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Applied Perspectives on Pre-Columbian Maya Water Management Systems: What are the Insights for Water Security?

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[–] Abstract and Keywords

Water security is a fundamental global challenge for humanity. Suggesting that scholars, water management engineers, and policy-makers draw from a wide range of examples, this chapter argues that knowledge gained from archaeological research provides unique insights into the long-term function and efficacy of water management systems. This chapter presents six cases of water management systems in the pre-Columbian Maya lowlands, from the Yalahau, Puuc-Nohkakab, Petén Karst Plateau, and Belize River Valley subregions, that demonstrate significant variation; a product of the interplay between social, political, and economic factors and hydrological regimes. The analysis suggests four insights relevant for current water security concerns: (1) water management systems are characterized by a diversity of solutions, (2) water scarcity promotes increased management investments that result in long-term vulnerability, (3) water abundance does not require complex management systems but increases the risk for mismanagement, and (4) institutional and technological diversity provide flexibility and greater security.

Keywords: pre-Columbian, lowland Maya, water management, water security, applied archaeology

Introduction

Building resilient and socially just water management systems that meet the water security needs of all people is a fundamental global challenge for humanity. We define water security as the situation whereby people have physical and economic access to water of sufficient quantity and quality to meet their physiological needs, including drinking water, water for food production and processing, and water for sanitation. A water management system is the sequence of actions that links water 'production, processing, distribution, consumption, and waste management, as well as all the associated regulatory institutions and activities' (Pothukuchi and Kaufman, 2000: 113). Throughout history, the demand for water security and functioning water management systems has been a catalyst of social cooperation as well as a source of human conflict (Scarborough, 2003). The need for designing secure water management systems is urgent since fresh water of adequate quality for human consumption is a finite resource, and it can be argued that we have entered a global post-peak-water scenario with rapidly inflating costs for meeting rising demands on a diminishing supply.

Contemporary challenges for resilient water management systems that provide water security are growing at an alarming global rate, with explicit issues not dissimilar to those dealt with by past societies at regional and local scales. Suggesting that scholars, water management engineers, and policy-makers draw from a wide range of examples, we argue that knowledge gained from archaeological research provides unique insights into the long-term function and efficacy of water management systems. Our data sets introduce and identify factors that have established water security in the past as well as demonstrate vulnerabilities in different socio-environmental contexts; contexts frequently concealed from current planners and policy-makers because insufficient time has elapsed for evaluating these processes. We present a series of water management systems in the pre-Columbian Maya lowlands that demonstrate significant variation; with this variation being product of the interplay between social, political, and economic factors and hydrological regimes. We outline and contextualize these systems, discuss their efficacy for water security, and conclude with some implications for current concerns.

The Maya Lowlands

The Maya lowlands cover about 250,000 km^2 within present-day Mexico, Guatemala, Belize, and Honduras. Lowland Maya prehistory unfolded over several millennia with the development of state polities, urban centres, long-distance exchange networks, innovative technologies, and complex resource management systems by the first millennium BC. Long-term lowland history suggests a series of broad regional and subregional cycles of growth, decline, and reorganization during the course of the Preclassic (1000 BC–AD 250), Classic (AD 250–1000), and Postclassic periods (AD 1000–1500); processes in which long- and short-term rainfall variation seems to have played an important role (Kennett et al., 2012). Set in a highly heterogeneous tropical environment, the ancient Maya developed a series of water management systems to build water security. Although archaeologists have uncovered several different critical aspects of these systems, few have focused on assessing water security, as we do here.

Lowland hydrological regimes share the two basic characteristics of a tropical climate with a pronounced dry season, and a karst limestone geomorphological framework, but how these played out vary significantly. With a pronounced dry season from October to May, wet season precipitation generally follows a south-east to north-west gradient of decreasing rainfall, with nearly arid conditions (<500 mm) on the north-west coast of the Yucatán Peninsula, and averages of *c.*1,500–3,500 mm in the east and south. Similarly, karst solution processes of the limestone bedrock have acted to provide different opportunities and challenges for water security.

Pre-Columbian Lowland Maya Water Management Systems

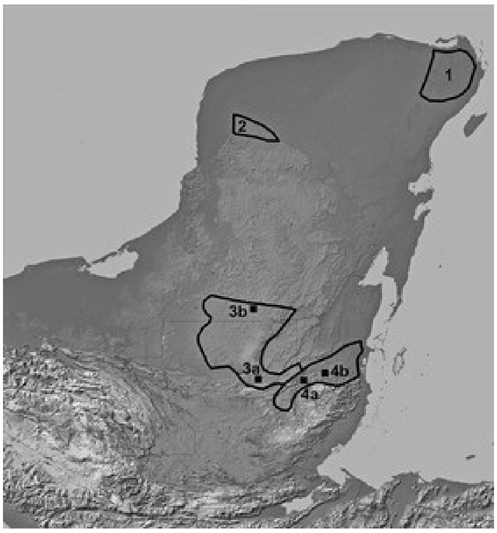

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Figure 1 The location of subregions and sites discussed in the chapter: (1) Yalahau, (2) Puuc-Nohkakab, (3a) the Petén Karst Plateau: Tikal, (3b) the Petén Karst Plateau: Calakmul, (4a) the Belize River Valley: X-Ual-Canil, and (4b) the Belize River Valley: Saturday Creek. Plotted by Christian Isendahl on a modified map from NASA available online: <http://www2.jpl.nasa.gov/srtm/central_america.html> (accessed 22 November 2011).

How the Maya addressed the particulars of local hydrological regimes to increase water security varied both spatially and temporally. Dunning and Beach (2010: Fig. 23.2) recognize 27 physiographic subregions in the lowlands; the six cases presented here (drawn from those with which we are most familiar) cover four of these regions (Fig. 1). Although inadequate for nomothetic conclusions, the cases do elucidate significant security challenges and opportunities that water management systems can address.

The Yalahau Subregion

The Yalahau subregion of the north-east Yucatán Peninsula is a water-rich setting. Annual precipitation averages about 1,200 mm, while a sea breeze convergence at the north-east corner of the peninsula results in frequent storms that often raise annual rainfall in the Yalahau area to over 2,000 mm. While lacking in surface rivers, the area is characterized by a system of north–south trending freshwater wetlands that have formed in a series of linear depressions. These wetlands represent the exposed surface of the aquifer, supplemented by rainwater run-off, and cover about 134 km^2 distributed over 170 separate wetlands. Today, the water level follows an annual cycle of rising and falling, but most areas contain moist soils and isolated water bodies even during the height of the dry season. The water contained is generally clean and clear, rather than the humic swamp-water one might expect.

The regional aquifer represents one of the most abundant freshwater reserves in Mexico and is today pumped to supply the freshwater needs of the Cancun-to-Tulum urban/resort area (Delgado et al., 2010). The water table is less than 5 m below the surface and can easily be accessed by excavation through the relatively soft limestone bedrock. Modern wells, both hand-dug and drilled, are the most common source of household water. Excavated wells were also a common feature in the past, providing an abundant and easily managed supply of household water, including pot irrigation of home gardens (Winzler and Fedick, 1995). The aquifer is also accessed by numerous natural sinkholes (*cenotes*).

Water management strategies by necessity extend to agricultural soils, since the dry season potentially stresses agricultural systems. The importance of soil moisture management is a key component of water management concerns for both modern and pre-Columbian Maya of the subregion. Soils of the Yalahau uplands are dominated by thick, dark, humus-rich topsoils that in general have high nutrient status, are well drained while also having excellent moisture retaining properties, and are easily worked with hand-cultivation technology. The main limitation is shallow depth to bedrock. However, this perceived limitation by standard soil descriptive methods is deceptive since the limestone bedrock is riddled with cavities that hold significant amounts of soil. The pre-Columbian Maya probably made use of these recesses for precision agriculture (Flores-Delgadillo et al., 2011), i.e. they adapted crop and land management to the different conditions of a heterogeneous environment. In addition to providing a deeper rooting environment and sometimes direct access to the aquifer for plants with deep root systems, soils in bedrock cavities retain moisture longer than surface topsoil. Moreover, gravel mulching that maintains moisture in soil-filled gravel piles was used for vegetable gardening and tree cropping, as it is today (Fedick and Morrison, 2004).

Soil fertility in upland home gardens was maintained through application of periphyton, an algae-dominated bio-mat that grows in the wetlands (Morrison and Cózatl-Manzano, 2003). Experiments demonstrate that periphyton is a potent bio-fertilizer and indicate that exploitation of periphyton was carefully managed since its removal would have drastic consequences on the supply of bio-fertilizer and the stability of the wetland ecosystem (Morrison and Cózatl-Manzano, 2003). The use of periphyton as fertilizer represents management of a wetland resource to improve upland cultivation systems. Mapping of the wetlands reveals a widespread system of constructed rock-alignment features that likely served to control water and soil movement in some form of cultivation system, and may also have served in part to manage the growth of periphyton.

Owing to the abundance of easily accessible water resources, there is scant evidence of water management institutions above the household level. It is interesting to note that this region—while having quite high occupation levels during the Late Preclassic and beginning of the Early Classic periods (*c.*100 BC–AD 350)—did not develop any strong centralized authority, as indicated in other regions by massive public architecture and other monuments. The Yalahau region may represent the opposite end of the scale for the argument that water management was an important factor in the development of centralized authority (for a summary of this discussion see Scarborough, 2003).

The Puuc-Nohkakab Subregion

The Puuc-Nohkakab subregion is a wedge-shaped zone of very gently folded, bedded limestone covering some 1,300 km^2 in the north-west of the Yucatán Peninsula. The soilscape is diverse, but deep, well-drained, and permeable soils among the most productive in the Maya lowlands dominate, warranting the denomination Nohkakab, or 'the place of good earth' (Dunning 1992, 2008). The region receives about 1,150 mm of annual rainfall, but the marked dry season and lack of accessible groundwater make year-round water security a serious issue (Isendahl, 2011). Large-scale agro-urban settlement began relatively late in the Puuc-Nohkakab subregion, towards the Late Classic period (AD 600–800), when numerous cities were established and regional population densities multiplied fast to make the Puuc-Nohkakab subregion among the most densely populated in the lowlands during the Terminal Classic (AD 800–1000). Classic Puuc culture flourished relatively briefly, however, and by about AD 925–1100 major monumental building construction ceased and the population curve reversed, eventually resulting in near abandonment. This process probably involved the inability of the political leadership to adjust the economy to diminishing returns after all prime farmlands had been put under the digging stick, thus prompting an organizational crisis (Isendahl et al., 2014).

To deal with seasonal scarcity and build water security, the pre-Columbian Puuc-Nohkakab Maya developed a water management system that included two main hydro-technological devices designed to capture and store rainwater: large, open, still-water reservoirs (*aguadas*) and small underground water cisterns (*chultuns*). Cisterns formed the main supplier for domestic water consumption and were managed at the household level. These cisterns were constructed by puncturing the subsoil calcite cap-rock layer to shape a channel leading to a storage chamber excavated in the underlying soft dolomite marl. The surface around the channel opening was kept clean from rubbish and vegetation to facilitate capture of rainwater, and the walls of the underground chamber were plastered to prevent seepage (Zapata Peraza, 1989). These chambers varied significantly in size and could store from 5,000 litres up to 100,000 litres of rainwater (McAnany, 1990: 268). Most Puuc-Nohkakab Maya household-based urban farmsteads are associated with one or several underground water cisterns that could secure domestic water for drinking, food processing, cleaning, and pot irrigation of home gardens if fed by sufficient rainfall.

Water reservoirs with the potential to store much greater volumes than the average cistern are widespread in the subregion, occurring at most regional cities. Reservoirs were likely managed at a higher level than the household in the socio-administrative organization of Puuc-Nohkakab cities, at the urban neighbourhood, city, or polity leadership level, depending on their location in the agro-urban landscape, the amount of construction labour invested, and their storage capacities. Reservoirs were constructed by excavating relatively shallow natural depressions to enhance storage capacities. At Xuch, for instance, up to 10,000 m^3 of soil was moved—probably from the depression floor—to construct a berm around a reservoir that held close to 100,000 m^3 of water; i.e. 100,000,000 litres, or one thousand times the capacity of the largest household-level cistern (Isendahl, 2011).

Puuc-Nohkakab reservoirs played an important economic role in water security, probably in the pot irrigation of nearby fields and to refill household water cisterns (Dunning et al., 2014b), but also functioned in political activities as a place for large-scale public politico-religious ceremonies and in the cosmological understanding of landscape and place (Isendahl, 2011). Investing in reservoirs had significant economic implications with start-up and maintenance costs (Isendahl et al., 2014). While these investments clearly increased water security for a time, long-term vulnerability likely occurred. Once depopulation began, labour availability dropped and water management systems deteriorated; reoccupation would have required a sizeable investment to refurbish these systems (Dunning et al., 2012). Large-scale investments in infrastructure are long-term, high-risk ventures in generating dependence on continued future investments, with such costs explaining low reoccupation rates of the Puuc-Nohkakab subregion following the economic and organizational crises of the Terminal Classic; the latter likely worsening owing to recurring droughts (Medina Elizade et al., 2010). Paradoxically, the water security reservoirs initially helped to build, thus probably acting as settlement attractors, generated high social and political dependencies and economic vulnerability (Isendahl et al., 2014).

The Petén Karst Plateau Subregion: Tikal

Both Tikal and Calakmul are located in the elevated interior of the southern lowlands (Dunning et al., 2012). This area of complex, uplifted karst terrain is essentially devoid of perennial surface water sources and accessible groundwater, similar to the situation in Puuc-Nohkakab. To concentrate population year-round in urban centres the

Maya by necessity developed systems to capture and store rainwater (annual precipitation rates averaging around 1,500–2,000 mm).

At Tikal, this system took the form of prepared catchment areas and elevated reservoirs set within the city centre and the extensive zone of urban sprawl; a water system found both unique and conventional depending on local or worldwide assessments, respectively (Scarborough, 2003; Scarborough and Burnside, 2010; Scarborough and Lucero, 2011). At the highest elevation was a series of large reservoirs in the city's civic-ceremonial centre created by damming the uppermost reaches of seasonal streams that drained the ridge upon which central Tikal was constructed. Eventually these dams were elevated and widened both to retain more water and to create broad causeways connecting prominent architectural groups and plazas. Much of the rain that fell on the plastered buildings and plazas in the city centre was directed into these central reservoirs (Scarborough et al., 2012; Scarborough and Gallopin, 1991).

Another set of reservoirs were positioned along the lower flanks of the central ridge where natural slope breaks facilitated water capture. These reservoirs were located well within the residential zone of Tikal, but also adjacent to, or just upstream from 'pocket *bajos*' (relatively flat areas of deeper and potentially highly productive soil within the otherwise rugged karst upland). Although in topographically similar positions, these reservoirs may have served varied purposes. For example, the Perdido Reservoir was created to protect the downstream pocket *bajo* (and presumed agricultural fields) from flooding and, perhaps, to supply irrigation water when conditions permitted. In contrast, the Corriental Reservoir apparently included a sand filtration system to create a more potable water source (Scarborough et al., 2012; Tankersley et al., 2011).

Further afield, the residential area of Tikal sprawled out to include progressively lower-lying terrain (Puleston, 1983). Dotting this agro-urban sprawl landscape are numerous reservoirs, most typically either along the margins of *bajos* or within the floodplain of the Rio Holmul and its tributaries (Fialko, 2005), some of which may have been used to provide water for nearby terraced fields. While the chronology of the water management system is only partly understood, part of the central reservoir complex was constructed early in the Late Preclassic period (500 BC–AD 100) to impound water from a small natural spring—a feature that may have factored in the establishment of settlement at Tikal (Scarborough et al., 2012). Other parts of the system have initial construction dates in the Early Classic (AD 200–600) and seemingly all components of the water management system continued to be modified through the Late Classic period as urban population levels reached their zenith.

The transition from the Late Preclassic to the Early Classic period was a time of great change in the Maya lowlands (Grube, 1995), including wide-scale city abandonment in this subregion—a phenomenon that may be linked to increasing drought frequency and severity and the great vulnerability of that region to such a perturbation (Hansen et al., 2002; Wahl et al., 2007; Dunning et al., 2014a). In other parts of the Maya lowlands, abandonment was much more sporadic or did not occur at all. A few kilometres north-east of Tikal, in the Three Rivers Horst and Graben physiographic subregion, the neighbouring centres of San Bartolo and Xultun experienced very different fates: San Bartolo was rapidly abandoned whereas Xultun grew and prospered in the Early Classic and later. Notably, Xultun possessed at least six sizeable urban reservoirs whereas San Bartolo had only one, a pattern that suggests that the leaders or populace of Xultun may have more effectively adapted to changing climate than those at San Bartolo (Akpinar-Ferrand et al., 2012). It is plausible that the reservoir system at Tikal may have been constructed or expanded in part as an adaptation to increasing regional aridity in the last century of the Late Preclassic (Dunning et al., 2014a). By the Late Classic, many urban centres in the elevated interior areas of the southern lowlands had built structured water management systems featuring paved catchment surfaces and topographically strategic reservoirs (Scarborough, 1993; Dunning et al., 1999). At the urban fringe and hinterland beyond, smaller communities created more modest versions of these reservoirs, and individual households created tanks for residential use (Akpinar-Ferrand et al., 2012; Weiss-Krejci and Sabbas, 2002).

The Petén Karst Plateau Subregion: Calakmul

Calakmul is located on a promontory overlooking a large *bajo* (Folan et al., 2001). However, domesticated plant growth in the *bajo* was hampered by high gypsum salt content in the sediments (Gunn et al., 2009) possibly due to the subsurface limestone strata having been veneered with ejecta material from the Chicxulub impact (Perry et al., 2010). The presence of soil gypsum salts meant that spring water was probably not useful for sustenance and that uncontaminated water had to be captured during the rainy season and protected from infiltration (annual precipitation averaging 1,300 mm). A complex system of reservoirs and canals was constructed on the catchment slope to the south-east and on the Calakmul promontory to capture, distribute, and store rainwater (Domínguez Carrasco, 1991; Geovannini Acuña, 2008). Each of these reservoirs was probably managed by populations from surrounding residential neighbourhoods (Gunn et al., 2002).

To protect stored rainwater from salt infiltration and secure high water quality, reservoirs were sealed with masonry. This is evident in the largest reservoir at Calakmul—the largest man-made water reservoir in the Maya lowlands—and in other reservoirs and canals (Domínguez Carrasco, 1991). Analysis of structures and canals indicate that platforms with altars and corbelled arches were located along the canals (Fletcher and Gann, 1994), suggesting to some a priestly cast of water controllers as observed in other parts of the world (Scarborough and Burnside, 2010).

A first crucial need prior to the large-scale settling of the Calakmul zone was to make the *bajo* arable. Although it is possible that accumulation of culluvium was an unintended consequence of deforestation, early settlers in the Late Preclassic may have deforested the slopes of the *bajo* so that sediments could wash into the *bajo* margins, providing a kilometre-wide band of arable land along its edge (Gunn et al., 2002). The upper reaches of the *bajo* were more naturally desalinized than lower in the system. Around the base of the city, reservoirs were built to catch water at the bottom of each natural, intermittent stream (*arroyo*) (Folan et al., 2001). The water in these lower reservoirs was likely used for irrigation (possibly by pot irrigation) to intensify agriculture by facilitating multi-seasonal crops. However, the irrigation system might have been more complex: recent evidence suggests an arrangement of gridded field systems and canals (Geovannini Acuña, 2008), which may also have been used to transport food produced along the *bajo* edge to the central precincts of the city of Calakmul.

It has long been assumed that agriculture at Calakmul was based primarily on long-fallow swidden agriculture (*milpa* agriculture), possibly supplemented by minor intensive cultivation systems (Folan et al., 2008; Gunn et al., 1995). However, accumulating evidence points to at least three modes of agrosystems: house gardens (*solares*), infields (walled fields known as *alberradas* and/or terraces), and *milpa* outfields (probably confined to within 6 km of residences). Current estimates suggest that the agrosystem at Calakmul had the potential to support only about one-fifth of the estimated population. Transport canals add another dimension to this field system, extending the reach of *milpa* and other kinds of agricultural production beyond what is efficient for conventional land-based transport of bulk food produce. In addition, recent reassessments of earlier field mapping indicate a substantial area of walled fields on the southern end of the Calakmul promontory overlooking the *bajo*, rather than on the *bajo* margin. For these fields to be cultivable during the dry season, the well-drained areas would demand water management to extend cropping beyond the rainy season.

A model of the overall water management system is one in which sediments and yearly doses of nutrients from annual burning, incineration of bedrock in upland *milpas*, and human waste were cycled downward into the *bajo*-margin slopes to increase *bajo*-edge fertility. Nutrients were then cycled back into the city as food. Sediments were retained in the *bajo* edge through a system of canals, dams, and lakes used as sedimentation catchments, while salts were cycled out to the sea by release of salinized water (Gunn et al., 2012).

Overall, the water management systems at both Calakmul and Tikal were highly adapted to the general aspects of the elevated interior region of the Maya lowlands and the nuances of their place-specific topography and hydrology, thus allowing for the concentration of large urban populations. Nevertheless, the maintenance needs of these large hydraulic infrastructure systems ultimately limited their resiliency and made these urban systems susceptible to environmental and political perturbations, similar to that in the Puuc-Nohkakab subregion (Dunning et al., 2012).

The Belize River Valley Subregion: X-Ual-Canil

X-Ual-Canil is situated on a high hill above Monkey Falls on the east side of the Macal River in the upper Belize River Valley. The area receives on average 1,650 mm of rain annually (Wyatt, 2008: 67). X-Ual-Canil fits within the 'middle level' of the pre-Columbian Maya settlement continuum (Iannone, 2004), which consists of a range of small settlements exhibiting considerable diversity in terms of their developmental sequences, degree of architectural elaboration, artefactual inventories, and symbolic content (Iannone, 2003). At X-Ual-Canil, archaeological investigations indicate that a number of small household-based farmsteads were established during the Terminal

Preclassic (AD 100–250) at the base of the hill, adjacent to prime agricultural lands adjoining the Macal River, but that the hilltop centre was not constructed until the Late Classic (AD 675–810). These early farmsteads experienced moderate prosperity over time as indicated by increasing size and complexity. This social landscape persisted until the first major constructions were undertaken on the hilltop centre building complex.

Much of the X-Ual-Canil centre appears to have been built in one major construction event some time during the early eighth century, with few subsequent modifications. Elite administrative-type buildings dominate the western and northern sides of the main public plaza. Conspicuous by their absence are indications that anyone, regardless of rank or status, was actively laying ancestral claim to the hilltop itself, given that there is no eastern ancestor shrine in the public plaza and no evidence that ancestor veneration rituals were carried out anywhere in the X-Ual-Canil centre. The centre's principal residential courtyard is also puzzling in that it contains only one possible sub-elite residential building. Although the courtyard has a formal entrance, it is only moderately restricted with respect to visual and physical access. Moreover, two of the largest buildings in the courtyard were completely devoid of internal features, and they are posited to have served as spaces to store large amounts of agricultural surplus. Other features at the summit and below Monkey Falls hill help us understand the unique characteristics of X-Ual-Canil.

The X-Ual-Canil centre is immediately surrounded by a number of currently dry reservoirs that appear strategically positioned at the head of a series of natural gullies designed to collect run-off and channel it down to the base of the hill. Pot irrigation of adjacent agricultural fields (some terraced) was likely accommodated by agrarian households since the Terminal Preclassic. A number of other water control features, such as possible collection pools and strategically placed check dams made of large boulders are also associated with the irrigation system. Given evidence for early occupation adjacent to the agricultural fields, it is plausible that X-Ual-Canil was established as a special settlement node aimed at incorporating an extant farming population into a broader micro-regional alliance centred at a major centre nearby, possibly Cahal Pech or Pacbitun. The principal goal of this integration would have been to generate and store agricultural surplus. This incorporation was partially achieved through administrative means, but there was also a degree of ritual and ideological integration as evidenced by two principal ritual features at the site. Both associated with the 'headwaters' of two of the principal drainage channels, they include a causeway termini shrine/stela/altar complex (its peripheral location and lack of offerings implying that it was not associated with the veneration of specific community ancestors) and a ball court. It seems plausible that fertility rituals where carried out in association with these features to promote assimilation of the existing farming population.

In summary, X-Ual-Canil corresponds closely to Scarborough's (1998) concept of the Late Classic 'water mountain'. By constructing hydro-technological features, the hilltop itself became a specialized economic and ritual node on the landscape that was specifically intended to collect and redistribute water to increase agricultural productivity. When the system was maintained—which apparently was not for very long, likely less than a century during the eighth century—it transported a significant volume of water to the agricultural sectors at the base of the Monkey Falls hill. The water management network did, however, also lead to a certain level of path dependency and possibly diminishing returns over time due to the administrative costs of maintaining such a facility, especially during periods of decreasing precipitation in the eighth and ninth centuries, which might explain why the channels that once watered X-Ual-Canil's field system are no longer maintained, but meander through over-grazed, often desiccated cattle pastures.

The Belize River Valley Subregion: Saturday Creek

The Saturday Creek case forms a contrast to those of the elevated interior where people relied on water management systems focused on reservoirs and their concomitant socio-political infrastructure. Saturday Creek is a minor settlement located on rich alluvium at 20 m above mean sea level along the north side of the Belize River. From at least 900 BC through to AD 1500 the Maya lived in farmsteads (100–151 structures/km^2) consisting of solitary mounds and mound groups (*plazuelas*) of two to four buildings dispersed around a site core, which includes a ball court, temples, and elite compounds (Lucero, 2006). The presence of exotics (i.e. materials and manufactured artefacts that had been transported considerable distances, for instance central Mexican obsidian, polished hematite items, jade, and marine shell) in commoner farmsteads and elite compounds indicates that the local population of farmers, part-time specialists (e.g. potters), and elite landowners were successful in generating some degree of affluence.

This section of the Belize River Valley receives higher annual rainfall (2,160 mm) than most regional capitals, and benefited from annual run-off from the elevated interior, supplying enough water to last throughout the dry season and depositing clayey soils on the lower floodplain terraces that remain saturated for most of the year. The rich alluvial soils are excellently suited for a series of important crops such as maize, beans, squash, cacao, and cotton (Lucero et al., 2004). Farmers did not need to invest in hydro-technological innovations to store rainwater or for irrigation because water was plentiful (indeed, irrigation systems could not be used since the river is located downslope via a series of natural terraces); nor did they need to construct agricultural terraces since they could rely on recessional floodplain agriculture and rainfall.

In contrast to Tikal and Calakmul, Saturday Creek lacked kings, tribute payments, royal palaces, hieroglyph inscriptions, and landesque capital such as reservoirs, canals, irrigation systems, and agricultural terracing. This might indicate an inability of aspiring leaders to gain control of water and extensive alluvium, preventing them from acquiring political power. As in the Yalahau subregion, with plentiful water resources farmers did not need to rely on political leaders to supply dry-season water like they did at the most powerful Maya cities via reservoirs (such as at Tikal, for instance).

The impact of the multi-year droughts that took place between AD 800 and 900 (Medina Elizade et al., 2010) differed at Saturday Creek when compared to the major powerhouses. On a day-to-day basis, things did not seem to change much for Saturday Creek's inhabitants; they did not face failing landesque investments like many of their peers elsewhere (Lucero et al., 2011). Living along a well-fed river with rich alluvium allowed them to weather several droughts and continue living as they had done for over two millennia. Not surprisingly, they had less access to long-distance exchange items due to disruptions in the trade system, but they soon obtained exotics from sea trade to the north and east. In the end, political collapse occurring in the elevated interior of the southern lowlands had a relatively weak impact on a community who were little involved in a royal interaction sphere. In brief, Saturday Creek was a stable, sustainable, and long-lasting community, as were many comparable small-scale settlements in similar environments, such as Barton Ramie (Lucero, 2002), especially given that people continued to live and farm long after the regional cities were abandoned. Occupation did, however, gradually diminish, and Saturday Creek was abandoned about AD 1500 for reasons that are still unclear (Lucero, 2006).

Implications for Water Security

We suggest that these cases of pre-Columbian Maya water management systems offer several insights relevant for current water security concerns. These include the following.

Water Management Systems are Characterized by a Diversity of Solutions

The water management systems presented demonstrate significant spatial variation across the Maya lowlands; a reflection that building water security is based on solutions that address locally specific conditions. This basic observation implies that no 'blanket' solution to water security issues—institutional, hydro-technological, or otherwise—can accommodate the multitude of challenges and opportunities that sustainable water management systems will need to address at different locations. Instead, to build water security at the regional and global scales, water resource management systems need to maintain a series of spatially diverse options that are responsive not only to local needs but also to the dynamics and variability of climatic and hydrological conditions played out in each landscape.

Water Scarcity Promotes Increased Management Investments that Result in Long-Term Vulnerability

Water scarcity in the Puuc-Nohkakab and Petén Karst Plateau subregions motivated investments in water reservoirs. Constructing, maintaining, and controlling such facilities seem to have formed an important power-base for the political elites of these societies. It should be noted that the correlation between central control of irrigation and the development of elites is demonstrably not true in all cases and our observation is not a support of a nomothetic Wittfogelian conclusion (see e.g. Scarborough, 2003). Although centralized control of reservoirs safeguarded water availability and sustenance, constant maintenance costs increased the vulnerability of the water management system to economic perturbations and proved ultimately unsustainable. Given the inflating costs associated with building global water security in a post-peak-water scenario, the failure of the Maya to maintain reservoir systems over the long term offers a cautionary tale against increasing dependence on significant economic overhead generation as the main avenue for realizing sustainable global water security.

Water Abundance Does Not Require Complex Management Systems but Increases the Risk for Mismanagement

The data sets from the water-rich areas of the Yalahau and Belize River Valley subregions demonstrate less complex forms of social organization, further indicating that limited water control efforts may influence social and political power-base relationships. With abundant water supplies readily available to all, populations in these areas were not as dependent on costly large-scale hydro-technologies investments for water security, and their water management systems demonstrate a high degree of sustainability and resilience to economic and political crises as well as climatic stress events, as shown in the Saturday Creek case. Nevertheless, the risk we see with a history of plentiful access to water is the 'deception of abundance', i.e. the perception that abundance is normal and can continue uninterrupted and indefinitely. When supplies are perceived as infinite, the resource is often mismanaged and it can have devastating effects on longer-term resource availability—particularly when combined with maximizing business strategies. This phenomenon is not only evident in the Yalahau region today, where groundwater waste and contamination is a growing concern due to the booming tourist resorts on the Caribbean peninsular coast, but also glaringly obvious elsewhere in the modern environmental record of Europe, the United States, and China.

Institutional and Technological Diversity Provide Flexibility and Greater Security

In evaluating insights for water security from the pre-Columbian Maya, we need to take a two-pronged approach: (1) the role of water management in political systems; and (2) the efficacy of water management systems to provide water security at the individual, household, and lower-community levels. For instance, in the Puuc-Nohkakab region the water management system included two major hydro-technological innovations. As we have seen, the centralized component of large-scale water reservoirs contributed to urban water security, but depended on high investment costs that proved unsustainable to maintain. Residential water cisterns, however, depended solely on the labour of the household to construct and maintain. The residential Maya farmstead with associated gardens and an autonomous water management component formed a functional unit and a capacity—flexibility—to reorganize into less complex forms of settlements and buffer themselves from significant aspects of political turmoil. One important insight for sustainability is that a water management system that maintains institutional flexibility and a series of diverse hydro-technological options—rather than relying on singular solutions—will better build water security resilience against shocks, such as economic perturbations or climate change.

In this chapter we have barely scratched the surface of pre-Columbian Maya water management system diversity or how the Maya addressed their particular landscape opportunities and challenges. The efficacy of their decisions as elucidated by the archaeological record points to the multitude of insights that ancient history and environmental studies can offer to build secure water management systems in a global post-peak-water scenario. For this applied discourse of archaeology to be a meaningful endeavour and effectively disseminate research results in a pertinent manner, it will require that archaeologists participate as invited players in water resource planning. The challenges to future water management systems are daunting for hydrological engineers, planners, and policy-makers; to neglect the relevance of deep-time perspectives and broad frames of analytical reference for water security issues will surely be a mistake. This chapter is an attempt to redirect the dialogue.

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Applied Perspectives on Pre-Columbian Maya Water Management Systems: What are the Insights for Water Security?, Christian Isendahl, Vernon L. Scarborough, Joel D. Gunn, Nicholas P. Dunning, Scott L. Fedick, Gyles Iannone, and Lisa J. Lucero 27. Beyond Rhetoric: Towards a Framework for an Applied Historical Ecology of Urban Planning, Paul Sinclair, Christian Isendahl, and Stephan Barthel 28. Culture, Power, History: Implications for Understanding Global Environmental Change, E. Christian Wells 29. Energy Gain and the Evolution of Organization, Joseph A. Tainter and T. F. H. Allen 30. Conclusion: Anthropocentric Historical Ecology, Applied Archaeology, and the Future of a Useable Past, Christian Isendahl and Daryl Stump. Explore Perspectives. What is a perspective? Perspectives are different frameworks from which to explore the knowledge around sustainable sanitation and water management. Perspectives are like filters: they compile and structure the information that relate to a given focus theme, region or context.Â Stored urine is a concentrated source of nutrients that can be applied as a liquid fertilizer in agriculture and replace all or some commercialâ€¦ View Factsheet.Â The Water and Nutrient Cycle Perspective recognizes that sectoral approaches are not going to solve the global water and sanitation crisis. Instead, holistic approaches that consider the entire water cycle from source to sea, and that look critically analyse the human influence thereupon are required. Smart water management systems can provide a more resilient and efficient water supply system, reducing costs and improving sustainability. High-technology solutions for the water sector include digital meters and sensors, supervisory control and data acquisition (SCADA) systems, and geographic information systems (GIS). This explainer is adapted from proceedings of a workshop conducted by the Asian Development Bank (ADB) in Tashkent, Uzbekistan for the water sector. The workshop introduced smart systems and focused on remote monitoring of water networks using smart meters and other instruments. Why Smart Technology? Smart technology can change conventional water and wastewater systems into instrumented, interconnected, and intelligent systems. Sharing Multiple Perspectives on Burning: Towards a Participatory and Intercultural Fire Management Policy in Venezuela, Brazil, and Guyana. Previous Article in Journal. Weâ€™re Not Doing Enough Prescribed Fire in the Western United States to Mitigate Wildfire Risk.Â Pre-Columbian Fire Management Linked to Refractory Black Carbon Emissions in the Amazon. by. Monica M. Arienzo.Â Previous research indicates that pre-Columbian fire management practices were the dominant driver of fire activity during the late Holocene (after ~3500 cal yr BP) at Lake CaranÃ£ [41 , 42].