartolo-Xultun intersite area by the Late Classic Period (2007). Based on the volumes of the investigated aguadas alone, we see that aguadas of the study area had a vital part in the area’s Maya water management systems to support Maya populations’ water needs for drinking, household and agricultural purposes.

Also, archaeological investigations around San Bartolo and Xultun have confirmed the sites’ large-scale abandonments at the end of the Late Preclassic period at San Bartolo, and in the Terminal Classic at Xultun (Garrison, 2007). Investigations indicate that the cities of San Bartolo and Xultun had completely different water management strategies. While San Bartolo had only one urban reservoir, Xultun is known to have at least six (Dunning et al. 2008). The differences between the two cities in terms of water management are further demonstrated by plastering of at least one large-sized aguada outside of the site center at Xultun. These dissimilarities may help explain why one city was abandoned at the end of Late Preclassic and the other one continued to prosper through the Late Classic, especially in light of episodic regional climatic drying.
CONCLUSION

Aguadas can provide a variety of useful information about the nature of past human activities and environmental events in a given region. The four aguadas investigated in San Bartolo and Xultun were useful in informing us about ancient Maya land-use that included agricultural practices, vegetation change, mining, and water management strategies.

We found that the ancient Maya of the study area lived in a difficult landscape with seasonal water scarcity that was plagued by two significant climatic drying episodes. Yet, they overcame their limited water resources through the use of various water management strategies that included modification of dissolution and collapse sinkholes and quarries, creating aguadas. Aguadas helped collect rainwater for drinking and for other purposes. We find it important to study the resilience of the Maya and their adaptation to the extended climatic drying period in the 2nd century AD, and yet their decimation, and altogether abandonment, of their settlements in the San Bartolo-Xultun and other regions of the Maya Lowlands during the 9th century AD. Further studies of aguadas in the Maya Lowlands may shed additional light on the nature of these water management adaptations and the nature of their success and failure.

RESUMEN

Aguadas, o charcas naturales o artificiales, fueron fuentes significativas de agua para la civilización antigua del los Mayas. Aguadas son comunes en las Tierras Bajas Mayas y hacen las ubicaciones valiosas para recoger datos arqueológicos y paleoambientales. Este artículo discute la investigación realizada en cuatro aguadas alrededor de dos sitios Mayas adyacentes, San Bartolo y Xultun en Petén, Guatemala. San Bartolo y Xultun fueron establecidos durante el período Preclásico. Sin embargo, los destinos de los dos sitios variaron, como Xultun continuó prosperar mientras la ciudad de San Bartolo fue abandonada cerca del fin del periodo Preclásico Tardío. Discutimos que aguadas proporciona indicios importantes para comprender el destino de estas dos antiguas comunidades y muchos otros en las Tierras Bajas Mayas.

Acknowledgements. We would like to thank the anonymous reviewers, Dr. Warren Huff and Dr. Vernon Scarborough for their valuable inputs and suggestions. The work reported in this article was funded by a National Science Foundation grant to Nicholas Dunning. The work was
accomplished as part of the Proyecto Arqueológico San Bartolo directed by William Saturno and Monica Urquizu.
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Table 1. Upland, Transitional and Bajo forests San Bartolo-Xultun Intersite Area.
Table 2. Soil analysis results from Aguadas Chintiko, Delirio and Los Tambos.

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**Figure 1.** Map of the study area.

**Figure 2.** Pollen profile from Aguadas Chintiko and Los Loros.
Figure 3a. Excavation drawings, Aguadas Los Loros and Chintiko.
Figure 3b. Excavation drawings, Aguadas Delirio and Los Tambos.
Figure 4. Images of carbonized remains and mineral aggregates: (a) Vitaceae; (b) Poaceae; (c) Lauraceae; (d) Cleome spinosa; (e) Mineral aggregates.
Figure 5. Evidence of plaster-lining in Op 23SBG1, Aguada Los Tambos.
Figure 6. XRD and SEM/EDS analysis of calcareous material from Aguada Los Tambos.
Figure 7. Comparative SEM/EDS analysis between Aguadas of Los Tambos and San Bartolo.
TOK’, NAL, HA’: Ancient Maya Resource Management at an Aguada in Northwestern Belize

Estella Weiss-Krejci*, Ezgi Akpinar-Ferrand, Nicholas P. Dunning, Michael Brandl, John G. Jones, David Lentz

Abstract
Aguada Elusiva, a small aguada close to La Milpa ancient Maya site. Aguada Elusiva was investigated by our research team starting in 2003. The interior part and the periphery of the aguada were excavated, and a core sample was taken from its floor for pollen and sediment analysis. The aguada revealed evidence of multiple-resource use.

INTRODUCTION

For the inhabitants of most areas of the interior of the Yucatan Peninsula water has always been a critically important resource. An annual four to six month-long dry season, karst hydrology and an elevation between one and three-hundred meters above sea level combine to make surface water scarce to non-existent for months on end. Whereas seasonal desiccation has been a limiting factor for modern settlement in this region, the ancient Maya adapted various types of rain and runoff catchment and storage systems including urban and rural reservoirs, household tanks, cisterns and wells (Bullard 1960:353; Carr and Hazard 1961:13–14; Dunning et al. 1999; Harrison 1993; Johnston 2004; Robichaux 2002; Scarborough 1993:27–59; 1998; Scarborough and Gallopin 1991; Weiss-Krejci and Sabbas 2002). A legacy of these efforts observable in the present-day landscape, are numerous depressions. Those that today hold water are called aguadas. They are most abundant along the edges of seasonally inundated wetlands (bajos) but can also be found on patches of low ground in upland areas (Bullard 1960:363; Carr and Hazard 1961:13; Siemens 1979:380; Weller 2006:34). In some regions of the Petén Karst
Plateau, *aguadas* constitute the only available dry-season water sources. People exploiting the forest for *chicle* and tree logs as of the end of the nineteenth century regularly set up camp at such water holes. Like travelers in a desert, the early archeological explorers also moved along these paths (e.g. Maler 1911:5; Maudslay 1889–1902, 3:49; Thompson 1938).

Archaeologists have long noted a close correlation between ancient settlement remains and *aguadas* in these parts of the Maya Lowlands and emphasized their role in the colonization of this region (e.g. Bullard 1960:364; Folan et al. 1995:330; Morley 1938:1:25-29; Quintana and Wurster 2001:9-10; Scarborough 1993:26; Smith 1950:84). Yet scientific investigation has been carried out in and around these features only since the 1980s (e.g. Domínguez and Folan 1996; Dunning et al. 2003; Grube and Paap 2010; Scarborough et al. 1995; Wahl et al. 2007). The careful study of *aguadas* provides an opportunity to glean important information about human-environment interactions in the Maya Lowlands. Many of these former reservoirs appear to have begun as natural depressions whereas others may have originated as chert and limestone quarries, both of which were modified to enhance water storage. For archaeologists and paleoecologists seeking to understand the history of environmental change and land use in the Maya Lowlands the record of pollen and other information preserved within the aguada clays offer rare and important glimpses of ancient landscapes.

The research reported here summarizes results of investigations, which took place in and around Aguada Lagunita Elusiva, an ancient Maya reservoir (17°49′40.42″N, 89°00′17.54″W). The *aguada* is a roughly circular feature ranging between 27 and 30 m in diameter, with a surface of 615 m² and a present capacity of approx. 450 000 liters. It is located in the Rio Bravo Conservation and Management Area in northwestern Belize owned (Figure 1) and managed by the non-profit organization Programme for Belize (PfB). This ecologically diverse biological reserve includes a variety of ancient Maya settlements, which have been investigated by the La Milpa Archaeological Project (LaMAP) and the Programme for Belize Archaeological Project (PfBAP) (e.g. Hammond and Tourtellot 2003; Scarborough and Valdez 2009; Tourtellot et al. 2003).

Aguada Lagunita is located 5 km east/southeast from the center of the large Maya site of La Milpa and 2 km southeast of the PfB Research Station. It can be accessed in a 40 minute walk through the Lagunita Trail to the east of the station. The *aguada* and its surroundings were mapped by Tourtellot in 2002 (Figure 2), and investigated by Dunning in 2003. Excavations
directed by Akpinar-Ferrand and Weiss-Krejci took place between 2008 and 2010 (Akpinar-Ferrand et al. in review; Weiss-Krejci 2009:157–164; Weiss-Krejci and Brandl 2011). The title “Elusiva” was given to the *aguada* in 2003 because of the difficulty Dunning’s research team had in locating it and to distinguish this place from other “lagunitas” (Dunning 2003).

**Occupation history and initial research questions**

In the past, numerous permanently dry depressions on the Belizean side of the La Lucha Uplands have received scientific attention (e.g. Brewer 2007; Me-Bar 2005; Scarborough et al. 1995; Weiss-Krejci 2004; Weiss-Krejci and Sabbas 2002). In contrast, only few upland *aguadas* have been investigated so far. In 1992, ten core samples were taken from the large La Milpa aguada, which is located a little over 5 km west of Aguada Lagunita Elusiva (Figure 1). The water-retaining character of this depression may have attracted a pioneer population settling at La Milpa (Scarborough et al. 1995:112), which was a nucleated and modest-sized community in the Late Preclassic (400 BC-AD250) (Hammond and Tourtellot 2003:42; Martinez 2009). Several excavations were made in the La Milpa Aguada in 1997 demonstrating that this reservoir began as a quarry and revealing a *buk’te* (stone-lied filtration well in its floor). One sediment core and five excavation units covering a total area of 14 m2 provided data from Turtle Pond, an aguada located at the PfB research station and about 2 km northwest of Aguada Lagunita Elusiva (Chmilar 2005). Turtle Pond is associated with the Medicinal Trail site (Scarborough and Valdez 2009:216-220), which was also occupied in the Late Preclassic.

Apart from gaining a better general understanding of *aguadas* in the upland region surrounding La Milpa, one of our goals was to better grasp the role of this particular reservoir as a potential pioneer water resource and demonstrate its use history. Research on the LaMAP East Transect, which runs from west to east approx. 350 m north of the aguada (Figure 1), shows some evidence for early occupation (Sagebiel 2005:620). Not Preclassic, but Early Classic (AD 250-600) in date, the area north of the *aguada* contains evidence for the earliest occupation on the East Transect (Everson 2003:304-326; Operations G32-G35 between E 10 070 and E 11 630). This suggests that Aguada Lagunita Elusiva may have served as a water resource for the first settlers of this area. Though La Milpa had grown into a considerable ceremonial center by the Early Classic and its elite populations were associating themselves with other sites of the central Maya Lowlands, such as Rio Azul to the west in today’s Guatemala and the powerful
center of Tikal (Hammond and Tourtellot 2003:42-43; Sullivan and Sagebiel 2003:29), the region around Aguada Lagunita Elusiva was probably not under the dominance of Early Classic La Milpa. Based on a gap in Early Classic occupation on the East Transect between E 7750 and E 9000 (between 1.7 and 3 km east of the La Milpa center) it is more likely that another, yet unidentified site controlled this area (Everson 2003:326; Sagebiel 2005: 621).

From Everson’s excavations we know that some of the East Transect Early Classic house mounds to the north were reutilized in the Late/Terminal Classic (Late Classic II/III, AD 700-900) (Everson 2003: 304-326) but there is little evidence for seventh century AD (Late Classic I) occupation. As a matter of fact, the entire Three Rivers Region seems to have suffered a temporary downturn in the seventh century (Sullivan and Sagebiel 2003), which was probably a result of Tikal’s political crisis and subsequent withdrawal from the region (Martin and Grube 2008). A tremendous population increase, possibly by immigration from the west (Hageman and Lohse 2003) occurred in the second half of the Late Classic between AD 700 and 800 (Hammond and Tourtellot 2004). At La Milpa, monumental architecture in the site core was rebuilt repeatedly, and at this time the residential zone of the city expanded to an estimated area of about 78 square kilometers, reaching approx. 5 km eastward from the center, more or less as far as Aguada Lagunita Elusiva. Much of the newly expanded residential zone was densely settled. Population estimates range between ca. 500 and 800 people per km² (e.g. Hageman and Lohse 2003; Scarborough et al. 1995; Tourtellot, Rose and Hammond 1996) and the peak population of La Milpa in the eighth century AD is estimated to have reached approximately 46,000 people.

The many field walls and terraces are seen as evidence for intensive cultivation during this time period and the reason for eventual exhaustion of the land (Dunning et al. 1999, 2003; Hagemnan and Lohse 2003; Hughbanks 1998; Tourtellot et al. 2003). One characteristic of Aguada Lagunita Elusiva is the presence of “box terraces” close to it (Figure 2). In Maya archaeological contexts, rectangular or boxed terraces are believed to act as seedbeds or intensive gardens that most likely allowed Maya farmers a better control of their areas of cultivation in terms of fertilization, pest control, and the application of water (Dunning 2004; Dunning and Beach 1994:58; Lohse 2004:129). Usually box terraces are closely associated with residential areas but not found in conjunction with aguadas, though there are box terraces surrounding a small urban reservoir at the site of Tamarindito, Guatemela (Beach and Dunning 1997).
few house mounds are located near the aguada, one of which we excavated, Aguada Lagunita Elusiva is situated in an area of low residential density. Approx. 350 m directly north at N6000/E11 000 on the East Transect (Figure 2) there is no residential architecture. On the same transect, 150 m to the east and 250 m to the west of E11000, field walls and a few house mounds appear. As will be discussed in detail below, pollen and other evidence indicate that Aguada Lagunita Elusiva was situated in an area of intensive agricultural production.

Apart from its obvious function as a source for water (as well as possibly clay for pottery), one other distinctive characteristic of Aguada Lagunita Elusiva and its immediate surrounding landscape is the large quantity of chert. Before starting our excavation we already had noticed large chert cobbles in several parts of the aguada surface and Brandl identified a chert knapping site in one of the adjacent dry stream beds. Though many aguadas are believed to have originated as localized natural solution features (Jennings 1985:106; Lene 1997; Siemens 1978), the use as quarries or a combination of natural and cultural processes is also suggested for some aguadas (Hester and Shafer 1984; Beach et al. 2008; Akpınar-Ferrand and Dunning 2011). Although we always assumed that the use as a water resource was the prime motive to construct or enhance Aguada Lagunita Elusiva, we suspect that obtaining chert may have been a welcome side effect of these activities. As we will show, chert quarrying and the search for suitable construction and tool manufacturing materials remained an important subsistence activity until the region was abandoned.

Finally, aguadas may not have only served as important locations for pioneering populations but remained of some importance for sporadic visitors after the Classic period (post 900 AD). Between 800 and 830 AD elite activity at La Milpa and other sites ceased (Hammond et al. 1998) and rapid depopulation of the entire area followed (Hammond and Tourtellot 2004). La Milpa was visited sporadically in the Postclassic and Colonial periods (Hammond and Bobo 1994) but there seems to be no evidence for Postclassic occupation in Everson’s excavation units north of the aguada. We hoped to discover evidence for late use of the aguada, but so far the only material recovered is trash, predominantly in the form of glass bottles, left behind by twentieth century chicleros and loggers who clearly camped near this and other aguadas.
Geology, climate, vegetation and fauna in the area of Aguada Lagunita Elusiva

Aguada Lagunita Elusiva is located 130 m above sea level on a low slope and is surrounded by a system of seasonal streams that discharge into a nearby bajo. The aguada is part of the La Lucha Uplands of the Three Rivers physiographic region, which occupies the fractured eastern side of the central Peten Karst Plateau. Geologically the area is dominated by Late Cretaceous-Paleogene (“Early Tertiary”) marine carbonates, mainly limestone and marl. Prolonged and extensive physical and chemical weathering of carbonate bedrock has led to the development of today’s mature karst landscape, characterized by bajos, rugged ridges and conical hills (Dunning et al. 1998:88, 2003:14-15). The weathering processes are also responsible for the creation of chert deposits which appear in residual layers in a variety of locations (Lewis 2003:131; Tourtellot et al. 2003:44) and are extremely prevalent in and around the aguada.

The study area is characterized by a tropical dry/wet climate. April through October, daily mean temperatures average around 27 ºC and November through March they drop to about 23 ºC. Aguada Lagunita Elusiva is dependent on rainfall as its only source of refill water, and about 80-85% of the precipitation in the region occurs during the wet season between June and December. Today, annual rainfall in the region varies between 1400 and 1800 mm (Belize Meteorological Service, Rio Bravo Station). Our field observations through many years show that the aguada usually desiccates during the dry season but rapidly fills up at the onset of the rainy season in June or July (Figure 3). [Footnote 1]

The geological and climatic characteristics of the region lead to significant variation in the region’s hydrology, soils and vegetation types. The well-drained sloping landscapes of the La Lucha Uplands are usually mantled with thin, calcareous soils (Rendolls) supporting “upland forest” – a mixture of subtropical moist forest species (Dunning et al. 2003:16). The vegetation around the aguada includes aquatic grasses, upland forests, and also a concentration of Corozo Palm (*Orbignya cohune*) (Dunning 2003). Corozo palms are usually found on deep and well-drained soils, typically on higher elevations next to bajos (Dunning et al. 2003:17). Around Aguada Lagunita Elusiva, the soils consist of thin upland Rendolls. However, in the immediate vicinity and the interior of the aguada, soils are deeper and gleyed due to restricted internal drainage. The vegetation in the aguada interior fluctuates with the weather conditions. In May 2008, the wet inner part of the aguada was covered by a thick carpet of free floating fern *Salvinia*
minima (Figure 3). In May 2009, the aguada center was moist but without any vegetation. In June 2010, the inner part of the aguada was dry and overgrown with the sedge Cladium jamaicense.

Additionally the aguada and its surrounding area are an important habitat for the local terrestrial and aquatic fauna. In the dry season the muddy parts of the aguada are usually covered with hoof and wallowing prints of medium-sized to large mammals (probably tapir, deer and peccary). We also observed four specimens of aquatic and semi-aquatic turtles: one Mexican snapping turtle Chelydra serpentina rossignoni (May 29, 2008), one Honduran slider Trachemys scripta venusta (May 22, 2009), one white lipped mud turtle Kinosternon leucostomum leucostomum (June 4, 2010) and one red-cheeked mud turtle Kinosternon cruentatum (June 15, 2010).

**METHODOLOGY**

Our field methods consisted in sediment coring, excavation in and around the aguada, landscape survey (partially using maps provided by Gair Tourtellot) as well as subsequent analysis of collected materials. In 2003 Dunning’s team extracted a single sediment core with a Livingstone Piston Corer from the center of Aguada Lagunita Elusiva, as well as amended Tourtellot’s map and made shallow surface strip excavations in the aguada to better expose the tops of rock alignments (figure 2).

The sediment core’s initial length of 220 cm was compacted to 120 cm during extraction and extrusion. Sediment found in the upper 30 cm was excluded from analysis because of our observations of extensive bioturbation in this section (mostly due to animal wallowing). The core was sliced, described, and subsampled for pollen at 10 cm intervals. Carbon samples from 45 and 65 cm were submitted for Accelerator Mass Spectrometer (AMS) dating (Beta Analytic Inc.). Pollen was analyzed By John G. Jones in the Pollen Laboratory at Washington State University.

During pollen analysis, Lycopodium spp. spores were added to each sample, and carbonates were removed with 10% HCl, silicates with 50% HF, and humates with 2-5% KOH. An acetolysis procedure (Erdtman, 1960) eliminated unwanted organics; pollen and charcoal was isolated from the remaining minerals with heavy density separation using ZnCl (Sp.G. 2.00).
Pollen identification was done with a Jenaval compound stereomicroscope at 400-1250x magnification, and minimum 200-grain counts were made for each sample.

In 2008, Akpinar-Ferrand opened four excavation units of 1x1.5 to 2m size in the area surrounding the aguada (Fig 2). Soil samples from all four units were floated (mesh size 10-30) and paleobotanic plant remains identified in the lab using a light microscope and photographed with an attached camera. The analysis was completed at the University of Cincinnati’s Biology Department with the help of David Lentz.

Between 2008 and 2010, Weiss-Krejci and her team opened eleven units in the aguada uncovering an area of 18.75 m² (Figure 2). Unit sizes varied from 2 x 2 m to 0.5 x 1 m. Since it was impossible to screen the sticky aguada clay, artifacts were extracted in the process of excavation and numerous flotation samples were also taken. Single-artifact and debitage analysis of lithic materials was performed by Brandl in 2009 and 2010. Hard matter from one unit additionally underwent mini- and microdebitage analysis. Additionally, Brandl undertook extensive survey of the surrounding region in a perimeter of some 150m², collecting chert samples from dry stream beds and comparing them with the aguada chert.

**RESULTS**

**Excavations in the aguada**

With the exception of Op. 1, Subop. F (2x2 m), which was opened in the southern part of the aguada, all remaining ten excavation units (Op. 1 Subops. A-E, G-K) are located in the northern/central part and are connected to each other (Figure 4). So far, we have reached bedrock only in Subop. G. Our excavations revealed that the aguada had been heavily modified by the ancient Maya and was subject to multiple complex, post-construction processes. In Subops. A, C, D, G, H and the northwestern parts of Subops. B and G an artificially constructed chert cobbles feature appeared between five and ten centimeters below topsoil (Figure 5 and 6). In the eastern parts of Subops. A, B and E the cobbles are located much deeper (approximately 75cm) and were covered by a thick clay and gleyed clay layer (Figure 7 and Figure 8). A probable function of the chert cobbles feature was to inhibit erosion when water gushed in during heavy rains as well as to ease access to the aguada center when the water level started to drop during the dry season – in other words, to make the aguada a more useful water supply for a longer during the year.
In the southeastern parts of Subop. I, J and K we were not able to uncover a cobble layer at all, because in this location the layer probably had been removed by the Maya. Based on one diagnostic rim sherd (Lemonal cream, Late Classic III) recovered from the bottom of the ancient excavation (Subop. K, collapse layer approx. 175 below datum and 80 cm below the surface, Figure 9) we know that this event took place in or before the Late Classic. The digging of large holes into the aguada fulfills the simple purpose of providing access to a lowering water table during the dry season as well as temporarily increasing water-holding capacity. Evidence for such activities was also uncovered in Subop. E (Figure 10, Lot E-6) as well as in Subop. H (Figure 5). In Subop. H the pit was probably dug in modern times, probably by chicleros or loggers for in the pit we found a small green bottle (Figure 11). From Eric Thompson’s 1938 diary we know that digging pits for water in dry aguadas was common among the loggers.

In Subop. F the chert layer, although starting immediately below topsoil (Figure 12), was approx. one meter thick and embedded in clay (Figure 13). We think that in this part the chert feature is part of the aguada embankment, which extends out for several meters (compare Op. 2, Subop. D).

Chert Analysis

Apart from a few ceramic sherds chert is the predominant component of cultural material found in the aguada. These rocks range from large boulders to tools and debitage. During our research we tried to answer two main questions. 1) Where did the cobble feature chert come from? 2) Is there any evidence for tool production and knapping? Before addressing these questions it is necessary to provide some basic information about the genesis of chert and chert deposits in northwestern Belize.

The origin of chert and chert deposits in northwestern Belize

The deposition of the marine carbonates, which make up most of the geology of the La Lucha Uplands, dates from between the Late Cretaceous (until 65.5 million years ago) and the middle Paleogene (“Lower Tertiary” until end of Eocene 33.9 mya). During this time period the Yucatan Platform was a high terrace covered by a shallow ocean (Barrett 2004:75–76; King et al. 1992; Lene 1997; Wilson 1980; Wright et al. 1954). From the Late Cretaceous throughout the Paleogene and the Early Neogene (Miocene 23-5.3 mya) when the Yucatan Peninsula was still
covered by sea water, chert layers started to form. The chert formation processes are not yet fully understood. Chert is defined as a micro- to cryptocrystalline quartz variety of sedimentary origin. It occurs in bedded and nodular deposits, mainly linked to limestone or dolomite formations.

Chert exists on top of karstic hills, which, due to their consistency of more endurable rock material than the surrounding formations remain as residual pieces of the former high terrace. Natural erosion also led to massive accumulation of material in and around small and large landscape depressions, especially in bajos, where chert appears as a secondary inclusion in the limestone matrix see also (Tourtellot et al. 2003:44). Chert quarrying at such locations does not require major technological inputs. Digging a shallow pit to the depth of the residual layer within the raw material is generally sufficient to expose and liberate chert inclusions. Stream beds are another common chert source for many watercourses wash out large amounts of material from the uppermost chert layer during the rainy season (Lewis 2003; Tourtellot et al. 2003:44). Stream beds thus form secondary deposits. The simple gathering of nodules as they are exposed or washed out is the easiest way to obtain knappable raw materials.

**The provenience of the chert materials found in the aguada's interior rock feature**

Concerning the first question on the provenance of the construction material, two possibilities come to mind: a) the chert used for the aguada construction was delivered from chert sources in the vicinity of the aguada, such as the surrounding drainages, or b) the chert boulders originate from residual layers exposed in the aguada itself. In order to answer this question Brandl sampled a range of chert varieties occurring in the surrounding region in a perimeter of some 150m² and compared it with the aguada chert. Altogether, over 50 chert samples from the structures within the aguada (primarily from Suboperations E and G) and approximately the same amount from the surrounding drainages were macroscopically and microscopically investigated. Color, knapping properties and fossil inclusions were used as a basis for comparison. The direct comparison between the aguada and non-aguada chert reveals a certain similarity but also significant differences. The aguada cobble feature chert is more yellowish, whereas the chert from the creek is blue-grey. Raw material used for knapping shows higher quality in the aguada than in the drainages. Though rare, macrofossils occur in the some chert from the drainages, whereas chert from the aguada rock feature shows no visible fossil inclusions.
Similarly, the chert used for the aguada cobble feature is also different from natural chert deposits within the aguada bedrock, which we exposed in Subop. G. The first variation from the bedrock chert is the obvious difference in the size of the rocks. On average, the rocks in the constructions measure at least 15-30 cm in diameter. The rocks found in the bedrock are much smaller. The variety of colour and the surface structure are additional sharp distinctions. We therefore conclude that the massive nodular and tabular chert boulders which were used for the construction of the aguada chert cobble feature are likely to have originated from the natural uppermost residual chert layer of the aguada. Due to extensive past quarrying activities, this layer in the meantime has completely disappeared. Presumably better quality chert form this deposit was largely consumed in tool making while the poorer quality stone was used for construction.

Artifact and debitage analysis

Our second research question concerned stone tool production in and around the aguada which we addressed through artifact and debitage analysis. Most of the pieces from the aguada are simple flakes, primary surface flakes and secondary surface flakes, which indicates core preparation and the production of expedient tools. Biface preparation is demonstrated by the presence of half finished products and thinning flakes. Blades are clearly underrepresented (Figure 14). It is clear that most of the aguada’s chert assemblages are leftovers from lithic production and only a few tools have really been used as such by the ancient Maya. Only 67 out of 1,982 investigated pieces show the influence of fire, most of them in the topsoil layer of Subop. H (see Figure 15). The fire events are possibly related to a recent disturbance by chicleros or loggers, especially because the burnt pieces are accompanied by modern finds such as a twentieth century glass bottle and a squeezed-out Colgate toothpaste tube made in Jamaica.

Massive waste from intense flint knapping activities (pieces bigger than 10mm in length) was found in all units during the excavations. Some waste seems to have been intentionally placed within the rock assemblages by the constructors. In Suboperations G and F the waste is directly associated with the rock construction. In Suboperation E it was directly on top of the lower stone layer (note the sudden rise between Lots E-8 and E-9 in Table 1), which we interpret as part of an artificially constructed aguada floor. We assume that this massive waste (including
macro-, mini- and microdebitage, see below) was intentionally placed within the rock assemblages to fill the gaps between the larger rocks and make the floor surface more even.

Another essential question was whether or not the knapping waste originates from one of the nearby knapping sites in the dry stream beds discovered by Brandl during survey or if knapping took place right next to the aguada’s waterfront. The question was answered by conducting an aimed analysis of the mini- and microdebitage from selected samples out of Suboperation E through flotation (see Table 1). The results clearly show a high quantity of mini- and especially microdebitage (up to 10mm resp. smaller than 10mm) which indicates that knapping activities did take place in the aguada. Hence the microdebitage analysis proves that lithic artefacts have been produced on site. With only a few exceptions, the raw material of knapping waste from all units matches the raw material of the chert boulders used for the rock constructions. These differences can be explained by possible renovation activities – building up of rock structures upon already existing ones - or even revitalization of the agueda as a water reservoir in the eighth century.

Excavations around the aguada

Op. 2, Subops. A, B, C, D is depicted on Tourtellot’s map (Figure 2). Op. 2, Subop. A was located 20 m to the east of the aguada in front of a house mound. It revealed a layer of uniformly placed rocks at 30 cm below the surface, which we interpret as a kind of floor. The layer above this floor (between 20 to 30cms below the surface) contained some lithics, pottery sherds, plaster remains and pieces of carbon. A flotation sample was taken from this layer (see below).

Op. 2, Subop. B was conducted 40 m to the south of the first unit and in the middle of an open land patch surrounded by berms which we identified as a box terrace. Within the excavation unit chert flakes as well as a large oval biface, possibly an agricultural tool, started to appear at 10 cm below the surface (Figure 16). The excavation was halted at a depth of 30 cm below the surface when a high quantity of rocks ranging from 10 cm to 30 cm in length and width made further exploration difficult (flotation sample was taken from between 20 and 30 cm).

Op. 2, Subop. C was located 15 m to the southwest of the aguada, in a low, flat area between a field wall and the slope that descends into the aguada. The first lithics in this unit
appeared at 10 cm below the surface and became quite dense between 20 and 30 cm. We encountered fragments of actual tools and abundant chert flakes. Between 30 and 40 cm (soil sample taken), we observed smaller to much larger rock pieces in dark grey gleyed soil. At 40 cm below the surface we had to stop the excavation because water started to seep in.

Op. 2, Subop. D took place at the southern margin of the aguada. A clayey horizon which started at 10 cm and reached until a depth of 30 cm contained no cultural materials. However at 20 cm below the surface, we started to observe mineral aggregates (metal oxides) that result from intensive chemical weathering (Essington 2003). These nodules could easily be mistaken for carbonized seeds (Akpinar-Ferrand et al. in review). At 30 cm, we encountered pottery sherds and a biface lithic before we hit a layer that went another 60 cm consisting of rocks of various sizes. Overall between 30 and 90 cm, we found the soil to be light gray gley with no additional evidence of cultural material. A flotation sample taken from this unit did not produce seeds or plant remains of any interest. This was the deepest of our units and reached until 90 cm below the surface.

We have not been able to date ceramics from these excavations though we suspect that all uncovered features excavated around the aguada date not earlier than the second part of the Late Classic.

**Plant remains**

The floated soil from the layer above the floor in Op. 2, Subop. A (unit 20 m to the east of the aguada in front of a house mound) revealed Cyperaceae (sedge family), Fabaceae (legume family), Asteraceae (aster family), Araceae (Arum family, also colloquially known as aroid) and *Cecropia peltata* (pumpwood or trumpet tree species). Fabaceae or Leguminosae is an economically important family of plants, but in this instance, based on the seed size it is not believed that the plant was cultivated (David Lentz, personal communication 2010). The Araceae family is known to be common in wet areas. Like Cyperaceae and Asteraceae, *Cecropia peltata* (Figure 17) is also a weedy species and can be found in cleared areas or secondary growth (Lentz and Dickau 2005). A particularly interesting economic aspect of this specie is reported by Standley and Steyermark (1946): “its split trunk is sometimes employed as troughs or conduits for conducting water.” While it is possible that the Maya were cultivating this plant near the aguada, it is more likely that it was opportunistically harvested.
A soil sample taken from the box terrace (Op. 2, Subop. B), from between 20 and 30 cm below topsoil and above a high concentration of rocks contained only one identifiable seed. It belongs to the family of Solanaceae (flowering plants) that contains a number of important cultigens (Rahman and Paterson 2010). The seed could not be identified to the specie.

In the flotation sample from Op. 2, Subop. C between 30 and 40 cm below topsoil, we were able to identify only one specimen. It belongs to the family of Portulacaceae that ranges from herbaceous plants to soft-wooded shrubs or small trees (Phillips 2002).

Additionally, analysis of one sample from within the aguada (Op. 1, Subop. E, Lot 8) by David Goldstein also revealed one aster seed (*Viguiera* sp.) as well one example of Arecaceae (palm family) and Combretaceae (flowering plant).

**Core stratigraphy and pollen analysis**

The Aguada Lagunita Elusiva sediment core initially had a column length of 220 cm, which was compacted to 120 cm during extraction and extrusion. Sediment found in the upper 30 cm was excluded from analysis because of extensive bioturbation in this section (mostly due to animal wallowing). The core was sliced, described, and subsampled for pollen at 10 cm intervals. The sediment core produced two radiocarbon dates. Organic matter taken at 65 cm revealed a date of 1490±40 BP which corresponds to the range of AD 460–650 (p= .95, 2σ) or a medium date of AD 580 (transition from late Early Classic to early Late Classic). The second sample at 45 cm produced 930±40 BP which corresponds to the period AD 1020–1200 (p= .95, 2σ) or a medium date of AD 1100 (Early Postclassic). Between 30 and 70 cm, the core consisted of 35-45% organic matter and preserved a large amount of pollen. There were no signs of bioturbation or other stratigraphic disruptions between 30 and 70 cm, but compression may have occurred unevenly within the sediment making dating according to stratigraphic position only approximate. Below 70 cm the core consisted of light gray clay with orange mottling, signifying past drying, and less than 5% organic matter, and no preserved pollen. Based on the two AMS dates and the apparent vertical integrity of the sediments within the core, it appears that Aguada Lagunita Elusiva was not dredged in at least the deepest section after about AD 500. Four zones are identifiable with the pollen preserved in the core between 35 and 70 cm (Figure 18).
Zone 4 (Early Classic III, approx. AD 400-600). Zone 4 starts at 70 cm and extends to 65 cm; the lowest part of the core with preserved pollen. This zone is indicative of conditions around the aguada in the fifth and/or sixth century AD. The pollen is dominated by high percentages of herbs and cultigens comprising close to 75% of the total pollen count. The higher proportion of herbs and cultigen taxa to the arboreal taxa demonstrates extensive human impact around the aguada. This is also corroborated by the presence of weedy and secondary taxa of Asteraceae, Borreria and Mimosa. Moreover, Zea mays pollen (maize) reaches a significant 10% level in zone 4. The high percentage of Zea mays points to evidence of sustained maize farming in the immediate vicinity of the aguada, as this species is insect pollinated and its large pollen grains do not travel far (Leyden 2002). Additionally, the presence of pollen from the trees Coccoloba, Sapotaceae and Orbignya cohune shows that these were probably economically valuable species cultivated by the Maya near the aguada (Pohl et al. 1996; Lohse 2007).

Zone 3 (Late Classic I, approx. AD 600-700). Zone 3 extends from 65 to 60 cm in the core and probably reflects conditions around the aguada in the seventh century AD, a time period which is characterized by a population decline in the Three Rivers Region (Sullivan and Sagebiel 2003:27). The percentages of herbs and cultigens stabilize at a significant 80% of the total pollen count while arboreal taxa maintain a collective percentage up to 20%. Cyperaceae increase to 15% of the total pollen count, and Cladium also appear. Fluctuation in the aquatic species may represent a change in water availability or indication that these species were not removed by the Maya during this time (see Wahl et al. 2007:219). The weedy taxa of Asteraceae display a dramatic decrease from 25% at the end of zone 4 to less than 5% by the end of zone 3, while Chenopodiaceae and Amaranthaceae (=Cheno-Ams) appear. Additionally, Poaceae (flowering grasses) show a significant increase up to 55% of the total pollen count. Zea mays pollen is still abundant; however, it falls to less than 5% by the end of zone 3. The high forest taxon Myrtaceae (myrtle family) also begins to appear. Overall, we may begin to see a decrease in agricultural activities around Aguada Elusiva with an accompanying increase in the secondary growth, as well as perhaps less maintenance of the aguada itself.

Zone 2 (Late Classic II/III, approx. AD 700-900). In zone 2, between 60 to 50 cm in the core – especially at the upper end, the count of herbs and cultigens that had reached 80% in zone 3,
decreases to an approximate ~50% of the total pollen count. Poaceae that reached 55% in zone 3 are stable until the middle of zone 2 (until 55 cm), then drastically decline to 15% of the total pollen count. Asteraceae which had dropped to 5% at the end of zone 3 slightly increase and Cyperaceae fluctuate through zone 2. *Zea mays* pollen is still present, however in much lower amounts than in the previous zones. At the upper end of zone 2 around 50 cm, there is a large spike in fern spores, followed by an increase in high forest arboreal species and mangroves (e.g. Combretaceae). The fern spike may well represent an incursion of bracken fern (*Pteridium aquilinium*), an aggressive species that thrives in nutrient poor soil. It is noted for invading over-cropped fields in the southern Maya Lowlands and for being difficult to remove once established (Pérez-Salicrup 2004). The dramatic decrease in cultigens in correlation with a sudden decrease in fern spores is consistent with the archaeological record which suggests that the region was rapidly deserted around AD 830 (Hammond et al. 1998; Hammond and Tourtellot 2004). We assume that by AD 900, the area around the aguada was largely, if not completely, abandoned and recolonized by upland forest.

**Zone 1 (Postclassic and later, after AD 900).** In zone 1, between 50 and 35 cm of the core, herbs and cultigens drop to about 10% of the total pollen count, whereas the arboreal taxa attain their highest levels at 30%. In this zone, we see much lower levels or altogether disappearance of cultigens and the disturbance taxa. Clearance indicators, such as Poaceae also drop to less than 5%, while *Zea mays* pollen completely disappears by the middle of zone 1. Following the ~AD 1100 date obtained at 45 cm, the core reflects continued abandonment of the Maya activities and forest recovery.

**CONCLUSIONS**

Our research results allow a partial reconstruction of the history of events in and around the aguada from the Early Classic to the present time. This picture does not incorporate a fine stratigraphy and, of course, not every event that eventually took place in the area, but gives a broad outline of the most important stages as far as comprehensible at the present state of research. Most likely, Aguada Lagunita Elusiva originated as a shallow natural depression. The first settlers removed the most massive chert boulders for further use and left behind small nodules only of the size of a human fist, which we encountered in the bedrock of Subop. G.
Subsequently, massive multi-phase anthropogenic changes took place in the aguada. Rock fixtures guaranteeing better accessibility, water inflow regulation and preserving the water resource were structured. Such behaviour can be observed throughout the Maya lowlands where clay and plaster linings as well as limestone pavements exist (Akpinar-Ferrand and Dunning 2011).

Obviously, the Maya used those materials which were most easily accessible. In the case of Aguada Lagunita Elusiva the most abundant material was chert. The raw material used most likely came from the original top chert layer dug out of the aguada, especially those which were of lesser quality and not suitable for lithic tool production.

Whether the first phase of aguada modification coincides with initial quarrying activities cannot be said with certainty at the moment nor can this event be dated at the moment. It is possible that the aguada dates to the time of the Late Preclassic – Early Classic transition, a period that saw widespread investment in the Maya Lowlands, probably tied to episodes of increased drought frequency and severity (Dunning et al. 2011). The sediment core sample shows that the aguada was used as a water resource by the ancient Maya at least in the last part of the Early Classic (fifth/sixth centuries AD). During that time period the aguada was two meters deeper at its center and was able to hold twice as much water as today (ca. 900,000 liters), though sediment began to accumulate thereafter.

Already in the Early Classic, the aguada was located in an area of intense agricultural production. The amount of maize pollen recovered at this level in the core is unprecedented. That is not to say that this was the only thing being grown since many other crops produce even less pollen than maize.

Although the pollen from the sediment core indicates a slight hiatus (less intensive land use and probably population reduction) in the seventh century associated with a short phase of abandonment, possibly connected to the Tikal Hiatus (see Sullivan and Sagebiel 2003), agricultural production resurfaces in the eight century. Archaeologically the massive Late Classic agricultural production is evident through a series of terraces including box terraces. Although we do not have direct dates for the terraces and walls near the aguada, these features have been dated exclusively to the Late Classic at La Milpa and elsewhere in the Programme for Belize (Hughbanks 1998; Tourtellot et al. 2003). Furthermore, the flotation samples taken from all of
the excavations around the aguada yielded a number of carbonized ancient micro and macro plant remains. Some of the remains could only be identified to the family, but *Cecropia peltata* could be identified to the species. This species’ recorded use for conducting water with its split trunk during ethnographic studies of Guatemala by mid-20th century is particularly interesting in an aguada context.

Weedy species (indicative of disturbance and cultivation), as encountered in Op. 2, Subop. A beside the house mound belonging to the families of Cyperaceae and Asteraceae, are also evident in the pollen from the 2003 core. All of the types of seeds recovered in Op. 2 Subop. A have also been recovered in midden deposits at the small site of Guijarral located several kilometers north of Aguada Lagunita Elusiva (Hageman and Goldstein 2009).

That the soils were eventually exhausted is indicated by the pollen signals and in line with profiles obtained from other *aguadas* in the Maya Lowlands (e.g. Webster et al., 2005; Wahl et al., 2007; Dunning et al., 2005; Akpinar-Ferrand et al. 2011, etc.). The rapid rise or spike in fern spores is very impressive, and likely a field exhaustion signature.

Since lithic waste is present in all aguada units and levels, as well as in the surrounding dry stream beds and also showed up in peripheral excavations, we conclude that Aguada Lagunita Elusiva also was an important chert resource and production site throughout its occupation history. Aguada Lagunita Elusiva was characterized by a multi-resource economy in which water, agricultural products, chert and clay may have provided the kind of economic independence that was necessary for people living the furthest from large centres. However, if the area around the aguada fell under the jurisdiction of La Milpa (5 km to the west) as proposed by Tourtellot et al. 2003, or to another center (e.g. Wari Camp 4.5 km to the east) at various points in time for now remains an open question.

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Footnote 1:
Precipitation of a little over 235 mm seems sufficient to fill the reservoir in its current dry state. The formula for calculating aguada fill-up is as follows: aguada surface plus catchment area (three times the aguada surface) multiplied with precipitation and 30 percent deduction for catchment seepage \[615 \times 3 \times 235 - (\left(\frac{615}{100} \times 3\right) \times 235)\] = 448 027.5 liters. This calculation is supported by field observations. On May 29, 2008, tropical storm Arthur hit Belize bringing 217 mm of precipitation. When we visited the aguada again on June 3, it was almost full. On the other hand, not only lack of rain can be responsible for the aguada’s desiccation. On May 28, 2009 we experienced an earthquake (7.1 on the Richter Scale) which hit the Caribbean Coast of Honduras and Belize. As a result the aguada dropped about half a meter at the center causing whatever little water was left in it to disappear.
<table>
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<th>Lot description</th>
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<td>Brown top soil (3 cm)</td>
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<td>6</td>
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<td>Gray glazed clay (8 cm), below Lots 6 and 7</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>Gray glazed layer (3 cm), beside Lot 10, above Lot 11; remains of sealing layer</td>
<td>E-9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Brown grey deposit (2 cm), above Lot 11; sealing layer</td>
<td>E-10</td>
<td>3</td>
<td>1</td>
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**Table 1. Microdebitage Analysis**
Figure 1. Belize and PfB

Figure 2. Tourtellot’s aguada map with locations of Subops. 2 A-D.
Figure 3. On May 18, 2008 the wet part of the aguada was covered by a thick fern carpet of *Salvinia minima*; B: when we returned nine days later the carpet of green fern was much reduced. On May 29, 2008 tropical storm Arthur hit Belize bringing 217mm of rain. C: When we visited the aguada again on June 3, 2008 it was almost full.

Figure 4. Plan and profile of aguada with Op. 1 Subops.
Figure 5. Plan of aguada northern excavations with cobble feature
Figure 6. Op. 1 Subops. D, H, I, G
Figure 7. Op. 1 Subops. A, B
Figure 8. Subop. E
Figure 9. Lot subsections
Figure 10. Lot E-6

Figure 11. Op. 1 Subop. G and H
Figure 12. Op. 1 Subop. F
Figure 13. Subop. F

Figure 14. Lithic tool production distribution
**Figure 15.** Lithics in Op.1 Subops.

**Figure 16.** SubOp.2 B.
Figure 17. *Cecropia Peltata* from Op.2, Subop. A
Figure 18. Pollen profile from Aguada Elusiva
5. Article 3

Aguadas: An Integral Component of Ancient Maya Water Management Systems in the Maya Lowlands

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Abstract

Studies of water management in the Maya region contribute significantly to our understanding of ancient Maya Civilization. Aguadas, water storage ponds of varying size, have been an understudied aspect of Maya water management systems. Recognizing the origins and the function of aguadas will provide a more complete picture of ancient Maya water management strategies. In this study, we compiled a list of the available aguada investigations focusing particularly on the southern Maya Lowlands, then synthesized and analyzed these studies in order to develop a comparative framework for understanding aguadas as vital ancient Maya water resources.

INTRODUCTION

Water has been of paramount concern for Maya peoples inhabiting much of the Yucatan Peninsula for millennia. The karst nature of this landmass and a highly seasonal distribution of rainfall have made the capture and storage of rainwater a necessity for much of the region’s history. Across a wide swath of the interior Maya Lowlands, the Maya exploited sinkholes and natural depressions, and, where nature did not provide, utilized quarried depressions for water retention. Collectively, thousands of aguadas (or water-holding ponds) are found wherever the Maya resided in the seasonally parched interior on the peninsula. The study of aguadas is essential to understanding water management among the Maya and its role in the development of ancient Maya Civilization. However, comparatively little research has been done on these features and that which has been completed has not been effectively synthesized. Since a single
term “aguada” is, in fact, being applied to a variety of related, but distinct features there is a significant need for clarification.

In reconnaissance surveys of the early twentieth century, the close spatial association of aguadas with ancient Maya settlements was frequently noted (Maler, 1908; Cole, 1910; Ricketson and Kidder, 1930; Lundell, 1933). During a Pan American Airways and Carnegie Institution of Washington collaborative exploration in 1929, expedition members were also surprised to see most of what was recorded in earlier maps as lakes were in actuality aguadas (Ricketson and Kidder, 1930). In the mid-twentieth century, Scholes and Roys witnessed local populations dependent on aguadas as an important water supply in the northwestern fringes of the southern Maya Lowlands (1948). In the Petén savannas, Lundell similarly noted the importance of aguadas for local populations, especially during the dry seasons (1937). In the following decades, studies continued to record modern communities relying on their aguadas for their water needs (Cowgill and Hutchinson, 1966; Puleston, 1973; Adams, 1981). In short, while it has long been known that aguadas were an important resource for Maya populations, relatively little specific attention has been given to these features.

In this study, we compiled a list of the available aguada investigations focusing particularly on the southern Maya Lowlands, then synthesized and analyzed these studies in order to develop a comparative framework for understanding aguadas as vital ancient Maya water resources. We believe recognizing the origins and the function of aguadas will provide a more complete picture of ancient Maya water management strategies. However, it should be pointed out that our survey is far from comprehensive and, furthermore, large areas of the Lowlands remained unsurveyed at the onset of the twenty-first century (Johnston et al. 2001). As a result, many water management features, such as aguadas, are undocumented.

**Types of Aguadas: Definition and Classification**

To date, studies of southern Maya Lowlands have revealed a variety of ancient Maya water management strategies reflecting the region’s unique environment. These strategies included shallow wells tapping sporadic perched aquifers, large urban reservoirs, and small household tanks and cisterns (chultuns) (Siemens, 1978; Scarborough, 1993; Krejci-Weiss and Sabbas, 2002; Johnston, 2004; Wahl et al., 2007). Aguadas, as water resources, have been
continuously mentioned in the studies of southern Maya Lowlands. The word *aguada* in Spanish denotes a “watering place”. In Yukatek Maya the word *akal* is used to refer to aguadas, though this same word may refer to larger, seasonally-inundated depressions. The Maya words *tz’anet* or *dzonot* or the Spanish word *cenote* stands for steep-walled exposed water feature that reaches below the water table (Monroe, 1970). Cenotes should not be confused with aguadas as they imply connections to an underlying water table, and form a different geologic feature from the closed-system of an aguada.

The size, nature, and origins of aguadas appear to vary both between and within regions. In some instances, aguadas clearly begin as dolines or karst sinkholes that have partially filled with sediment. However, in other instances large amounts of human modification are evident and the origins of aguadas may be obscure. In other instances, aguadas may have an entirely cultural origin, probably beginning as quarries and later modified to retain water.

Tectonic activity has had a significant role in the spatial distribution and formation of aguadas. It has been observed that faulting and folding largely control the distribution of natural aguadas in the southern Maya Lowlands, as the limestone dissolution and sinkhole formation is concentrated along fractures created by these processes (Beach et al., 2003, Ramos et al., 2004). In Alta Verapaz, Guatemala, remote sensing studies have shown that synclines direct the spatial distribution of bajos, and dissolution features such as sinkholes typically form along their main anticline axes (Ramos et al., 2004). In archaeological studies, aguadas have been largely observed at the margins of bajos (poljes) (Bullard, 1960; Siemens, 1978; Dahlin et al., 1980; Dunning and Beach, 1994; Wahl et al., 2007). Siemens believed the suitability of bajo margins for aguada formation or construction was an important reason for attracting early ancient Maya settlements to these areas (1978). In the absence of fractures, limestone dissolution is still observed to take place, yielding a more random and less concentrated spatial distribution.

Studies in the Maya Lowlands have provided a variety of descriptions for aguadas. These descriptions range from “less permanent pools that are ancient cenotes with sloping sides” (Cole, 1910); “surface water pools” (Higbee, 1948); “broad shallow depressions” (Flores-Nava, 1994; Monroe, 1970; Matheny, 1976); “sinkholes and shallow water deposits” (Lundell, 1937; Cervantes-Martinez et al., 2002; Acuña, 2008); “a water body that is isolated from the underlying aquifer by an organic or clay basin seal” (Schmitter-Soto et al., 2002; Hodell et al.,
“small ponds associated with topographic depressions” (Wahl et al., 2007); and “small dissolution dolines” (Beach et al., 2008). These descriptions identify aguadas as either collapse, solution sinkhole features, or as small ponds that accumulated in shallow depressions. It should be noted that while most aguadas are modified versions of natural karst features, they may also result from quarrying or engineering activities of the ancient Maya. These features are typically called reservoirs with plaster and/or stone lining if found in the site-centers, or aguadas if found in the hinterlands (most likely with no plaster lining). The origins of aguadas are usually difficult to discern without excavation, and using a blanket statement to describe their origins may not be accurate.

Following Arredondo-Figueroa and Flores-Nava (1992) and Flores-Nava (1994), we group aguadas into three categories: permanent sinkhole aguadas; seasonal shallow basin aguadas (dissolution dolines); and quarry aguadas.

**Permanent Sinkhole Aguadas**

Dissolution of the carbonate rock comprising the Yucatan Peninsula has led to the formation of underground caves, and also epigean or exposed systems (Cervantes-Martinez et al., 2002). The exposed systems include cenotes, in addition to the permanent sinkholes and seasonal shallow basins that are both locally known as aguadas. Sinkholes (dolines) usually result from collapse or subsidence of the land surface due to the removal of the underlying rock layers by continuous dissolution by water or by direct solution of the surface rock (Flores-Nava, 1994).

The sinkholes that are known as “cenotes” in the Yucatan Peninsula will usually be open systems, meaning the bottom of the sinkhole is still connected to an aquifer. The closed types of collapse sinkholes identified as aguadas or permanent sinkhole aguadas have been cut-off from the underlying water table by sedimentary and organic matter blockage over time. Permanent sinkhole types of aguadas may display steep walls reflecting their origin as former cenotes or may have tapering sides. Additionally, these kinds of aguadas are only fed by rainfall and water-run off as a means for water accumulation (Flores-Nava, 1994; Cervantes-Martinez et al., 2002; Schmitter-Soto et al., 2002).
Permanent sinkhole aguadas will display depth ranges of up to 15 m and their areas can extend from less than a hectare to several hectares (Monroe, 1970; Schmitter-Soto et al., 2002). Permanent sinkhole aguadas rarely go dry mostly due to their depth. This type of aguada is most common in regions where cenotes are also found, such as the northern Yucatán karst plain, other coastal lowlands, and parts of the southern Petén, where the permanent water table is relatively close to the ground surface (Dunning et al. 1998). These features are less common across interior portions of the Lowlands where the water table is much deeper.

There are additional water features in the Maya Lowlands known as “lagunas”. Foster and Turner (2004) define them as “solution features that retain water in their deeper parts throughout the year.” While there is no technical distinction between aguadas and lagunas, on a relative scale local people commonly refer to larger water-filled depressions as lagunas and smaller (non-cenote) features as aguadas.

**Seasonal Shallow Basin Aguadas**

The solution depressions that pit and scar the surface rock layers in the karstic Maya Lowlands result in the formation of the second types of aguadas, namely, seasonal shallow basin aguadas. These formations, often referred to as dissolution dolines, are a typical feature of karst landscapes in humid locations (Ford and Williams, 1989). A distinction must be made between permanent sinkhole aguadas and seasonal shallow basin aguadas, where the latter formation takes place by direct solution of the surface rock (Monroe, 1970). Deep permanent sinkhole aguadas become less common and shallow seasonal basin aguadas become more prevalent as the land elevation, precipitation and soil depth rises as one moves towards south on the Yucatan Peninsula (south of Sierrita de Ticul Range, Mexico), (Flores-Nava, 1994).

Water in shallow depression basin aguadas originates from precipitation and run-off. These features are usually made impervious by the organically rich and less permeable clayey sediments that are deposited in their floor, a process similar to what takes place in permanent sinkhole aguadas. The seasonal shallow depression aguadas exhibit two ecological phases of “dilution” and “concentration” (Flores-Nava, 1994). In the early dilution phase, when the rains begin during the wet season, nutrients such as phosphorus and nitrogen are suddenly released into the water setting off a high primary productivity and successive links of the trophic chain
(limnetic fauna, zooplankton, etc). In the concentration phase during the dry season, nutrients supplement the dry aguada sediments in the floor of the aguada, leading to vegetation cover that retains the nutrients until the following wet season (Arredondo-Figueroa and Flores-Nava, 1992; Flores-Nava, 1994).

It has been pointed out that the nutrient rich soils from the floor of the seasonal aguadas during dry seasons have been utilized by present-day rural Maya populations to grow fast maturing crops of beans and chili, in addition to high-nutrient-demand crops, such as corn. Rural Maya have also been known to dredge the fertile bottom soils of these types of seasonal aguadas and apply them to improve the soils of less fertile areas (Flores-Nava, 1994). Corroborating these modern observations, a study in the Petexbatun region has shown that karstic sinkholes (drained rejolladas and aguadas) were very attractive locations for the ancient Maya, as they were found, surrounded by remains of settlements and agricultural terraces. The same study tied the interest of the Maya to the presence of fertile but largely erodible soils in the upper slopes of these formations, and also to the deep, cumulic soils that accumulate on their floors (Dunning and Beach, 1994).

**Quarry Aguadas**

Contemporary and ancient human activities have led to the creation of man-made ponds in the Yucatan Peninsula (Hester and Shafer, 1984; Flores-Nava, 1994; Beach et al., 2008). In particular, the ancient Maya created anthropogenic depressions from limestone and chert quarrying activities resulting in the third type of aguadas: quarry aguadas. In order to be used as reservoirs, quarries had to be lined with an impermeable layer. This was due to the fact that fractured limestone surfaces would not be suitable for water storage. At the site of San Bartolo in the northeast Petén, a Middle Preclassic stone quarry was converted into a reservoir with a thick plaster lining (Garrison and Dunning 2009; Akpinar-Ferrand et al. in review). At the nearby Aguada Tintal an apparent chert quarry was sealed to retain water with a combination of stone and clay (Akpinar-Ferrand et al. in review).

**The origin of the “impervious layer” commonly encountered in aguadas**

Given the differing origins of aguadas, the natural permeability of these features is highly variable. The “ubiquitous” impervious layer seen in many aguadas usually consists of clay and
organic debris (Ancona, 1889; Mathewson, 1977; Siemens, 1978; Adams, 1981; Scarborough et al., 1995; Beach and Dunning, 1997; Gill, 2000). The degree to which this impervious layer is man-made or natural likely varies from aguada to aguada. In karst studies, clay washing into depressions has been shown to seal the joints and cracks in sinkholes. Also, as plant life takes place in the sealed platforms, resultant organic acid is instrumental in widening the depression by dissolving more of the exposed rock. The clay engendered from the solution process has been observed to be water resistant, as well (Ford and Williams, 1989; Istrianet, 2011). X-ray diffraction analysis of sediment samples from Aguada Santa Ana Vieja in central Petén showed different types of clay minerals to be present in the aguada’s sediments, revealing that clay acting as a sealant in aguadas could originate from a variety of geomorphic and geologic processes (Cowgill and Hutchinson, 1966).

Coring and excavations in some aguadas have encountered hard, oxidized clay layers. These appear to represent periods of severe desiccation during which the clay floor of the aguada essentially baked into an adobe-like state, and may correlate with periods of increased regional aridity. For example, such layers were found in Aguada Tintal and Aguada Terminos and dated to the end of the Late Preclassic period (Dunning et al. 2011; Dunning et al. 2012). Both of these aguadas were utilized in later periods and dredged of sediments at least once, but the hardened clay layer was left in place, either because it would have been highly labor intensive to remove it or because it formed an effective impervious liner.

**METHODOLOGY: A COMPARATIVE FRAMEWORK**

For this study, we created a database of aguada information with the aim of recognizing patterns in aguada characteristics. The majority of the aguadas selected for the study were situated away from site-centers, such as in hinterlands, city margins and exurbs of minor and major ancient Maya centers. Geographically, the chosen aguadas are located between the Sierrita de Ticul hills in Mexico to the north and the Copan Valley in Honduras to the south. We also included two aguadas from the north of Sierrita de Ticul to better represent the characteristics of permanent sinkhole aguadas as these types of aguadas are uncommon in most areas of the southern Maya Lowlands.
During the compilation of the database, it became apparent that aguada investigators have not been uniform in their descriptions, in their terminology, or in their field methods. We populated the database only if an aguada attribute was mentioned by the investigators. If a particular characteristic was not recorded, it does not necessarily mean that this quality did not exist, only that it was not mentioned. Thus, the absence of specific attributes may reflect variation in the depth of investigation as much as it reflects actual variation among aguadas.

Based on the details provided, it became possible to classify recorded observations into ten descriptive fields to help with the categorization of aguadas:

- **Aguada Type**: permanent sinkhole, seasonal depression or quarry aguada.
- **Aguada Location**: karst plain, uplands, transitional uplands, edge of bajo, inside a bajo.
- **Type of Lining Inside the Aguada**: plaster, impervious clay layer, stone lining, combination.
- **Volume of the Aguada (range)**: 0-2500 m³, 2500-5000 m³, 5000-10000 m³, 10,000-15,000 m³, 15,000-20,000 m³.
- **Evidence of Maya Engineering**: presence of berms, canals, siltation tanks, drainage channel, *buk’te*, etc.
- **Evidence for nearby Agriculture**: agricultural pollen signature, box terraces/terraces around the aguada, agricultural tools, etc.
- **Evidence of Chert Working**: presence of lithic debitage, etc. around the aguada.
- **Evidence of Settlement around the Aguada**: existence of house mounds up to 300 m from the aguada.
- **Aguada Shape**: circular, oval/elliptical, rectangular, irregular.
- **Water permanence**: perennial, seasonally dry

The descriptive fields were used to create a detailed table in which all studied aguadas were listed with an assigned number along with the sources where these aguadas are described (**Table 1**). A total of forty-five aguadas were analyzed in this study. The known attributes of each aguada are listed in Table 2.
The volumes of the aguadas were estimated from dimensions given by the investigators using the modified elliptical cone volume formula adopted from Brewer (2007):

\[ \text{Volume} = H \left(\frac{1}{2}\right) \pi \left(\frac{L}{2}\right) \left(\frac{W}{2}\right) \]

Where \( H, \pi, L, W \) defined as: Aguada Elusiva Dunning, 2003 Krejci-Weiss et al., 2011

\( H = \) Height, \( \pi = \) Pi, \( L = \)Length, \( W = \)Width

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<th>Aguada Name</th>
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<td>Aguada X-Pooch</td>
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<td>2</td>
<td>Aguada X-Caamal</td>
<td>Hodell et al., 2005</td>
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<td>Aguada Chanchen</td>
<td>Flores-Nava, 1994; Huchim-Herrera 1991</td>
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<td>Xcoch S Aguada</td>
<td>Dunning et al., 2011</td>
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<td>5</td>
<td>Dos Hombres Aguada 1</td>
<td>Lohse, 2004</td>
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<td>6</td>
<td>Dos Hombres Aguada 2</td>
<td>Lohse, 2004</td>
</tr>
<tr>
<td>7</td>
<td>Aguada La Milpa</td>
<td>Scarborough et al., 1995</td>
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<td>8</td>
<td>Aguada Elusiva</td>
<td>Dunning, 2003, Krejci-Weiss et al., 2011</td>
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<td>Aguada Turtle Pond</td>
<td>Chmilar, 2005</td>
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<td>Brewer, 2007</td>
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<td>Aguada 23 (Mirador)</td>
<td>Matheny et al., 1980</td>
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<td>Aguada Bolocantial</td>
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<td>Aguada Catolina</td>
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<td>(44)</td>
<td>Aguada Petapilla</td>
<td>Webster et al., 2005</td>
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**Table 1.** List of aguadas with their assigned number.
RESULTS

A pattern analysis of the forty-five aguadas investigated is shown in Table 2. A number of patterns are readily apparent. For example, regardless of the location or type, the majority of the study aguadas displayed signs of Maya engineering, and evidence of nearby ancient Maya settlement and agriculture. Other attributes varied more among the types and locations of aguadas.

None of the permanent sinkhole aguadas had volumes lower than 2500 m³, and all of them except for one were described as possessing a clay lining (the Aguada Yaxnic investigated by Lundell [1937], though it is not known if he probed for a lining).

All aguadas with either a plaster or combination lining, had volumes larger than 2500 m³, except for one. These aguadas had shapes that ranged from circular, oval/elliptical, rectangular/geometric to irregular, irrespective of being located in the uplands, transitional uplands, edge of a bajo or within a bajo. It is possible that the labor intensive aguada modification projects, such as lining an aguada with plaster, were undertaken to create large domestic water sources away from site-centers. The production of plaster, in particular, was a truly resource-intensive activity (Garrison, 2007). A good example to this type of aguada is the presence of a plastered aguada, Aguada Los Tambos (#38), situated 2.2 km away from the Xultun site-center, but within the settlement “ex-urbs” of that large site (Akpinar-Ferrand et al. in review).

The areas and volumes of permanent sinkhole, shallow depression and quarry pond aguadas can be similar. Thus, it is difficult to distinguish aguada types based on their areal extents and volumes alone. However, when calculating the aguada volumes, we noticed that shallow depression and quarry aguadas tend to be less deep than the permanent sinkhole aguadas. Additionally, all of the listed permanent types of aguadas hold water year around, unlike the seasonal shallow depression and quarry types of aguadas which tend to dry out under current conditions.
A maxim in physical geography states that the shape of a freshwater feature is generally correlated with its geological origin. In Yucatan Peninsula, a circular shape is usually attributed to naturally formed water bodies, such as sinkholes with water (Cervantes-Martinez et al., 2002). Our own observations also support the idea that permanent sinkhole aguadas tend to have a naturally circular shape reflective of their origins. Since these aguadas are usually deeper and naturally lined, they also tend to show little evidence of human modification. However, Wahl et al., describing a lined aguada at the edge of a bajo in the Mirador Basin, pointed to the circular outline of the aguada as an indication of an anthropogenic origin (2007). Bullard (1960) also described many of the “more permanent aguadas” in northeastern Petén having signs of Maya modification and circular shapes of 50 to 100 m in diameter.

Lundell (1937) described aguadas in the Petén uplands as being usually oval in shape and varying greatly in size and depth. We found that all of the aguadas classed as oval/elliptical in shape occurred in upland contexts, except for one aguada (# 18, listed under “inside bajo” category). Two of these aguadas were further listed under all three categories of “quarry”, “uplands” and “oval/elliptical”. Other aguadas in the “uplands” category that did not have “oval/elliptical” shape were all classed as “circular”, except one listed as “irregular” in shape. It is likely that the relative variation in the upland aguada shapes reflects their outright anthropogenic origin or large amounts of human modification, a finding consistent with the typically dense settlement surrounding these features. Furthermore, recently updated Google Earth program with high resolution images allowed researchers to observe more upland aguada shapes in the southern Maya Lowlands (Ben Thomas personal communication, 2011). The Google Earth snapshots of upland aguadas in the vicinity of Tikal further confirms our findings on upland aguada shape variability (figure 2).

Based on our overall observations, it now appears that certain differences among aguadas point to the fact that individual characteristics for aguadas vary throughout the Maya Lowlands. Yet, some general patterns about aguadas also emerge. Most notably, in contexts where water was more naturally scarce, greater investments were seemingly made in either the modification of natural depressions or in the outright creation of reservoirs (typically taking advantage of former quarries). This relationship actually occurred at multiple scales. In regions such as those characterized by karst plains with many natural cenotes and permanent sinkhole type aguadas,
there is comparatively little investment in hydrologic engineering, whereas regions with severe seasonal water scarcity saw heavy investment in water management. Similarly, within regions with little natural endowment in perennial water, investment in aguada modification or creation was most heavily concentrated in areas with higher population density such as uplands, transitional uplands and along the margins of bajos.

**DISCUSSION**

Historically, traveling in the southern Maya Lowlands during the dry season, a day’s journey was described as twelve to fifteen miles, or the distance between larger aguadas with more perennial water, as streams and springs were not present or were unknown (Ricketson, 1933). In general, archaeological surveys continue to reveal a close relationship between aguadas and ancient Maya settlements (Maler, 1908; Cole, 1910; Ricketson and Kidder, 1930; Lundell, 1933; Bullard, 1960; Culbert et al., 1990; Lohse, 2004; Dunning et al., 2010). However, the region’s archaeological reconnaissance is still far from complete (e.g. Quintana and Wurster, 2003), and there is also a dearth of studies that identify aguadas through remote sensing (e.g. Thomas, 2010). It is now apparent that a large number of aguadas remain undocumented in the southern Maya Lowlands.

So far, the majority of the aguada investigations have been undertaken by archaeologists and other scientists who are interested in ancient settlement patterns, climate change, land use and the overall function of aguadas as ancient Maya water resources. As one of the few standing water resources available in the Maya Lowlands, aguadas do make valuable locations for obtaining paleoenvironmental proxy data. As a result, scientists have been collecting data from them since the 1960s (Cowgill & Hutchinson, 1966; Brenner et al., 1990; Dunning et al. 2003; Hodell et al., 2005; Beach et al., 2008; Dunning et al., 2010; Akpinar-Ferrand et al. in review). Aguadas generally allow for localized, site-specific data collection and sometimes are preferred to other water bodies (i.e. large lakes) depending on the purpose of one’s study (e.g. Hodell et al., 2005; Johnston et al. 2001). But, since aguadas functioned as valuable water resources for the Maya, their periodic dredging to maintain their water holding capacities has sometimes proven problematic for the purpose of collecting undisturbed sediment, although not always (Dunning et al. 2003; Wahl et al., 2007; Beach et al., 2008; Dunning et al., 2009; Akpinar-Ferrand et al. in review).
In Maya studies, the function of aguadas among other Maya water management strategies is not a topic that has been addressed in detail. Lucero (2002) has pointed out that hinterland aguadas would not have the necessary potential to support large populations throughout dry seasons. At issue are the inefficient size of aguadas, the potability of standing water bodies, and also the possibility of higher evaporation rates in hinterland aguadas rather than in larger reservoirs maintained in the city-centers. In particular, Lucero indicated that standing water would become stagnant, requiring a considerable amount of effort and man-power to keep clean. For this reason, the Maya communities around natural aguadas may not have had the incentive to enhance catchment systems, enlarge the capacity, or maintain aguadas (Lucero, 2002). However, our own investigations, and findings over the years suggest otherwise.

Our own work and that of others summarized in this report, indicate that most hinterland aguadas were heavily engineered and modified to catch rainwater or surface run-off for a variety of ancient Maya needs, including both for consumption and for agriculture. Certain aguadas revealed evidence of enlargement and use of plaster or a combination of materials for lining. As aforementioned, these are labor and resource intensive investments likely undertaken to create domestic water access-points. Intriguingly, modern studies have shown that lime kills pathogens in freshwater bodies (Ganguly et al., 1999). However undeliberate, it is possible that the dissolving plaster-lining in aguadas and in site-center reservoirs released lime into the water, which could result in the reduction of water-borne diseases for the local populations using them.

Further in Lucero’s view, the availability of drinking water in aguadas would have been a problem due to the stagnant nature of the water during the dry season without considerable effort to keep aguadas clean and well-maintained (2002). We have already seen evidence suggesting that the ancient Maya spent considerable amount of time modifying and maintaining their aguadas, including the activity of dredging. In certain aguadas, investigators have also come across buk’te constructions (stone-lined filtration wells in the floors of aguadas) (Huchim-Herrera 1991; Dunning 1992; Dunning et al. 2003; Johnston, 2004; Krejci-Weiss and Brandl, 2009), conveying the Maya’s intention to keep their aguadas functional for obtaining potable water throughout dry seasons.

On the availability of drinking water, reports since the early explorations of Yucatan Peninsula have shown that aguada water was commonly used for drinking by explorers,
chicleros, small modern settlements, and archaeological camps (Stephens, 1860; Scholes and Roys, 1948; Higbee, 1948; Matheny et al., 1980; Adams, 1981). Lucero (2002) describes the presence of *Nymphaea ampla* (water lily) in central-reservoirs as an indication of good water quality since these plants are known to grow in clean and still water (Lucero, 2002). *Nymphaea* plants were also likely useful in preventing excess evaporation, while reducing organic waste in water (Matheny, 1978; Davis-Salazar, 2003). To date, a number of pollen studies have recovered *Nympahaea* pollen from ancient sediment within aguadas, where this species is no longer found (Dunning et al., 2005; Wahl et al., 2007; Akpinar-Ferrand et al. in review). We propose here that the former presence of water lilies within hinterland aguadas is further evidence that at least some of these features were intended to collect and store potable water.

To address Lucero’s final assertion that aguadas were not big enough to support hinterland Maya populations; we turn to other studies that address this point empirically. Regarding water volumes from small depressions and natural sinkholes, Krejci-Weiss and Sabbas (2002) demonstrated, using real precipitation and evaporation data, that a small depression with 57,000 liter (57m³) capacity, would have supported 47 people with 4.8 liters daily water per capita. Based on the same data, the study calculated 250 people would be supported year-round with a 228,000 liter (228 m³) depression. If we consider the fact that most hinterland aguadas covered in this study to be much bigger in volume (2,500 to 10,000 m³), one can begin to imagine the immense water storage capacity of modified aguadas serving hinterland Maya populations, while also keeping in mind that most aguadas remain undocumented.

However, we should still remember that aguadas in the southern Maya Lowlands are subject to a cyclic pattern based on the seasonal availability of precipitation. Examples of aguadas becoming contaminated and becoming a health hazard because of water being reduced to low and polluted levels were recorded in the past decades (e.g., Adams, 1981). During extremely dry years during the ancient Maya period, aguadas likely had similar problems supporting local populations both because of diminished capacity and associated health risks.

Evidence so far suggests that aguadas served as important nodes for agriculture, as well as most likely for domestic water for hinterland ancient Maya populations. For example, in the Puuc region, Xcoch Aguada South 1 was located within a karst depression (kankabal) with rich soil (Dunning et al. 2011). Although badly damaged by modern agricultural development, two small canals appear to have linked the aguada with surrounding farmland probably to facilitate
localized irrigation (figure 3). The approximate 9,000 m³ of this aguada was much more than needed to support the relatively small population in this peripheral part of the ancient Xcoch community which could also draw upon residential cisterns (chultuns) for water. One of the largest aguadas known in the Maya Lowlands, Aguada Maya, is located within the sprawling depression known as the Bajo La Justa in the Petén. The lack of settlement near this enormous rectangular aguada and a possible canal draining the aguada into surrounding land strongly suggest its use for agriculture (Kunen et al. 2000; Dunning et al. 2002; Sever and Irwin 2003). On the outskirts of Tikal, the bajo-margin Aguada Terminos was situated adjacent to areas of agricultural terracing suggesting possible pot irrigation. As mentioned earlier, wherever ancient pollen has been recovered within aguada sediment that pollen includes cultigens, some which (e.g., manioc, cotton, and maize) broadcast pollen over relatively short distances indicating that these crops were being grown adjacent to the aguada.

It appears that aguadas may have also served as locations to gather animal protein for the ancient Maya, such as Pomacea snails and fish. Pomacea shells are frequently found within aguadas since the species is associated with wet environments (Matheny, 1980; Dunning et al., 2010). Moholy-Nagy’s (1978) analysis of *Pomacea flagellata* (a species associated with aguadas and reservoirs) at Tikal concluded that these snails were eaten by the city’s ancient inhabitants. *Pomacea flagellata* was unlikely a major source of protein and calories, but was possibly important in the marginal diet of the ancient habitants.

Besides the mollusk *Pomacea flagellata*, aguadas sometimes host various fish species (Hubbs, 1935; Murie, 1935; Goulden, 1966). Murie observed an aguada in Uaxactun teeming with several species of fish that died as soon as the water evaporated during the dry season (Murie, 1935). Even though direct evidence has not yet been recovered, it is a possibility that aguadas may have been exploited by the ancient Maya for aquaculture similar to the canals within wetland “agro-aquacultural” field systems. This use for certain aguadas would not be surprising given the naturally present fish species within them during the wet season.

Modern-day scholars studying aguadas in the state of Yucatan (Mexico) found seasonal shallow depression and quarry types of aguadas to be attractive locations for aquaculture. In the specific case of seasonal shallow depression aguadas, the adaptation of rotational management combining agriculture and aquaculture was advised (Flores-Nava, 1994). Arredondo et al.’s
(1982) study described the placement of 18 gr of tilapia in a seasonal shallow depression aguada in central Mexico (0.8 fish/m²) with a resultant 450 kg/ha tilapia yield that required no additional feeding. Flores-Nava (1994) further suggested the introduction of endogenous fish species in early June, when the oxygen levels are stable, and the harvest of fish in December. During the dry season, Flores-Nava pointed to the value of the nutrient-concentrated sediments exposed within aguadas as the water recedes, for intensive agriculture that focuses on fast-growing crops (Flores-Nava, 1994). Utilization of aguadas in this manner could have constituted an ideal rotational management technique for the ancient Maya by maximizing their food production, but further investigation is necessary to test this idea.

CONCLUSION

Although the word “aguada” is commonly used to water-holding ponds throughout the Maya Lowlands, it is clear that a great a variation exists among these features, including wide ranges in size, shape, and location. Most aguadas are closely associated with ancient Maya settlements including those found in the “hinterlands” (urban fringes and rural contexts) such as those we have examined here. While most aguadas appear to have an at least partially natural origin, the large majority exhibit evidence of significant modification by the ancient Maya. A preponderance of evidence indicates that these aguadas were maintained as sources of potable water. Additionally at least some may have supported localized agricultural irrigation and possibly aquaculture. The forty-five aguadas reported on in this study represent only a fraction of the thousands of these features within the Maya Lowlands. Aguadas were clearly of great importance to the ancient Maya and focused investigation of these features is called for. Their study will greatly aid in understanding the settlement dynamics of the Maya Lowlands both because of their importance as a critical resource for the Maya and because of the important paleoenvironmental information still locked with their sediments.
<table>
<thead>
<tr>
<th>Type of Aguada</th>
<th>Descriptive Fields</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permanent Sinkhole</strong></td>
<td>1, 2, 42, 43, 44, 45</td>
</tr>
<tr>
<td><strong>Seasonal Depression</strong></td>
<td>3, 7, 9, 10, 11, 13, 20, 22, 23, 24, 29, 36, 39</td>
</tr>
<tr>
<td><strong>Quarry</strong></td>
<td>14, 15, 17, 19, 30, 31, 34, 38, 40, 41</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Karst Plain</strong></td>
<td>1, 2, 44</td>
</tr>
<tr>
<td><strong>Uplands</strong></td>
<td>7, 9, 10, 11, 14, 21, 25, 29, 33, 34, 35, 40, 45</td>
</tr>
<tr>
<td><strong>Transitional Uplands</strong></td>
<td>5, 6, 8, 24, 32, 42</td>
</tr>
<tr>
<td><strong>Edge of Bajo</strong></td>
<td>12, 13, 15, 19, 22, 26, 28, 36, 37</td>
</tr>
<tr>
<td><strong>Inside Bajo</strong></td>
<td>18, 20, 23, 27, 30</td>
</tr>
<tr>
<td><strong>Type of Lining</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Plastered</strong></td>
<td>27, 35</td>
</tr>
<tr>
<td><strong>Stone</strong></td>
<td>8, 12, 22, 33, 40, 41</td>
</tr>
<tr>
<td><strong>Clay Impervious</strong></td>
<td>1, 2, 3, 9, 10, 13, 14, 17, 18, 19, 26, 28, 32, 37, 43, 44</td>
</tr>
<tr>
<td><strong>Combination</strong></td>
<td>4, 11, 15, 16</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td></td>
</tr>
<tr>
<td>0-2,500 m$^3$</td>
<td>8, 9, 10, 11, 12, 13, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 31, 32, 33, 34, 35, 36, 37, 40, 43</td>
</tr>
<tr>
<td>2,500-5,000 m$^3$</td>
<td>16, 19, 23, 24, 27, 29, 33, 42</td>
</tr>
<tr>
<td>5,000-10,000 m$^3$</td>
<td>4, 35, 40, 45</td>
</tr>
<tr>
<td>10,000-15,000 m$^3$</td>
<td>1, 5, 6, 41, 44</td>
</tr>
<tr>
<td>15,000-20,000 m$^3$</td>
<td>2, 15, 30, 43</td>
</tr>
<tr>
<td><strong>Evidence of Maya Engineering</strong></td>
<td>4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 31, 32, 33, 34, 35, 37, 40, 43</td>
</tr>
<tr>
<td><strong>Evidence of Agriculture</strong></td>
<td>4, 5, 6, 7, 8, 9, 10, 15, 19, 23, 26, 27, 30, 31, 32, 33, 35, 37, 39, 41, 42, 43, 45</td>
</tr>
<tr>
<td><strong>Evidence of Tool Working</strong></td>
<td>8, 9, 10, 19, 21, 32, 34</td>
</tr>
<tr>
<td><strong>Evidence of Settlement</strong></td>
<td>4, 5, 6, 7, 8, 9, 10, 11, 15, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 31, 32, 33, 35, 36, 37, 40, 41, 43</td>
</tr>
<tr>
<td><strong>Shape</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Circular</strong></td>
<td>1, 2, 4, 8, 15, 18, 21, 22, 24, 26, 27, 31, 33, 43, 44, 45</td>
</tr>
<tr>
<td><strong>Oval/Elliptical</strong></td>
<td>7, 9, 10, 23, 25, 34, 40</td>
</tr>
<tr>
<td><strong>Rectangular/Geometric</strong></td>
<td>12, 30</td>
</tr>
<tr>
<td><strong>Irregular</strong></td>
<td>5, 6, 19, 20, 32, 35</td>
</tr>
<tr>
<td><strong>Seasonally Dries</strong></td>
<td>5, 6, 11, 12, 14, 19, 20, 21, 22, 23, 24, 25, 28, 29</td>
</tr>
</tbody>
</table>

**Table 2. Aguada Descriptive Fields**
Figure 1. Map showing location of study aguadas.
Figure 2. Newly identified upland aguadas with different shapes in the vicinity of Tikal by Benjamin Thomas.
Figure 3. Xcoch Aguada South 1 map and section drawing.
6. Conclusion

The dissertation was organized into four main parts: Literature Review; Article 1; Article 2, and Article 3. In the literature review section, we examined aguadas in the context of the southern Maya Lowlands’ climate and environment, Maya water management systems, settlement patterns, and for the availability of paleoenvironmental proxy data in aguadas.

In Article 1, we looked at four aguadas situated close to two Ancient Maya sites in northeast Guatemala. Investigations revealed that the aguadas served various purposes around the two sites of interest. Our findings not only demonstrated that the aguadas were used in activities such as agriculture and chert processing, but also displayed evidence of ancient Maya low-technology engineering solutions to help store water in a water poor area, which included the use of berms, silting tanks, stone-pavement, and plaster-lining.

In Article 2, our research results allowed a partial reconstruction of the history of events in and around Aguada Elusiva from the Early Classic to the present time. Most likely, Aguada Elusiva originated as a shallow natural depression, and massive multi-phase anthropogenic changes took place in and around it afterwards. Article 2 revealed that Aguada Elusiva had a multi-resource use in which water, agricultural products, chert and clay may have provided the kind of economic independence that was necessary for people living the furthest from large centres.

In the last article, Article 3, we showed that most of our study aguadas (sample of forty-five) were closely associated with ancient Maya settlements including those found in the hinterlands. Also, while most aguadas appeared to have an at least partially natural origin, the large majority exhibited evidence of significant modification by the ancient Maya. In Article 3, aguadas’ significance as agricultural hubs, potable water sources, and as important providers for paleoenvironmental data in a region with low surface water was further discussed.

Overall, through the research presented in this dissertation, we aimed to provide a better understanding of aguadas within ancient Maya water management systems, and help recognize aguadas in the broader framework of cultural ecology and geography of the southern...
Maya Lowlands. Aguada research in the southern Maya Lowlands currently stands scarce, yet is much needed to fully understand ancient Maya water management systems. This dissertation aimed to begin seriously investigating the significance of aguadas as potable water sources, agricultural hubs, as well as for their function as valuable paleoenvironmental data providers.
Bibliography


Hubbs, C.L. 1935. *Fresh-Water Fishes Collected in British Honduras and Guatemala*. Michigan University Museum of Zoology Miscellaneous Publications No. 28


Thompson E.J. 1938 Diary. (Waiting to hear from co-author)


## APPENDIX A

### Pollen Interpretations

<table>
<thead>
<tr>
<th>HERBS CULTIGENS</th>
<th>ENDEMIC</th>
<th>ECONOMICALLY IMPORTANT</th>
<th>POSSIBLE INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambrosia</td>
<td></td>
<td></td>
<td>Disturbance indicator (Mueller et al., 2009).</td>
</tr>
<tr>
<td>Asteraceae</td>
<td>Members of asteraceae are common herbaceous plants in bajos (Wahl et al., 2007).</td>
<td>Disturbance indicator (Mueller et al., 2009).</td>
<td></td>
</tr>
<tr>
<td>Borreria</td>
<td></td>
<td></td>
<td>A field weed normally encountered in pollen samples from cultivated areas (Lohse, 2004).</td>
</tr>
<tr>
<td>Chenopodiaceae- Amaranthaceae</td>
<td></td>
<td></td>
<td>Disturbance indicator (ambrosia, asteraceae, chenopodiaceae sometimes come about with first appearance of zea pollen (Kepecs &amp; Boucher, 1996; Mueller et al., 2009).</td>
</tr>
<tr>
<td>Capsicum sp.</td>
<td></td>
<td>Chili Peppers</td>
<td>Agriculture.</td>
</tr>
<tr>
<td>Chydorus eurynotus and Chydorus Pubescens</td>
<td></td>
<td></td>
<td>Indicate presence of water, dilution (Cowgill and Hutchinson, 1966).</td>
</tr>
<tr>
<td>Compositae</td>
<td></td>
<td></td>
<td>Disturbance indicator (Kepecs &amp; Boucher, 1996).</td>
</tr>
<tr>
<td>Cucurbita sp.</td>
<td></td>
<td>Squash</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>Members of cyperaceae and asteraceae families are the most common herbaceous plants in bajos (Wahl et al., 2007).</td>
<td>Lack of cyperaceae, fern spores, and other aquatics indication that people may have periodically cleaned out the aguada (Wahl et al., 2007).</td>
<td></td>
</tr>
<tr>
<td>Euryalona</td>
<td></td>
<td></td>
<td>Indicate the presence</td>
</tr>
<tr>
<td>Species</td>
<td>Description</td>
<td>Usage</td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><em>Gossypium</em></td>
<td>Cotton</td>
<td>Agriculture</td>
<td></td>
</tr>
<tr>
<td><em>Hyacinth</em></td>
<td>Possibly used in Ancient Maya period to retard evaporation (Matheny, 1978).</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Isoetes sp.</em></td>
<td>Water plant, if found indication of an aguada (Matheny, 1978).</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Nymphaea ampla</em></td>
<td>Possibly used in Ancient Maya times to retard evaporation (Matheny, 1978).</td>
<td>The increase in Nymphaea pollen may reflect changes in hydrology from climate change or human manipulation (Wahl et al., 2007)</td>
<td></td>
</tr>
<tr>
<td><em>Pistia stratiotes</em></td>
<td>Grows on the surface of water. Water temperature readings in ponds show lechuga helped reduce the water temperature by several degrees. (Matheny, 1978) Possibly from Florida or South America.</td>
<td>Reduces evaporation (Matheny, 1983).</td>
<td></td>
</tr>
<tr>
<td><em>Panicum</em></td>
<td></td>
<td>Grasses known to invade cleared areas (Wahl et al., 2007)</td>
<td></td>
</tr>
<tr>
<td><em>Paspalum</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Phaseolus vulgaris</em></td>
<td>Bean</td>
<td>Agriculture</td>
<td></td>
</tr>
<tr>
<td><em>Phragmites</em></td>
<td>An aquatic grass, common in agricultural canals on the Northern Yucatan Peninsula (Wahl et al., 2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preteridium aquilinium (Bracken Fern) (Dunning, 2009)</td>
<td>High fern counts are typical of many aguadas in their final years of heavy occupation and may represent an incursion of bracken fern, an aggressive species that thrives in nutrient poor soil and is well known invasive in depleted fields in the S. Maya Lowlands (Perez-Salicrup, 2004, Dunning, 2006 &amp; 2009).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poaceae</td>
<td>Dominating poaceae could convey widespread agricultural disturbance. Poaceae profile may also reveal disturbance associated with lime production. An alternative justification for the grass pollen is that it came from plants growing within the reservoir (Wahl et al., 2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trema</td>
<td>In the absence of Zea and Cheno-Am % waning sharply, Trema and other species seem to increase. Trema is associated with vegetation that appears after fire events and dry conditions (Leyden, 1998).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Typha (Cattail) | Possible uses include: to weave mats, or for stuffing or padding, may also have been consumed by Maya (Crane, 1996).

Zea mays | Corn | Agriculture.

<table>
<thead>
<tr>
<th>ARBOREAL</th>
<th>FOUND NEXT TO THE AGUADAS</th>
<th>ECONOMICALLY IMPORTANT</th>
<th>POSSIBLE INTERPRETATION*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrocomia mexicana (Coyol Palm)</td>
<td>Edible (e.g. Cerros). High in fat, etho-Maya used to make hot dring and source of oil.</td>
<td>Grown to be eaten.</td>
<td></td>
</tr>
<tr>
<td>Anacardium (cashew)</td>
<td>Edible.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annona (Soursop)</td>
<td>Economic crop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brosimum (and other Moraceae)</td>
<td>Economic crop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brosimum alicastrum</td>
<td>Ramon nut, edible.</td>
<td>Edible.</td>
<td></td>
</tr>
<tr>
<td>Byrsonima crassifolia (Nance)</td>
<td>Yes. (Kepecs and Boucher, 1996) Edible, has vitamin A and C, as well as minerals (e.g. Cerros)</td>
<td>Grown to be eaten.</td>
<td></td>
</tr>
<tr>
<td>Bursera</td>
<td>Important component in traditional Maya lime burning (Wahl et al., 2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calocarpum mammosum (Mamey)</td>
<td>Edible (e.g. Cerros)</td>
<td>Grown to be eaten.</td>
<td></td>
</tr>
<tr>
<td>Carica (Papaya)</td>
<td>Edible</td>
<td>Grown to be eaten.</td>
<td></td>
</tr>
<tr>
<td>Chrysophyllum (Caimito)</td>
<td>Edible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combretaceae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cordia cf. dodecandra (Sericote)</td>
<td>Edible ?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crescentia (Jicara)</td>
<td>Edible</td>
<td>Grown to be eaten.</td>
<td></td>
</tr>
<tr>
<td>Brosimum alicastrum (Ramon)</td>
<td>Edible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bursera</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manilkara (Sapote)</td>
<td>Edible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mastichodendron (Subul)</td>
<td>Edible</td>
<td>Grown to be eaten.</td>
<td></td>
</tr>
<tr>
<td>Family</td>
<td>Species</td>
<td>Edible</td>
<td>Status</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------------</td>
<td>--------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Melastomataceae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myrtaceae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moraceae</td>
<td></td>
<td></td>
<td>Tropical moist taxa indicator (Mueller et al. 2009)</td>
</tr>
<tr>
<td></td>
<td>Persea (Avocado)</td>
<td>Possibly.</td>
<td>Grown to be eaten. Also found to be planted in association with nance and guyaba trees (Kepecs and Boucher, 1996)</td>
</tr>
<tr>
<td></td>
<td>Pimienta (All Spice)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protium (Copal Resin)</td>
<td></td>
<td>Grown to be eaten.</td>
</tr>
<tr>
<td></td>
<td>Psidium (Probable Guava)</td>
<td></td>
<td>Grown to be eaten.</td>
</tr>
<tr>
<td></td>
<td>Guayaba</td>
<td>Yes. (Kepecs and Boucher, 1996)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spondias (Hogplum)</td>
<td></td>
<td>Economically important.</td>
</tr>
</tbody>
</table>