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Infrastructures of moving water at the Maya site of Ucanal, Petén, Guatemala

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A B S T R A C T

It is increasingly common to conceptualize infrastructure not just as a built feature in the landscape, but as a shifting and entangled system that includes humans, different institutions and social groups, spiritual forces, and ecologies. These different aspects of infrastructure, however, are best identified at different temporal scales of analysis. Recent research at the Maya site of Ucanal in Petén, Guatemala, documents centrally managed water management features, such as canals and inverted causeways, that drain water away from the urban site core and into a nearby river, the Río Mopan. Their construction and use during the Terminal Classic period (ca. AD 830–1000), a period often associated with increasing aridity and drought, highlight the need to consider shorter temporal spans in which droughts were interspersed with hurricanes and periods of high precipitation. Furthermore, the consideration of even smaller temporal frames, on the order of annual dry-wet season cycles and daily practices, highlight the often overlooked aspects of ancient Maya water infrastructure systems: the labor necessary to maintain and repair canals and roads, deities or supernatural forces responsible for life-giving and life-taking rains, and the labor of common peoples who hauled water on a daily basis.

1. Introduction

It is increasingly common to conceptualize infrastructure as not just a physical component of the built landscape, but as a constantly shifting entanglement of people, institutions, goods, and built constructions that enable the flow of people, water, waste, energy, and resources (Ertsen, 2016; Larkin, 2013; Morrison, 2015; Smith, 2016). In other words, if we look at the different connecting components of infrastructure, we are in a better position to understand how infrastructure projects work, how they are experienced, what they mean to different people, and how they fail. We find, however, that these different components of infrastructure are often implicated at different temporal scales and thus, a multi-temporal approach provides a more holistic examination of an archaeology of infrastructure (see also Ertsen, 2016).

We examine, in particular, water infrastructure at the Classic period Maya site of Ucanal in Petén, Guatemala. Most research on Maya water infrastructure systems highlight water capture and storage for agriculture and potable water provisioning (Lucero, 1999; Scarborough, 1993, 2003, 2006; Seefeld, 2018; Wyatt, 2014). These systems are often explored in relation to the long-term rise and fall of Maya centers whose prosperity and longevity was undoubtedly tied to their accessibility and provisioning of water. Our recent research at the site of Ucanal documents many water infrastructure features rarely considered as part of Classic Maya water infrastructure systems, such as flood-control canals, inverted causeways, ballcourts, and portable water systems involving water storage jars. We find that substantial investments were made to get rid of water. Such efforts are seemingly incongruent with grand narratives of drought at the very end of the Classic period when the site was extensively occupied. Nonetheless, they accord with paleoclimate data recorded at smaller temporal scales. Furthermore, we find that the consideration of different temporal dynamics of water infrastructure – from annual dry-wet season cycles to daily water needs – highlight the often overlooked components of Maya water infrastructure systems, such as the people who maintained and repaired water canals and inverted causeways and who hauled water to households and activity areas on a daily basis.

2. Infrastructure and its approaches

Traditionally and in most quotidian forms of usage, the term infrastructure denotes the basic physical and organizational structures and facilities (such as buildings, roads, power supplies) that facilitate the operation of a society (Oxford Living Dictionary, Collins English Dictionary). In stark contrast to an emphasis on the built landscape as infrastructure, archaeologist Normal Yoffee (2016:1055), drawing inspiration from Michael Mann's infrastructural power, puts his focus on people. He refers to infrastructures as the "groups of people and their leaders who stand apart from or are not a part of the institutions of the state" to underscore the heterarchical power relations of smaller-scale social groups in the constitution of ancient urban societies.

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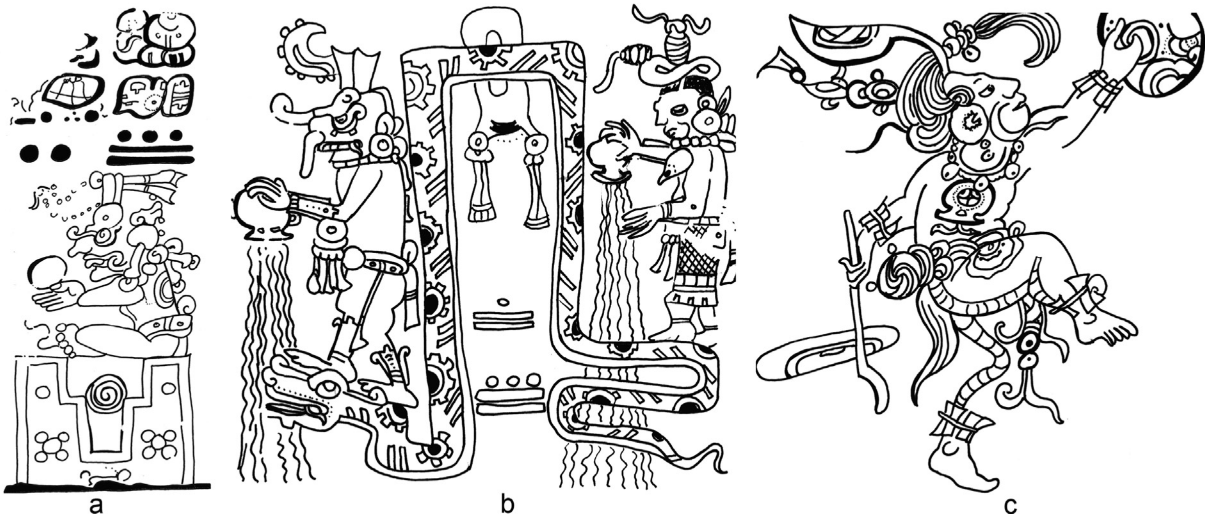

Fig. 1. Depictions of supernatural figures responsible for storms and rainwater: (a) Postclassic Maya Chaak depicted within a ballcourt (drawing by C. Halperin after Dresden Codex; Förstemann p.41); (b) Postclassic Chaak and Chaak Chel pouring water from water jars as a symbolic releasing of the rains (drawing by C. Halperin after Madrid Codex; Brasseur de Bourbourg and Leon de Rosny; Plate 27); (c) Classic period Chaak with inverted water jar around his neck (drawing by C. Halperin of a section of vessel K0521 www.famsi.org).

Many social science notions of infrastructure, however, emphasize the intimate and dynamic relationship of the landscape and people, breaking down human-object, human-environmental divisions. For example, Marxist thinkers often characterize infrastructure, the economic base of society, as comprised of both the forces of production (the physical tools, machines, land and ecological conditions, built features [infrastructures in the colloquial sense of the term] + human labor) and the relations of production whereby the material infrastructures were not to be understood as separate from the people acting in the material world and from the power relations between them (Godelier, 1978; Marx and Engles, 1970). For example, while modern aboriginal housing in Australia may have all the physical components for a water infrastructure system in the form of housing, toilets, sinks, and pipes, an ineffective administrative system, endemic racism, and structural inequalities have helped create a situation in which many of the pipes outside the house do not connect to a water disposal system and thus do not actually constitute as infrastructure (Lea and Pholeros, 2010).

Coupled Infrastructure Systems (CIS) approaches from the fields of urban planning, social ecology, and anthropology also underscore a reciprocal material-human-environmental dynamic whereby infrastructure is considered an integrated system of (1) human (knowledge); (2) social (social relations); (3) natural (ecosystems), (4) soft infrastructures (policy), and (5) hard (built) infrastructure (Anderies, 2006; Anderies et al., 2016; Tellman, 2018). They seek to integrate different temporal scales, such as small incremental decisions that enact large-term trends or the way accumulated practices, in the form of path dependency, structure later events. These approaches tend to privilege the power and decision-making capacities of centralized political authorities and the institutions they direct more so than ordinary peoples. In contrast, scholars of ancient Maya water infrastructure systems have found that household- and community-based organization of water infrastructure for agricultural and water provisioning was just as important to the workings of water flow and accessibility as centralized institutions headed by political leaders (Davis-Salazar, 2003; Lucero, 2006:20; Scarborough, 2003; Scarborough et al., 2003; Wyatt, 2014).

Other approaches inspired by Actor-Network theory and Entanglement theories have also underscored the intertwined relationships between human and built components of infrastructure (Dawdy, 2016; Ertsen, 2016). In such perspectives, built infrastructures (walls, streets, buildings, etc.) are conceived as agents in their own right – as enabling and constraining action and as part of the enactment of an on-going dialectic or dynamic of change. In a similar vein, Monica Smith (2016:164) notes that "Although infrastructure is conceived and designed with particular goals and capacities, its temporal and spatial scale means that it is a constant work in progress that engages numerous agents: civic authorities design and implement infrastructure; designated agencies maintain and repair infrastructure; and ordinary people utilize, modify, ignore or destroy it." While such dynamics transpire over the long term, it is the day-to-day, in particular, in which ordinary people are conceived as agents in infrastructure dynamics.

For example, in Smith's (2016) study of the mid first millennium city of Sisupalgarh, India, the city's gateway and rampart was a constant work in progress that included not only the engineers and architects to build the stone walls, but also the storms that damaged it, rulers who underwrote repairs for it, common workers who participated in its day-to-day maintenance (and lack thereof), and ordinary inhabitants whose daily movements were conditioned by the wall and who, in some cases, resisted the wall by building their houses counter to the urban master plan (Smith, 2016:172–173). It is these shorter term and daily performances, maintenance, and ruinations that are so commonly overlooked in investigations of ancient infrastructures (cf. Dawdy, 2016; Wilkinson, 2019).

Likewise, although deities and supernatural entities are generally not considered part of water infrastructure systems by modern scholars, many ancient peoples likely considered these forces as very much integral, if not essential, to water infrastructure systems. These connections have long been recognized in the Maya area since iconographic, epigraphic, ethnohistoric, and ethnographic data are particularly rich and underscore that Maya peoples considered the earth, rain, lightning, clouds, and other elements of the natural and built environment to be alive with vital forces (Bassie-Sweet, 1996; Bassie-Sweet, 2008; Houston, 2014; Houston and Stuart, 1996).

For example, Classic period iconography is replete with images of Chaak, a storm and lightning deity who is often depicted with watery and wind symbolism. He wears spiny oyster shell ear ornaments, holds a stone axe as a metaphor for a lightning bolt, and sometimes wears an upside-down water jar around his neck, which is evocative of his role in the provisioning of rains. Such supernatural entities were multiple and varied (Fig. 1). For example, Chaak Chel, a Postclassic elderly female deity had rain dispensing capabilities, and even more informal *wahy* spirits or "co-essences" could take the form of hurricanes and whirlwinds (Dunning and Houston, 2011:62). As such, many Maya scholars have argued that spiritual entities and rituals related to the petitioning

Fig. 2. Map of the Maya area with selected sites mentioned in the text.

of rains – or the staving off of malevolent forces, such as hurricanes or cyclones – were just as much a part of the workings of water infrastructure systems as the building of reservoirs (Lucero, 2006; Lucero and Fash, 2006; Isendahl and Persson, 2011; Scarborough, 1998). Thus, in considering a more integrative perspective of water infrastructure, we examine not only (1) the large temporal scale of water management that implicates the rise and fall of different Maya cities, but also the smaller-scale dynamics that consider (2) flood-drought episodes and the role of infrastructures built to weather them, (3) annual wet-dry season cycles that implicate both state authorities and ordinary peoples and finally, (4) daily practices that shed light on the most forgotten actors in water management systems, such as women and children.

3. The grand narrative of Classic Maya infrastructure

One of the enduring grand narratives of Classic Maya society is that the Classic period (ca. AD 300–830) was a period of abundance and prosperity in the Southern Maya Lowlands (Fig. 2). Such abundance was achieved, in part, from lessons learned in earlier periods of climatic instability and environmental degradation at the end of the Late Preclassic period (ca. 300 BCE – AD 300). For many centers it was during the Late Preclassic period or at the beginning of the Classic period in which terraces, reservoirs, and other water management features were constructed (Chase, 2016; Chase and Chase, 2017; Dahlin and Chase, 2014; Harrison, 1993; Leyden et al., 1998; O'Mansky and Dunning, 2004; Pyburn, 2003; Scarborough, 2003; Scarborough et al., 2012; Wyatt, 2014). For example, at the site of Tikal, the major reservoirs in the urban site core were constructed during the Late Preclassic and Early Classic periods with some refurbishments to these systems in the Late and Terminal Classic periods. Their construction often corresponds with monumental building programs of plaza spaces, elite residences, and temple-pyramids that required the large-scale quarrying of limestone building materials and resulted in concave zones later used for water reservoirs (Scarborough, 1998, 2003:50–52; Scarborough et al., 2012). Such water management projects were also underway at smaller centers, such as at Chau Hiix, Belize, where Late Preclassic/Early Classic inhabitants constructed canals and dams to channel water from lagoons to nearby agricultural fields (Pyburn, 2003). Despite these investments, the Terminal Classic period (ca. AD 830–1000) is known to have been characterized by drought too severe to be overcome by Classic infrastructure projects. These changes are thought to have led to a decline of the great Classic Maya centers (Gill et al., 2007; Douglas et al., 2015; Kennett et al., 2012; Shaw, 2003; Webster et al., 2007).

Nonetheless, in examining more refined archaeological and paleoclimate chronologies and in considering regional variability throughout the Maya area, many scholars have argued that such grand narratives are too simplistic, and in some cases inaccurate (Aimers, 2007; Aimers and Hodell, 2011:20; Iannone, 2014). Some Maya regions, such as the Usumacinta and Petexbatun regions, do not appear to have suffered from droughts at the end of the Classic period (Dunning et al., 1997; O'Mansky, 2014; Scherer and Golden, 2014). The water infrastructure at some sites, such as Palenque and Copan, focused heavily on drainage and flood water control with elaborate aqueducts, dams, canals, and roads that were designed to get rid of water rather than to store it (Davis-Salazar, 2006; French, 2007, 2009). In addition, speleothem records, which provide more fine-tuned temporal periods (on the order of annual to multi-decadal intervals) than lake sediment cores, reveal that the end of the Classic period included not just episodes of drought, but also episodes of extremely wet conditions (Frappier et al., 2014; Medina-Elizalde and Rohling, 2012; Smyth et al., 2017; Webster et al., 2007). Our research at the site of Ucanal, in Petén, Guatemala, contributes to these more nuanced, regionally-specific perspectives to underscore the more varied nature of water infrastructure systems that include the problems of having too much water (Dunning and Houston, 2011; Smyth et al., 2017).

4. Ucanal

The site of Ucanal is located in the Southern Maya Lowlands near the eastern Petén border of Guatemala (Fig. 2). The site, at approximately 7.5 km^2 in size, sits just west of the Río Mopan, a river system which descends from the Maya Mountains and makes its way east through Belize (Fig. 3). Low density settlement and smaller satellite centers, however, continued in all directions, including east of the river. The site of Ucanal is situated within a small pocket of outer bajo (a permeant wetland), an environmental zone that contrasts with most of northern Petén, which is characterized as an inner bajo zone of closed depression seasonal swamps (Seefeld, 2018:29–37). In addition to the river, several small streams run through the northern part of the site. Today, the region of Ucanal possesses an average annual rainfall of 1569 mm and thus is similar to annual precipitation ranges at Tikal (1558 mm) and Copan (1528 mm). Such precipitation measures are relatively average in the Maya area, above sites in northern Yucatan, such as Chichen Itza (1104 mm), but below much wetter regions, such as Palenque (2394 mm) in Chiapas, Mexico, and Caracol (3530 mm) in the Maya Mountains in Belize (www.climate-data.org).

Excavations by the Proyecto Atlas Arqueológico de Guatemala, directed by Juan Pedro Laporte, and more recently by the Proyecto Arqueológico Ucanal, directed by Christina Halperin and Jose Luis Garrido, reveal that the site of Ucanal was occupied from the Middle Preclassic to Early Postclassic periods (ca. 600 BCE – CE 1200) (Corzo et al., 1998; Laporte and Mejía, 2002; Halperin and Garrido, 2016, 2017, 2019). Similar to many sites in the Southern Maya Lowlands, it experienced substantial urban growth during the Late Preclassic and Late Classic periods with large-scale building construction of the ceremonial plaza spaces and residential zones of the site.

During the Early and Late Classic periods (ca. AD 300–830), Ucanal kings held the royal title of *k'anwitznal 'ajaw,* marking the site as the seat of the *k'anwitznal* kingdom. Although Early Classic occupation is more ephemeral and noticeable primarily in monumental architectural constructions of the site core, such as a finely stuccoed building with talud façade in Group J, it is clear that the site experienced a boom in population and urban construction during the Late Classic period. Of the 31 total groups excavated by both the Proyecto Atlas Arqueológico de Guatemala and the Proyecto Arqueológico Ucanal projects to date, 84% exhibit Late Classic construction. For much of the Classic period, Ucanal was subordinate to other larger polities, such as Tikal (during the Early Classic period), Naranjo from AD 698–744, and Caracol in AD 800 (Carter, 2016:244; Houston, 1983; Martin and Grube, 2000:34; Reents-Budet, 1994:300–305).

Unlike many Southern Lowland sites, however, population remained stable throughout the Terminal Classic period (ca. AD 830–1000) (Corzo et al., 1998; Halperin and Garrido, 2016, 2017; Laporte and Mejía, 2002). Terminal Classic residential groups were not constructed in new zones of the city. Rather, they largely overlaid previous Late Classic building episodes, indicating that there was

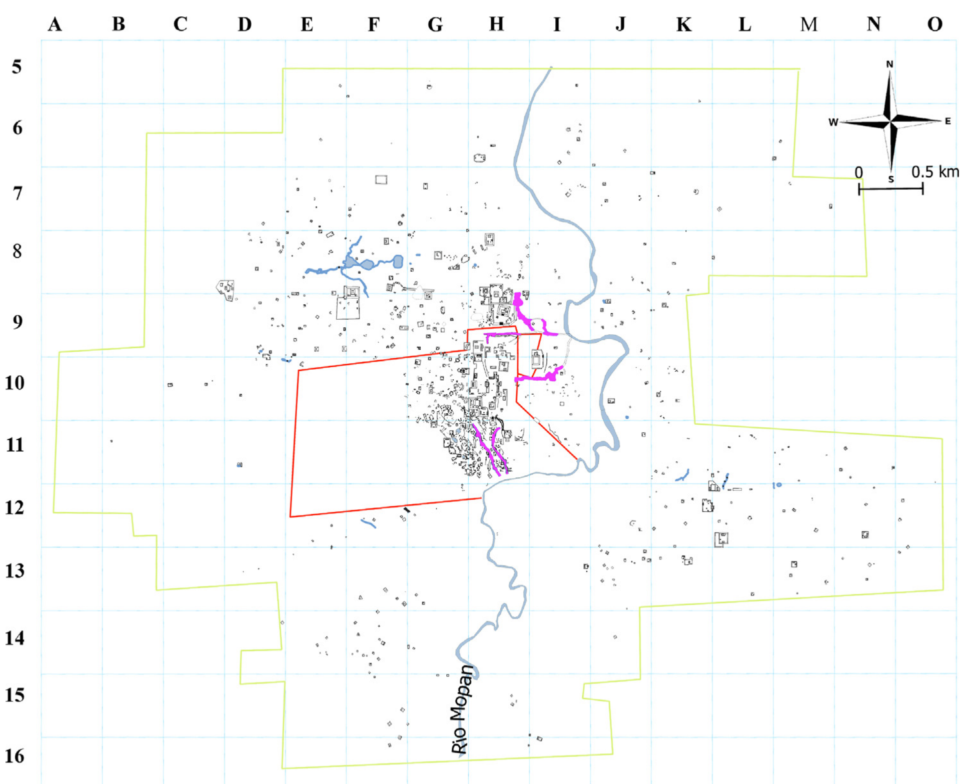

Fig. 3. Map of the site of Ucanal with natural waterways (blue) and built canals (in purple). Red lines are the limits of the national park protecting the site; yellow lines outline survey region mapped to date (note: survey in the western side of the national park is not currently complete). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

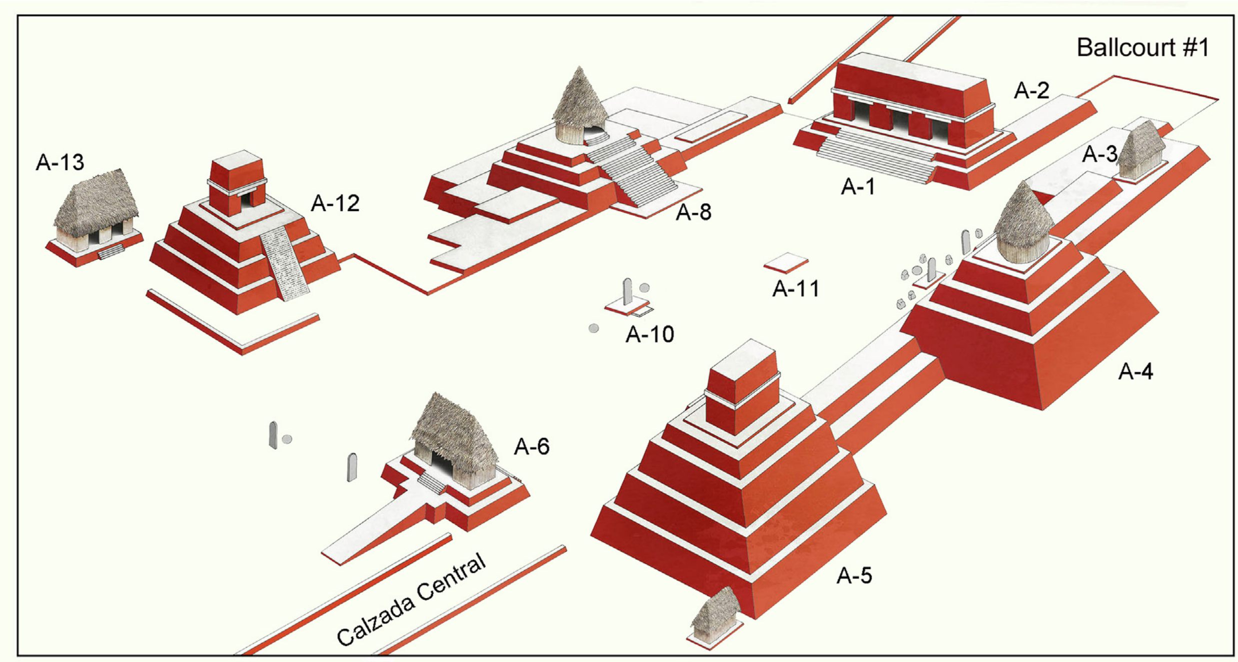

Fig. 4. Reconstruction of Plaza A, Ucanal (Sector H-10) (A labels refer to structure numbers; reconstruction drawing by Luis F. Luin based on topographic data by the Proyecto Arqueológico Ucanal).

significant continuity of occupation. At least 81% of the excavated architectural groups exhibit Terminal Classic period construction, and 97% were occupied during the Terminal Classic period. In addition, several new ceremonial buildings were built in previously unoccupied plaza spaces, such as the Group A ballcourt (Ballcourt #1), Temple-pyramid A-5, Temple-pyramid A-12, and Structure A-6 (Fig. 4). The *k'anwitznal* polity also became politically independent at this time. While many large political capitals, such as Tikal, Naranjo, Piedras Negras, and Dos Pilas, were in the midst of political crises and diminishing populations, Ucanal did not become an isolated or balkanized polity during this time. Rather, it was engaged in political alliances and economic exchanges with other flourishing Terminal Classic centers in both the Southern and Northern Maya Lowlands. Such prosperity, however, did not continue into the Postclassic period, as only 29% of excavated groups exhibit Early Postclassic occupation (ca. CE 1000–1200), and very little evidence of building construction is noted during this time.

The site is dotted with a number of water reservoirs or *aguadas*. The two largest reservoirs, Aguada #1 and Aguada #2, are located in the southern upland zone of the site where large, elite residential architecture is concentrated (Fig. 5). Elite and ceremonial zones of the city are located primarily on the highest elevations at between 215 and 230 m ASL, and smaller medium-sized and small-sized residences are located on all elevation zones but more commonly found at lower elevations (between 180 and 214 m ASL). Aguada #1 and Aguada #2, with the capacity to hold 1,276,000L and 2,629,000L of water respectively, were lined with large limestone blocks and contained a number of modified canalization routes and ramps that allowed rainwater run-off from plaza and residential spaces to feed into the reservoirs. Although they do not hold water today, the rippled water marks on the limestone blocks indicate that they were in use for a long period of time. It is likely that they were constructed during the Late Preclassic period when limestone was quarried for the large elite platforms nearby similar to other monumental construction projects elsewhere in Petén (Scarborough, 1991; Scarborough et al., 2012). Smaller *aguadas* have also been identified in the lower elevation zones. Unlike the large *aguadas* at the highest elevations, these smaller *aguadas* would have suffered poorer water quality since human excrement and waste water from high elevation residences would filter downward. Although none of the these *aguadas* have been excavated to date, the Proyecto Arqueológico Ucanal has excavated several other water infrastructure features of the site, such as water canals, ceremonial causeways, and residential zones.

5. Flood water canals and their implications for Terminal Classic droughts

Five monumental, human-modified canals have been identified at the site to date. All canals collect water from upland monumental zones of the city (where stuccoed plazas and building surfaces would have created the maximum rain-water run-off) and discharge water to the Río Mopan. As such, these canals were designed to prevent urban flooding and contrast with canals identified elsewhere in the Maya area that directed water into agricultural fields or reservoirs (Figs. 6 and 7, Table 1). Their location at the heart of the city and their large size suggest that their construction was organized or sponsored by centralized political authorities.

Considerable effort was made to slow the velocity of water drainage and prevent erosion. For example, all five canals contained turns and Z angle constructions that forced water to flow opposite in the direction of the vertical slope (Le Moine et al., 2017). In addition, check dams were built throughout the canal systems, helping slow down the flow of water. In Canals #1, #2, and #5, successive dams, comprising of simple limestone retaining walls running counter to the flow of water, created small reservoirs that could have been used as water collection points during the rainy season. All canals possessed stone wall or terrace walls along their edges, although it is unclear if such walls were continuous throughout the entire length of each canal since wall collapse and topsoil accumulation make visibility difficult from the ground surface. In some cases, multiple stone wall terraces were noted, such as in Canal #3, where canals were particularly deep (between 1 and 3 m in height).

Excavations of Canals #1, #2, and #3 further reveal that their construction anticipated sudden, heavy rains such as hurricanes or cyclones, in addition to lighter rainfall (Pérez Zambrano, 2017). The outside terrace walls along the sides of the canals were wide and high enough to account for heavy water flooding and also helped collect

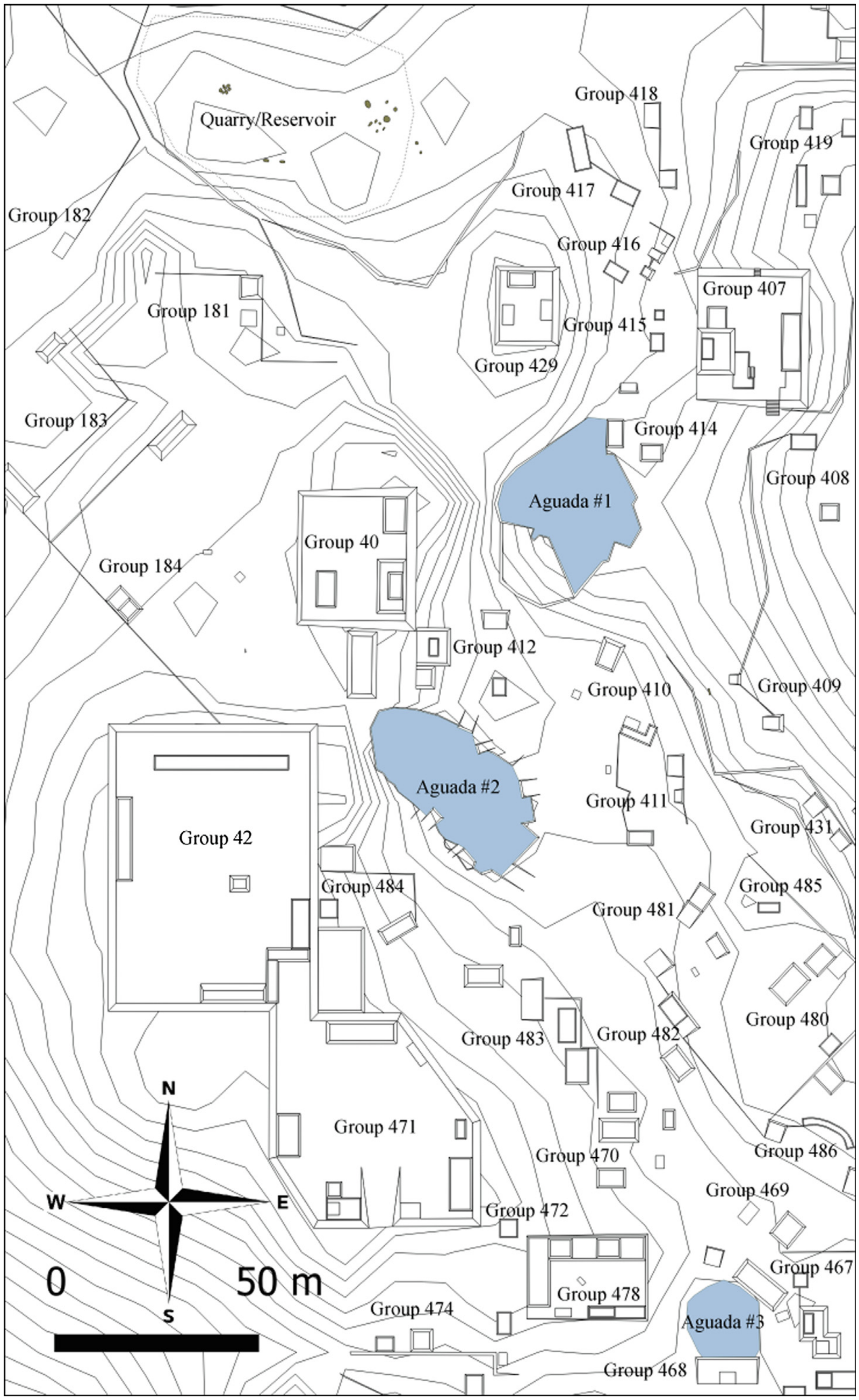

Fig. 5. Large reservoirs, Aguada #1 and Aguada #2, at the site of Ucanal (Sectors G-10 & G-11) (digitization by J-B. LeMoine).

water from the sides of the canal (Fig. 8). While some of the canal's construction may have taken advantage of natural slopes in the topography, a large extent of the canals were clearly excavated directly into bedrock. Some areas of the bedrock in Canal #3 were excavated in steps approximately 30 cm wide and 30–40 cm high (Fig. 8c). Inhabitants at the site also systematically excavated 50 cm wide channels at the bottom of and running longitudinal along the canal. These narrow channels in the bedrock ensured an efficient drainage of water during lighter rains. Excavations of Canal #3 also revealed a small check dam perpendicular to the lower channel excavated into bedrock. Since the check dam was not visible before excavations, it is possible that many more check dams are present but not identified from surface surveys.

Excavations of the wall fill that line the edges of Canal #1 and #2 indicate that the canals were constructed during the Terminal Classic period. In fact, both the interior accumulation of soil at the bottom, longitudinal zone of the canal and the wall fill along its edges contained

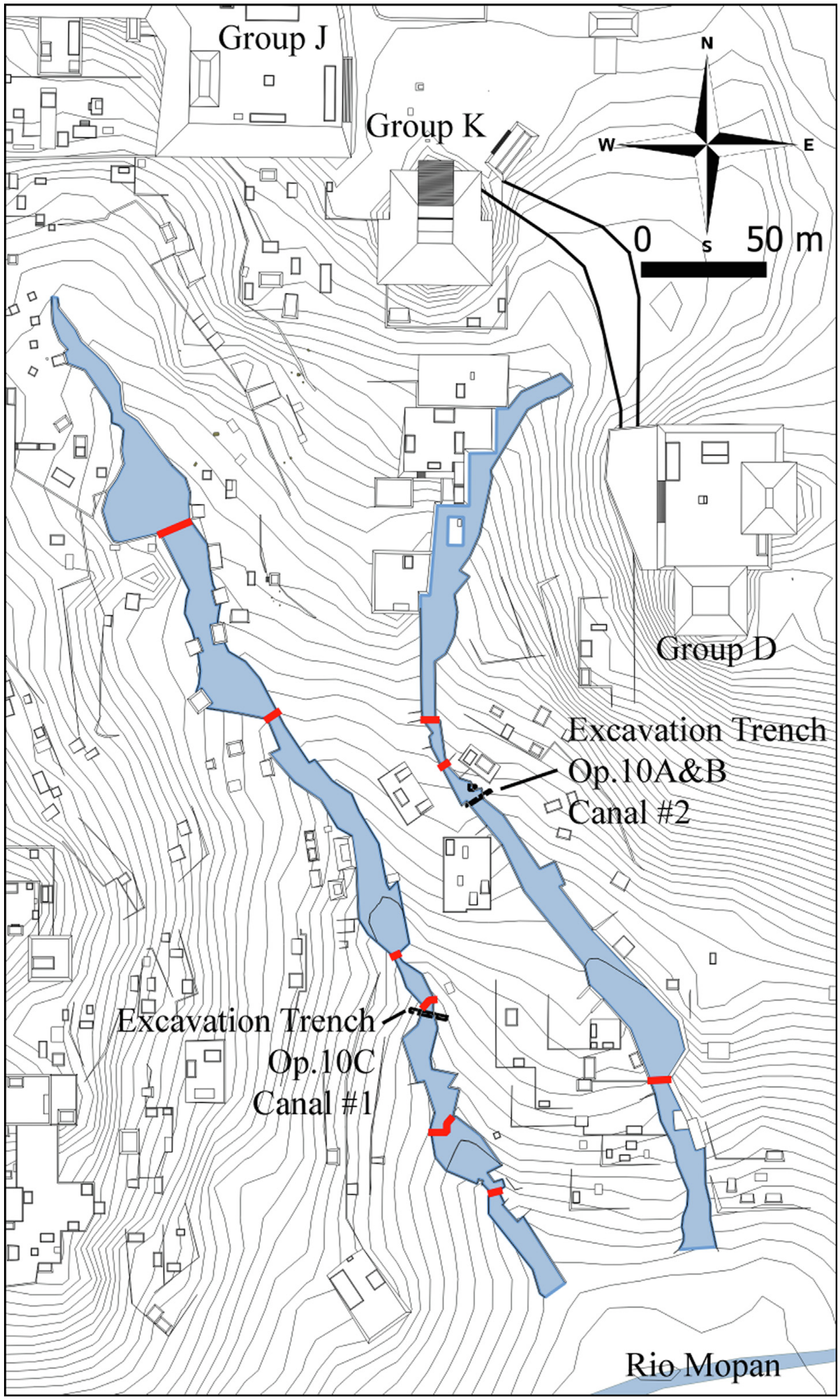

Fig. 6. Plan map of Ucanal's Canals #1 and #2 showing the location of dams (in red) and the location of excavations by the Proyecto Arqueologico Ucanal (Sector H-11) (digitization by J-B. LeMoine). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Terminal Classic ceramic sherds mixed with other secondary refuse, such as chert flakes, obsidian, and faunal remains. Excavations of Canal #3 did not expose canal wall fill layers that were deep enough to securely date the canal. Ceramic materials found within the narrow longitudinal canal drain and around the check dam, however, were Terminal Classic in date.

The Terminal Classic construction and use dates for the canals is seemingly at odds with many paleoclimate studies that indicate progressively drier climates during this time period (Douglas et al., 2015; Haug et al., 2003; Hodell et al., 1995; Kennett et al., 2012; Medina-Elizalde and Rohling, 2012). Nonetheless, when one examines smaller-scale time frames within these cases of drought, it is clear that droughts were interspersed with periods of high precipitation. Although the implications of such erratic climates are not discussed as much as the

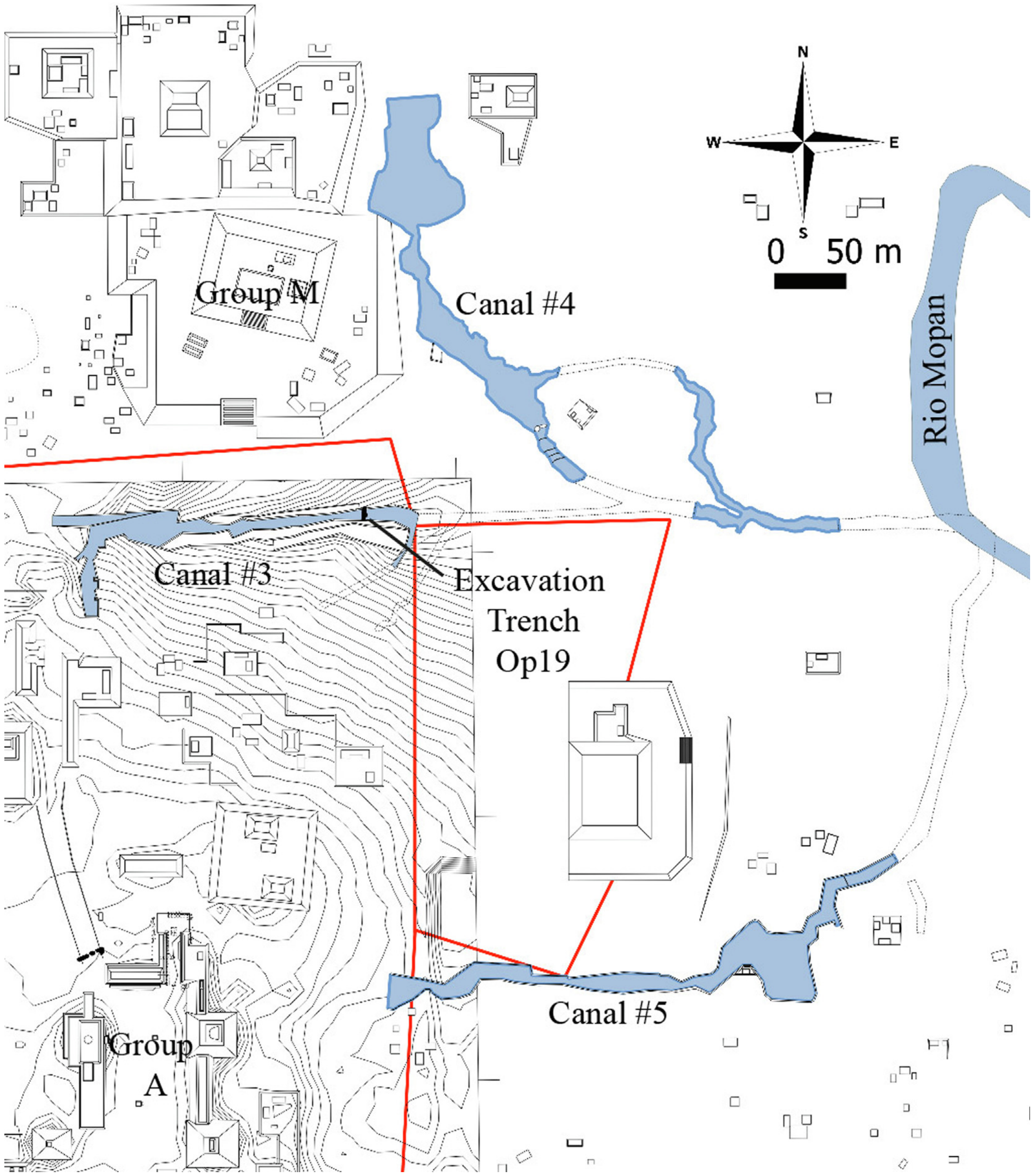

Fig. 7. Plan map of Ucanal's Canals #3, #4, and #5, showing the location of dams (in red) and the location of excavations by the Proyecto Arqueologico Ucanal (Sectors H-8, H-9, H-10, I-9, I-10) (digitization by J-B. LeMoine). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

problems of drought, the luminescence, color index, reflectance, carbon isotope, and oxygen isotope data from the speleothem record from the Macal Chasm cave in western Belize, which currently represents the closest known paleoenvironmental record to the site of Ucanal, reveals the possibility of such erratic dry-wet episodes (Webster et al., 2007:Fig. 8). Thus, water infrastructure projects at the site of Ucanal underscore the challenges of and solutions to too much water at the end of the Classic period.

6. Causeways and ballcourts as part of annual cycles of wet and dry seasons

In addition to flood control canals, inhabitants at the site of Ucanal constructed roads and monumental building features that captured and

Table 1
Ucanal canal features.

	Max. length (m)	Width (m)	Elevation difference from top to bottom (m)	% slope	Narrow interior channel	Number of dams and check dams	Z angle turns	Rock retaining walls
Canal #1	473	40–4	31.5	6.60	Yes	6	Yes	Yes
Canal #2	415	40–5	39.2	9.45	Yes	4	Yes	Yes
Canal #3	650	27–1	26.5	8.24	Yes	4	Yes	Yes
Canal #4	550	30–6	54.0	9.80	Unexcavated	6	Yes	Yes
Canal #5	403	13–5	14.0	3.50	Unexcavated	4	Yes	Yes

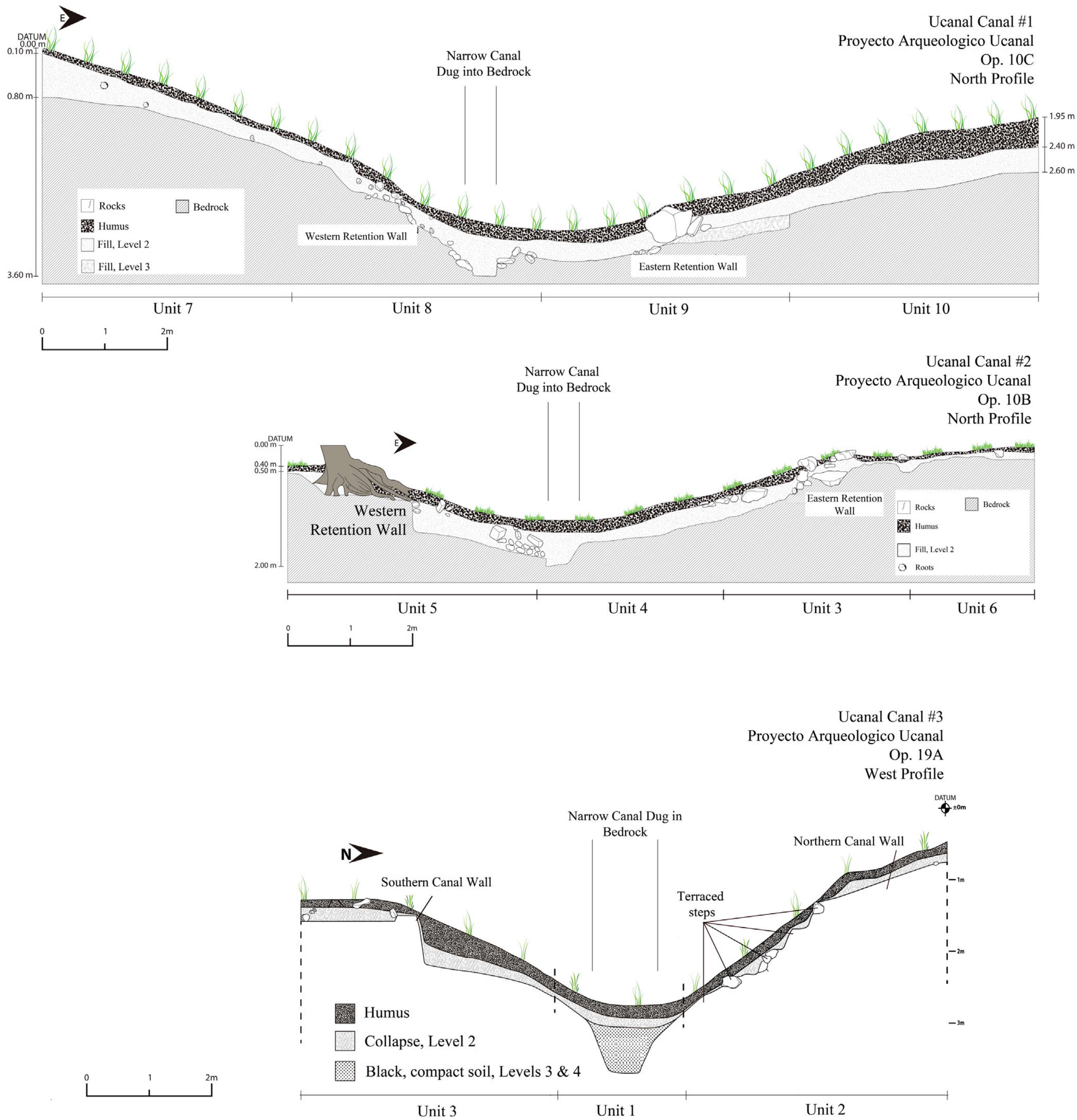

Fig. 8. Cross-section of Ucanal canal excavations: (a) Canal #1, (b) Canal #2, (c) Canal #3 (digitization by E. Perez Zambrano).

facilitated the flow of water. These features highlight, in particular, the annual cycles of wet and dry seasons, around which ruling elites and supernatural entities performed in public spectacles. Annual wet and dry season cycles would have also likely structured maintenance regimes in which ordinary peoples of the city would have been required to clean out the causeways and canals and likewise would have engaged in repairs in order for water infrastructure systems to work properly.

Most roads throughout the Maya area were raised, elevating a pathway above *bajos*, mud, and water accumulation (Chase and Chase, 2001; Keller, 2006; Shaw, 2001), and as such served to collect and dam water in reservoirs (Davis-Salazar, 2006; Scarborough et al., 2012). The inter-site causeways at the site of Ucanal, however, were not raised, but lined on both sides with low walls approx. 50 cm in height, a form of road we refer to here as "inverted causeways" to distinguish them from the more typical raised causeway (Fig. 9). As such, they did not dam up or restrict the movement of water, as at other sites. Rather, they helped direct water, much in the same way as the aforementioned canals. Thus, in addition to serving as the pathways in which people moved into and out of ceremonial plaza spaces, they also helped move water out of these same spaces. The Calzada Norte, for example, directed water out of Plaza A, the most elevated ceremonial plaza at the site, and moved water along the south side of Plaza B to eventually discharge into Canal #3 (Fig. 9). Likewise, the Calzada Central helped discharge water from the south side of Plaza A, then down to Plaza K, and eventually out to Canal # 2. Excavations of Calzada Norte reveals two construction phases of the inverted causeway, both of which date to the Terminal

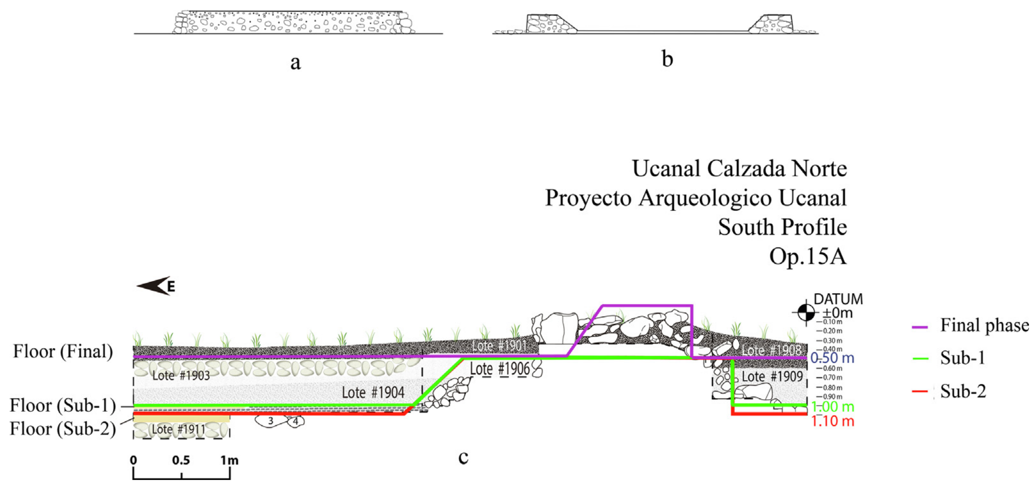

Fig. 9. Causeways in the Maya area: (a) schematic of typical raised causeway in the Maya area; (b) schematic of inverted causeway found at Ucanal (digitization by C. Halperin); (c) south profile of Calazada Norte's western wall (digitization by E. Perez Zambrano).

Classic period (the earlier one with a slightly wider raised causeway wall). Excavations also revealed Late Classic and Terminal Late Preclassic constructions below these remodellings, although they were not extensive enough to determine if they comprised an earlier plaza floor or an earlier causeway (Pérez Zambrano, 2019) (see Fig. 10).

In addition, two of the ballcourts at the site were specially engineered to allow for the annual flooding of the site's ballcourts. Total station survey of Ballcourt #1 reveals that its northern side is 30 cm lower than Plaza A (Fig. 4). Since the ballcourt is closed on this end, it is likely that the ballcourt filled with water during the rainy season. Excavations indicate that this ballcourt was constructed during the Terminal Classic period (Laporte and Mejía, 2002:6–7). In turn, the central alleyway of Ballcourt #3 served as a conduit of water during the rainy season whereby rainwater from the large temple pyramid (Group 249) and plaza area in front of the pyramid would have collected and flowed east through the playing alley of the ballcourt to be then channeled by the inverted causeway that lead to a reservoir, which continues to be a seasonally active *aguada* today (Fig. 11) (Le Moine et al., 2017).

Although most ballcourts in the Southern Maya Lowlands (Scarborough and Wilcox, 1991; Taladoire, 1981, 2003) were open courts and would not have channeled or captured water, Karl Taube (2018) has argued that some enclosed I-shaped ballcourts and sunken *palangana* courts would have purposefully held water. The water related features of enclosed ballcourts are further reinforced by *maquetas* or small-scale models of ballcourts that feature drains for water to flow within the *maqueta* itself and highlight the performative characteristics of water (Taladoire, 2012). As such, Taube (2018) argues that rainwater collection within life-sized ballcourts was a key part (or result of) the performances conducted within the ballcourt. Pre-Columbian imagery reveals that ballcourts were considered key access points to the watery underworld and to rain deities such as Chaak, the Maya storm god (Fig. 1a, c). Likewise, contemporary spectacles of ritual combat from Guerrero today are timed in early May to petition for rain, and the blood that spills from such ritual combats are considered to be potent forces that help bring the rains (Taube, 2018:295–297; Taube and Zender, 2009; Zolrich, 2008). According to epigraphic and iconographic records from the Classic period, it was elite men, in particular, who organized formal ceremonies around and directly played in the ballgame (Scarborough and Wilcox, 1991; Zender, 2004). Although more informal ballgames were undoubtedly played by a wide range of people, it was likely the formal elite- and state-sponsored games and ballcourt rituals that were publicly responsible for supplicating rain and storm deities and engaging with supernatural and sacred forces who chose to participate or not in the ceremonies and their aftermaths.

The more hidden part of water infrastructure systems, however, were the participants who cleaned and maintained the causeways, canals, and ceremonial buildings. In just the same way as modern politicians forget to budget funds for maintenance and repairs to ensure the long-term longevity of major infrastructure projects, archaeologists often overlook the labor required to maintain ancient infrastructure projects (Wilkinson, 2019). During the rainy season, retention walls for the canals and causeways would have been damaged, soil and garbage would have accumulated in the bottom of canals and along the edges of causeways preventing them from working properly, and stucco surfaces of causeways would have eroded from use and weathering. Arguably, inverted causeways would have required more regular upkeep than the typical raised causeways since they more easily collected dirt, leaves, and trash in its interior walkway zone. Ethnohistoric and ethnographic data indicate that community work projects also revolved around annual cycles and were considered part of ceremonial cycles of ritual obligations (Cancian, 1965; Redfield, 1962; Tozzer, 1941; Wells and Salazar, 2007).

7. Daily routines of ancient Maya water infrastructure systems

If we narrow our temporal lens even further to the level of daily practices, we are also able to highlight another overlooked component of ancient Maya water infrastructure systems. One of the basic daily tasks of some members of ancient Maya households was to fetch water in water jars. The labor to carry water to and from water sources to the house lot and the simple technology of *cantaros* or constricted-neck water jars are not usually considered a part of water infrastructure systems (Fig. 12). Nevertheless, if we are to take more recent social science notions of infrastructure seriously, it is essential to consider these living, breathing, moving components of water infrastructure systems since they were responsible for moving water in reverse directions of the canals and rainwater flow: from reservoirs and rivers to households. A water infrastructure system simply does not work if water jars and the labor to carry them do not connect the reservoirs and rivers with the activity areas in which water is needed. Such cumulative labor was enormous as it required the movement of between 2 and 5L of water per adult person for drinking water consumption alone and would have required even more for the washing, cleaning, cooking, and house lot gardening needs of a single family (Seefeld, 2018:70).

Among contemporary Maya households who do not have access to running water, these daily tasks often fall to the women and children of the household (Fig. 12a) (Reina and Hill, 1978). Children as young as 8–10 are known to carry water jars that weigh 30–35lbs each on a daily basis. Apart from storm and rain deities, the rare Pre-Columbian

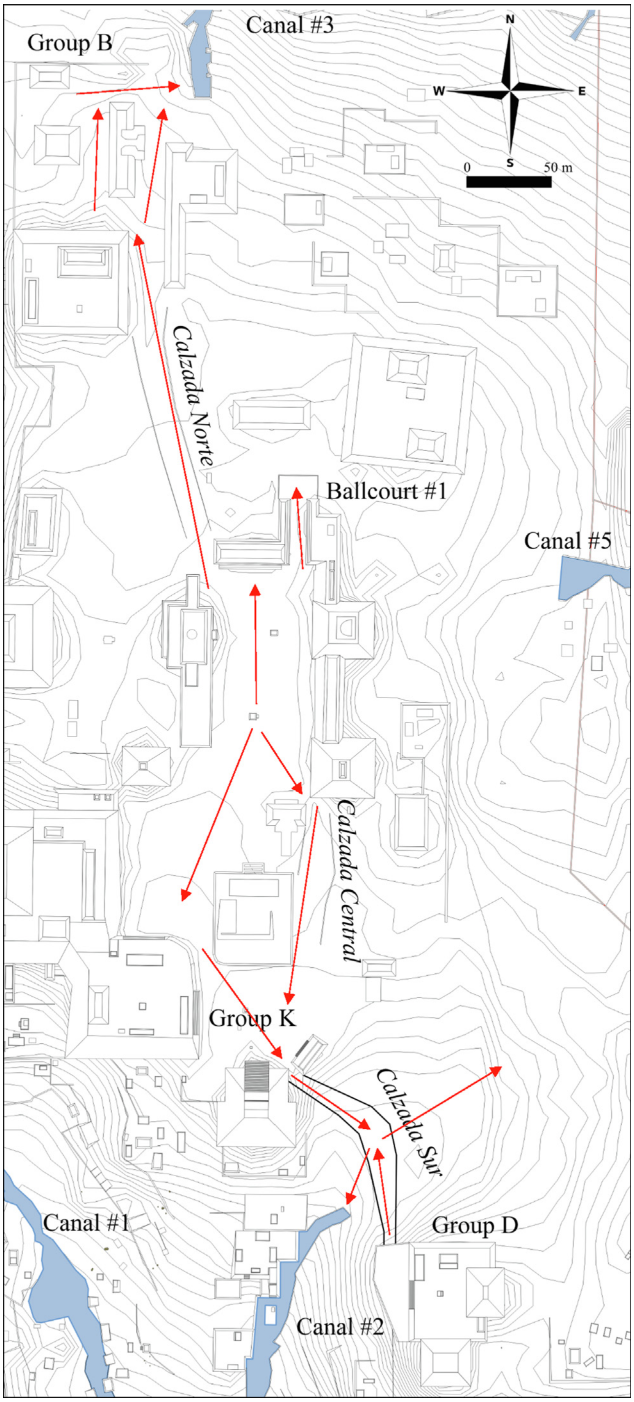

Fig. 10. Plan map of inverted causeways connected to Plaza A at the site of Ucanal with arrows indicating direction of surface water flow.

depictions of humans carrying water jars are depictions of women, such as ceramic figurines from Piedras Negras (Fig. 12b) (Ivic de Monterroso, 2002:487–488) and from Lubaantun (Joyce 1933:Plate IV:4).

Analyses of ceramics excavated from 17 different architectural groups at the site of Ucanal by the Proyecto Arqueológico Ucanal reveals that *cantaro* vessel densities were inversely proportion to the wealth and size of these groups (Fig. 13). Vessel densities were measured by the number of vessels per surface area excavated. The highest density of *cantaro* sherds are found in small, commoner households and the lowest density of *cantaro* vessels were found in the large, elite households. Such distributions are counter to the fact that large, elite households would have comprised greater numbers of people that required greater quantities of water for daily needs per household. Elsewhere in the Maya area, masonry roofs of elite buildings were sometimes outfitted with roof drainage canals or gutters, which could have stored rainwater near the buildings themselves, saving transportation costs to the reservoir, stream, or river for these more privileged households (Davis-Salazar, 2006:130–131). Despite the likelihood that *cantaros* served multiple uses, the Ucanal *cantaro* vessel densities suggest commoner households, in particular, were highly implicated in the labor involved in water collecting and hauling for daily needs. Without this labor, however, water from reservoirs, streams, and rivers simply did not connect to households and activity areas.

8. Discussion

Thus, by examining multiple temporal lenses in relation to water infrastructures at the Maya site of Ucanal, Guatemala, we are able to better address the different social actors (human and non-human), experiences, and challenges people at the site faced. It is clear that the grand narrative of the Classic Maya rise and fall as tied to droughts has resonance only on a broad temporal and spatial level of abstraction (Aimers, 2007; Aimers and Hodell, 2011). In contrast, attention to regional variability reveals that polities across the Maya area faced different environmental challenges and infrastructural solutions. Studies of water infrastructure at the site of Palenque and Copan, for example, reveal that urban projects were dedicated to drainage and flood control, and for some water-rich regions, such as the Petén Lakes area and the Usumacinta river zone, droughts likely had less of an effect on the rise and fall of political centers of power. Likewise, the water canals and causeways at the site of Ucanal were designed to get rid of, rather than to store, water. Such finds contribute to a more regionally heterogenous understanding of Maya water infrastructure systems. These data also push one to consider the possibility of shorter-term drought-hurricane cycles. Constant and gradual climate changes affect decisions and adaptations differently than severe spikes and dips in precipitation.

Rather than a focus solely on built infrastructure features, however, both CIS approaches to and approaches inspired by Entanglement and Actor-network-theory emphasize the intimate, interlinked relationships between different components of infrastructure including different human and non-human actors, political and social institutions, and ecosystems. For example, while the decisions of political authorities to organize the construction of flood control canals at the site of Ucanal may have helped expand or at least stabilize urban settlement and ceremonial space during the Terminal Classic period, these built features were also dependent on humans. Canals and causeways depended on human labor not only for their construction but for their on-going maintenance and repair. Such labor, which was likely organized on an annual basis at the end of the rainy season, helped keep water infrastructure systems clean and ensured their basic functionality. The reduction in population at the site of Ucanal during the Early Postclassic period may have disrupted such relationships, since the size of the canals and causeways remained the same even if the number of inhabitants available to keep up with large urban infrastructure projects diminished.

Ancient Maya water infrastructure also depended on spiritual forces and supernatural beings to provide rainwater, the critical element that was captured, channelled, and disposed of in built water infrastructure. The bringing of rain depended on a long-standing sacred contract that dictated a reciprocal relationship between humans and spiritual and supernatural beings (Christenson, 2007; Schele and Miller, 1986). It was the role of elite political authorities, in particular, to hold annual ceremonies timed at the onset of the rainy season to appease and make offerings to rain, wind, and storm deities who would then bring both benevolent and highly destructive rains. Ballcourts, however, were not the only public ceremonial features that captured and ceremoniously put water on public display. Excavations in one of the earliest Mesoamerican civic centers, the Olmec site of San Lorenzo, uncovered a basalt

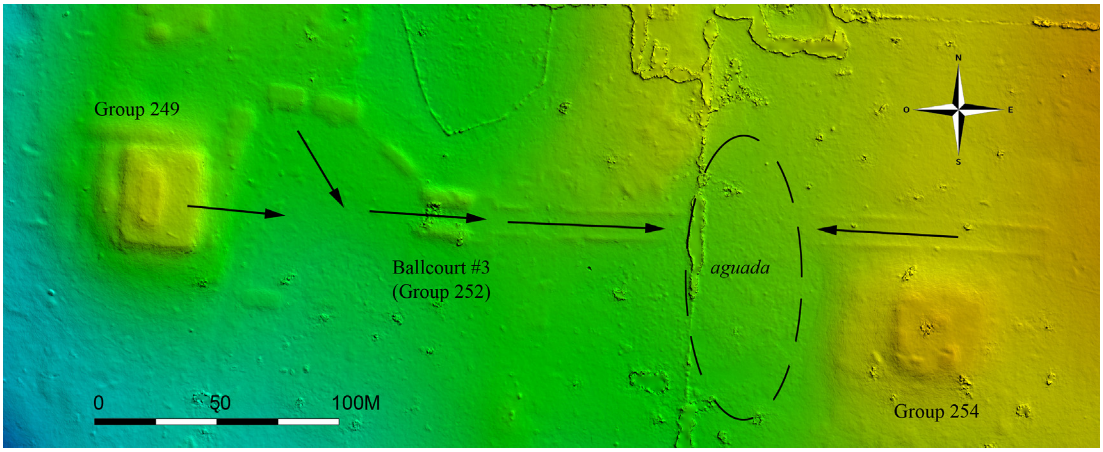

Fig. 11. Digital elevation model of Ucanal's Ballcourt #3 with arrows showing the direction of surface water flow (Sectors F-8, G-8, G-9).

drainage network in the elite ceremonial zone of the site (Diehl, 2004:36-39). Quatrefoil-shaped (4-petaled) pools, a symbol of earthly openings to the watery underworld, were constructed for ritual manipulation of water in the public plaza spaces of Middle Preclassic La-Blanca and Late to Terminal Classic Machaquíla, Guatemala (Graham, 1967:59; Love and Guernsey, 2007; see also Źrałka and Koszkul, 2015). Likewise, city planners purposefully linked ceremonial architecture to caves, the dwelling places of ancestors, deities, and from where life-giving forces of clouds and rains are thought to emerge (Brady and Ashmore, 1999; Brady and Prufer, 2005; Ishihara, 2008). These ceremonial constructions allowed Mesoamerican rulers to situate themselves at key access points to wind and storm deities and at the center of the cosmos.

It is by focusing on the daily temporal cycles of water infrastructures, however, that we are able to better see the ordinary and bottom-up perspectives of infrastructures outlined by Karl Marx, Norman Yoffee, and Monica Smith. On a large temporal-scale, the daily human labor component of water infrastructures is easily overlooked since Pre-Columbian cities, as a whole, did not possess running water

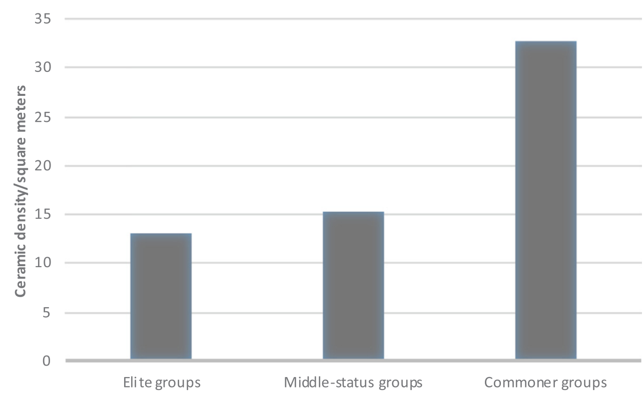

Fig. 13. Densities of Late and Terminal Classic period *cantaro* (restricted neck jar) vessels by architectural group rank (architectural group rank was determined by calculations of architectural volume; Elite, Rank 1 between 100,000–1,001 m^3, Middle-status, Rank 2 between 1,000–201 m^3, Commoner, Rank 3 between 200–1 m^3).

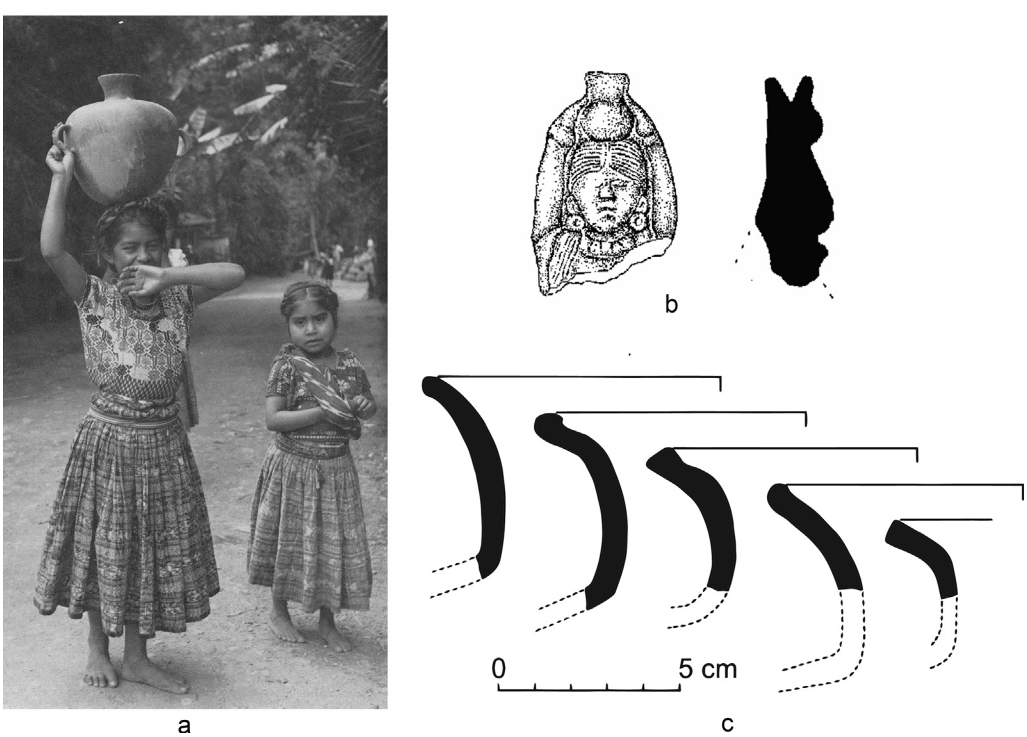

Fig. 12. Hauling water with water jars: (a) Maya girl from Chinautla with water jar (5 lbs when empty; 35 lbs when full of water) (after Reina and Hill, 1978:Plate 387); (b) Late Classic ceramic figurine of woman with water jar on her head, Piedras Negras (center-part as a feminine hairstyle) (after Ivic de Monterroso, 2002:Fig. 9); (c) profiles of Terminal Classic restricted neck jars (*cantaros*) from the site of Ucanal (Peten Gloss ware, Maquina Group, UCA12A-5-2-923; UCA12A-8-3-935; UCA12A-8-3-935, UCA12A-8-3-935, UCA10B-5-3-715) (drawings by M. Cano).

infrastructure with pipes and water pumps. Yet, for both Pre-Coumbian and even some communities today, norms in the division of household labor, house location, household size, and household wealth or status were highly consequential to those who actually had to fetch water on a daily basis. Ceramic density data from Ucanal indicate that such burdens may have fallen disproportionally on lower-status commoners, and iconographic and ethnographic data indicate that within households in general, such burdens may have often fallen to women and children. In another study of the historic period Caribbean islands, Mark Hauser (2017) similarly finds that the most vulnerable members of society, such as slaves, were disproportionally the ones who had to fetch and haul water. These human components, however, were no less critical to water infrastructure systems than the material installations of canals or the participation of spiritual forces in the bringing of water.

9. Conclusion

Ancient Maya water infrastructures have often been studied as a critical factor in the rise and fall of Maya cities and rural communities over the long term. Although many previous studies reveal that water capture and storage facilities for agriculture and potable drinking water were essential to many communities in the Maya Lowlands, recent research from the site of Ucanal indicates that substantial investments were also made to channel and get rid of water in the form of canals and inverted causeways. Many of these large-scale constructions were undertaken during the Terminal Classic, a time period most commonly associated with droughts identified using paleoclimate proxies. These finds push one to consider shorter time frames in the way in which climate was experienced whereby hurricanes and wet episodes might have been interspersed with overall drier climate trends.

Ancient Maya water infrastructure systems at Ucanal, however, were not limited to large-scale centrally built flood control features. The inverted causeways and ballcourts at the site provide an example of civic engineering to channel water in and through ceremonial buildings at the annual arrival of the wet season. These public water displays in the ballcourts were likely a part of, or end result of, games and ceremonies that required elite authority figures and the community at large to carry out sacrifices, rituals, and offerings, on the one hand, and the agency of deities and supernatural forces to reciprocate in releasing rain in ample but not excessive force, on the other hand. While the role of political authorities has long been recognized in the construction and ritual dynamics of large-scale water infrastructure projects, our expansive consideration of ancient water infrastructure underscores that the physical components of infrastructure were very much dependent on the human labor of ordinary peoples to maintain them on an-going basis. Likewise, the consideration of the daily needs of water transport using water jars sheds light on one of the most overlooked but most critical aspects of water infrastructure systems since they were a vital connecting piece of water movement. Thus, for some, the experience of water infrastructure may have involved situating oneself at the intersection of an engineered built landscape and cosmic forces of the earth, for others it was an arduous daily burden.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2019.101102.

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