1 Sustaining freshwater security and community wealth

Diversity and change in the pre-Columbian Maya lowlands

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The archaeology of freshwater security

> The centrality of freshwater in our lives cannot be overestimated. Water has been a major factor in the rise and fall of civilizations. It has been a source of tensions and fierce competition between nations that could become worse if present trends continue. Lack of access to water for meeting basic needs such as health, hygiene and food security undermines development and inflicts enormous hardship on more than a billion members of the human family. And its quality reveals everything, right or wrong, that we do in safeguarding the global environment.
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> (Annan, 2003: xix)

Freshwater security is a global challenge that requires foresight in planning and begs learning from past experiences. Freshwater security is minimally the situation wherein people have access to water of sufficient quality and quantity to meet their physiological needs, including drinking water, water for food production and processing and water for sanitation (Barthel and Isendahl, 2013: 224; see also FAO, 1996). This definition centres on the basic necessities of individuals and leaves out a host of other ecosystem services provided by the hydrological cycle (see also Bakker, 2002; Orlove and Caton, 2010). Factoring these in further emphasises the point that whatever the size, however organised and no matter which biome is inhabited, all societies past, present and future, had or have to deal with freshwater security (see also Wutich and Brewis, 2014). Although global freshwater use is currently within the boundaries of a safe-operating space for humanity (Rockström et al., 2009; Steffen et al., 2015), the uncertainty and lack of adequate freshwater provisioning is regionally acute (Sadoff et al., 2015). Over the past century the total volume of freshwater consumption has expanded rapidly and socially asymmetrically (e.g. McNeill, 2000: 120–122), pushing towards a global post-peak-freshwater situation with decreasing volumes of clean freshwater available to an increasing number of people, and coming at a higher cost. Even without considering the shifting boundary conditions of hydrological cycles that climate change implies, freshwater security forms a daunting global challenge (e.g. Gleick, 2014). Indeed, failing to address this challenge is, as former secretary general to the United Nations Kofi Annan (2003: xix) indicates, an unacceptable humanitarian failure.

Archaeology certainly cannot solve these issues. But since its research generates perspectives, interpretive frameworks and empirical data on the past that no other discipline does, archaeologists can provide endemic insights on freshwater security that provide some leads for the gargantuan task of building sustainable freshwater security at multiple scales. Archaeologists, however, are rarely consulted on key sustainability issues to which they can potentially contribute. Consider, for instance, that of a total of 468 scientific contributors to the most recent report of the Intergovernmental Panel on Climate Change (IPCC, 2014) 202 (43%) were from the social sciences and humanities. Of these, 130 (64%) were economists. One contributor was a historian, but no archaeologist was involved (Poul Holm, personal communication, 2016). Thus, no contributor elucidated the long-term dynamics of socio-ecological systems from archaeology's anthropocentric perspective. This suggests that archaeologists need to find platforms where their voice is heard in prolific scientific-based sustainability fora and that we are well advised to channel our insights to disciplines that decision-makers consult. From the IPCC example, striking a good rapport with Earth scientists and economists does seem particularly productive. Hence, recently the American Anthropological Association Climate Change Task Force published a report that brings to the forefront how people, communities and societies respond and have responded to climate change (Fiske et al., 2015) – topics largely lacking in IPCC (2014) and similar international reports.

The basic scope of the archaeology of freshwater security is twofold. First, it generates case studies of the opportunities and challenges that people in the past have addressed to attain freshwater security, and their successes or failures to do so. Second, it employs archaeology's unique anthropocentric perspective to study the long-term, socio-ecological dynamics framing freshwater security under different and changing conditions, usually focusing on the Holocene to Anthropocene period of the last c. 11,500 years.

But there are caveats. As Lane (2015) notes, what is considered as long-term differs between the disciplines and is dependent on the kind and relative scale of the longevity of the processes analysed. Hence, 'the long-term' needs always to be specified rather than implied. The temporal frame of reference within which the archaeological analyses of freshwater security operate usually extends from a few hundred years to two or three millennia, i.e. over the *longue durée* in the popular parole of the French Annales school of historians (Braudel, 1980). However, there is no standard frame of reference. This has important consequences for how we construct, evaluate and ultimately project the sustainability of social institutions addressing freshwater security. Although not unproblematic, the archaeological perspective is unique in terms of being able to track the effects of relatively slowly changing variables

(Carpenter et al., 2001), i.e. processes with long-term temporal lags that otherwise might go unnoticed, such as the gradual long-term effects of a maximising productive strategy on the sustainability of an agricultural economy's resource base. As an anthropocentric science, archaeology is concerned with what people have done, why they did so, and determining the outcome of these actions, both short- and long-term. That human practice involves both calculated and unrealised tradeoffs playing out over different temporal and spatial scales and social domains to undermine socio-ecological resilience have been recognised in the sustainability sciences for some time (e.g. Janssen and Anderies, 2007). For instance, Nelson and colleagues' (2010) comparative study of pre-Columbian agricultural systems of the North American southwest demonstrates the so-called robustness–vulnerability tradeoffs at work in managing freshwater security and offers insights on the relatively high resilience capacity of flexible small-scale technological solutions (see also Hegmon, 2017). Although the archaeological record cannot provide blueprints for implementing freshwater security because of our living in a globalised world with exponentially greater numbers of people, it does offer a pool of experience of challenges, strategies, practices, successes and failures from which to draw.

Today the tropics host over 40% of the world's population (a proportion expected to expand to 50% by 2050) (State of the Tropics, 2014: xii), with nearly half estimated to be susceptible to water stress (State of the Tropics, 2014: 55). It is, thus, critical and timely to discuss freshwater security in the tropics with an ultimate goal of addressing present concerns. This chapter discusses freshwater security among the pre-Columbian Maya in tropical Central America. We offer some examples of how the Maya developed water management systems in different regions and how efficient these were in providing freshwater security sustainably (see also Tainter et al., this volume). In this and other tropical regions worldwide, unless freshwater security is maintained, not only will shortages worsen, but water-borne diseases will proliferate. People will suffer.

The Maya lowlands are environmentally heterogeneous and different regions presented challenges as well as opportunities within certain socio-political, cultural, historical and environmental constraints to address freshwater security. For instance, the Maya had no beasts-of-burden or wheel-based transport and several regions lacked water-borne transport routes. Since people often had to carry goods, distant production of bulk food was relatively inefficient and contributed to an emphasis on urban farming in the total food resource framework (Isendahl, 2012; Barthel and Isendahl, 2013; Isendahl and Smith, 2013). In response to this diversity, a variety of water management systems were developed in different social and historical contexts (Lucero, 2006; Isendahl et al., 2016; see also Dunning and Beach, 2010). In this chapter, we initially focus on two regional examples of how the Maya addressed freshwater security: the Puuc-Nohkakab region in the northern Maya lowlands of the Yucatán Peninsula, and the Petén Karst Plateau of the southern Maya lowland interior (Figure 1.1). As we will see, although these regions are located in different

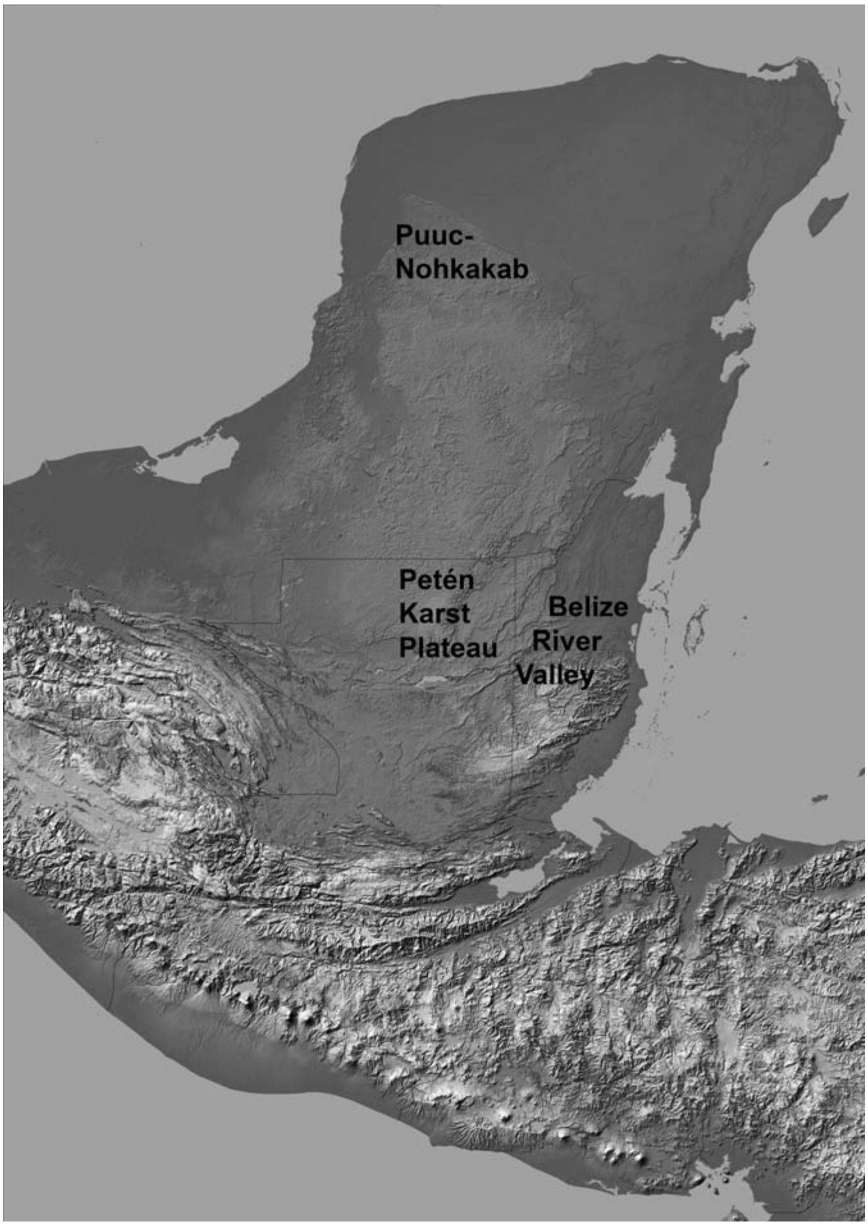

Figure 1.1 The Maya region with the physiographic sub-regions discussed in the text indicated (plotted by C. Isendahl on a modified map from NASA, www2.jpl.nasa.gov/srtm/central_america.html; accessed 22 November 2011)

areas with different cultural histories and environments, there are significant similarities in the general pattern of how freshwater security was addressed and the consequences of these water management systems for long-term societal sustainability. We then present a third, contrasting case study based on the site Saturday Creek in the Belize River Valley, immediately to the east of the Petén Karst Plateau. Saturday Creek brings in considerable dissonance to the first two cases presented on how pre-Columbian Maya water management systems performed in addressing freshwater security long-term.

Theoretical baseline

As an initial point of departure for purposes of our discussion, we provisionally suggest that long-term freshwater security is equivalent to a sustainable water management system and can largely be understood as a result of successful problem-solving. A water management system is here broadly defined as the sequence of activities that link water 'production, processing, distribution, consumption and waste management, as well as all the associated regulatory institutions and activities' (Pothukuchi and Kaufman, 2000: 113). Tainter and colleagues (Tainter, 2006; Tainter and Taylor, 2014; Tainter and Allen, 2015) argue that sustainability emerges from success at solving problems, and that technological and institutional complexity – defined as 'differentiation in both structure and behavior, and/or degree of organisation or constraint' (Tainter, 2006: 92) – is not only a powerful tool for problem-solving, but also that complexity requires resources and involves costs to be maintained.

Complex water management systems depending on management-intensive hydro-technological solutions, for instance, those dependent on investments in a system of reservoirs, distribution canals and other large-scale landesque capital features (i.e. landscape transformations made to increase productivity), carry relatively high costs. Although the solutions applied to build freshwater security by increasing technological sophistication and involving complex forms of management organisation may be highly effective for a time, they require resources such as up-front investment and ongoing maintenance costs, which carry with them a long-term series of inbuilt costs that can limit the future capacity to adapt (Scarborough and Burnside, 2010). Maladaptation and responsive inertia (i.e. too little too late) may be associated with sunk-cost effects, i.e. that decisions are based on past investments rather than future returns (Janssen and Scheffer, 2004). These may contribute to path dependency (e.g. Pierson, 2000) as high start-up costs once in place have prohibitively large transaction costs to fundamental change, even under increasing inefficiency, and thus limits the range of alternative solutions.

Decreasing productivity can be situated in relation to the economy's broader status of net energy gain, an approach to contextualise cost/benefit ratios at the systemic level introduced to archaeology in an analysis of the long-term sustainability of Roman imperial economy (see, e.g. Tainter and Allen, 2015). The approach examines patterns of large-scale social change, how these patterns are linked to transitions in net energy gain and the consequences of such transitions for the sustainability of socio-ecological systems. The key concept is energy returned on energy invested (EROI) and tracks how societies deal with transitions from phases of high to low EROI (or vice versa), associating each phase with a series of resource exploitation conditions and behaviours (see Tainter et al., this volume). The basis of economic and political power in early complex agricultural societies is the ability to accumulate energy (*sensu* Odum, 1996); and political economies can be understood as the practices and processes by which some social groups, controlled energy at the expense of other groups. The details of Maya political economies are matters of debate (e.g. Masson and Freidel, 2002; McAnany and Wells, 2008), but strategies to control agricultural produce and human labour is a fundamental principle of gaining social, political and economic privilege. In these competitive agro-economies, the control of labour, productive land and freshwater sources would provide the basis for yielding high EROI that potentially could support a growing population, surplus production, landesque investments, monumental architecture and centralised institutions. According to the model (Tainter and Allen, 2015; also Tainter et al., this volume), phases of high EROI tend to be of relatively short duration; the supply of key resources, initially abundant and/or concentrated, diminishes relatively rapidly owing to inefficient management. As the demand for resources increases (e.g. due to population growth, organisational complexity and conspicuous consumption) and becomes scarcer, it requires higher investment costs to maintain production levels, forcing a transition from a phase of high to low EROI. In a phase of low EROI, key resources are usually scarce, dispersed and produce relatively little surplus per capita, thus requiring efficient management. Hence, water management systems play out over a set of socioeconomic conditions that change over time.

In this chapter, we discuss how the water management system of each case study tracked in relation to increasing/decreasing freshwater security on the one hand and increasing/decreasing community wealth on the other (see also Isendahl and Heckbert, 2016). The relationship between freshwater security and community wealth is often assumed as one of linear co-dependency, each preconditioning the other. However, tracking the history of water management systems in these cases suggests that the dynamics between community wealth and freshwater security is complex, non-linear and may potentially trigger unanticipated, emergent properties in the socio-ecological system.

In our analyses, we show that freshwater security is determined from biophysical conditions, mainly, precipitation and surface and sub-surface water availability, and available hydro-technologies and institutions, which change over time. As a relative indicator of community wealth, we use a rough assessment of temporal changes in population numbers and the amount of architectural investment made, on the basic assumption that the number of people that can be sustained and the ability to invest in construction combined are reasonable proxies for community wealth (cf., Smith, 2015). We are aware of several assumption caveats, most importantly the asymmetrical distribution of wealth, but suggest that our approach forms a valid basis for initial review.

The Maya lowlands

The Maya lowlands cover about 250,000 km^2 in present-day southeastern Mexico, Guatemala, Belize and Honduras. The Maya lowlands have high biodiversity. The resources the Maya relied upon were diverse but dispersed, a fact that is mirrored in the settlement pattern of Maya cities, where residential units are scattered but clustering around civic-ceremonial centres of urban functions. This settlement system can be understood as extensive agro-urban landscapes inter-fingering built areas with cultivated space (Isendahl, 2012). Also mirroring the nature and diversity of resources are the diverse and small-scale extensive and intensive subsistence technologies used – including dams, canals, terraces and raised fields – for growing the major staples of maize, beans and squash in house gardens, short-fallow infields, long-fallow outfields, or combinations of these strategies (Harrison and Turner, 1978; Killion, 1990; Lentz et al., 2014). The Maya also took advantage of the diverse forest flora and fauna in the forested landscape they managed (Ford and Nigh, 2015). Pre-Columbian Maya society developed with significant regional differences in the lowlands, but state polities, urban settlements, long-distance economic and social networks, innovative technologies and diverse resource management systems emerged by the first millennium BCE. The long-term history of the lowlands suggests a series of regional and sub-regional cycles of growth, decline and re-organisation during the course of the Preclassic (2000 BCE–CE 250), Classic (CE 250–1000), and Postclassic periods (CE 1000–1550), in which long- and short-term rainfall variations played important roles by introducing challenges and opportunities for freshwater security (e.g. Lucero, 2006; Lucero et al., 2011).

Pre-Columbian iconography and inscriptions show how vital water was to the Maya (Finamore and Houston, 2010). Rainfall dependency was a major part of Maya life. Too much water or not enough was something which the Maya dealt with through the seasons, including hurricanes, tropical storms, seasonal drought, and so on (Isendahl, 2011; Lucero et al., 2011). Water needed to be controlled and distributed in the wet season, collected, stored and conserved for the dry season and allocated throughout the year (Lucero et al., 2015: 1143). Freshwater security became critical for daily drinking needs, especially as the dry season wore on when water supplies decreased, and water quality declined. Cooking of the staples of maize and beans also required water, as did ceramic and plaster manufacture, and other quotidian needs. The hydrological regimes of the lowlands are diverse but share two basic characteristics: a tropical climate with pronounced wet and dry seasons, and karst limestone geomorphology where the permeable bedrock absorbs much of the rainfall. How these characteristics played out as challenges and opportunities for freshwater security varied cross-regionally.

Freshwater security and community wealth in the Maya lowlands

The Puuc-Nohkakab

The Puuc-Nohkakab forms a physiographic sub-region of the northern lowlands with very gently folded, bedded limestone and significant soil diversity including deep, well-drained, nutrient-rich soils with relatively high soil organic matter that rank among the lowlands' most productive (Dunning, 1992). Indeed, ethnohistorical sources suggest that the region was considered *nohkakab*, 'the place of good earth' (Isendahl et al., 2014: 46). The lack of natural freshwater supplies was, however, a constraining factor. The climate is seasonally dry with regional annual averages currently at about 1150 mm, and common anomalies include a wet season dry and the unproductive rainfall from hurricanes and tropical storms (Isendahl, 2011). There are very few water-bearing karst landforms such as *cenotes* (natural sinkholes) and caves, and the permeable limestone prevents permanent water bodies and streams from forming.

Initial conditions of sparse habitation and no permanent freshwater sources in a region with a seasonally dry climate suggest low community wealth and low water security. This phase dates to sometime before the growth of a dense regional network of agro-urban settlements in the Late Classic (i.e. pre-CE 550). In the main, pre-Late Classic settlement probably consisted of small, dispersed dwellings occupied on a seasonal basis during the rainy season, but there were also a few early centres possibly going back to the Middle Preclassic (800–300 BCE) (Smyth et al., 2014). Preclassic occupation may represent a phase of exploration, predating full-scale exploitation (see Bocinsky et al., 2016), with principally seasonal settlement and cultivation.

Solving challenges to water sustenance and increasing agricultural labour would provide basic conditions for a transition to high EROI. Freshwater security was addressed through the use of two main hydro-technological solutions: large open still-water reservoirs and small underground water cisterns (Isendahl, 2011). Both captured and stored rainwater for multiple purposes: household and elite consumption, garden and field pot irrigation and in ritual and ceremonial activities. Household cisterns were constructed by excavating a chamber in the soft marl layer of the bedrock, typically in the centre of the residential patio group. Rainwater filled the cistern through a narrow, circular, vertical tunnel and cistern walls were plastered to prevent seepage. The cistern formed the main source of water for domestic use in each residential unit, probably including pot irrigation of kitchen gardens. Whether the know-how to construct and provide maintenance on cisterns was common knowledge or required skilled craftsmen is debatable. Cistern construction may have been the responsibility of household heads, assisted by household dwellers and neighbours, and with some element of consulting with an experienced and skilled cistern-builder in a system of obligations within the urban neighbourhood level of social organisation (Isendahl and Heckbert, 2016; see also

Isendahl and Smith, 2013). Once constructed, the daily running of the cistern (principally sweeping the catchment surface surrounding the cistern opening) and consumption of water was managed by the farmstead dwellers themselves. However, re-plastering and other major maintenance work may have required special skills not usually found within the average household.

Open, still-water reservoirs with the capacity to store large volumes are quite widespread in the Puuc-Nohkakab, with 38 reservoirs currently recorded (Isendahl, 2011: 185). The formation of reservoirs involved both geomorphological processes and hydro-technological engineering. They were constructed by modifying flatland depressions, originally formed by karst processes associated with structural fracturing in the bedrock, to control seepage and enhance storage capacities, often involving considerable labour investments (Siemens, 1978: 136–137; Dunning, 1992: 22–23; Isendahl, 2011: 189–191). Reservoirs come in many different sizes and associations: Uxmal, the largest regional city, had 13, but there were also cities without reservoirs (Isendahl, 2011: 189; Isendahl et al., 2014: 47).

Reservoirs played a decisive role for freshwater security in the Puuc-Nohkakab. They may have been used in field pot irrigation and to refill water cisterns (Isendahl et al., 2014: 46) and also likely functioned in political activities as a place for large-scale public ceremonies, as often suggested by their relative location in the landscape and from the occurrence of fine wares and ceremonial ceramics in reservoir contexts. Depending on the amount of labour invested in construction and maintenance, and their location in the agro-urban landscape and storage capacities, reservoirs may have been managed at different levels in the socio-administrative organisation of Puuc-Nohkakab cities above the household level (Isendahl, 2011: 185; Isendahl et al., 2014: 46). McAnany (1995: 91; see also Isendahl and Smith, 2013: 136–137) suggests that the lineage-based leadership of the urban neighbourhood was in a key position to supervise agricultural production, organise labour, distribute resource rights to households and control and coordinate the flow of tribute up a hierarchy of social obligations. It is a reasonable assumption that their role was as central regarding the management of water resources. For instance, replenishing cisterns from reservoirs is likely to have involved negotiation, supervision and sanction among and by urban neighbourhood elites.

The early dates associated with a few proto-urban settlement centres, such as Xcoch (Smyth et al., 2014), suggests an initial phase of slow growth and exploration. But the settlement data indicates that this phase was punctuated in the Late Classic (CE 550–800) with considerable growth acceleration, moving from limited exploration to large-scale exploitation. Late Classic acceleration may have marked a situation when different variable conditions were just right for high energy gain: a significant reserve of under-exploited soil resources, a water management system that addressed vital freshwater security issues at the scale that was needed, an agricultural labour force with growth potential, and an infrastructure to organise and manage exploitation strategies. The established water management system and the resulting positive feedback in further investments mirror increasing freshwater security and community wealth in a phase of high EROI.

The development of a water management system was linked to increasing and costly regional social complexity, and an exploitation strategy aimed towards agro-economic maximisation. The Late Classic to early Terminal Classic (c. CE 550–900) was a period of agro-urban expansion and consolidation, seeing the establishment and growth of a network of urban, semi-urban and lesser settlements throughout the region. More land was brought under cultivation, and freshwater security was based on the reservoir/cistern hydro-technological complex. In the competitive agro-economy, regional populations grew, and labour yielded high returns that financed central institutions and associated urban services and functions. Continued growth during this period indicates an increasing ability to generate community wealth with maintained freshwater security. However, there is ample evidence of what can be understood as conspicuous elite consumption expressed in elaborate monumental building projects and large-scale ceremonialism at centres, not only indicating political integration and economic maximisation (Isendahl et al., 2014: 47–49), but also suggesting mismanagement of abundant resources in a phase of high EROI. For instance, at the end of the 9th century CE, the resources invested in constructing the House of the Governor and the Nunnery Quadrangle at the Puuc-Nohkakab polity capital of Uxmal were investments in the monstrous visual symbols (Fletcher, 1977) of the elite. This point in time seems to be the apogee of wealth generation before the energy gain ratio scaled down.

A transition to a phase of low energy gain followed. This transition was a result of the synergetic effects of conspicuous elite consumption, increasing sustenance needs from a growing population, no supplies of unclaimed farmland, intensified cropping and decreasing surplus production, while pressure to feed the population and to maintain costly central institutions and water reservoirs remained (Isendahl et al., 2014: 49). In effect, more people worked, they worked harder, but most gained less. These conditions levelled out growth as well as stretched the water management system to its limits (or beyond). Once pushed into producing maximum yields, the agro-economy could support production levels no more than 75 years before crashing, according to one estimate (Andrews, 2004), suggesting that this phase of a socio-ecological system at its productive limit extended over a relatively short period of the mid-Terminal Classic, perhaps around CE 900–950 (Isendahl and Heckbert, 2016).

By at least the end of the Terminal Classic (CE 950–1000), there was widespread depopulation in the Puuc-Nohkakab region, particularly of cities but possibly of non-urban areas as well (Carmean et al., 2004; Braswell et al., 2011; Simms et al., 2012), thus losing community wealth and the capacity to build freshwater security. Urban diaspora indicates that the complex organisation of social institutions was unable to make the organisational decisions necessary to adapt to the changing conditions of a transition from high to low EROI, setting off an accelerating downward spiral of function loss. Attempts to maintain the status quo were misdirected as seen at many centres (e.g. Uxmal), where rulers initiated large-scale monumental construction projects as the agro-economy entered a phase of low EROI at a time when there was a need to downscale and address the loss of key resources (labour and an effective blue-green infrastructure of freshwater security and fertile soil resources), suggesting systemic rigidity and non-adaptability, and therefore, vulnerability to crisis (Isendahl et al., 2014: 49–50). Furthermore, palaeo-climatic data (e.g. Medina-Elizalde et al., 2010) indicate several prolonged droughts during the Terminal Classic, and multiannual droughts provided particularly difficult challenges to freshwater security whenever it occurred. However, extreme climate events must have been particularly challenging in the turmoil situation at the end of the Terminal Classic and are likely to have accelerated the pace of function loss (Isendahl et al., 2014: 50).

The boom-and-crash character of the Puuc-Nohkakab agro-economy suggests a situation where a complex form of social organisation had locked into a path dependent on sustained growth, failed to adapt to diminishing returns and was unable to adopt alternative social, economic and organisational pathways. The incentive to maintain investments in the water management system deteriorated, resulting in rapid loss of freshwater security. Reoccupation of the Puuc-Nohkakab region would have required considerable investments to refurbish the reservoir/cistern hydro-technological complex and readdress freshwater security by tenable solutions (Dunning et al., 2012: 3655). These resettlement costs help explain the slow process of reoccupation in the region, which have yet to reach population numbers and densities of the early Terminal Classic period, some 1100 years ago, nor are they likely to do so within the foreseeable future (Isendahl et al., 2014: 50).

The southern lowland interior

The southern lowland interior is in itself a highly diverse region consisting of a series of physiographic sub-regions characterised by variations in precipitation patterns, drainage, topography, and soil and geomorphic processes (Dunning and Beach, 2010). Several of the largest and most powerful pre-Columbian Maya cities of the southern lowland interior, including Calakmul, El Mirador, Nakbe, Naranjo and Tikal, were located on the Petén Karst Plateau, an uplifted karst terrain of limestone hills and ridges with annual rainfall averaging c. 1,500–2,000 mm (Isendahl et al., 2016). While the Petén has limited surface water, essentially lacking perennial surface freshwater sources and accessible potable groundwater, it has large plots of fertile soils. In fact, most of the largest Classic cities of the southern lowland interior are found in areas with large plots of fertile soils, little potable surface water and surrounded in parts by seasonal wetlands or *bajos* (e.g. Culbert, 1997; Dunning et al., 2003; Lucero et al., 2014). These initial, pre-exploitation conditions were quite similar to those in the Puuc-Nohkakab – low freshwater security and low community wealth – with considerable growth potential owing to the availability of fertile soils constrained principally by poor access to freshwater.

Following a long period of exploration (see Bocinsky et al., 2016), the Maya began to occupy the Petén in the Middle Preclassic (c. 1200–250 BCE) (Ford, 1986: 59, 80–82), which formed a transition towards large-scale exploitation in a phase of high EROI. Elite lineages appeared by c. 900 BCE, the first kings by c. 100 BCE and by the Classic period (c. CE 250–850), numerous agro-urban landscapes had emerged, each constituting a city-state governed by a king. Towards the end of the Classic period (between c. CE 550 and 850), the interior southern lowlands witnessed its highest population size and density, as well as its greatest extent of kingship. They accomplished the feats for which they are famous – royal temples, palaces and tombs, inscriptions, painted ceramics, incised jades and obsidian items and long-distance trade – without beasts of burden, wheeled carts, metal tools, or extensive road and irrigation systems. Although the period from the Middle Preclassic to the Late Classic was not a period of constant regional growth—there were at least two instances of temporary recession – it follows a general trend of increasing community wealth in the Petén over c. 1,500 years.

To concentrate sedentary populations in the Petén the Maya had to develop systems to strengthen freshwater security. During the annual drought, even many of the *bajos* that make up about 40% of the southern lowlands became desiccated (Dunning et al., 2006). The rainy season often brought flooding, hurricanes, turbid waters, debris-clogged and un-navigable rivers, erosion, mudslides and crop damage. If the Maya planted too soon before rains began, planted seeds would rot; if they planted too late, that is, rains started earlier than predicted, seeds did not germinate (Isendahl, 2011). To address the constraints of rainfall seasonality and heterogeneous distribution of soils, the Maya transformed the Petén landscape in order to access, control and improve water and soil resources, from small-scale, household-based management systems to large-scale landesque investments in city centres (Lucero et al., 2014: 30).

As in the Puuc-Nohkakab region, large-scale reservoirs contributed to the central functions of city centres and acted as a counterforce against the tendency of populations to follow the dispersed nature of tropical resource distributions and subsistence practices that made it challenging for kings to integrate them (Lucero, 2003). In return for contributing towards freshwater security, and in addition to other services such as public events and ceremonies and markets, commoners provided labour, staple goods, local produce and services via tribute and exchange, thus funding the political economy and central social institutions (Lucero et al., 2015: 1140–1141). The increasingly larger reservoir systems, at Tikal for instance, became interwoven with the urban layout (e.g. ceremonial roads or *sacbeob* simultaneously serving as dams) (Scarborough et al., 2012) and required resources continuously for construction, elaboration and maintenance (Figure 1.2). In areas without reservoirs, people likely stored water in jars and other containers replenished daily during the rainy season. During the dry season, however, they needed access to potable water, which they found in the reservoir systems in city centres.

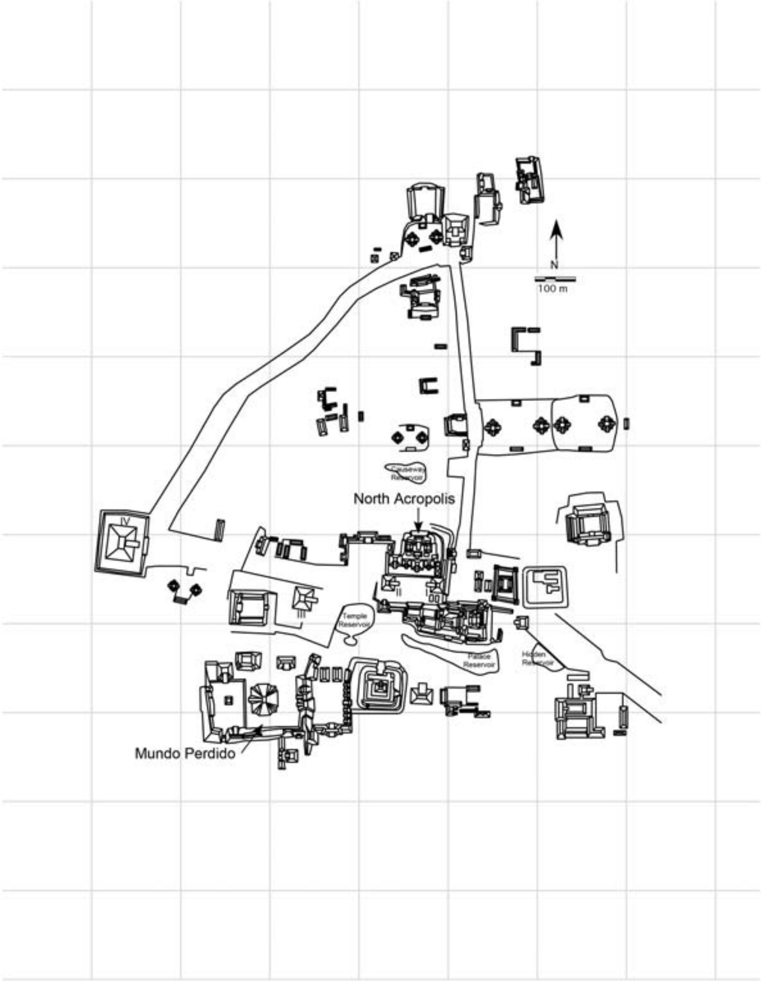

Figure 1.2 Map of the city centre at Tikal (redrawn by L. J. Lucero from Martin and Grube, 2008: 24).

The longevity of the city-states of the southern lowland interior can, as Scarborough (1993: 19–20) notes, 'be attributed to their successful, uninterrupted, accretive landscape engineering, an adaptation in part conditioned by a seasonally limited water supply and the fragility of the wet-dry tropical forest'. In fact, the Maya made landesque investments to manage freshwater even before they built monumental constructions in the Late Preclassic (Scarborough, 1998). These consisted of wetland reclamation and passive or concave micro-watershed systems where the Maya worked with existing geographic features, such as depressions at El Mirador (Scarborough, 1993). Investing in freshwater security was a key factor for a surging political economy, ushering in a phase of high EROI and increasing community wealth in the region. Some of the earliest experiments with large-scale water systems failed, however, perhaps as a result of silt build-up (Hansen et al., 2002) and/or drought (Medina-Elizalde et al., 2016) as seen at El Mirador and Nakbe, abandoned by c. CE 150. Continued regional population growth throughout the Early Classic (c. CE 250–550) resulted in kings organising the construction of increasingly larger and more sophisticated reservoirs, a trend that continued into the Late Classic period (c. CE 550–850) when political power and population size reached their zenith. By this time, the Maya relied on sophisticated reservoir systems epitomised by elevated convex macro-watershed systems where reservoirs, dams and channels were designed to capture and store water (Scarborough et al., 2012). At Tikal, the water catchment system could hold more than 900,000 m^3 of water. The controlled release from elevated reservoirs downslope serviced tens of thousands of subjects, supplying freshwater to households and for irrigation (Scarborough, 2003: 51, 110–111). However, with increasingly complex and interwoven water and political systems followed growing dependency and vulnerability.

In the southern lowland interior, the peak population density and apogee of political power were attained during the eight and early 9th centuries CE, epitomised at Tikal, Calakmul and Caracol. With increasing power came greater reliance on water management systems that intensified the vulnerability of water security. Yet kings continued to construct monumental structures, as well as attempted to extend their power through warfare and political alliances with other centre elites. A millennium trend of increasing growth was wearing off as EROI scaled down after centuries of full-scale exploitation under a maximising economic paradigm. Decreasing revenues in the Late Classic would have been more efficiently managed by investing in new technologies or practices. Identifying the structural problem of instability in the political economy and finding new solutions would be a more sustainable strategy than conspicuous consumption and warfare, particularly in the face of increasing climate instability. Increasing path dependency revolving around massive, interlinked reservoir systems in the face of growing populations and soil degradation in some areas decreased security at all levels, resulting in an increasingly volatile situation politically, economically and socially.

In the southern lowlands, the Terminal Classic (c. CE 800–900) encompassed a massive urban diaspora out of the interior zone and its former powerhouses Tikal, Calakmul, Caracol and most other centres (Lucero, 2006: 24–25; Lucero et al., 2015). Kings failed their subjects when reservoir systems failed in the face of several prolonged droughts that occurred from c. CE 800 to 900 (Douglas et al., 2015; Medina-Elizalde et al., 2010). Freshwater security in the region fell to an all-time low, as did community wealth. Approximately 90% of the population ultimately left the interior southern lowlands (Turner and Sabloff, 2012: 13908). While each of the hundreds of Maya cities had its own specific circumstances and history, in the end, farmers abandoned kings, their desiccated reservoirs, and their royal stages – i.e. the city centres of these agro-urban landscapes. Thus, the political systems faltered but farmers adapted and persevered, albeit in different places, and relied on different political systems (e.g. shared rulership in several northern lowland settlements) and smaller scale water management systems.

An alternative trajectory: Saturday Creek, Belize River Valley

To contrast the Puuc-Nohkakab and Petén cases, which jointly deliver a fairly uniform picture of the ability of Classic Maya political economies to provide freshwater security over several hundred years in the case of the former, to more than a millennium in the case of the latter, based on complex water management systems involving considerable investments and requiring continued maintenance, we present a case study suggesting an alternative trajectory.

The people at Saturday Creek, located in the Belize River Valley region immediately to the west of the Petén Karst Plateau, did not rely on a water management system based on high-investment landesque capital such as those in the Puuc-Nohkakab or the Petén Karst Plateau, nor were they directly dependent on their concomitant socio-political infrastructure (Lucero, 2006: 67–113). This minor settlement is located on rich alluvium at an altitude of 20 m above mean sea level along the north side of the Belize River with the mean annual rainfall at 2,160 mm, i.e. higher than in the southern lowland interior. Belize River Valley region 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. In the interior, at the height of the dry season, river levels drop and become dangerous (by exposing rock formations), increasingly dirty (silt, bacteria) and unnavigable, but this was not the case at Saturday Creek. Initial conditions were thus significantly different from the Puuc-Nohkakab and the Petén, with a high degree of freshwater security from relatively high precipitation rates and an access to streaming water. Furthermore, the rich alluvial soils were very well suited for recessional floodplain agriculture of key crops such as maize, beans, squash, cacao and cotton (Lucero et al., 2004).

Hence, the Maya at Saturday Creek did not need to make large investments in landesque capital such as reservoirs, canals, or irrigation systems to provide year-round freshwater security, neither for household consumption nor for cultivation. From at least 900 BCE through to CE 1500 the people at Saturday Creek lived in farmsteads consisting of two to four buildings dispersed around a settlement centre with a ball court, temples and elite compounds (Lucero, 2006: 67–113) (Figure 1.3). Saturday Creek formed an extensive settlement; a dispersed community of wealthy and less wealthy farmers likely cultivating all along the Belize River alluvium (Harrison-Buck et al., 2015). These features and the presence of imported goods in both commoner farmsteads and elite compounds demonstrate that the local population was successful in generating some degree of community wealth. However, in contrast to the powerful

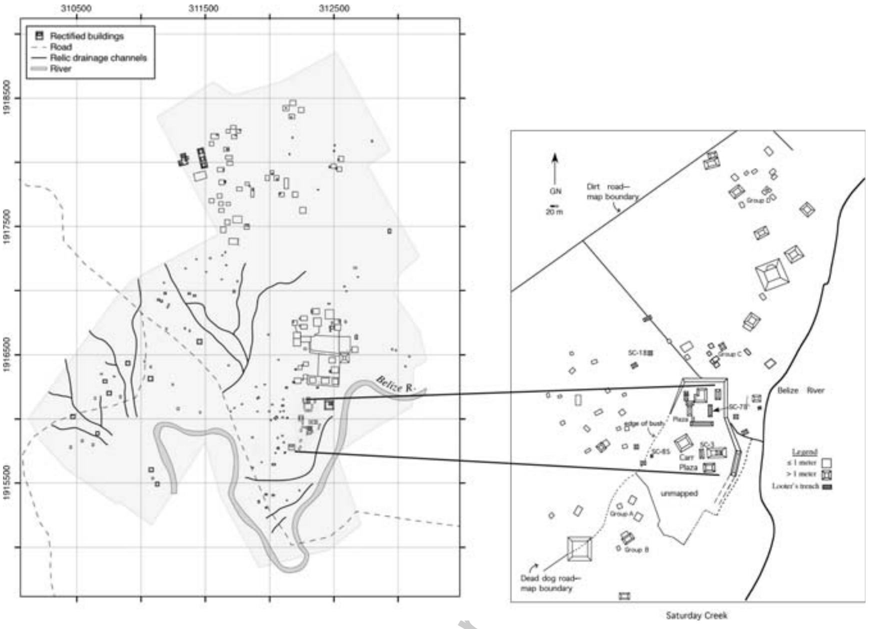

Figure 1.3 Map of the pre-Columbian Maya settlement at Saturday Creek (Harrison-Buck et al., 2016: figure 3).

city-states of the Petén, such as Tikal and Calakmul, Saturday Creek lacked kings, tribute payments, royal palaces and hieroglyph inscriptions; there were no monstrous visual symbols of elite conspicuous consumption (Lucero, 2006: 67–113; Isendahl et al., 2016).

Freshwater security was maintained throughout c. 2,500 years of pre-Columbian occupation at Saturday Creek. The multi-year droughts during the 9th century CE (Medina-Elizalde et al., 2010) that had a significant impact on the stability of the city-states in the Petén, do not seem to have affected Saturday Creek's inhabitants since they were not dependent on landesque investments for freshwater security and community wealth (Lucero et al., 2011). When the Petén city-states collapsed, long-distance exchange networks failed resulting in less access to trade items, thus affecting community wealth. However, exotics were soon obtained via a reorganised trade network focusing on sea trade to the north and east. Until Saturday Creek was largely abandoned (for reasons that are still unclear) in about CE 1500, freshwater security was at a consistently high level. Community wealth, as deducted from population numbers and densities and monumental construction, was more moderate than at the powerful city-states in the Puuc-Nohkakab and the Petén, but it was clearly more stable and sustainable, and had little fluctuation in EROI once settled and the institution of recessional agriculture had been worked out. At Saturday Creek, people might have enjoyed less community wealth than in the Puuc-Nohkakab or the Petén, but they did so more equitably and for longer.

Concluding discussion

Equitable community wealth and freshwater security are critical issues in our time, dependent on current environmental, socio-economic, technological and institutional conditions. The Puuc-Nohkakab of the northern Maya lowlands and the Petén Karst Plateau of the southern Maya lowlands are historical examples of approaches to freshwater security where investments in water management systems initially solved factors constraining development in areas with rich soils but seasonally unsecure water resources. However, over time, increased dependency triggered vulnerabilities to economic and political crises. Initially, these water management systems yielded high returns on investment, contributing to freshwater security and community wealth. Over time the sunk costs of this strategy yielded decreasing returns on such investments. As reservoirs became increasingly more complex, kings relied on them more and more to attract subjects in order to control labour and produce. Increasing complexity went hand in hand with increasing inflexibility, decreasing diversity and greater interdependence. The more kings relied on reservoirs, the more vulnerable and inflexible their system became. Kings lost power; farmers moved on and adapted, and continue to do so, as the seven–ten million Maya currently living in present-day Guatemala, Belize, and southeastern Mexico attest. The growing dissonance between reliance on increasingly complex material technologies and long-term survival has interesting and important implications for the present (see Fletcher, 2002; Scarborough and Lucero, 2010; Barthel and Isendahl, 2013; Ingram, this volume; Isendahl and Heckbert, 2016). One lesson is that top-down mitigation alone will not work towards addressing current issues on sustainability and global environmental change. The case of Saturday Creek points in the same direction. The people living there enjoyed relatively high freshwater security and moderate community wealth, and did so over two and half millennia, without a costly organisational superstructure such as the political systems of the Tikal or Calakmul city-states of the southern lowland interior. The contrast between such a water management system, not requiring landesque investments and constant maintenance costs, with the complex reservoir systems is striking, not least by their relative longevity, from about 400 years in the Puuc-Nohkakab case, more than 1000 years at Tikal and to the 2,500 years at Saturday Creek.

The archaeological perspective is particularly important in focusing on the very long-time perspective when thinking about the sustainability of socio-ecological systems or institutions, such as approaches towards managing freshwater security. In the mainstream discourse, sustainability is hardly ever defined and commonly vaguely associated with *indefinitely*. From the archaeological record we know for certain that no system or institution works indefinitely and without social or environmental tradeoffs (e.g. Hegmon, 2017). Was the

Puuc-Nohkakab approach to freshwater security by constructing reservoirs sustainable? To put it in a comparative perspective, it lasted as long as the time-period from the start of the European Thirty Years War until today. The longevity of the Tikal system of reservoirs takes us as far back as the time of the Viking raids on the British Isles. At Saturday Creek, people relied on the Belize River to provide freshwater and sediments for a time-period about as long as from today, back to the time of the founding of Rome. Embedded in these integrated systems to manage freshwater are past developments and investments required to construct complex water management systems, many of which require incremental costs which bequests society today with opportunities and liabilities inherited from the past. Many of these require long timescales, such as gradual shifts in regional climate, invention of technology, or evolution of governance systems for water management systems. Learning from the archaeological record allows us to examine how water management systems of the past have contributed to sustainability over the long term.

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