Pre-Columbian Roads as Landscape Capital

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Abstract

Archaeological remains of roads are often neglected in settlement surveys. Because they are found between sites, roads are an important component of the landscape. In this paper, we apply the concept of landscape capital as defined by Harold Brookfield to pre-Columbian roads in the Amazon region of northeastern Bolivia. Previous studies have documented the importance of raised earthen causeways for transportation and communication between settlements across the seasonally inundated savannas. In this paper, we propose that farmers also used networks of causeways to manage water for savanna agriculture. Topography and cultural features at local and regional scales are modeled to simulate floodwater flow and capture within fields. The results provide insights about how generations of farmers engineered and managed this environment as landscape capital.

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Introduction

The study of past and contemporary trails, paths, and roads is relevant to political economy, history, sociology, urban planning, folklore, development, and anthropology. The archaeology of Landscape provides a unique perspective on trails, paths, and roads. Landscape is a useful concept for understanding the role of trails, paths, and roads in the everyday lives of people in the past and present. Archaeological examination of trails, paths, and roads as physical landscape features and formal built environment provides insights about economic infrastructure, social interaction, social organization, engineering, worldview, and indigenous knowledge that are often unavailable to ethnographers and historians. Trails, paths and roads can be subtle or imposing features of the landscape as built environment. As such, they recursively structure and reflect ongoing daily and special activities and document change and discontinuity when interpreted as palimpsests. In this paper, we show how roads are a central element of the pre-Columbian agrarian and densely populated landscape in the savannas of the Llanos de Mojos of the Bolivian Amazon. In addition to their transportation and communication functions, roads played a key role in water management, topographic transformation, and engineering of the environment at a regional scale. As vast infrastructure of labor investment in permanent land improvement by generations of pre-Columbian peoples, roads became important landscape capital. This engineered landscape continues to structure the lives of contemporary peoples and the environment in subtle and direct ways.

The Concept of Landscape Capital

Agricultural landscapes are patterned built environments, a large scale accumulation or palimpsest created by generations of inhabitants who have imposed their structures on the land (e.g., Denevan 2001, Doolittle 2000, Turner and Whitmore 2001). These landscapes are places where people lived their everyday lives, working, traveling, and farming. These same landscapes contain and express elements of the non-routine ritual, sacred, aesthetic, and political realms. This relationship between humans and the landscape is well described by the concepts inhabitation (Barrett 1999) and taskscape (Ingold 1993). An essential attribute of landscape features is their recursive nature—they are both models of and models for society (Erickson, this volume). In all cases, nature is transformed in the process of production through labor, society, and history. This transformation can result in land improvements and/or degradation over time (citations). The improvements on the land accumulate through the efforts of generations of inhabitants, each exploiting and adding to the accumulation of labor. Substantial landscape accumulation, often at monumental and regional scale, can be made over short periods with heavy labor investments, or through a long-term accretion process, as noted by Doolittle (198?). Brookfield (1986, 2001; Brookfield and Blakie 1987) proposed the term *landscape capital* or *landesque capital* to describe this version of fixed capital. [1] Once created, landscape capital is inherited, used, and maintained by later generations (2001:216). This important concept is often ignored in discussions of the impact of native people's activities on the environment, judgments as to whether these transformations are positive or negative, and documentation of intensification of agriculture. The often highly patterned, physical nature or materiality of landscape capital makes it a logical focus of archaeological investigation. The landscape capital of complex and highly evolved anthropogenic landscapes is amenable to archaeological and historical ecological investigation as a physical record of human activities over the short and long term (Fisher 2004; Balée and Erickson 2006b).

Trails, paths, and roads are landscape features with material expressions of both patterned human movement through everyday repetitive activities and the physical structures that channel human activities through their division of space into place, territory, boundary, access, and orientation (Ingold 1993; Tilley 1994, 2003; Snead 1995). Roads are expressions of agency, practice, and structure (Erickson, this volume). In this paper, we explore the use of formal roads to facilitate movement and channelize people and natural resources, in this specific case, water for water management and agricultural production. These practices of water management range from the local to regional in scale and integration. This technology and landscape infrastructure has important implications for soil fertility and sustainability in the past and present. In our case study, the indigenous knowledge of engineering is embedded in the physical structure of the landscape. Our approach is to do “reverse engineering” using mapping, excavations, and survey to determine the structure, function, and meaning from the highly patterned archaeological remains.

The Bolivian Amazon

The Bolivian Amazon or Llanos de Mojos (or Llanos de Moxos; Plains of Mojos) is a seasonally flooded tropical savanna located in the southwestern Amazon River basin in the Department of the Beni, Bolivia (Figure 1). The Bolivian Amazon lies between the Andes Mountains to the west and the highlands of southwestern Brazil to the east and the Pantanal and Chaco regions to the southeast. The region is drained by the Madeira River which flows into the Amazon River some 1500 km to the north.

The Bolivian Amazon is a relatively flat landscape, with elevations varying by a few meters. The climate is warm and humid, with sharp seasonality in rainfall. The wet season peaks between December and March and the inundation produced by the heavy seasonal rains, as well as rising river levels downstream, threatens crop agriculture and ranching. Occasionally, as much as 50% of the landscape is underwater. During the dry season between June to September, water becomes scarce and modern farming and ranching are difficult. In broad strokes, the environment is a mosaic of forests, savannas and wetlands, all subject to a strong seasonal cycle of rainfall and inundation.

Today, cattle ranching dominates the cultural landscape. Ranchers move their herds across long distances, from areas near permanent wetlands in the dry season, to high refuges during the wet season. In general, savannas are not farmed, but ranchers regularly burn the savannas to encourage new grass and keep the forest at bay. The importance of burning to the savanna is illustrated by the encroachment of forest on savanna between 1975 and 2001 as ranching activity declined.

Ranchers, native peoples, and colonists establish gardens, orchards, and slash and burn fields within the better drained gallery forests and forest islands. Key crops today are manioc, maize, sweet potato, squash, New World taro, and rice. Most communities are within gallery forests and forest islands adjacent to large ranches and urban areas.

The savanna, wetland, and forest mosaic are home to a rich fauna and flora. A variety of wading birds and other waterfowl are native, as is the rhea, or New World ostrich. The rivers, lakes, swamps, and seasonally inundated savannas are full of fish, caimans, and river turtles. Major game animals include deer, peccary, capybara, tapir, paca, armadillo, and agouti. Although today hunting carries more prestige than fishing, the latter is probably more important in terms of food production.

Pre-Columbian Roads in the Bolivian Amazon

The Bolivian Amazon is a highly patterned cultural landscape of earthworks and settlements. Earthworks include settlement mounds, raised fields, causeways, canals, reservoirs, and fish weirs (Denevan 1966, 2001; Erickson 1996, 1999, 2000a, 2000b, 2006a; Erickson and Balée 2006, Walker 2004). Roads, in this case raised earthen causeways with associated canals, are common landscape features that crisscross the savannas, wetlands, and forests of the region (Denevan 1966, 1991; Erickson 2000, 2001; Lee 1996; Pinto Parada 1987). We use the formal term *road* rather than trail or path to highlight the intentionality, design, monumentality, and engineering that was used to create them. Within the larger domain of roads, we use the term *causeway* and *causeway-canal* for the linear earthworks characteristic of the Bolivian Amazon. The canals that are always associated with causeways are aquatic roads for canoe traffic (Erickson, this volume).

Causeways are flanked by canals on one or both sides where earth was removed to raise the road platform (Figure 2). Although badly eroded by cattle ranching and farming activities, causeways are visible from the air as dark lines of trees and bushes that stand out against the grasses of the savanna (Figure 3). Canals are marked by aquatic vegetation and standing water during the wet season. Causeways range in elevation from 0.2 to 2m and width from 1 to 20m. Causeways are generally found in seasonally inundated areas of poor drainage, but are rarely found in permanent wetlands. Most causeways are straight over lengths ranging from tens of meters to kilometers. Causeways are often connected to other causeways which form impressive regional scale networks. Many causeways connect archaeological settlements or settlements and raised fields. We now turn to the hypothesis that roads were created for water management and served as a permanent feature of landscape capital for the farmers that created and used them, in addition to transportation and communication (Nordenskiöld 1916; Denevan 1991; Erickson, this volume).

Roads as Engineered Hydraulic Works

Three types of inundation combine to impact the landscapes and lifeways of the Bolivian Amazon. The first type of inundation results when larger downstream rivers are at full capacity, which blocks drainage from smaller rivers, causing inundation of large areas upstream. The second type of inundation is the outcome of heavy local rainfall. Rains can leave 20 or 30cm of standing water on poorly drained terrain of higher elevations, even though these areas are unaffected by inundation from adjacent rivers. During the dry season, this rainwater drains or evaporates quickly and the effects are temporary. During the wet season, when the river levels and the water table are high, local rainfall inundates large areas. Modern inhabitants refer to the first two types of inundation “water from below” and “water from above.” The third type of inundation results from heavy rainfall in the upper drainage basins (swamps at headwaters of regional rivers and Andean mountain headwaters of the larger and longer rivers) which produces bank overflow as the rivers cross the Bolivian Amazon.

Most of the inundation in the Bolivian Amazon is what is termed “benign flooding” (Siemens 1996:133). In these hydraulic regimes, overflowing rivers with sources in the Andes and within the region, local rainfall, runoff, and rising water tables, and backup of drainage in the lower reaches of river systems gently covers much of the flat landscape with a sheet of water. In the savannas and low-lying forests, this inundation generally ranges from a few centimeters to several meters deep. Although shallow, the mass of water at the height of the rainy season is millions of cubic meters (Hanagarth 1993; Langstroth 1996).

The “wetland margin,” the surface effected by the rise and fall of the floodwaters (Siemens 1996), is vast and heterogeneous in a flat landscape such as the Bolivian Amazon. The classic distinction between floodplain and upland (*várzea* and *terra firme*) (Lathrap 1970), in Amazonian studies, does not apply to the Bolivian Amazon because most of the landscape is inundated to some degree at various times. The highest ground is often adjacent to the rivers themselves—the linear levee formations of sediments dumped by the slowing of flow velocity during hundreds of years of inundation. These geomorphological features support gallery forests and most modern agriculture is practiced there using slash and burn, agroforestry, and gardening. The back swamps or wetlands between rivers are generally the lowest elevations and often hold water year round. The savannas, wetlands, and forests are crosscut by abandoned river channels, meander scars, and their associated levees. Sections of these levees also support forest islands and thin gallery forest. Other prominent features include shallow “oriented lakes” (both open and choked with vegetation) and other permanent wetlands (Plafker 1963; Denevan 1966; Hanagarth 1993; Barba et al. 2004).

To many modern inhabitants, government institutions, and non-government agencies, the seasonal cycles of inundation are limitations to growth and development of the region. In contrast, the pre-Columbian farmers of the Bolivian Amazon were attracted to this dynamic landscape and took advantage of the seasonal cycles of inundation. The inhabitants practiced a form of passive recessional floodwater agriculture and enhanced and exaggerated its effect through massive transformation of the landscape. In contrast to traditional irrigation in arid and temperate environments, the natural cycles of water were exploited using simple earthworks to channel and manage water at a regional scale. In other settings of benign flooding, recessional floodwater farming involves check dams and dikes to retain moisture in soils that are planted after floodwater and runoff recede. Pre-Columbian farmers in the Bolivian Amazon planted their crops during the period of inundation, taking advantage of the water management provided by a variety of earthworks.

Kenneth Lee (1979; 1996) proposed that earthworks of the Bolivian Amazon were used as water enclosures that could be opened and closed for sustained agricultural production. He argued that fields would be flooded for a period of many years for the cultivation of water hyacinth (tarope) and other aquatic flora and fauna which would later be incorporated into the soil as a green manure and organic matter for food crops when the fields were drained. Jorge Flores and Percy Paz documented similar cycling of intentional inundation and draining of fields for sustained production in sunken gardens or *qochas* in the Andean highlands (Flores and Paz 198?; Erickson 2000). Raised field experiments have demonstrated the value of using water hyacinth as green manure in the Bolivian Amazon (C. Perez 2000; T. Perez 2000; Stab and Arce 2002, Barba et al. 2004; Saveedra 2006).

In this chapter, we examine the hypothesis that causeways and canals were constructed as water management infrastructure in addition to transportation and communication functions. In contrast to western obsession to drain what are considered marginal wetlands for agriculture, farmers in the Bolivian Amazon may have intentionally expanded wetlands and wetland productivity through earthwork construction, which impedes, rather than enhances, drainage (Erickson 1979; 2006b). The pre-Columbian farmers did not use causeways as dikes to prevent inundation of fields and settlements; but rather expand and enhance inundation for agricultural production. At the same time, impounding water by well placed causeways and creation of deep canals improved and extended the season of transportation by canoe across the landscape.

Our hypothesis that causeways were used to manage inundations and enhance wetlands comes from numerous observations of unintentional pooling of water behind modern raised causeways in the Bolivian Amazon. In 1979, a massive lake was formed to the south of the newly constructed raised road between San Borja and San Ignacio (some 15km east of the study site of the Arizona Ranch). In 1983, the raised road between Trinidad and Puerto Almacén blocked the natural flow and created a huge body of water that washed over and destroyed the road surface, which made it impassable for many weeks (Figure 4). In both cases, engineers determined that the road construction crew did not install the required number of drains in the raised road. Erickson (1980) mapped causeway structures that functioned as dikes to impound water and create artificial wetlands north of the town of San Borja.

Water management is also central to the recently documented fish weir system of Baures and its associated causeway-canals (Erickson 2000). The fish weirs are low “zigzag” earthen causeways between forest islands which channel shallow floodwaters through funnel like openings where basket fish traps could have been placed. Palm-lined ponds associated with these openings hold water and fish during the dry season. Similar hydraulic manipulation has been documented for raised fields around Lake Titicaca, Bolivia and Peru. Smith and colleagues (1968:361) noted that raised fields and dead end canals “would definitely have hindered systematic drainage or would have done nothing to assist it” and conclude that this was a conscious effort to conserve water. Similar arguments were made by Lennon (1982, 1983) and Erickson (1980, 1988, 1993, 1996, 2006a).

During the wet season in the Bolivian Amazon, low causeways of a meter elevation between locations of higher ground can impound huge amounts of water with minimal effort. Within raised field systems with canals occupying 50% of the surface area, massive amounts of water can be maintained within the artificial topography (although usually not throughout the entire year) [cite figures for examples from Erickson 2000, 2006a]. Here the canals of raised fields and associated causeways function as micro-catchment basins connected to a network of canals, streams, rivers, and other water bodies. The major goals of the pre-Columbian peoples who created these earthworks were to catch runoff early in rainy season and hold water on savanna longer into dry season to extend growing seasons and reduce risk. Additional benefits included management of aquatic fauna and flora, both economic species and those that can be recycled as organic material for sustainable production. The tens of thousands of kilometers of linear terrestrial-aquatic interface created by construction of causeways and canals and raised field platforms and canals has the potential to significantly raise agricultural productivity, biomass, and biodiversity at the local and regional scales (Figure 5) [cite figures here from Erickson 2000, 2004 for Mojos.

The Middle Apere River Region

Pre-Columbian causeways and canals in the Bolivian Amazon are found along the tributaries of the Mamoré River, which crosses the region south to north and in the northeastern part of the region, around the modern town of Baures (Figure 6; Erickson, this volume). We discuss causeways in savannas along one of the Mamoré river tributaries, the Apere River.

Although flat and featureless to the untrained eye, the Middle Apere River region has considerable local ecological and topographical heterogeneity. In general, the diverse topography supporting a mosaic of gallery forest, savanna, and wetlands is a record of the movements of various rivers over tens of thousands of years. Large, active, sediment laden rivers with headwaters in the Andes Mountains, such as the Beni, Mamoré, and Madre de Dios, meander across the landscape within defined floodplains. In contrast, smaller tributaries such as the Apere River are more stable in their course and have low, forested levees slightly higher than the surrounding savanna. These tributaries are interspersed with relic river courses, where water accumulates but does not flow, and forest islands on higher levees.

In this savanna, seasons are defined by the annual wet and dry seasons (Figure 7). During the wet season, whether an area is inundated or not is determined by the small topographic variations associated with active and extinct river levees and channels, wetlands, and seasonal streams. In this study, we examine and compare the difference between the natural flow of water based on general geomorphology and hydrology and the anthropogenic flow of water, where geomorphology and hydrology has been transformed by the construction and maintenance of earthworks. Pre-Columbian farmers of the Bolivian Amazon superimposed their anthropogenic, cultural landscape on the complex dynamic palimpsest of natural history.

Methods

Causeways were mapped using digitized aerial photographs, which were georeferenced in relation to GPS points and visible landmarks on LANDSAT ETM images. Causeways and blocks of raised fields were digitized on-screen (Figure 8). A digital elevation model (DEM) is based on shuttle-borne radar data (SRTM). The SRTM DEM (Figure 9) is unsuitable for comparing the ground elevations of forested and non-forested areas, because the radar records the tops of trees rather than the surface of the earth. However, for comparisons across non-forested savanna, the data are useful.

The DEM was used to create two models of water flows. The Natural Landscape Model (Figure 10) was based on the original SRTM DEM, processed to "fill in" basins created through flaws in the data.[2] This model simulates the flow of water over the landscape without taking into account the effect of causeways. The Modified Landscape Model is based on the same processed SRTM DEM (Figure 11). In this model, the elevations of pixels crossed by the digitized causeways were raised by one meter to simulate original causeway elevations which are too small in scale to be recognized in the 90m pixel DEM . Comparison of the two models shows the difference between a hypothetical natural landscape and a modified landscape. The differences between these two models represent the hydraulic effects of causeways.

The Middle Apere River Landscape

Our case study focuses on an anthropogenic landscape in the Middle Apere River in the central Bolivian Amazon. The savanna is broad and open, and forests are generally confined to galleries along the rivers, with a ratio of forest to savanna of 85% to 15%. Along the Middle Apere River, causeways, canals, raised fields, settlement mounds, and occupation sites cover an area larger than 60 square kilometers along both sides of the river. Raised fields extend nearly continuously on the levee backslope from the river channel to the edge of permanent wetlands about 3km. A number of long causeways crisscross the area of raised fields.

The narrow corridor between the Apere and Matos rivers is a regional center for cattle ranching and therefore the savannas to the northwest of the Apere River have been transformed by decades of cattle grazing, airstrip and ranch construction, the establishment of an all-weather road. Causeways and raised fields are better preserved on the southeast side of the Apere River.

Analysis and Results

Comparing the Natural Landscape Model and the Modified Landscape Model, (Figures 10-14), the flow of water indicate that the local backslope is a more important hydrological feature than the overall regional slope of the landscape towards the north-northeast. The change in elevation is approximately 1m per 1km down the backslope and 1m per 10km to the north-northeast. As a result, water first drains away from the Apere River to the northwest and southeast and later drains to the north-northeast during the wet season. Water flow is not simple, but the general direction of the flow is clearly down the backslopes first, and with the overall regional trend second.

Other drainage characteristics can be inferred from the terrain topography described above. During periods of local rainfall, runoff would flow down the backslopes perpendicular to the river in the back swamps (wetlands?) rather than fill the river and flow northeast. When the rivers cresting during flood maximum, quantities of water continues to flow down the backslope perpendicular to the river; but most backed up water now flows to the northeast in the back swamps, river channel, and seasonal rivers.

When the causeways are used to modify the DEM and the analysis is run a second time to make the Modified Landscape Model, the effects of the causeways on local drainage are clear (Figure 11). The causeways that are parallel or close to the river may block some runoff from draining into the river; their effect is minimal on hydrology at the height of the wet season. These causeways may have functioned to protect the backslopes from floodwater from the river, but their height (less than 1 meter) suggests their impact was insignificant.

Causeways that are perpendicular to the river divert and isolate some of the curving flow of water down the backslope, but do not impede the general flow of water or impound large bodies of water due to their low elevation and small cross-section. These causeways were not meant to withstand large volumes of water from river channels and bank overflow. Instead, they probably channeled and organized smaller and slower moving flow of water, like those resulting from rain runoff or seasonal expansion of the permanent wetlands. Most of the year, water soaks into the soil rather than running off due to the relatively flat slope and low water table. Instead of diverting over bank flow from the river onto the savanna, the hydrological function of the causeways at on the Middle Apere River may have been to divide areas where local rainfall and floodwater were harvested for agriculture and longer canoe access to wetlands during the dry season.

Throughout the year, access to the wetlands for fishing, hunting, collection of aquatic resources was improved through causeway construction.

The raised fields between the causeways also had hydraulic functions (Figure 12). These raised fields are organized in blocks averaging 3.2 ha, oriented roughly to the intercardinal directions, which correspond to the general course of the Apere River (i.e., perpendicular or parallel to the course of the river). Some exceptions to these orientations are found on the backslopes of abandoned river channels and within the wide sweeping meanders of the Apere River. Most fields are oriented perpendicular to the river course and in the direction of local slope.

Because the raised fields and raised field blocks have multiple orientations, the overall intent was not to retain all water nor drain all water. Many raised field canals are dead-end and raised field blocks are defined by earthen bunds (which also functioned as raised field platforms). The overall effect was the creation of micro-water catchment basins. When optimal water levels within raised field blocks were reached, excess water would drain over the bunds into lower lying raised field blocks or the larger canals along causeways into the backswamps. Thus, raised field, canals, raised field blocks, and causeways created a sophisticated integrated system of water management.

Because the runoff from each block of raised fields affects neighboring blocks, farmers would have to cooperate at the local level. Future analysis will model the effect of raised field canals and bunds of raised field blocks on the drainage and retention of water across the backslopes and the relation between causeways and the raised field blocks associated with them.

The relationship between causeways and raised fields on the Middle Apere River can be explored by examining the orientation of canals on either side of causeways, and of the relationship between raised field blocks and causeways. The orientations and positions of causeways and patterns of raised field blocks are clearly integrated. Causeways and field blocks have the same orientations (with a few exceptions) and causeways rarely divide individual blocks. The analysis suggests that causeways and raised fields were designed, built, and maintained as locally integrated farming system. The integration suggests that the causeways and raised fields were created at the same time or gradually co-evolved as generations of farmers learned how to engineer the local hydrology and invested in permanent landscape capital.

The combination of raised field canals and causeways enhanced natural wetland and artificially expanded wetlands over large areas. The engineering features also captured early rains and impounded water well into the dry season when most of the savanna dried out. The builders of these raised fields and causeways were familiar with the syncopated rhythm of the river, rain, and seasons. Farmers used earthworks to create a structured anthropogenic landscape that used those rhythms and the local topography to enhance farming, hunting, and fishing, in addition to transportation and communication between settlements and people and resources.

Discussion and Conclusions

On a flat, seasonally inundated landscape, the construction of earthworks such as causeways will affect local and regional hydrology, regardless of intent. Because normal annual inundation during the wet season and drying out of the landscape in the dry season are massive processes in scale and intensity, causeways could not completely control water. We hypothesize that the imposition of causeways on the landscape altered the benign flooding in ways that benefited the inhabitants.

As infrastructure association with agriculture, causeways probably affected the water levels in fields. Typical Amazonian crops such as manioc and sweet potatoes need dry soils, although *Xanthosoma*, identified in raised field excavations, thrives in humid soils. At the same time, all crops need sufficient water to thrive. Raised field platforms were a simple method of keeping crops above the water.

Although the environments at the regional level are roughly similar, pre-Columbian peoples created landscapes in different ways in different locations throughout the Bolivian Amazon. At Esperanza ranch, as in most locations, causeways are either parallel or perpendicular to river courses. Causeways are usually associated with agricultural fields.

When local topography and associated raised fields are considered, causeways appear to function to create, expand, and manage wetlands at a local and regional structure. In addition, these water management systems enhanced the productivity of economic resources of natural wetlands. Finally, by slowing and changing the flows of sediment rich water, causeways could have increased the accumulation sediment and resultant increased soil fertility.

Pre-Columbian peoples created, inhabited and actively managed these anthropogenic landscapes. Regular burning of the savanna protected against the encroaching forest. The water management represented by causeways was one technology of many.

Causeways functioned as landscape capital: land tenure and territory markers, means of transportation of people and crops, networks of communication between settlements and between settlements and fields. The farmers created causeways and successive generations inherited their agricultural fields and hydraulic management strategies. They were highly visible statements of the organization of labor by the community, and the ties between that community and the land. The people who created and maintained this landscape capital invested their labor and probably considered these improvements aesthetic components of an orderly cultural landscape.

The chronology of landscape construction at Esperanza ranch and elsewhere is important. Calculations of the amount of labor required to build fields, dig ditches, and build causeways produce values measured in person-days, for the time required to build a given feature. Determining whether these landscapes were built through accretion or were constructed all at once depends on other evidence. Settlement evidence that includes sequences of radiocarbon dates over several thousand years suggests that accretion was the dominant process no matter how large some building events might have been. The annual labor costs of maintenance are also an important factor to consider. The overall design of the system was laid out from the beginning including orientation and the spacing of raised field and causeways. No earthworks required large groups of workers to build any specific feature.

The Bolivian Amazon provides a valuable comparative case for other wetland focused complex cultures in the Americas, including the Aztecs in Central Mexico and the Mississippians in North America. To these cultures, wetland environments were sought out rather than avoided.

This case study shows that the concept of landscape capital can be understood through the archaeological record. The archaeological study of landscape capital also contributes to an understanding pre-Columbian indigenous knowledge. In this case, we address how local knowledge conserved, enhanced and managed water, aquatic resources, and wetland agriculture through the engineering of the landscape. Archaeology is uniquely positioned to study the local and regional histories of particular landscapes and show how its inhabitants were able to sustain resources and populations over centuries and millennia.

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Figures

Figure 1. The Llanos de Mojos (shown in gray) of the Bolivian Amazon in relation to western South America and the Amazon Basin.

Figure 2. Causeways are flanked by canals on one or both sides where earth was removed to form the road platform.

Figure 3. Pre-Columbian causeways (white linear features) and adjacent canals (darker lines of aquatic vegetation) crossing the savanna near the Jerusalem Ranch, Middle Apere River. Causeways are still used by local ranchers and farmers.

Figure 4. The raised road between the City of Trinidad and the Puerto Almacén unintentionally impounding a large lake to the left in 1985.

Figure 5. Reconstruction of raised fields and canals highlighting the terrestrial-aquatic ecotone or edge created by their construction (Drawings by Clark Erickson).

Figure 6. The Middle Apere River and Baures region in the Bolivian Amazon.

Figure 7. Reconstruction of causeways, canals, and raised fields between adjacent rivers in the Bolivian Amazon: a) dry season, b) early wet season, c) height of wet season, d) late wet season, and d) dry season (Drawings by Clark Erickson).

Figure 8. Causeways (light orange lines) and raised field blocks (white lines) overlaid on an aerial photograph, which was georeferenced using GPS points and LANDSAT data. Scale, orientation and location of this and the next six figures are constant.

Figure 9. Causeways overlaid on a digital elevation model (DEM) made from shuttle-borne radar data (SRTM). The elevations in the savanna range from about 148 to 154 m.a.s.l..

Figure 10. The Model of Natural Landscape. The Model shows how water moves down the levee backslopes and away from the Apere River. Progressively lighter shades of blue represent the accumulation of moving water.

Figure 11. The Model of Modified Landscape. The Model shows how causeways change the flow of water down the levee backslopes and away from the Apere River. Progressively lighter shades of blue represent the accumulation of moving water.

Figure 12. Causeways and raised field blocks overlaid on the Model of Modified Landscape.

Figure 13. An unsupervised classification (in which pixels with similar properties are grouped together) of LANDSAT ETM+ data from 2001. The three green shades are

interpreted as forest vegetation and the eight brown shades are interpreted as savanna vegetation.

Figure 14. A combination of unsupervised classifications of LANDSAT ETM+ data from 1975 and 2001. Dark green pixels are forest in both images, light green pixels are forest only in the 2001 image, and pink pixels are forest only in the 1975 image. The analysis documents a change in forest cover of 15% to 19% from 1975 to 2001.

Endnotes

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[1] Brookfield 2001:216 "Capital and skills can be combined with labor in very different ways, Yet this also is not simple because capital and skills are not simple categories. Working capital is used along with labor and technical skills. Fixed capital, or landesque capital, must be created before it can be used. Whether it is created quickly or incrementally, it can endure for a long time, as this book has amply demonstrated. Landesque capital, used by today's cultivators, is not a current input but an inheritance, requiring only maintenance."
Also pp. 55, 71, 171, 174-5, 182, 214, 216.

[2] The appropriateness of this approach is confirmed by the USGS Hyrdrosheds project, which is carrying out the same procedure using SRTM around the world (http://hydrosheds.cr.usgs.gov/).