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## **Palenque Hydro-Archaeology Project**



**Research Year:** 2005

**Culture:** Maya

**Chronology:** Classic

**Location:** Northern Chiapas, México

**Site:** Palenque

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## **Abstract**

In July of 2005, the Palenque Hydro-Archaeology Project (PHAP) began monitoring the climatic and hydrological conditions on the site's escarpment. A weather station and stream sensors were installed and programmed to take readings on 20-minute intervals for two consecutive years. This new approach, hydro-archaeology, utilizes models and tools from hydrology, climatology, meteorology, geology, and archaeology to better understand the urban environment of the ruined city.

The Maya of Palenque constructed an elaborate system of subterranean canals and drains in order to manage the numerous streams that flow through its borders. We know that many of these water management features were a part of the city planning because several courses were found beneath monumental temples and palaces. If archaeologists could view the pre-city landscape and see what the Maya architects saw, the reasons for the massive investment of labor would become clearer. PHAP's ultimate goal is to reconstruct a pre-urban view of Palenque in hopes of understanding why the ancient Maya chose the existing urban plan.

Recent studies have suggested several major droughts in the Maya world during Classic times (A.D. 300-900). One of these droughts (A.D. 780-910) corresponds with Palenque's abandonment at A.D. 799. The final product produced from this research will hopefully reveal new answers about the ancient Maya of Palenque and their knowledge of city planning.

## **Resumen**

En julio del 2005, el Proyecto Hidro-Arqueológico de Palenque (PHAP), empezó controlando las condiciones climáticas e hidrológicas en la escarpa del sitio. Se instaló y programó una estación climatológica y sensores de corriente para tomar lecturas en intervalos de 20 minutos, por dos años consecutivos. Este nuevo acercamiento de hidro-arqueología, utiliza modelos e instrumentos de hidrología, climatología, meteorología, geología, y arqueología para entender mejor el ambiente urbano de las ruinas de Palenque.

Los mayas de Palenque construyeron un sistema elaborado de canales y desagües subterráneos, para manejar las numerosas corrientes que fluyen por sus fronteras. Sabemos que muchos de estos sistemas de riego, eran una parte del planeamiento de la ciudad, ya que varios cursos corren debajo de los templos y palacios monumentales. Si los arqueólogos pudieran ver el paisaje de la pre-ciudad, y ver lo que los arquitectos mayas vieron, serían más claras las razones para la inversión masiva de trabajo. La meta principal de PHAP, es reconstruir una vista pre-urbana de Palenque con la esperanza de comprender, porqué los antiguos mayas escogieron el plano urbano existente.

Estudios recientes han sugerido varias y grandes sequías en el mundo maya durante el período clásico (300-900 d.C.). Una de estas sequías (780-910 d.C.) corresponde con el abandono de Palenque en 799 d.C. Se espera que el producto final de esta investigación, revele nuevas respuestas acerca de los antiguos mayas de Palenque y el conocimiento de la planificación de la ciudad.

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Figure 1. Palenque location map. (Modified from Weaver, 1981.)

## Introduction

The Classic Maya of Mesoamerica have long been famous for their technological achievements. Most large Maya centers, such as Tikal and Caracol, are located in environments that generate a heavy dependency on rainfall for human consumption and agriculture. By contrast, Palenque, located in the foothills of northern Chiapas, México, is unique for its water-saturated landscape (Figure 1). While the Maya of most other urban centers were concerned with storing water, the Palenqueños were devising methods of managing an abundance of it (French 2002). It is this aspect that makes this site ecologically distinctive. The hydro-archaeological approach is the application of paleoclimatological and hydrological modeling to a site in order to determine how its water systems functioned. Once applied to Palenque, subsequent computer simulations

will show: 1) how much livable civic terrain existed in Palenque prior to water management implementation, 2) what levels of rainfall were needed to cause escarpment flooding, and 3) the amount of rainfall necessary to recharge the watershed sufficient enough to sustain an urban population. Palenque is a superb location for this study because of the high levels of rainfall and the numerous perennial waterways located within the site boundary.

The Palenque Hydro-Archaeology Project (PHAP) focuses on the ruins of Palenque ([Figure 2](#)) and not the modern town of Palenque, which is located 8 km north of the archaeological site, yet both, are linked by water. The modern city of Palenque and its 60,000 inhabitants rely heavily on water that is pumped directly from the Otolum, an important stream originating in the mountains to the south, and flows beneath the ancient city's main plaza. During the early summer of 2005, the perennial springs that feed the Otolum went dry. Because the town of Palenque lacks the resources to monitor stream flow and rainfall, this minor drought came without warning. Five days and much panic passed prior to a regenerative rainfall. As the population of modern Palenque grows, the stress on environmental resources increases. PHAP is dedicated to working with the townspeople and city planners of Palenque with the aim of heading off future problems caused by droughts, and creating a knowledge base for water systems in the area through technology and education. By teaching the townspeople how to monitor water usage, stream flow, and rainfall, they can be better prepared when the next dry spell occurs. In accordance with these plans, I have agreed to transfer ownership of the project weather station to the Palenque National Park and train a technician of their choosing to monitor it when the project is completed in January, 2008.

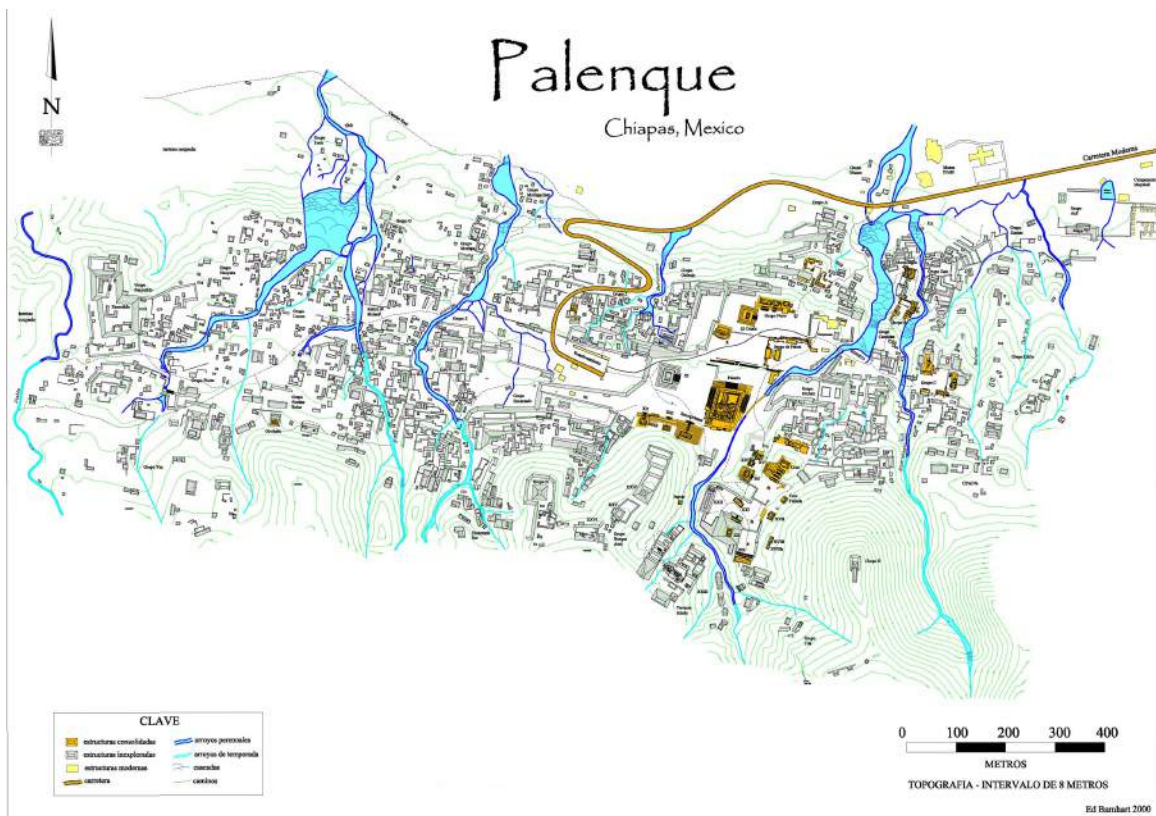


Figure 2. Palenque site map.

## Background

While the public waterworks at other Maya lowland sites tend to focus on providing drinking water and/or irrigation, Palenque's water management provided erosion control and increased the amount of flat civic terrain (French 2002). R.M. Adams (1966) suggests that "technological augmentations" had to be developed for urban centers to become more productive by guaranteeing and increasing monumental public works. Water management stands as one of the most important of these augmentations, along with advances toward exact and predictive sciences and a centralized accumulation of wealth.

Paradoxically, we know relatively little about developments in water management through time, the relationship of growth and refinement of this technology relative to ancient environmental regimes, nor the details of its role in the processes of human cultural change and expansion. This lack of knowledge is partly due to the difficulty in finding well-preserved evidence of water management systems and associated features in the New World. PHAP is addressing these problems in hopes of eliciting a better understanding of cultural developments in the Maya Lowlands and contributing information to parallel studies in other regions of Mesoamerica. Additionally, the hydro-archaeological approach has the capability to produce models applicable to similar research worldwide.





**Figure 3. Palenque's subterranean palace aqueduct.**

Built on a narrow escarpment surrounded by steep hills, sheer cliffs, and deep arroyos, Palenque suffered a scarcity of livable terrain. Many natural waterways flowed across the flat topography and created a disjointed landscape unfit for a large community. In a unique attempt to increase the amount of public space, the ancient Palenqueños constructed several subterranean aqueducts and covered over preexisting streams. By doing so, they increased the size of their plazas in order to create surface areas large enough to maintain normal civic life within a major Maya center (French 2002).



**Figure 4. Ruined section of aqueduct.**

The Palenque Mapping Project (PMP) began creating the first structural and topographic map of the site in 1998 ([Figure 2](#)). With support from FAMSI, [The Palenque Mapping Project](#) managed to complete the most accurate map of any Maya site to date (Barnhart 2001). During the survey, the team frequently noted the existence of unique



water management features such as subterranean aqueducts ([Figure 3](#), [Figure 4](#), shown above, and [Figure 5](#), shown below), bridges, dams, drains, walled channels, and pools. This evidence suggests that the Palenqueños built such features to manage the numerous perennial springs located throughout the site.

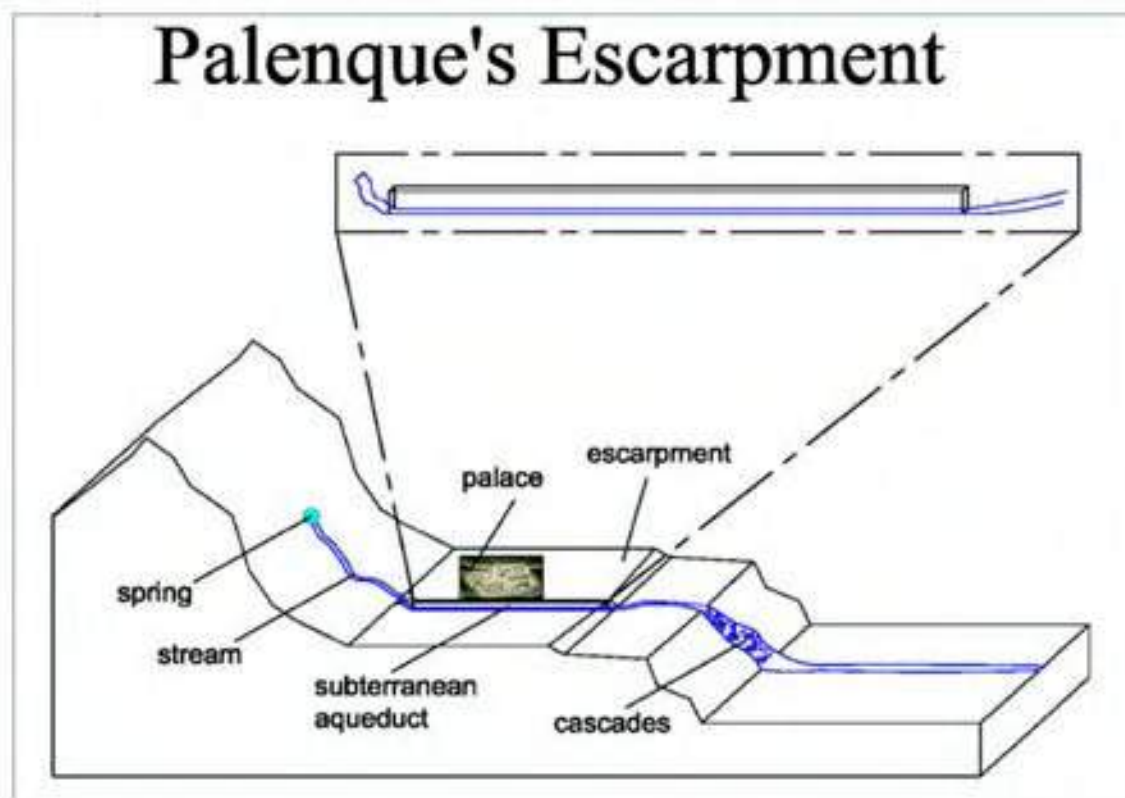


Figure 5. Palenque's escarpment profile.

### The Hydro-archaeological Approach

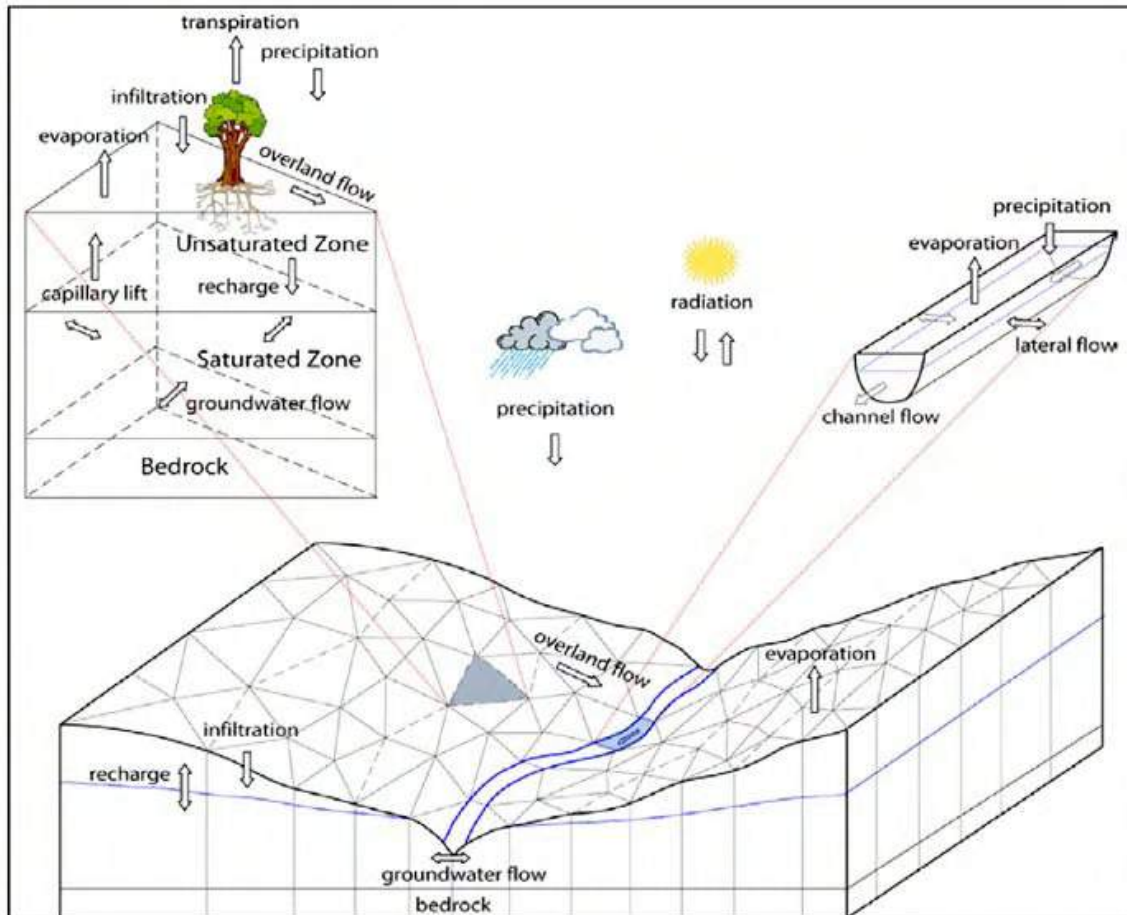
PHAP's research design includes a sensitivity analysis based on a computer model of the Palenque drainage system. To provide input data for the model, the following data are currently being collected at the site. The Otolum stream that flows through the city's center is being monitored daily for 24 consecutive months to calculate both streamflow and baseflow. Soil throughout the site will be tested in May, 2007, for permeability to determine groundwater recharge rates by taking core samples randomly selected throughout the site. Rainfall is also be monitored on a daily basis. The rainfall data will then be entered into a Hydstra software program that will produce 3-D simulations of the landscape. Once a hydrological model is established under the landscape's current conditions, variables such as aqueducts, dams, and walled channels can be removed to model how the water would have flowed through the site without the interference of such features.

This pre-city view of the landscape will demonstrate the limited potential for urban development without the implementation of complex water management features. The model will allow many different views of the site by manipulating water management feature layers and by changing the rainfall patterns and amounts. Most importantly, a reconstruction of Classic Period Palenque (A.D. 300-800) will be made by overlaying the hydrological model with the PMP AutoCad map. These simulations will demonstrate pre-urban quantities of civic terrain as well as demonstrate flood events.

For decades, meteorologists, hydrologists, and engineers have worked together in preparing our public works for flood events (i.e. the capability of a bridge to withstand a river's 100-year flood). After the meteorologist records the weather and the hydrologist monitors the river, the engineer designs the bridge capable of withstanding X amount of water pressure caused by X amount of rainfall. There has been much success in this multi-disciplinary approach in predicting the effects of hydrological events, but rarely used in understanding the distant past. PHAP will, for the first time, reconstruct the water management of an ancient city through hydro-archaeological modeling, using a similar multi-disciplinary approach. Reconstructions of the climate faced by the engineers of Palenque are vital to the success of the described hydro-archaeological model.

Paleoclimatic data is needed to validate the hydrological model that is to be used for this research. In lieu of the local climatic proxy, PHAP must rely on a more general paleoclimatic record. Performing a time series analysis based on paleoclimatic data gathered from various locations throughout the Maya Lowlands in conjunction with the Palmer Drought Severity Index (PDSI) will provide a proxy suitable for the necessary computer simulations.

Major hydrological processes within the terrestrial hydrological cycle operate over a wide range of time scales with interactions among them ranging from uncoupled to strongly coupled. Numerical simulation of coupled nonlinear hydrologic processes requires an efficient and flexible approach. In this analysis, a new strategy for integrated hydrological modeling will be implemented. This method reduces governing partial differential equations (PDE) to ordinary differential equations (ODE) using the semi-discrete finite volume method (FVM). This leads to a local ODE system, referred to as the model kernel, which is distributed on an unstructured triangular irregular network (TIN) constructed from domain decomposition using Delaunay Triangulation. The global ODE system is formed by combining local ODE system over the entire domain and the system is solved with an efficient ODE solver. The finite volume elements are prisms, projected from the TIN generated with constraints. The constraints are related to the river network and watershed boundary, elevation contours, etc. The model is designed to capture "dynamics" in multiple processes while maintaining the conservation of mass at all cells, as guaranteed by the finite volume formulation (Qu and Duffy, in press). A hypothetical case is presented to demonstrate the flexibility and utility of this model ([Figure 6](#)).



**Figure 6. User-specified discretization forming three finite volume model domains from the original DEM and stream network for the Río Grande. The model includes perennial and ephemeral channels.**

The data necessary for the model are currently being gathered using the latest technology in hydrological instrumentation. Stream flow is being monitored on a 15-minute interval with SOLINST Levellogger™ Automatic Pressure Transducer/Data Loggers (Figure 7, shown below). The Levellogger™ is a miniature (2 cm × 13 cm), self-contained datalogger designed for recording groundwater levels in monitoring streams. The Levelloggers are anchored directly into the streambed and require a manual download of the data every six months. Once data have been recorded, it is downloaded and will be exported into a database for the visualization and modeling.



**Figure 7. SOLINST Levelogger™ Automatic Pressure Transducer.**

Rainfall data are currently collected using a Campbell Scientific CR10X datalogger and Remote Weather Station ([Figure 8](#)). This device accurately measures air temperature, wind direction, wind speed, rainfall, barometric pressure, relative humidity, solar intensity, and soil/water temperature. The weather station is self-contained on a 3 m tripod. The CR10X attaches to the base of the tripod and can store up to 21,000 measurements.



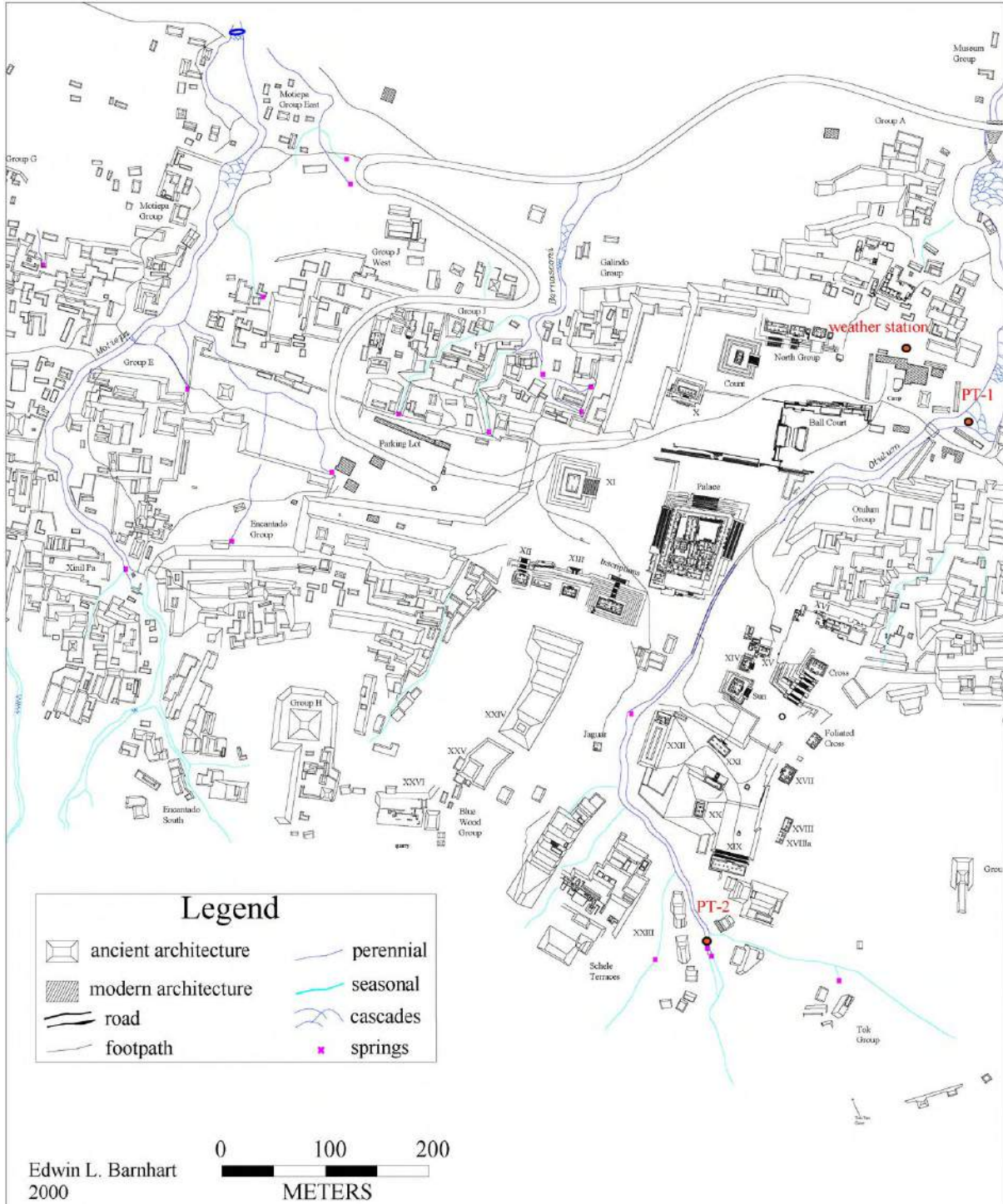


**Figure 8. The Campbell Scientific CR10X datalogger and Remote Weather Station.**

Soil core samples will be taken using a 4 cm core bit that will provide soil permeability data. The locations for coring will be at key locations near the nine waterways and will consciously avoid architectural features. Soil permeability is central to understanding the groundwater recharge and storm runoff rates. The soil cores will also provide insight into the topography of the escarpment prior to land alterations conducted by the ancient Maya. The pre-city topography will offer a view of how the water flowed over the escarpment without the benefits of water management.

### **2005 Field Season**

The Palenque Hydro-Archaeology Project (PHAP) was initiated in late July, 2005. The adventure began in University Park, Pennsylvania with my 1998 Subaru Outback filled to the brim with a full meteorology station, stream gauge sensors, a few clothes, and my golden retriever, Dusty. Following a five-day delay at the border and two more driving south to Chiapas, arrival at Palenque was achieved. A few days later, the arduous task of installing the hydrological and climatological equipment started.



**Figure 9. Equipment location map.**

The equipment installation started with anchoring the two pressure transducers in the bed of the Otolum stream. Pressure transducer 1 (PT-1) was placed in the south at the Otolum's source (OT-S1 and OT-S2); while PT-2 was anchored at the escarpment's



northern edge ([Figure 9](#)). For optimal performance, the sensors cannot be allowed to move at all during data recording. With the help of local entrepreneur, Chato Morales, four stainless steel ringlets were constructed to fit tightly around the ends of the transducers. Next, the heads of four large stainless steel screws were removed. Each ringlet was then welded atop the threaded base of each altered screw. After drilling two starter holes (approximately 15 cm apart) into the bedrock of the stream, I was able to screw the ringlets tightly in place. This allowed each transducer to slide through its two anchored ringlets, which were then secured into place with plastic ties ([Figure 10](#), shown below).



**Figure 10. Viewing the anchored pressure transducer through a glass cooking dish.**



**Figure 11. Kirk French drilling the holes in streambed for PT-1 with extended drill bit.**

Drilling into the streambed was quite an adventure within itself. I was armed with a 14-volt cordless drill and an extended drill-bit so as to not get the drill wet ([Figure 11](#), shown above). This method worked flawlessly with the installation of PT-1, but not so well for PT-2. The water level at the stream's headwaters was much deeper than any drill-bit I could find in Palenque. The need to drill underwater without an underwater drill posed a large problem, but one that could be overcome with a little ingenuity. To keep the water away from the body of the drill, I cut out the bottom of a 5-gallon water jug (*garrafón*), sealed the top with plastic tape, and placed the drill inside ([Figures 12](#) and [Figure 13](#), shown below). This wild apparatus (that looked like a robot's arm) kept the drill dry, but created a lot of pressure due to buoyancy. It took several people pushing down on and holding the *garrafón* in place while I drilled the hole in the bedrock of the stream ([Figure 14](#), shown below).





Figure 12. Marcus French with the garrafón contraption.



Figure 13. Kirk French drilling holes for PT-2 with the *garrafón* contraption.



**Figure 14. LeAndra Luecke and Hannah French assisting with the buoyant garrafón.**

Installation of the Campbell Scientific CR10X full meteorological station revealed a new set of difficulties. The location for the weather station required security from vandalism and a 5 m radius absent of arboreal foliage. The only logical choice was in the backyard of INAH's archaeologists' *campamento* ([Figure 9](#)) on the northern edge of the escarpment, because it is the only area within the site that meets the above criteria. INAH archaeologist, Miguel Angel Vazquez, was invaluable with his assistance in attaining swift approval for the installation of the weather station at this ideal location.



**Figure 15. Interior of the CR10X Datalogger.**

In early August, the weather station's 3 m tripod was anchored and all associated instruments were attached and wired to the datalogger ([Figure 15](#), shown above). The next step was connecting the laptop to the datalogger to insure functionality ([Figure 16](#), shown below). The cable supplied for this operation was incorrect and Campbell Scientific informed me it would take several weeks before I could receive the correct cable. In addition, the solar panel was not properly recharging the battery. After exhausting all avenues to resolve these issues, and with my teaching assistant duties at Pennsylvania State starting the next week, I was forced to return home.



**Figure 16. Kirk French downloading climatic data from the CR10X.**

Five months later, in mid-December, I returned to Palenque with several types of cables, an improved soil sensor, and new battery. I downloaded the stored data from the datalogger and quickly analyzed it for inconsistencies. Luckily, all equipment was functioning properly during my absence, except for an intermittent reading from the rain gauge. Upon closer inspection, my team and I discovered that a nest of ants had made a new home in the tipping bucket of the rain gauge, thus obstructing data recording. This problem was soon remedied with pesticide. Project member, Alonso Mendez, agreed to return every few weeks to give the rain gauge another dose of ant food in hopes of avoiding future problems. When I left Palenque in late December, the weather station was operating perfectly.

Both pressure transducers were also checked and both had survived their first rainy season without a problem. I will return to the site in early March, 2006, with Penn State hydrologist, Christopher Duffy, to check all equipment and download ten weeks of data.



## Conclusion

The Palenque water management systems were a response to demands that were modified through time, due to a changing social and environmental context. Ultimately, the proposed research will compare the functionality of the city's water management during the intensive rainy season to that of its four-month dry season (French 2002), looking for ways in which Palenque's history of growth sheds light on possible population movements and other demographic and political forces at work through time. In addition, the models generated from the research could provide new views of Palenque's demise because of inefficient responses to climate change. Knowing the aridity of Palenque would allow for the calculation of its watershed's threshold for abandonment.

Throughout the Maya region, as well as in other parts of the world, archaeologists have conducted water management research in an attempt to reconstruct how past societies manipulated and used water (Wittfogel 1957, Butzer 1976, Bray 1986, Lansing 1991, Scarborough 1983). The problem with these archaeological studies is they rarely incorporate the basic concepts of hydrology (i.e. stream flow, baseflow, storm runoff, groundwater recharge, etc.). This lack of basic hydrological knowledge encourages high levels of conjecture. PHAP will reduce the number of assumptions generally used in archaeology by applying proven, scientific methodology.

## Acknowledgements

I would like to sincerely thank the following people for their contribution to the Palenque Hydro-Archaeology Project. Their generosity made the first season a success.

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