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Visualizing the Past/Peopling the Past

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**Water on the Landscape of the Pre-Columbian Bolivian Amazon**

**ABSTRACT**

This project examines the interaction between water and the landscape of the Pre-Columbian Bolivian Amazon, specifically how this landscape was seasonally flooded and how earthworks were used by the precolumbian inhabitants of the region to capture, manage, and retain floodwater for use in transportation, communication, fishing, and agriculture. To visualize this dynamic waterscape, a mesh of the landscape was built and used in a realistic physical water simulation. Using relevant archaeological, ethnographic, and historical literature and photographs of the earthworks and local environment, a timelapse animation of the landscape was created to show the cycle of inundation.

**INTRODUCTION**

For centuries, wetlands have been one of the most important ecosystems on Earth. Wetlands, which include marshes, fens, bogs, swamps, and more, are home to incredible biodiversity and support many biological, hydrological, chemical, and physical processes essential for environmental maintenance and welfare (Maltby 1991:11). Despite their known environmental benefits, wetlands are also some of the world’s most threatened ecosystems. An analysis from 2014 suggests an 87 percent decrease in natural wetland area globally since pre-industrial times (Walpole and Davidson 2018:595). In the United States and Europe especially, modifying wetlands for other non-wetland uses was perceived to increase productivity and land value. In colonial and pre-colonial times, the driving force behind wetland drainage was agricultural development. More recently, the association of wetlands with diseases like malaria and schistosomiasis has been used to support urban and suburban development plans (Maltby 1991:10).

However, the idea that wetlands cannot be productive is a misconception. In less-industrialized countries, people still depend on wetland resources for water quality maintenance, natural flood retention, fishing, and hunting. In Mali, freshwater fishing contributes to three percent of the country’s gross national product, and 90 percent of its fish are from the Inner Niger Delta, an area of vast wetlands, lakes, and floodplains. On the Sudd floodplains in Sudan, the wild herbivores that graze in dry season provide a quarter of the animal meat consumed by the local people. In addition to fishing and hunting, wetlands also form the basis of flood recession agriculture and floating rice cultivation (Maltby 1991:11-12).

Seasonally-inundated wetlands usually experience one or more of the following flooding processes: pluvial, fluvial, or backwater. Pluvial flooding, also known as surface flooding, is the result of heavy or prolonged precipitation. Floodwater accumulates as water tables rise, soils become waterlogged, and surface runoff builds up. Fluvial flooding is the result of rivers and streams overflowing their banks. As continued precipitation causes river water to rise, water is pushed out onto the landscape. Backwater or upstream flooding is caused by floodwater backup and constraints on the river further downstream. As a lower basin fills or rivers become narrower, water is forced back upstream and out of its banks (Erickson et al. 2018b:6).

In the Llanos (“plains”) de Moxos of the Bolivian Amazon, a flat landscape of seasonally-inundated savanna and wetland and forest islands near the present-day village of Baures (Erickson et al 2018b:3), all three processes are present to some degree. In recent decades, severe flooding in the region has been attributed to backwater flooding, specifically to floodwater backup from sub-basins associated with the Madeira river. Although less documentation is available from the precolumbian time period, archaeological evidence shows that pre-Columbian inhabitants in the area may have experienced something similar (Erickson et al 2018b:6). Flooding in the Bolivian Amazon was common and cyclical, with three to six months of wet season followed by three to six months of dry season. Wet season was characterized by heavy rainfall, waterlogging, and predictable flooding (Erickson et al. 2018b:3). Francisco Eder, a Jesuit priest who lived in the Baures region for 15 years in the early 1700s, describes the near-continuous precipitation in the wet season, claiming rainfall could last up to nine consecutive days at a time (Eder 2009:81). In the beginning of the wet season, local ponding occurred as a result of pluvial flooding in poorly drained lower areas of the landscape. With continued heavy rainfall, these ponds would expand and blend together until most of the savanna was underwater (Erickson et al. 2018b:6). At the beginning of January, rivers would already be overflowing, and while rains stopped around March, (Eder 2009:81), floods could last until August. Eder compared looking out into the flooded savanna to looking out across the sea (Eder 2009:83) (Figures 1-2).

Because of these conditions, the survival of a large civilization in the Bolivian Amazon was difficult. The natives in the Baures region encountered by Francisco Eder were likely the most civilized group there. To manage the floods, the Baure built moats and palisades protecting their villages and used earthworks for transportation, communication, fishing, agriculture, and flood water retention (Erickson n.d.). The Baures savannas contained “forest islands,” naturally raised areas that stayed above water when the rest of the landscape became flooded (Eder 2009:81). Connecting these forest islands was a vast network of earthen causeways (raised roads) accompanied on each side by a water-filled canal (Erickson i.p.:27) (Figure 3). While backwater flooding was difficult to control, this earthwork network was constructed with pluvial and fluvial flooding in mind (Erickson et al. 2018b:6). Causeways were used year-round for walking or other forms of foot traffic, and during the dry season, the canals allowed for canoe travel (Erickson i.p.:27). During the various stages of the wet season, causeways also helped to capture and hold water and maintain it at optimal levels (Erickson i.p.:30) (Figures 4-6). Smaller structures were used for water management in agriculture and fishing. As water receded, fish that had left the river during wet season were trapped in artificial ponds and networks of fish weirs (low earthen corrals) that formed between raised earthworks (Erickson i.p.:32-33). By placing basket fish traps in the small openings where fish weir earthworks changed directions, fish were easily and efficiently caught by fishermen, providing an important source of protein (Erickson i.p.:34) (Figures 7-9).

**GOAL**

The primary goal of this project is to create an educational digital model of how water on the pre-Columbian Bolivian landscape interacted with the network of natural and manmade earthworks on the savanna. Using Google Earth, a region approximately three kilometers by five kilometers was selected. After this representative portion of the landscape was chosen, a relatively detailed three-dimensional mesh model of the area must be built in Maya. To visualize the annual cycle of inundation, accurate earthworks, forest islands, and flat savanna based on the selected region were modelled into the digital mesh. The final water simulation will be performed on the model in Houdini. To impact the viewer, the model must be detailed, and the rain must interact with the model realistically. The final product will be an animation showcasing a timelapse of the landscape as seasons change throughout the year based on the rendered images from the simulation.

**PROCESS**

**Research**

According to Merriam-Webster, a simulation is “the imitative representation of the functioning of one system or process by means of the functioning of another” (Merriam-Webster). A computer simulation is therefore an imitation of such a system or process on a virtual machine. For this project, I am using a hydraulic simulation, which uses particles and properties of water to mimic how water would react in a physical environment. This hydraulic simulation will be used to model the seasonal flooding process of the Baures region of the Bolivian Amazon.

Before starting the project, I met with Dr. Badler to discuss the feasibility of the project and whether I could realistically complete it by the deadline. The project was originally planned for Unreal Engine, but upon further exploration of the idea, I realized performing a physical simulation in Unreal would be challenging. While Unreal Engine has an “ocean” or water shader, the texture is simply applied to a planar surface. Although a waterplane may look like water, the water texture is attached to the plane, and will not interact with other objects like a fluid. Creating the illusion of water in Unreal Engine may be simple, but for my project, I wanted the water to physically interact with the landscape.

Since Unreal Engine does not provide any physical water assets, creating a physically-based flood would require coding. To realistically model water, hydraulic simulations typically use particles that are programmed to interact with each other and with other surfaces in particular ways. All the properties of water, such as surface tension, cohesion, and adhesion, must be considered, and mathematical formulas are used to calculate where a particle would be at any second given these properties. Writing code for a particle simulation is an involved process, and writing code for a fluid simulation is even more so. I have no experience doing either, meaning using Unreal Engine was not a feasible possibility.

Dr. Badler suggested I use Houdini, a special effects software. Because Houdini has built in simulations, including both particle simulations and fluid simulations, I would avoid writing any code. After much debate, I decided to proceed with the project. With no prior experience with Houdini, I spent a few days learning the interface and exploring the software before attempting a complex fluid simulation. I followed an online tutorial to make a simple beach and wave simulation. This included creating a mesh model of a beach and using a fluid simulation to create waves crashing against the beach, adjusting for fluid friction and adding other properties like wind (Zheng 2014). While this was unrelated to flooding in the Amazon, I learned important concepts about fluid properties and setting up passive colliders, or objects which the fluid interacts with.

At the same time, I conducted research on the role of pre-Columbian earthworks and the annual cycles of inundation that the landscape experienced. Dr. Erickson provided me with many resources to use, which included several of his own papers on the subject, in addition to archaeological, ethnographic, and historical literature and images of the earthworks and landscape used in his presentations. These resources provided detailed information needed for my simulation to be grounded in a temporal and spatial local context. I also used some of the observations made by Francisco Eder, but because the document was translated from French, some of his metaphors were lost in translation. Dr. Erickson’s work was my primary source of information throughout this process.

**Virtual Reconstruction**

To build this project, the following software applications were used: Google Earth Pro, Autodesk Maya 2018, Autodesk MudBox 2018, SideFX Houdini FX 17, and Adobe After Effects CS6. First, a region of typical landscape was chosen based on photographs and Google Earth satellite imagery (Figure 10). Using these photographic references, this landscape was then built in Maya and textured in MudBox. The model was then imported into Houdini and Houdini’s water simulations were used to mimic rainwater and flooding. Houdini’s render engine, Mantra, was used to capture the final images of the entire simulation, and these renders were edited as a timelapse in Adobe After Effects.

**1. Landscape Modeling and Texturing**

I first modeled the landscape in Maya. To do so, I first imported relevant reference images into Maya and traced them to obtain an outline of the forest islands and major earthworks within the seasonally inundated savanna (Figure 11-12). Once complete, I extruded the forest islands (Figure 13). The lines I drew for the earthworks, specifically causeways and fishing weirs, were extruded into linear hollow tubes. The causeways were extruded using a tube with a larger radius, and fishing weirs that could be seen from the photograph were extruded using tubes with a smaller radius (Figure 14). Once all earthworks were extruded and made three-dimensional, I created a high-polygon plane and placed it a few kilometers above all the extruded shapes. I then ran an nCloth simulation: the plane was simulated in Maya as a cloth, and the extruded shapes were passive colliders, or objects that would affect the shape of the cloth. As the polygon plane “falls” down, the extruded forms will influence the way the plane distorts. Basically, the polygon plane is like a cloth, and running the simulation is like dropping a cloth over a set of objects (where the extruded forms are the objects). I increased the Stickiness of the cloth to prevent it from sliding off the objects during the simulation (this acts like increasing the cloth’s friction), and I allowed the cloth to fall and settle for a few minutes. Using this cloth simulation method, I was able to obtain an accurate landscape that was not perfectly flat nor too geometric (Figures 15-16).

Because the cloth simulation resulted in a high-polygon object, I went into the Mesh tools and used Reduce to bring down the polygon count. I then used the Sculpt and Smooth tools (Modeling Tools in Maya) to finetune parts of the cloth simulation and add additional details into the mesh, such as canals adjacent to the causeways. The Sculpt tool was used to pull out parts of the mesh (much like adding or removing clay from a sculpture, and the Smooth tool was used to flatten out areas where elevation differences appeared too extreme. To reduce the polygon count even more, I deleted the edges of the plane that were unaffected by the cloth simulation and extruded the flat landscape into a block (Figure 17).

I exported the landscape model as an .obj file from Maya and opened it in MudBox, a tool used for drawing textures. I made additional cosmetic edits with the Sculpt and Smooth tools in MudBox to further refine the canals and causeways (MudBox and Maya are made by Autodesk and share many tools), and then I began painting on my texture. I used a combination of colored brushes and stamps to draw and color directly onto my landscape model. Once the coloring was complete, I painted a Bump map. This map adds a three-dimensional texture to the surface that affects how light bounces off an object without changing any geometry. As the name would suggest, a Bump map can be used to add small bumps and roughness to a surface. I added roughness to the ground throughout the entire landscape, and I textured the forest islands to appear covered in trees. When I was satisfied with both texture maps, I exported the layers as image files and saved them as my texture files (Figures 18-19).

**3. Houdini Set-Up**

With no prior experience in Houdini, I spent time learning the interface and following a tutorial to get started. After understanding the basic navigation, I worked on exporting my landscape model from MudBox as an .fbx file. The geometry from this file was then imported into Houdini. Since the geometry was not attached to any of the textures I painted earlier, I created a material shader in Houdini to attach the texture files to the landscape model. The painted grass and trees were added as a color map to the material, meaning any object with that material would be that color, and the bump map was attached afterward. I assigned this material shader to the landscape geometry so that the landscape would have the correct coloring and roughness, and I added two large area lights around the scene (Figure 20). Finally, I set up two cameras to capture different views (Figures 21-22).

**2. Rain simulation**

The simulation of rain, an essential part of the project, proved to be more difficult than I anticipated. I initially used an on-shelf FLIP fluid (Figure 23). Similar to the beach tutorial, I made a box and simply converted that box into fluid particles. I set the landscape as a passive collider, and simply let the fluid to fall. In the beach tutorial, the fluid particles from the box were dropped from directly over the shore, but to simulate rain, I tried dropping these particles from a much greater height (Figure 24). However, this approach failed. The rain fell in huge sheets rather than smaller droplets, even when I tried to add another mesh to slow it down. Due to the high polycount of the landscape, using a large volume of FLIP fluid was also inefficient. Physically simulating the huge volume of fluid used nearly all my laptop’s available memory and CPU. Some files were so large that I could not even open them. Fortunately, Houdini saves a duplicate backup file whenever saved; I simply returned to an earlier iteration and tried again. My laptop crashed several more times through the entire process. After many hours of rendering, the final rendered image was unacceptable (Figure 25).

To solve this, I used a POP network, or a particle simulation. Following a tutorial on rain simulation and wetmaps (Sayed 2018), I was able to get better results (Figures 26-27). Rather than using real fluids, a glass shader was applied to give the particles a water-like appearance. I originally attached geometry to each particle to give the particles a “waterdrop” shape, but I removed this later to reduce render time (Figures 28). I was able to set the droplets to “slide” when hitting the landscape surface, meaning they begin to pool in the lower areas of the land (Figure 29). This technique replicated the earlier stages of the wet season determined by archaeologists and hydrologists. I also added special behavior so that the rain would “splash” on impact (Figure 30). However, the water from this simulation did not flood the digital landscape as occurs in the Bolivian Amazon.

**3. Flooding simulation**

To achieve flooding, I made a separate simulation using the FLIP fluid method that was attempted earlier. I was unable to include the rain and fluid simulation in the same file due to size and render time. As an alternative, I rendered separate videos of the same landscape under different conditions and combined them in post-production. For this fluid, I made a series of FLIP fluid containers and placed them throughout the landscape. I set up the landscape mesh as a passive collider so that the fluid particles from this container reacted to the landscape the way real floodwater would behave. To reflect floods in the Bolivian Amazon, these containers were strategically placed behind the simulated causeways. After examining the simulation in the preview window, I found the best flooding results around frames 120 to 140 in the simulation timeline (Figure 31). To simulate varying flood levels, I ran the simulation multiple times, increasing or decreasing fluid container volumes between each iteration. From these previews, I also selected a new final camera angle.

**4. Final Houdini Set-Up**

The final camera angle I selected showed the edge of the landscape mesh. To create a more realistic scene, I added clouds in the “sky” above the landscape mesh. For each cloud I built, I placed a sphere polygon mesh into the scene and deformed its shape through stretching. I then attached a Mountain node to the sphere, causing further deformation. Finally, I attached a Cloud VDB and Cloud Noise node to the deformed sphere, which converted the polygon mesh into cloud fog. I added a light inside each cloud and placed them strategically to cover the empty background behind the landscape mesh (Figure 32).

Because a single frame could take up to fifteen minutes to render, I was very efficient with my renders. For the raining scenes, I rendered one out of every three frames, and I rendered a total of 28 frames that could be looped in post-production. When rendering the flooded landscape, I rendered three to five images per flood level at five-frame intervals (rendered one out of every five frames). With six different flood levels, I had six sets of images and 24 in total (Figures 34-39). I sorted each set of images into its own folder to prepare for Adobe After Effects.

**4. Post-Production**

Since each folder contained only the images that were rendered together, I imported each set of images as a looping video. I used a static image of the dry landscape as the base of the entire animation. I overlayed the rainfall over the landscape and turned down the opacity of the droplets for a subtler effect. I also used Adobe’s built-in rain effect to create denser rainfall and to help the looping scenes appear more natural. After placing the floodwater videos in the timeline, I turned down the opacity of each so the transitions appeared more natural. In addition to simple fade-in and fade-out effects, I created a transition scene between each of the flood levels where water slowly rose or fell. To achieve this gradual transition, I used a layer mask on the transition scenes (Figure 40). When drawing a layer mask, the area of the scene inside the mask will be visible in the render, and the area of the scene outside the mask will be hidden. I put a fade-in effect on the masked transition scene and set the mask to grow or shrink with time. As the mask grew, surrounding floodwater was gradually revealed, and as the mask shrank, the floodwater seemed to disappear.

**RESULTS**

Finally, I had created a looping animation of the annual cycle of inundation on the landscape of the Bolivian Amazon. While experiencing many setbacks and difficulties, the result was successful. While satellite imagery and other data visualizations are probably more accurate than my simulated landscape model, satellite time lapse visualizations are difficult for audiences with no archaeological or hydrological background to interpret. As a result, the video animation is more effective. For this reason, my project can be used for education. Although all aspects of human water management in the Bolivian Amazon were not captured, the timelapse provides a basic starting point for showing the public how earthworks affected flooding and water flow on the landscape.

For descendants of the indigenous Baure, the video showcases the achievements of their ancestors and their understanding of the environment around them. For policy makers and environmentalists, the video shows the successful use of floodplains as productive land. The existence of the Baure people proves that large-scale agriculture is not the only method to support a civilization. Gentle flooding and seasonal inundation were an essential part of the ecosystem in the region, and rather than destroying this ecosystem, the indigenous people learned to reap its benefits. With the technology available today, keeping wetlands alive and using the resources they provide should be equally, if not more, plausible. The Baure set an example for wetland conservation and protection, and their descendants should take pride in that knowledge.

In the future, I would include people in the landscape scene to add life to the simulation and to give the landscape a human context; an important part of visualizing the past is peopling landscapes in specific spatial and temporal context. Unfortunately, I was unable to do so with this video. Additionally, Houdini has considerable potential, but due to my lack of experience with the software, I was unable to use all its tools. In particular, the entire flooding process could be simulated in a single file. I also tried and failed to implement a wetmap on the landscape, meaning the surface of the landscape would get change color when it collided with water droplets. In this case, if the wetmap darkened the color of the landscape, the landscape would appear wet when rain hit the surface, rather than just collecting water. Although my laptop is excellent for running most software, simulations in Houdini were demanding of the processor. With more experience and a better machine, I could achieve better results in a shorter amount of time.

**CONCLUSIONS**

Until relatively recently, many people thought the existence of an advanced civilization in the Bolivian Amazon was impossible. Over forty years ago, Betty Meggers at the Smithsonian Institution came to this exact conclusion. She believed that only intensive agriculture could produce enough food to sustain large settlements, and all previous attempts at intensive agriculture in the Amazon, even using modern technology, had failed due to poor soils, limited technology, lack of protein, and climate change (Erickson et al. 2018a). According to Meggers, only large settlements supported by abundant agricultural surplus had the resources to build cities and ceremonial centers, structures that define civilization. By this logic, lacking intensive agriculture in the Amazon, the indigenous people never developed advanced civilization. In an interview for BBC, Meggers says, “If you’re going to believe that the indigenous population had a secret that we haven’t discovered with all [of] our modern technology…that’s fine, but what is it?” (Sington 2002).

The belief that traditional agriculture is the only possible path to develop civilization is the same mindset that contributed to the destruction of so many wetlands. Rather than destroying the floodplains and savannas, the pre-Columbian Baure embraced the benefits of seasonal flooding and built a system to manage the floodwater. Especially in the Western world, only land that supports agriculture is seen as productive. As exhibited by countless past and present cases, this belief is far from the reality. While not contributing to society in the same way as agricultural fields, wetlands still hold extreme significance and are a resource-filled ecosystem. Wetlands are often overlooked as unusable land when instead they should be appreciated for their biodiversity and the benefits they give back to the environment. In the quest to understanding wetlands, studying “successful” wetlands and examining how they contributed to societies in the past can provide powerful insight and assist with protecting them in the future.

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