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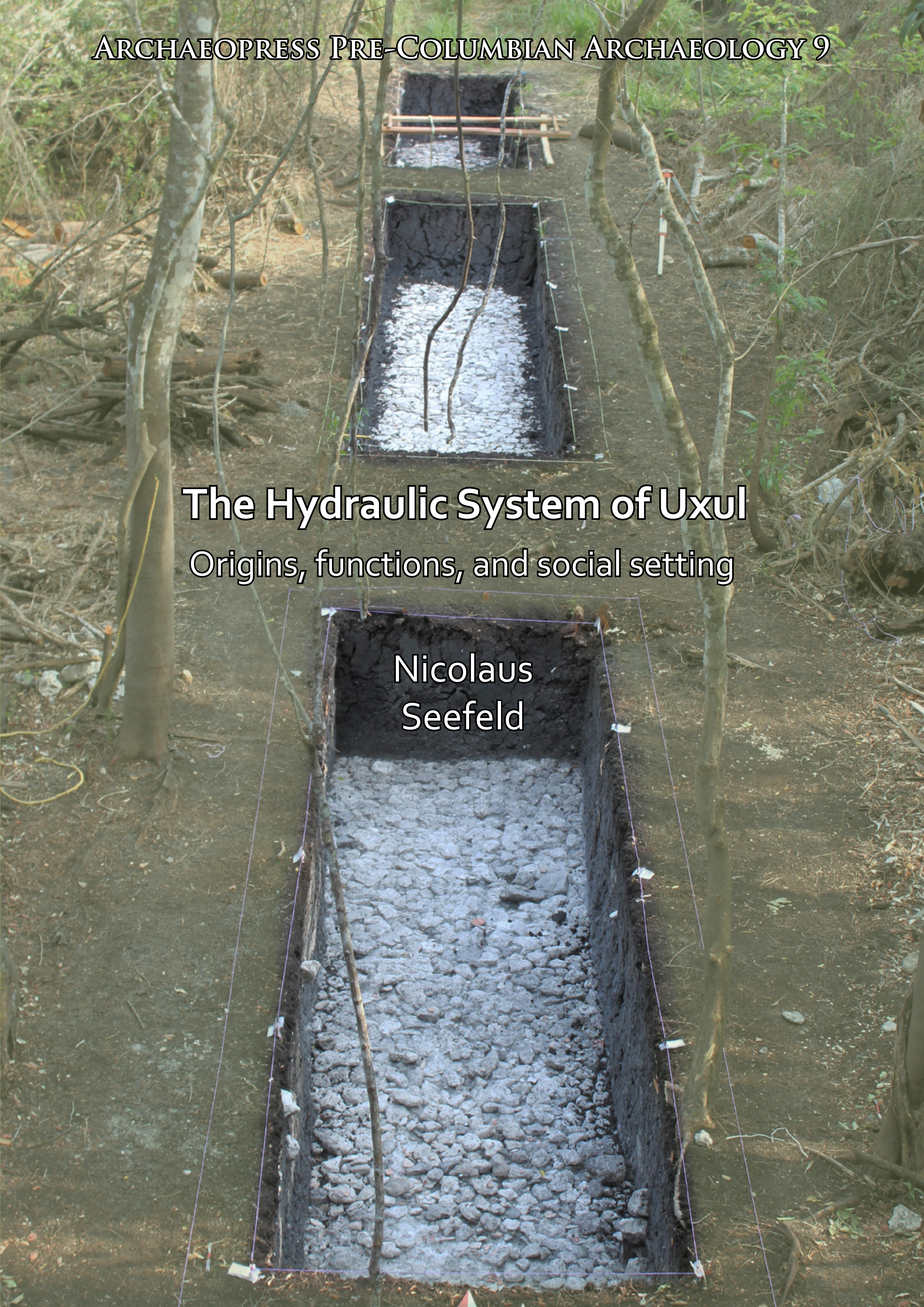

The Hydraulic System of Uxul

Origins, functions, and social setting

Nicolaus
Seefeld

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In memory of Sven Bayer (1978-2015)

Contents

List of figures

List of Tables

Foreword

In his book *Maya Civilization*, which was first published in 1993, Pat Culbert wrote that “this is an exciting time to be a Mayanist” (Culbert 1993: 160). There were several reasons for this excitement. Progress in deciphering the Mayan script had overturned the earlier romantic image of a peaceful and gentle people and transformed the Classic Maya from a prehistoric into a historic civilization. At the same time research into ancient Mayan settlement and wetland systems, in which Culbert himself had been actively involved since the 1970s (Adams et al. 1981), had disproved the notion of a slash-and-burn farming population inhabiting a largely empty landscape.

Twenty-five years later, one can confidently say that the study of ancient Maya civilization continues to be just as exciting. The origin of lowland Maya hieroglyphic writing has now been pushed back to at least the third century BC (Saturno et al. 2006) while LiDAR (Light Detection and Ranging) has revolutionized archaeological remote sensing in the Maya lowlands (Chase et al. 2011; Chase and Weishampel 2016) as well as in other forest regions of the world (Evans et al. 2013). The new data provide us with both a detailed picture of the scale of ancient landscape engineering and a much better idea of the size of the ancient populations.

For researchers who, like the author of this book and the author of this foreword, have invested a great deal of time and energy in tedious landscape surveys and excavations of water features within the tropical forests of the Maya lowlands, these new remote sensing technologies cause excitement. What once took archaeologists years can now be accomplished in comparatively little time if the necessary funds are available. However, while these new technologies may complement traditional fieldwork, they will never entirely replace it (Chase et al. 2011). This book provides good evidence for this.

The Hydraulic System of Uxul is based on Nicolaus Seefeld’s dissertation, the result of many years’ work. The core of the book consists of a detailed presentation of the results of his excavations of three hydraulic features at Uxul, Campeche, Mexico, which he conducted under the auspices of the University of Bonn between 2009 and 2014. The volume also includes a comprehensive discussion and summary of the history of research into water and land management in the Maya lowlands. The author discusses how the ancient Maya managed and mastered water in a landscape characterized by karst hydrology, seasonal and unpredictable levels of rainfall and an inaccessible water table. This critical resource initially supported and sustained an increase in population size but also created problems that may have contributed to the so-called collapse of Classic Maya civilization. Although the role of climate change and drought in the demise of Classic Maya society is a much debated issue, this book clearly shows the importance of water supply to survival in one of the most densely populated areas in human history.

Estella Weiss-Krejci
April 3, 2018
Austrian Academy of Sciences, Vienna, Austria

Preface

This present book is an updated and revised version of my doctoral dissertation that I completed and defended in 2017. It is the result of an extensive and intensive investigation project, which was determined to close an essential research gap – the understanding of the water management strategies of the Maya in pre-Hispanic times. Its central focus is the identification of the adaptation strategies that enabled a constant water supply of Classic Maya polities during the critical dry seasons. The starting point for this project consisted of the determination of the geological and climatic factors that cause recurring water scarcity in the Central Maya Lowlands. Building on these results, I focused on the reconstruction of the climatic conditions in the Central Maya Lowlands during the Late Classic Period, when this region was most densely populated. At the same time, the identification of adaptation strategies was constantly accompanied by the revision of hydraulic features that had been described by other scholars.

In 2009, I had the opportunity to participate in the Uxul Archaeological Project, which was launched the same year by the director, Nikolai Grube. At the onset of the project, only one water reservoir was known to exist, the western Aguada (later named *Aguada Occidental*), which had been discovered by Karl Ruppert and John Denison (1943: 17). During the first field season, I was responsible for the continuation of the topographic survey of the site. This process led to the discovery of another large water reservoir in the east of the site, which I subsequently named "Aguada Oriental" and archaeologically investigated in 2009. These initial results showed that Uxul not only featured an array of well-preserved hydraulic features, but a more complex hydraulic system than had been previously observed in a medium sized Maya polity. Based on these results, I received permission to pursue my own research project concentrating on the adaptation strategies of Uxul's pre-Hispanic inhabitants that had enabled a constant water supply for the settlement.

In the course of the investigation, several other hydraulic features of various scales were discovered and studied in Uxul and contributed to an increasingly precise understanding of the functionality and the development of the hydraulic system. Due to this intensive investigation, I soon defined the hydraulic system of Uxul as the central reference point of the broader study. While Uxul's hydraulic system was certainly highly adapted to the specific conditions of the local landscape, numerous other Maya polities had emerged and flourished in quite similar topographic conditions and, in effect, also overcame similar adversities. Accordingly, the functionality of the respective hydraulic features of Uxul could be transferred to hydraulic features of other sites in the Central Lowlands. In addition, the investigation of Uxul's hydraulic system allowed a comparative assessment of the overarching research question: The definition of the adaptation strategies of the pre-Hispanic population that enabled a constant water supply for settlements in the Central Maya Lowlands. Once it became clear that the site of investigation and the resulting data enabled a comprehensive evaluation of the research question, four questions were defined as the central goals of the present study:

(1) The determination of factors causing temporal water scarcity and the elaboration of the characteristic local and regional variations in water-availability within the landscape of the Maya Lowlands.

(2) The assessment of the different types, technical layout, functionality and geographic distribution of hydraulic features[1] that the pre-Hispanic Maya developed in order to allow a constant water supply for their settlements.

(3) The analysis of the function and development of Uxul's hydraulic system and its integration into the local landscape, the urban infrastructure and the different residential areas of the settlement.

(4) The elaboration of the inferences drawn from Uxul's hydraulic system on the form of society and governance in which it emerged and a general assessment of the relevance of water management in the politics of Late Classic Maya society.

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[1] Definition: Landscape modifications or constructions for the storage, transport and/or redistribution of water which are either visible in the landscape or can be identified by means of archaeological methods. In the following course of the dissertation, these elements will always be referred to as hydraulic features.

Acknowledgements

I would like to express my gratitude to all the friends and colleagues who enabled me to publish this book, which is based on my dissertation. I am grateful to my supervisor Prof Dr Karoline Noack (University of Bonn), for her help and courageous support throughout the preparation of this work. I am particularly thankful to Univ.-Doz. Dr Estella Weiss-Krejci (Austrian Academy of Sciences, Vienna), who gladly offered her support and expertise in the preperation of my dissertation and this book. Thanks to her valuable remarks, many critical aspects of this book underwent significant improvements. Moreover, I would like to thank Prof Dr Martin Bentz (University of Bonn) and Dr hab. Jarosław Źrałka (Jagiellonian University, Cracow) for their help and their participation in my dissertation committee. Furthermore, I am grateful to Prof Dr Nikolai Grube, director of the Uxul Archaeological Project, who was always deeply interested in the progress of my research project.

Over the course of many field seasons in Uxul, Dr Antonio Benavides-Castillo, Director of the Centro INAH Campeche, and his wife Sara Novelo Osorno were reliable friends and provided support in many logistic matters or medical emergencies. In this context, I would also like to thank Lirio Suárez Amendola, former director of the Centro INAH Campeche, and Marco Antonio Carvajal Correa, former museum director of the Centro INAH Campeche, for their kind cooperation in obtaining permissions for material-analyses as well as Dr Pedro Francisco Sánchez Nava, National coordinator of Archaeology of the INAH, Mexico, for his logistic support of our overall project. From the team of the Uxul Archaeological Project, I would also like to thank Julia Bach and Sara Dzul Góngora, who were responsible for the ceramic analysis and provided me with valuable information on the chronology of Uxul's hydraulic features.

The publication of this book also would have been impossible withouth the help and support of my publishers. In this respect, I would particularly like to thank David Davison and Ben Heaney of Archaeopress, who showed much patience in the publication process of this book and provided me with many valuable helpful suggestions.

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Thank you.

1 Introduction

Since the inception of Maya studies, the issue of water supply in Maya polities of the Central Lowlands during the Classic Period has been a matter of controversial debate. Due to the annually recurring dry seasons, the availability of water during this period is and has always been problematic. In the light of these conditions, the fact the pre-Hispanic Maya were able to establish, develop and maintain prosperous urban centers over long periods is difficult to explain. The longevity and resilience of the ancient Maya over a period of 1,500 years reveal significant cultural and environmental adaptations to a seasonally wet-dry tropical ecosystem inhabited by a sizable population (Scarborough *et al.* 2012: 12408). Population estimates for the southern Maya Lowlands in AD 700 suggest as many as five million people – a population-density much greater than the region supports today (Culbert and Rice 1990; Scarborough and Burnside 2010). These demographic figures indicate that the pre-Hispanic Maya had evidently developed effective adaptation strategies for survival in this landscape (Parry *et al.* 2007: 28; Scarborough *et al.* 1995: 98). However, even at the current state of Maya archaeology, these adaptation strategies are largely unknown and have barely experienced a systematic investigation.

1.1 Definition of the research question

Due to these circumstances, we are currently lacking an exact explanation of how the Classic Maya polities of the Central Lowlands secured a constant water supply. Even though the scientific community acknowledges the general existence of pre-Hispanic artificial water reservoirs, it is not aware of the historical development of hydraulic features and their sociopolitical relevance in Classic Maya society. Furthermore, many scholars still debate whether the pre-Hispanic climatic conditions of the Maya Lowlands had an effect on the formation of hydraulic features. A central cause for the continuing debate on the social relevance of water management and the influence of paleoclimatic conditions on the development of hydraulic systems is the imprecise understanding regarding the specific geological and climatic conditions in the different geographical regions of the Maya Lowlands (Fedick 1996).

1.2 Research goals

This book is focused on both the hydraulic system of Uxul and the hydraulic features of the Maya Lowlands in general. The main reason for the large number of open research questions is the fact that the scientific discussion on the historical development and sociopolitical relevance of water management in the Maya Lowlands is based on a very limited set of hydraulic features and thus fails to put particular findings into the broader geographical, historical, and social context. Therefore, the author tried to carry out a differentiated investigation and discussion of hydraulic features and the theories on their historical and sociopolitical relevance. In order to enable a systematic investigation of these open research questions, the author defined the four general research goals mentioned in the preface.

(1) Determination of factors causing temporal water scarcity and the elaboration of the characteristic local and regional variations in water-availability within the landscape of the Maya Lowlands. A precise determination of the different geological and climatic factors responsible for the temporal water scarcity in the Maya Lowlands is essential to understand the causes and effects of natural processes and to develop an understanding for the approaches of potential cultural adaptation strategies. In this regard, a differentiated knowledge of the regional variations in the geology, topography and climatic conditions are crucial in understanding the necessity and functionality of the different types of hydraulic features in the Maya Lowlands.

(2) Assessment of the different types, technical layout, functionality and geographic distribution of hydraulic features that the pre-Hispanic Maya developed in order to provide their settlements with a constant water supply. A precise overview on the geographic distribution of the different types of hydraulic features, their adaptation to the requirements of the specific landscape and their interaction

with other hydraulic features is fundamental for a well-founded understanding of how the pre-Hispanic Maya approached the construction of additional water sources. Furthermore, the differentiation of the various types of hydraulic features and their geographic distribution is important in order to investigate whether this geographic distribution was a reaction to the specific natural landscape or the result of purely cultural decisions.

(3) Analysis of the function and the development of Uxul's hydraulic system and its integration into the local landscape, the urban infrastructure and the different residential areas of the settlement. As pointed out, this book aims to resolve the open questions regarding the historical and social relevance of water management through the broad scope analysis of all published hydraulic features in the Maya Lowlands. Nevertheless, since the author was able to address and investigate many open research questions in the field, the hydraulic system of Uxul remains a central point of reference for the evaluation of the general social relevance of water management in the Maya Lowlands.

(4) Elaboration of the inferences drawn from Uxul's hydraulic system on the form of society and governance in which it emerged and a general assessment of the relevance of water management in the politics of Late Classic Maya society. Due to the lack of broadly based comparative investigations, it is first necessary to analyze and define the precise sociopolitical relevance of hydraulic features in different locations, epochs, and social strata of pre-Hispanic Maya society. Such a differentiated study is necessary to define the exact role of Uxul's hydraulic system for the local population and to define its relevance for the current state of research on water management in the Maya Lowlands.

1.3 Methods

In order to address the four main research goals, the author carried out an extensive literature review. This focused on defining the geological and climatic factors for water scarcity during the dry seasons and was complemented by the revision of the published data on the landscape and climate history of the Maya Lowlands. Simultaneously, the author analyzed all available publications on hydraulic features in the Maya Lowlands, many of which also included theories on their sociopolitical relevance in pre-Hispanic times to varying extents. Over the course of this project, the available publications on the landscape and climate history, the documented hydraulic systems and the theories on the historical and sociopolitical relevance of water management in the Maya Lowlands were gradually analyzed and incorporated into the general research objective. Furthermore, new publications were successively integrated in order to enable a differentiated presentation of the state of research. During this extensive study, the author was also able to observe many of the hydraulic features outside of Uxul in person. Apart from this broad scoped analysis of water management in the Maya Lowlands, the main method for answering the previously defined research goals was the archaeological investigation of Uxul's hydraulic system. In order to gain an understanding of the functionality of this hydraulic system and its adaptation to the local landscape, the author applied two basic research methods:

(1) A topographic survey of the settlement landscape to locate landscape modifications serving to divert and accumulate precipitation (see Figure 1.1a), and

(2) An archaeological investigation of these landscape modifications/hydraulic features to obtain data on the technology, chronology, and social implications of these modifications (see Figure 1.1b; Seefeld 2013a: 63).

For the purpose of enabling a thorough evaluation of the adaptation strategies of Uxul's pre-Hispanic inhabitants, the observations of the topographic surveys were continously consulted to better understand the characteristics of the local lsndscape and the cultural modifications. In the same way, the increased awareness of the drainage characteristics of the landscape, previous observations of the functionality ofUxul's hydraulic system all played a decisive role for defiining the location of specific excavation units.

Figure 1.1: The author during the topographic survey and excavations in Uxul.

The fieldwork was carried out as a component of the Uxul Archaeological Project, which began in March 2009. The project worked in collaboration with the Mexican Institute of Anthropology and History (INAH) and under the general direction of Prof Dr Nikolai Grube. Altogether, seven field seasons were conducted between 2009 and 2015. During the 2009 and 2010 field seasons, Dr Iken Paap held the position of field director. From 2011-2015, this position was held by Dr Kai Delvendahl. From 2009-2013, Dr Antonio Benavides Castillo of the Centro INAH Campeche was the Mexican co-director of the project. Throughout the entire duration of the project, funding was provided by the German Research Foundation (DFG). During the field seasons from 2009-2014, the author studied four different hydraulic features: The Aguada Occidental in 2010, the Aguada Oriental in 2009 and 2011, the influx canal to the Aguada Occidental in 2012 and an artificial cave in Group Q in 2013 and 2014.

1.4 Structure of this book

In order to enable the systematic processing and discussion of each defined research goal, the author structured this book in such a way that the causality of the different environmental factors causing water scarcity and the cultural adaptations to overcome them are clearly comprehensible.

Thus, the first main section of this dissertation, Chapter 2, addresses and defines the environmental factors that cause temporal water scarcity within the Central Maya Lowlands. At the onset, it provides a detailed description of the geologic history (Chapter 2.1.2), the different geological zones of the Central Maya Lowlands (Chapter 2.1.4) and the respective water sources of these different geological zones (Chapter 2.1.5). Building on this, the climate (Chapter 2.2), soils (Chapter 2.3) and landscape formations of the Yucatán Peninsula (Chapter 2.4) that are the results of geomorphological processes are outlined. After the presentation of the geomorphology of the Maya Lowlands, Chapter 3 focuses on the history of research regarding the issue of water supply in pre-Hispanic Maya settlements. The aim of this chapter is not to provide a complete review of the research, but to present the benchmark investigations and the general positions in the scientific discussion, which were extremely influential for the models of prehistoric climatic conditions that are presented in the upcoming chapter.

Due to its importance in the scientific discussion of water supply during the Late Classic Period, the climate history and landscape history of the Maya Lowlands (Chapter 4) are addressed in a specific section. In order to provide the reader with a better understanding of the existing models of the pre-Hispanic climatic conditions in the Maya Lowlands, Chapter 4 first covers: (1) the scientific methods applied for the reconstruction of past climates (Chapter 4.1), (2) the existing models of pre-Hispanic

climatic conditions (Chapter 4.2) and (3) the present state of knowledge of paleoclimatic studies (Chapter 4.3). Lastly, Chapter 4.4 provides a discussion of previous models of pre-Hispanic climatic conditions.
The second main section of this dissertation, Chapter 5, provides a review of hydraulic features in the Central Maya Lowlands. These hydraulic features can be identified as the immediate physical remains of pre-Hispanic adaptation strategies for the assurance of a constant water supply. Since this book is written from the perspective of an archaeologist, these features are of particular importance and have been the basis of all previously published theories on the historical and sociopolitical relevance of water management in pre-Hispanic Maya society. In order to enable a differentiated evaluation of these theories, the author defined three different perspectives from which hydraulic features can be analyzed and interpreted (see Figure 1.2):

(1) The technical design and functionality of a hydraulic feature or a hydraulic system,

(2) The historical development (formal and geographical distribution) of hydraulic features, and

(3) The social setting in which these hydraulic features emerged and/or their (potential) relevance for the pre-Hispanic Maya society.

In the author's opinion, it is highly important to separate the presentation and discussion of these three different perspectives. Whereas the first approach is merely descriptive and based on the thorough documentation of hydraulic features, the second and third represent superordinate levels of interpretation, which are presented and discussed in Chapter 8.

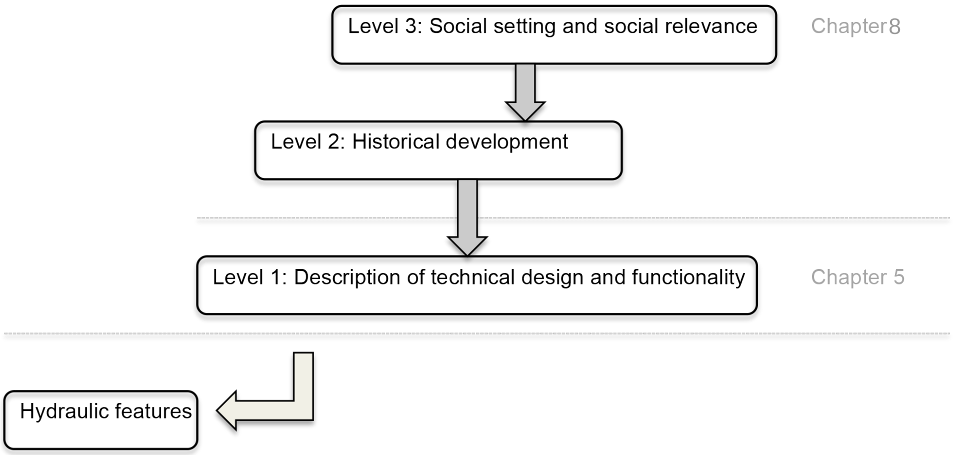

Figure 1.2: Schematic representation of the analysis of hydraulic features.

Chapter 5 however, will only illustrate and analyze the first perspective in the interpretation of hydraulic features – their technical design and functionality. Based on their structural composition and desired function, the wide range of hydraulic features can be subdivided into five main categories. The published examples of these features will be presented in specific subsections on canals (Chapter 5.2), terraces (Chapter 5.3), dam features (Chapter 5.4), drainage features (Chapter 5.5), reservoirs (Chapter 5.6) and complex hydraulic systems (Chapter 5.7). The main intention of this review is to provide the reader with an overview of the technological composition, functionality and geographic distribution of these different hydraulic features.

Based on the scientific understanding of the functionality of hydraulic features in the Maya Lowlands, Chapter 6 focuses on the third aspect of this book, the archaeological investigation of Uxul's hydraulic system. It begins with a brief introduction to the site of Uxul and the topographic location of its hydraulic features (Chapter 6.1) before presenting the results of the archaeological investigation (Chapter 6.2), the functionality of the respective features (Chapter 6.3) and the construction history of the hydraulic system (Chapter 6.4). In order to provide a summary on the presented systems, Chapter 7 presents the functional and spatial patterns of hydraulic features in the Maya Lowlands.

Focusing on the fourth aspect of this dissertation, Chapter 8 once again draws the attention to the whole Maya Lowland area and presents the theories on the social and political relevance of water management in pre-Hispanic Maya society. The first section (Chapter 8.2) focuses on the general theories on agricultural production and water management. Chapter 8.3 presents the published models on the historical development of water management in the Maya Lowlands. In succession, Chapter 8.4 introduces the published models on the social relevance of water management.

Based on this theoretical background, Chapter 8.5 introduces a set of newly developed criteria for evaluating the sociopolitical relevance of hydraulic features. These evaluation criteria are used to analyze the sociopolitical relevance of the hydraulic features in both Uxul (Chapter 8.6) and the rest of the Maya Lowlands (Chapter 8.7). In succession, Chapter 8.8 discusses the validity of the published theories on the social and political relevance based on the analyzed hydraulic features, while Chapter 8.9 provides a concluding evaluation.

As the final chapter of this book, Chapter 9 provides a summary and conclusion of the research objectives, and the results of this study. Chapter 9.1 then highlights the main environmental factors for the issue of water supply, while Chapter 9.2 summarizes the observations on the geographical distribution and functionality of hydraulic features. Next, Chapter 9.3 provides an overview on the history of research and the development of theories, before Chapter 9.4 defines the relevance of Uxul’s hydraulic systems for the general discussion of water management in the Maya Lowlands. Finally, Chapter 9 evaluates the current state of research (Chapter 9.5), defines the desiderata for future investigations (Chapter 9.6) and ends with a closing remark (Chapter 9.7).

2 Geomorphology of the Maya Lowlands

For the founding and growth of every known human settlement, a significant prerequisite is the assurance of constant water supply for all of its inhabitants. In the Central Maya Lowlands however, water is not a permanent resource for the majority of the year (Chmilar 2005: 69). The availability of water is determined by two basic factors:

Firstly, the Yucatán Peninsula consists of a permeable limestone-block almost completely devoid of surface-water due to the quick percolation of precipitation into the bedrock (Dunning *et al.* 2006: 82; Wahl *et al.* 2007: 214). Because of these circumstances, very few rivers and lakes were able to form. Furthermore, the aquifer lies at an inaccessible depth of 150 m in many regions (Nondédéo 2003: 29). Secondly, the Central Maya Lowlands' climate is marked by distinctly separate rainy seasons and dry seasons (Scarborough 1991: 125). As a result, the region is assigned to the "tropical monsoon" climate type (Wilson 1980: 24).

Currently, the combination of highly seasonal precipitation and the general absence of surface water represents a challenge for all those living within this habitat (Weiss-Krejci and Sabbas 2002: 343; Wilk 1985: 48). As already pointed out in Chapter 1, the main objective of this chapter is to familiarize the reader with the general geomorphologic conditions of the Central Maya Lowlands. This is fundamental to understand the complex interrelationships introduced in the following chapters of this dissertation. Resources are concentrated and distributed unevenly in different areas within the landscape (Chmilar 2006: 5; Fedick 1996). The patterning of resources is the result of several factors, with the geomorphology being the most determining factor. The primary environmental factors that led to the mosaic of habitats in the Lowlands are the varying soils, geomorphologic processes, gradients and drainage characteristics that result from the structural geology (Dunning and Beach 2000: 181).

2.1 Geology of the Central Maya Lowlands

> "*According to the wise, one of the things most needed by man is water, without which the earth cannot produce its fruits or man live ... In this respect nature has acted differently in this country from the rest of the world, where the rivers and springs flow above ground, whereas here all run in secret channels underground"* (de Landa 1978: 94-95 [1562]).

On the basis of its physical geography, the Maya culture area can be broadly subdivided into three different regions (Davis-Salazar 2001: 51; Sharer 1994: 20-24):

(1) The Lowlands

(2) The Highlands, and

(3) The Pacific Piedmont Region.

As the scientific issues discussed in this book are mostly confined to the Lowlands, the upcoming overview will mostly focus on this region. The Maya Lowlands represents a region commonly known as the "Yucatán Peninsula" (Nondédéo 2003: 27). This area is marked by a karstic limestone shelf that extends from the north of the Yucatán Peninsula down through the Petén region of Guatemala, altogether an area of about 350,000 km^2 (Beach *et al.* 2015a: 4; Coe 1999, Medina 1996: 5; Scarborough e al. 1995). Generally, the Lowlands are subdivided into the "Northern Lowlands" and the "Southern Lowlands", while some authors (e.g. Nondédéo 2003: 27) also use the category of the "Central Lowlands" (see Figure 2.1).

As Parry (2007: 5) correctly observes “a description of the actual boundaries is somewhat problematic as different divisions are drawn according to cultural and environmental parameters and according to the inclination of individual researchers” (see also Coe 1999; Ford 1996: 297; Harrison 1993: 76-77; Sharer 1994: 24).

The “Maya Area” is situated between the 17th and the 22nd latitude, between the 87th and the 91st western longitude and lies south of the Tropic of Cancer (Nondédéo 2003: 27). In political respects, this area is divided between five different countries: In Mexico, the federal states of Tabasco, Chiapas, Campeche, Yucatán and Quintana Roo; the entire territories of Guatemala and Belize and the western portions of Honduras and El Salvador (see Figure 2.1).

While most scholars identify the Northern Lowlands as the area defined by the federal states of Yucatán, Quintana Roo and northern Campeche, the Central Lowlands are usually defined as the southern parts of Campeche and Quintana Roo, the northern portions of Chiapas, the departments of Petén and Río Motagua (Guatemala), and the entire country of Belize (Chmilar 2005: 1; Nondédéo 2003: 27; see Figure 2.1). However, the southern frontier of the Southern Lowlands is poorly defined. Because the separation between the different “geographic areas” was not based on geological differences but on cultural parameters, most scholars draw the frontier of the Southern Lowlands at the transition-zone between the Lowlands and the Highlands (Nondédéo 2003: 27; Wadell 1938: 337; Wilson 1980; 7; see Figure 2.1). The Highlands are a volcanic mountain range that intersects the southern parts of Chiapas, Guatemala and El Salvador (Nondédéo 2003: 27; see Figure 2.1).

While the aforementioned geographic areas have mostly been defined by Maya archaeologists, the upcoming section provides a more detailed overview of the geological history and the geological processes that formed the present landscape.

2.1.1 Geological history of the Yucatán Peninsula

The geologic history of the Maya area is defined by limestone and karst developments, which led to the development of the karst block that dominates the Yucatán Peninsula (Chmilar 2005: 17; Middleton and Waltham 1986).

2.1.1.1 Formation of the Karst Block

Early on, this karst block was made up of a shallow marine platform formed by the slow accumulation of coral deposits and mollusk shells at the bottom of a shallow sea (Wilson 1980: 11). Two major forces then formed the hard limestone-matrix constituting the karst block: On the one hand, the accumulated coral deposits and mollusk shells solidified under high pressures, and on the other hand, the precipitation and dissolution of these deposits caused the loose particles to carbonize into the hard limestone-matrix (Graham 2003: 33; Nondédéo 2003: 27; Wilson 1980: 11).

The formation of these rocks took place during the Tertiary, a period between the Eocene and the Miocene (65.5 million years B.P. to 33.9 million years B.P.), making the Yucatán Peninsula a relatively recent geologic formation (Barrett 2004: 75-76; King *et al.* 1992; Lene 1997; Nondédéo 2003: 2; Weiss-Krejci *et al.* n.d.; West 1964: 73; Wilson 1980: 6; Wright *et al.* 1954). The shape of these limestones varies from pure, dense, hard crystalline limestones to impure, soft and amorphous carbonates (Day 2007). As a general rule, the limestone block becomes younger in age and lower in elevation from south to north (Brewer 2007: 16):

Thus, the oldest rocks were formed during the Mesozoic and are located in the southern and central portion of the Yucatán Peninsula (Akpinar 2011: 6). These rocks generally show a pure, dense, hard and crystalline consistency (Day 2007). Due to their older age, these geologic formations also tend to be more fractured and enabled the storage and flow of underground water between the open areas of the rock's formation (Villaruso and Ramos 2000). These geologic features lead to a scarcity of water sources near the surface.

Figure 2.1: Geographic zones of the Maya area (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

By contrast, the northern tip of the Yucatán Peninsula consists of more recent and superficial limestone formations, which developed during the Pliocene (Chmilar 2005: 17; Nondédéo 2003: 27 figure 2 above). These younger rocks are impure, soft, porous and amorphous carbonates (Day 2007). Moreover, the younger northern limestone is flatter and features a less pronounced relief than in the south (Chmilar 2005: 17).

After these formation processes, the Yucatán karst block remained a rigid mass throughout the majority of its later development (Brewer 2007: 16). While the block was originally submersed by the surrounding sea, a translatory motion from south to north lifted the stable tectonic unit in two different events. This process began at the end of the Tertiary and ended during the Pliocene (Nondédéo 2003: 27). Another important geologic component of several parts of the Yucatán Peninsula is chert[1], which appears in residual deposits (Weiss-Krejci and Brandl 2011: 152-153). After the formation of the Karst Block, the Yucatán Peninsula was subject to two geological forces of profound significance:

(1) The impact of the asteroid Chixculub, 65 million years B.P. (Cretaceous), and

(2) The position, placement and movement of two crustal blocks (Maya and Chortis) impacting the sedimentary history, landscape morphology, and the groundwater flow in the region (Dunning *et al.* 1998a; Graham 2003).

According to some scholars (e.g. Gill 2000), the impact of the Chixculub asteroid was responsible for the massive ecological catastrophe that led to the extinction of dinosaurs and other life forms (Brewer 2007: 16). The Chixculub crater crops out a Late Cretaceous layer of the central and southern Maya Lowlands (Beach *et al.* 2015: 5). Geologically, the differential solution in the area surrounding the Chixculub crater has resulted in numerous small sinkhole lakes (cenotes and *aguadas*) locally known as the “Ring of Cenotes” (Connors *et al.* 1995; Hodell *et al.* 2005; Perry *et al.* 2009; see Figure 2.2). After the formation of the karst block, the most defining factor for the geology of the Maya Lowlands was the dissolution of the limestone-block (Dunning and Beach 1994; Kueny and Day 2002).

2.1.1.2 Dissolution of the Karst Block

The limestone constituting the karstic terrain is easily dissolved in moist tropical climates (Walter and Breckle 1999: 139). In regions where the limestone has fractured due to internal buckling (e.g. in Horst and Graben landscapes), this process becomes even more evident (Johnston 2004: 277). Once rainwater comes in contact with the limestone,[2] it infiltrates into fractures and crevices, dissolves it during the process and gradually carries it off (Johnst on 2004a: 278; Price 1985: 19-20). The porosity of the rock further increases when subterranean fissures, pores or chasms are expanded and washed out by streams of water (Johnston 2004a: 278; Wilson 1980).

In the course of the geologic history, these weathering processes led to a diverse assortment of karst features including dry valleys, sinkholes, cave-systems and extensive subterranean drainage networks in the Yucatán karst block (Alvarado *et al.* 2001; Beach *et al.* 2015b: 259; Johnston 2004a: 277; Miller 1996; Whittow 1984: 290). On the surface, the same weathering processes formed a rugged territory defined by ridges, conical hills and uneven depressions (Dunning *et al.* 2003, 1998). Over the course of time, the limestone dissolution processes led to a landscape with a succession of slight hillocks with smooth slopes or alternating high and low zones (Nondédéo 2003: 27).

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[1] The term chert includes all SiO2 raw materials, which were used for the production of chipped stone tools.

[2] Limestone rocks have infiltration rates of up to 80% of the precipitations (Singhal and Gupta 1999: 289).

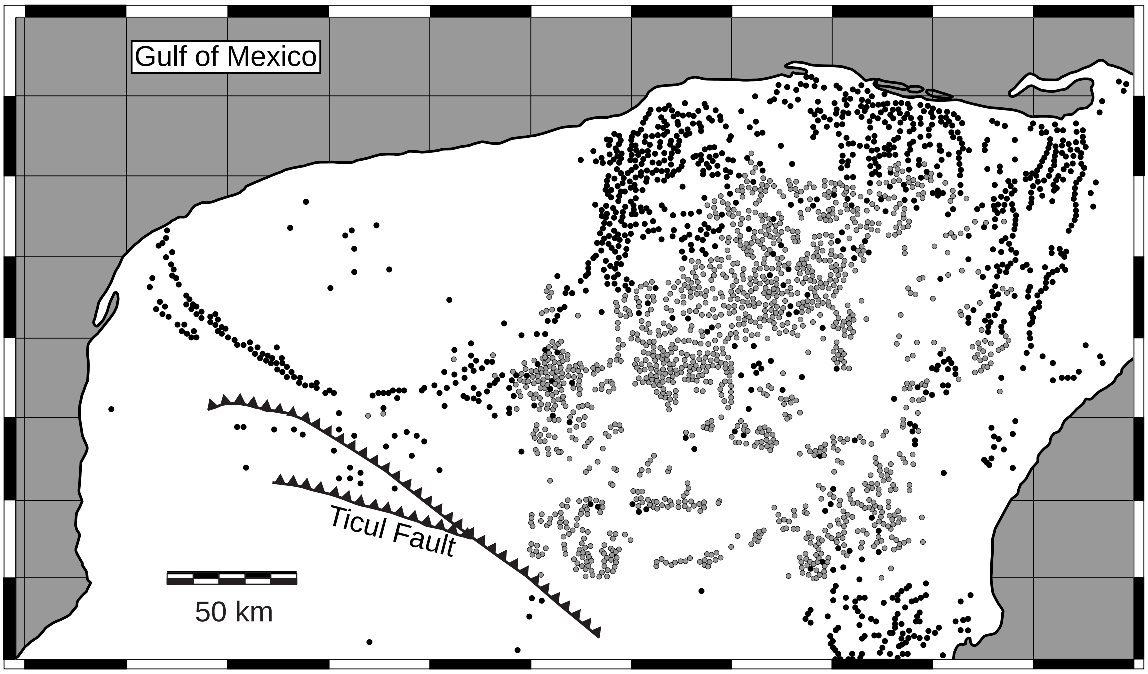

Figure 2.2: Karst features of the northern Yucatán Peninsula (redrawn after Connors *et al.* 1996: Figure 3). Filled circles indicate cenotes and other water-filled features; open circles indicate dry sinkholes. Reproduced with kind permission of Martin Connors.

2.1.2 Dissolution features

Along the northern coast, the surge produced small cavities, grooves and other minor dissolution features (Wilson 1980: 2). In exposed surfaces, the limestone-dissolution formed conduits with diameters of several centimeters and lengths of one to two meters (Finch 1964: 21). These processes also formed more extensive depressions known locally as *sartenejas* that feature steep or mildly declining borders and diameters of up to several meters (Wilson 1980: 12).

A common landscape-feature of all karst-environments are dolines. In the Maya karst block they developed in various different forms (Wilson 1980: 15). Dolines are formed either by weathering of the surface rock or through the removal of underlying rock layers by the continuous dissolution by water. Both processes lead to subsided or collapsed land surfaces (Akpinar and Dunning 2011: 108; Flores-Nava 1994). The most prominent and noted dolines of the Maya landscape are the *cenotes*.[3] The term *cenote* is usually used to describe precipitous, rocky and permanently waterbearing dolines in limestone and dolomite that are both touching the groundwater level and distributed within the landscape in a relatively homogenous fashion (Monroe 1970; Nondédéo 2003: 27; see Figure 2.7). On average, these dolines have a round shape and a diameter between 10 and 43 m (Nondédéo 2003: 27). Due to the increasing depth of the aquifer (see Chapter 2.1.4.1) however, they are mostly confined to the flat landscape of the Northern Lowlands where concentrations of cenotes have been identified in three areas:

One cluster was observed in the vicinity of Chichén Itzá, in the area from Libre Unión towards Valladolid and north of Peto until the northern coast (Wilson 1980: 12).[4] A second cluster could be identified 10 km to the north of the Sierrita de Ticul (Wilson 1980: 15).[5] The third concentration of cenotes can be

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[3] The Yucatecan terms *dz'onet* and *dzonot* or the Spanish term *cenote* refer to steep-walled, exposed collapse dolines that reach below the water table (Arnold 1971: 27; Monroe 1970; Roys 1939: 5; Wilson 1980: 15).

[4] "On our journey from Peto ... we had entered a region where the sources of the supply of water formed a new and distinctive feature in the face of the country, wilder, and, at first sight, perhaps creating a stronger feeling of admiration and wonder than even the extraordinary cuevas, aguadas, and senotes we had formerly encountered. These too, are called senotes, but they differ materially from those before presented, being immense circular holes, from sixty to two hundred feet in diameter, with broken, rocky, perpendicular sides from fifty to one hundred feet deep, and having at the bottom a great body of water, of an unknown depth, always about the same level, supposed to be supplied by subterranean rivers" (Stephens 1962: 185).

[5] "This belt of dolines is approximately 2 km wide and extends near the village of San Fernando to the northwest of Maxcanú, 50 km towards the east, until past of Sacalum" (Wilson 1980: 15).

found within the basin formed by the impact of the Chixculub-meteorite in the northeast of the Yucatán Peninsula (Maldonado *et al.* 2012: 51). Within this crater, the karstic processes produced a wide range of small cenotes over a long period. These cenotes touched the aquifer that was located close to the surface and could thus be used as natural wells (Maldonado *et al.* 2012: 51; see Figure 2.2).

The same dissolution processes that formed dolines and other exposed systems also led to the development of subterranean cavities (Cervantes-Martinez *et al.* 2002). As in all karst environments, caves in the Maya Lowlands usually enabled easier access to groundwater (Brady and Ashmore 1999; Scarborough 1998: 149). In general, cave systems have been located in each region of the Maya Lowlands. Concentrations of described cave systems are not necessarily a reflection of the geologic situation, but rather the result of the research situation. For example, these concentrations have been reported in the Río Pasión area (Dunning and Beach 1994: 53-54; Johnston 2004a: 268). A prominent example of a cave in this region is the Cueva de los Murciélagos in Dos Pilas (Brady *et al.* 1997; Johnston 2004a: 268). Apart from the Río Pasión area, the cave systems of the Northern Lowlands have also experienced a more systematic exploration. Familiar examples of this area are the Actún Ha Cave and the Cave of Balakanché near Chichén Itzá, the Loltún Cave near Oxkutzcab, and the Xtacumbilxunam Cave near Bolonchén (Wilson 1980: 15). For the current population of the Northern Lowlands, caves are an important source for clean water *(zuhuy ha)*, which motivated some scholars to believe that the Pre-Hispanic Maya had employed the same concept (Wilson 1980: 15).

Another common dissolution feature of the karst block are poljes (Matheny and Matheny 2012: 37). Poljes have mostly leveled floors and can extend over several kilometers (Matheny and Matheny 2012: 37; Waele *et al.* 2009: 1-3). They are formed "due to differential erosion in areas where limestone rocks are in contact with less permeable rocks ..." (Matheny and Matheny 2012: 37; Sweeting 1972: 199-299). A prominent example for an extensive polje is the valley of Edzná. This polje formed during the Oligocene when seawater inundated the limestone block and produced a polje-depression, which is currently filled with alluvial material (Matheny and Matheny 2012: 37). The deposited sediment layers of the Oligocene are impermeable clays composed of kaolinite and montmorillonite (Perry *et al.* 2012). These clays tend to accumulate as deposits below surfaces soils (usually oxisols), which become water-saturated and mix with the superficial vegetation and cultural refuse (Matheny and Matheny 2012: 38; Matheny *et al.* 1983: 20).

2.1.3 Geological zones of the Maya Lowlands

Due to the described tectonic movements and dissolution processes, the Maya Lowlands are characterized by a wide array of different geological zones (Dunning and Beach 1994; Dunning *et al.* 1998a; Kueny and Day 2002). As the tectonic movements described above took place, the previously intact karst block fractured into several geologic subsections that are marked by lifted and subsides areas (horst-hills and graben-valleys) (Chmilar 2005: 17). Over the course of the geologic history, the faulting process of the fractured limestone-block created long escarpments and valleys with height differences of up to 100 meters (Beach *et al.* 2003; Dunning *et al.* 2003). Generally, the fractured limestone-block of today can be subdivided into 31 physiographic subsections (see Figure 2.3).

Whereas Belize, the Mexican State of Tabasco, the Pacific Coast, the Caribbean Coast and Quintana Roo are dominated by recent alluvial deposits, the northern third of the Yucatán Peninsula consists of Tertiary limestone (Brewer 2007: 158). The Southern portion of Chiapas, the Petén District, the Alta Verapaz and southern Belize are comprised of older limestones, and shales that formed during the Jurassic and Triassic periods (Brewer 2007: 16). These areas show a more pronounced relief energy, a higher elevation and a more developed drainage (Brewer 2007: 15).

The Caribbean Coast was formed 60 million years B.P. by deltaic progradation, which resulted in tidal, lagoonal, and alluvial deposits (Beach *et al.* 2009: 1711).

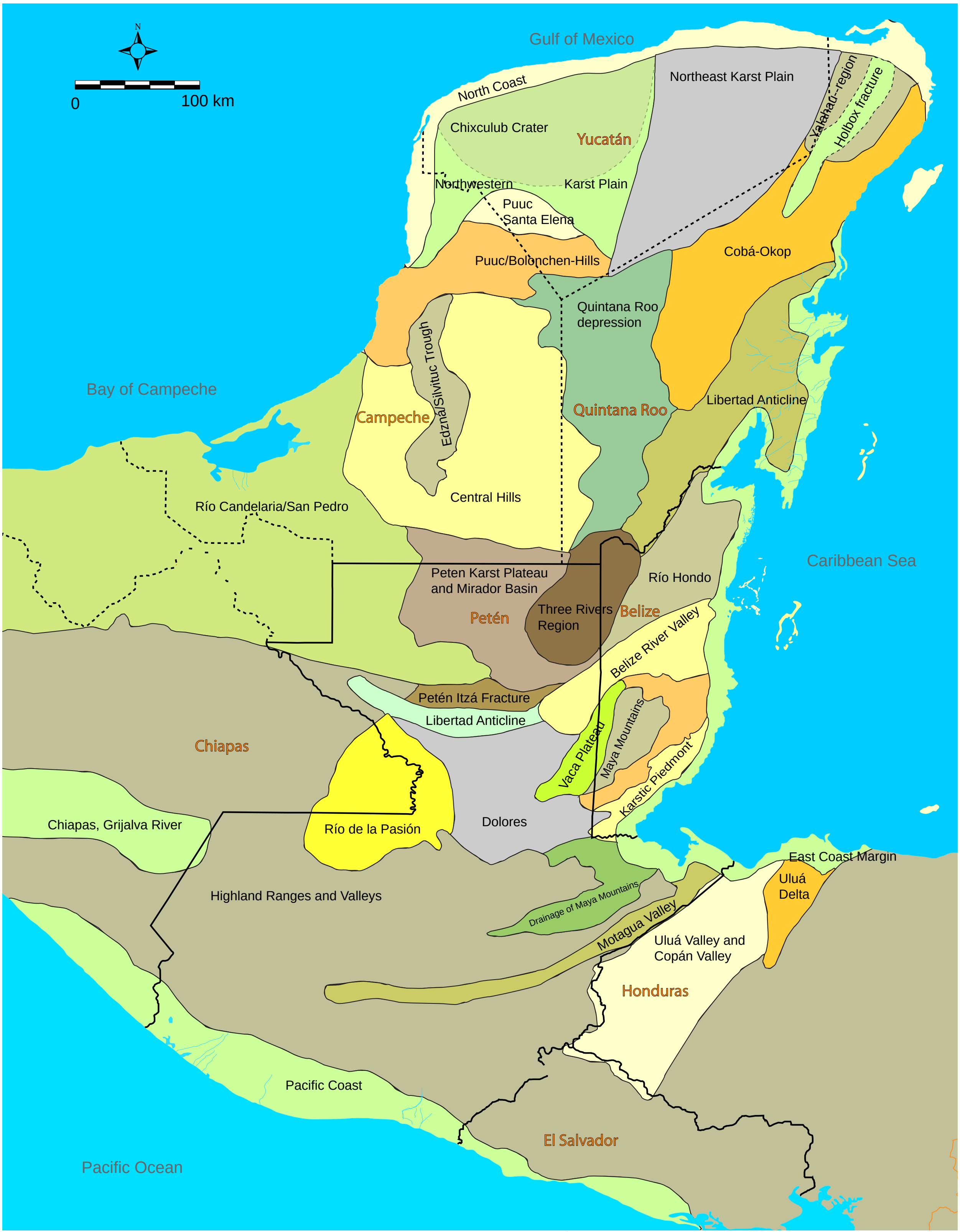

Figure 2.3: Map of the physiographic sub-regions in the Maya Lowlands (Map: N. Seefeld, redrawn after Dunning *et al.* 1998: Figure 1.). Reproduced with kind permission of Nicholas Pierce Dunning.

The Maya Mountains of central and southern Belize mostly consist of granite (Gill 2000). They represent a separated block from the Guatemalan Highlands and are composed of metamorphous deposits and Paleozoic granites (Brewer 2007: 16; Chmilar 2005: 17; Jacob 1995). They are located at the juncture of the

Yucatán karst block and the Highland to the south (Moyes 2006: 87). To the west and the east, the Maya Mountains are delimited by Cretaceous and Eocene limestone hills that are heavily dissected by Kegelkarst formations (Moyes 2006: 88).

The Three Rivers region (see Figure 2.3) received its name because the area is drained by three rivers, the Río Bravo, the Booth's River and the Río Azul (Brewer 2007: 12; Dunning *et al.* 2003). Geologically, the area is dominated by Early Tertiary marine carbonates, mainly limestone and marl (Weiss-Krejci *et al.* n.d.). Prolonged and extensive physical and chemical weathering of the bedrock had led to a rugged landscape marked by conical hills (Dunning *et al.* 1998: 88, 2003: 14-15, 2015: 6; Weiss-Krejci *et al.* n.d.). Geologically, it can be described as the "fractured eastern margin of the Petén Karst Plateau" (Dunning *et al.* 1998b: 93).

The Petén Karst Plateau and Mirador Basin feature a hydrophilic, mildly karsted limestone that falls on the far end of the hydraulic conductivity scale (Silverstein *et al.* 2009: 50). Furthermore, the landscape had no defined integrated drainage resulting in it being almost exclusively internal (Dunning *et al.* 2015b: 6). The Mirador Basin represents a structural subsidence basin of the Petén Karst Plateau (Dunning *et al.* 2015b: 6).

The Highland ranges and valleys form the largest and most consistent physiographic unit of the Maya area (Chmilar 2005: 17).

2.1.4 Water sources of the Yucatán Peninsula

The described geomorphological processes and the resulting geologic structure of the Maya Lowlands are fundamentally responsible for the allocation of subterranean and superficial water (Dunning and Beach 2000: 183).

2.1.4.1 Groundwater

In the case of groundwater, the geological history and the regional variations of the parent material are particularly influential, as the aquifer is generally more easily accessed in the Northern Lowlands (Nondédéo 2003: 27). This situation is caused by the fact that the depth of the groundwater-level decreases further to the north (Brenner *et al.* 2001: 95), which makes the groundwater in the Northern Lowlands more accessible than in the Central Lowlands (Brewer 2007: 21; Curtis *et al.* 1996: 38; Dunning and Beach 2000; Hammond and Ashmore 1981; Nondédéo 2003: 27; Scarborough 1993; Shaw 2003: 163; Siemens 1978; Southworth 1984, 1985; Turner and Harrison 1983: 250; Villaruso and Ramos 2000; Wilson 1980; see Figure 2.4):

In the northern plains, the aquifer depth is less than 27 m, while in the coastal region, freshwater is sometimes located less than one meter below the surface (Wilson 1980: 16). Along the north coast, freshwater occasionally sputters from dissolution canals and small springs (*ojos de agua*) that may appear at or below the sea level. According to Wilson (1980: 17), some of the *ojos de agua* are located immediately to the west of Progreso. According to Doehring and Butler (1974: 591), the highly penetrable limestone of the northern Maya Lowlands enables a freshwater layer to rest upon a layer of saltwater.[6] The low depth of the aquifer explains why water-bearing cenotes are mostly confined to the northern Maya lowlands.

Another obvious pattern is that the groundwater table to the south of the Sierrita de Ticul is located much deeper than in the Northern Lowlands. Wilson (1980: 17) illustrated this obvious connection by pointing out that the wells in Oxkutzcab meet the groundwater at a depth of 42 m and in the Puuc-region at an average depth of 65 m, whereas wells near Bolonchén needed to be drilled up to a depth of 135 m

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[6] According to Wilson (1980: 17), Doehring and Butler's (1974) models „supports the idea of Cole (1910), according to which inner regions create a hydrostatical pressure that pushes subterranean water from the inland towards the coasts".

(Dunning 1992: 20-22; Dunning *et al.* 1998: 22). In southern Campeche, the aquifer lies at a depth between 200 and 300 m (Nondédéo 2003: 28). These figures clearly illustrate that the depth of the groundwater-level gradually increases towards the south (Dunning *et al.* 2015b: 5).

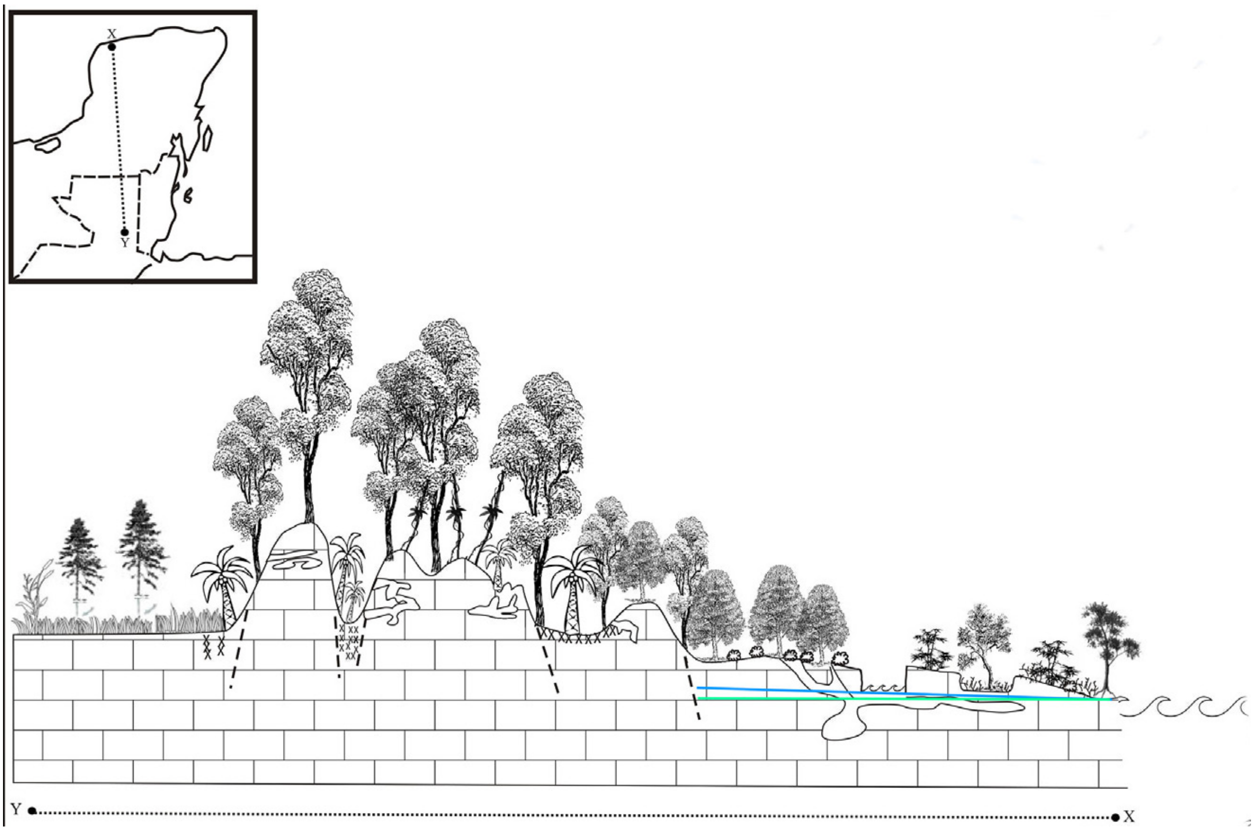

Figure 2.4: Geological, south to north-transect through the Yucatán Peninsula (modified from Beach *et al.* 2015a: Figure 4). Reproduced with kind permission of Timothy Beach and Elsevier.

2.1.4.1.1 Springs

Although the groundwater level is usually inaccessible in most portions of the Central Lowlands, the dissolution processes described in Chapter 2.1.1.2 led to several geological discontinuities, such as crevices or fractures. Johnston (2004a: 278) remarked that some of these geological discontinuities would have enabled the formation of groundwater fed springs (Singhal and Gupta 1999: 279, 287). According to Johnston (2004a: 268, 278), three different types of terrestrial (superficial) types of springs are characteristic for folded karst terrains:

(1) Scarp-foot springs

(2) Sources at the tip of escarpments, and

(3) Waterhole-springs

(1) Scarp-foot springs (filtration springs)

These springs develop in locations where permeable and impermeable layers are opposed, which allow the groundwater to penetrate through the permeable layer and reach the surface along the fault (Fetter 1994: 289; Hudak 2000: 29-30, 38-39; Johnston 2004a: 278). According to Johnston (2004a: 278), scarp-foot springs drain near the interference of upthrown and downthrown blocks (Fetter 1994: 289-290).

According to Silverstein *et al.* (2009: 51), rainfall would infiltrate into the phreatic zone or saturation zone. During the rainy season however, the saturation zone would ascend to a level that would inundate the vertisols of the bajos, which would result in surface flow and accumulation of the less permeable argillic soils. As the water table tends to retrace the topography, it usually rises to follow the contours of the hills (White 1988: 153-155; see Figure 2.5).

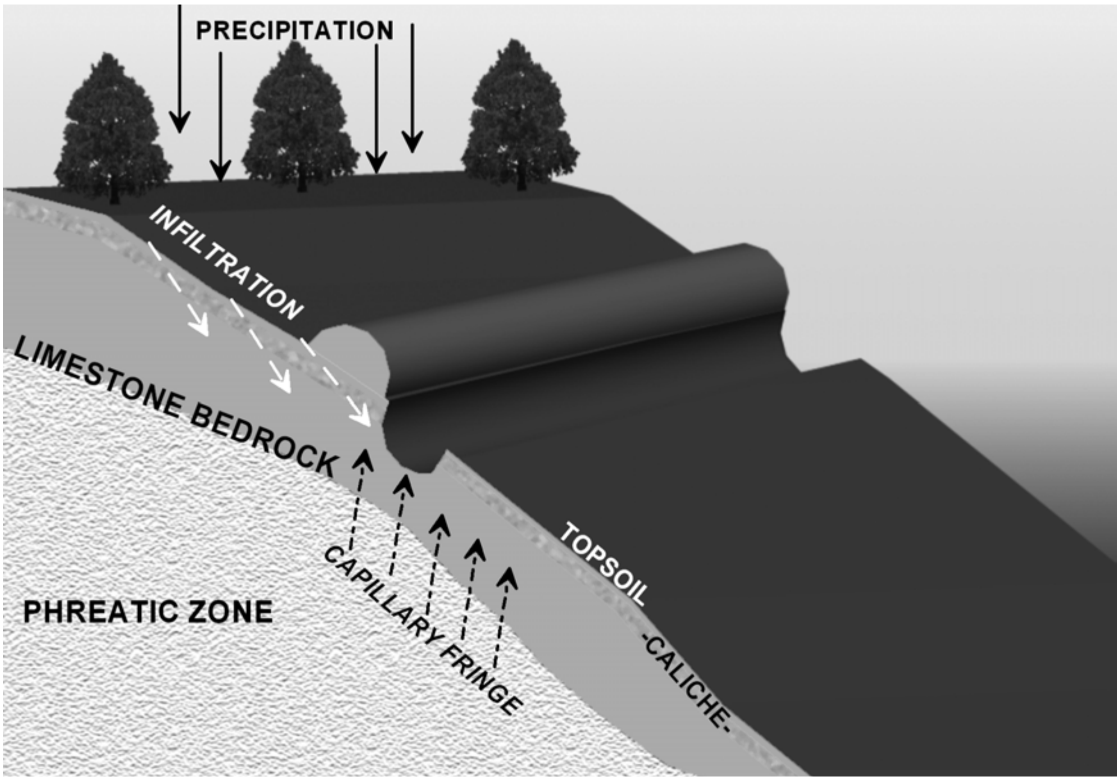

Figure 2.5: Model of the hydrologic process in scarp foot springs (source: Silverstein *et al.* 2009: Figure 6). Reproduced with kind permission of Jay Silverstein and Cambridge University Press.

(2) Sources at the tip of escarpments

As Fetter (1994: 278) noted, these sources develop in areas where vertical lying dissolution conduits (including disruptions increased throughout the dissolution of calcium carbonate) break the surface. Among other things, the flow rate is mainly determined by:

(a) Gaps and/or cavities, which connect the source with the groundwater table

(b) The size of the drainage area, which supplies the source with water, and

(c) The amount and intermittency[7] of precipitation (Schwartz and Zhang 2003: 202).

In cases where the gaps supplying the springs are narrow enough,[8] the flow rate of a spring can be very low.

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[7] Due to the forces of gravity, the flow rates of scarp foot springs are greater than those of sources at the tip of escarpments – except for those cases where the flow of sources at the tip of escarpment is influenced by artesian pressure.

[8] Such narrow gaps are quite common in groundwater circulation systems (Price 1985: 20). Johnston (2004a: 278) points out that "springs with narrow sluices and low flow rates can easily be plugged with depositions and sediment, which may cause, that its flow may be dispersed in the surrounding sediment or rock and therefor does not reach the surface. In such cases, occupants are able to access the water one or few meters below the surface" (Johnston 2004a: 278).

(3) Waterhole-springs

Waterhole-springs originate at the bottom of some buried water-holes (Fetter 1994: 289-299) and feature high discharge rates (Johnston 2004a: 268). According to Johnston (2004:a 268), these springs are typical landscape features of the Río Pasión area.

2.1.4.2 Rivers

As in the highlands, the rugged terrain of the Petén and the Maya Mountains produce considerable volumes of runoff. The regions surrounding these pronounced elevations exhibit a series of major and minor rivers (Beach *et al.* 2015a: 14). Since these rivers are mainly fed by runoff from these elevated portions, they are concentrated in the Southern Lowlands and the western and eastern border areas. Apart from the northwestern coast of the state of Yucatán, the Northern Lowlands do not exhibit any superficial streams (Beach *et al.* 2015a: 14; Wilson 1980: 17).

The drainage patterns of these river-systems are heavily influenced by the Elevated Interior Region (EIR) (Dunning *et al.* 2015b: 5) of the Maya Lowlands, a pronounced north-south-oriented elevation in the center of the Yucatán Peninsula (see Figure 2.6). Because of this north-south oriented spine, the rivers originating in this area drain either to the west or the east (see Figure 2.6).

The Río Candelaria, the Río Champotón[9] and the Río San Pedro are draining the EIR towards the west (Scarborough 1991: 125; 2003b). The Río Candelaria is the largest river-system of the Central Lowlands (Vargas 2012: 194). It is approximately 270 km long and its most important tributaries are the Río San Pedro and the Río Caribe, which merge in Boca Santa Isabel. The Río Candelaria originates in Guatemala, passes the site of El Tigre and stretches to Salto Grande 60 km further to the north. While the river measures 120 m in width close to El Tigre, at its mid-course it has a width of approximately 20 m (Chmilar 2005: 19; Jacob 1995; Nondédéo 2003: 27; Wilson 1980: 17; see Figure 2.6).

The Río Escondido, the Río Hondo/Río Azul/Río Uaxactun, the Río Holmul and the Belize River drain along the EIR towards the East (Chmilar 2005: 19; Jacob 1995; Nondédéo 2003: 27; Scarborough 1991: 125; 2003b; Wilson 1980: 17; see Figure 2.6).

Apart from these permanent rivers, the Maya Lowlands also feature some seasonal streams. These streams are known to drastically change their course and run dry for several years in a row (Nondédéo 2003: 28). The Ixcan Río, a river close to San Bartolo that connects several small bajos before draining into the Bajo de Azúcar is one example (Akpinar-Ferrand *et al.* 2012: 85; Garrison 2007; Garrison and Dunning 2009).

The primary river systems of the southern Maya lowlands are the Río Usumacinta and the Río Pasión (Beach *et al.* 2015a: 14; Brewer 2007: 21; Scarborough 2003b; see Figure 2.6). The western Usumacinta drainage is the dominant body of water in the region[10] and transports vast amounts of water. Each year, it carries 59 million cubic meters of water into the Gulf of Mexico. The Río Pasión features numerous tributaries such as the arroyo Subin, the arroyo Pucte and the arroyo el Chorro (Johnston 2004a: 268). Generally, the Río Pasión features deeply cut valleys fed by big springs (Johnston 2004:a 268).

Some of these springs are intermittent and originate from caves, such as the Cueva de los Murciélagos in Dos Pilas (Brady *et al.* 1997; Johnston 2004a: 268). Due to the irregular influx of water, the level of the Río Pasión fluctuates by up to five meters over the course of a year (Alvarado Najarro 2013: 126). The rising water table during the rainy season frequently causes extended inundations (Alvarado Najarro 2013: 126).

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[9] According to Matheny and Matheny (2012: 38), the Río Champotón forms part of the Edzná valley-Polje.

[10] Golden and Scherer (2012: 70) point out, that the Usumacinta is Mesoamerica's largest river and the 7th largest river of the world. Approximately 42% of Guatemala is drained by the Usumacinta or one of its tributaries and its production represents 30% of the fresh water in Mexico (Gunn and Folan 2000: 238; Golden and Scherer 2012: 70).

At the current state of research, the river-systems of the Maya Lowlands have not been studied in great detail yet (Beach *et al.* 2015a: 15). Nevertheless, many scholars (Beach *et al.* 2015a; Brewer 2007; Scarborough 2003b: 85) have pointed out that the geologic characteristics of the landscape make the river-systems unsuitable for irrigation-agriculture – even the permanently water-bearing rivers.

Figure 2.6: Map of the river systems in the Maya Lowlands (Map: N. Seefeld. Modified from Pope and Dahlin 1989: Figure 1. Reproduced with kind permisssion of Kevin O. Pope. Base map was.modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

In the case of the Usumacinta, the poorly defined floodplains and the deeply incised channels prohibit large-scale irrigation projects (Brewer 2007: 21; Scarborough 2003b: 21). In the case of the Río Azul/Río Hondo system, the flow of water could also enable irrigation of the floodplains. However, the adsorption and dispersion characteristics of the porous limestone watersheds results in extreme water-level fluctuations between the dry season and the rainy season. This prohibits the installation of intensified agricultural systems (Siemens 1978). According to Brewer (2007: 21), these conditions would "preclude annual floodplain renewal and prevent the use of sophisticated water diversion techniques"

2.1.4.3 Still bodies of water

Due to the scarcity of river systems, the most important sources of water in the Maya Lowlands are still bodies of water, which feature a wide range of forms and characteristics (Nondédéo 2003: 27). As Figure 2.7 indicates, lakes are mostly confined to the eastern and the southwestern portion of the Maya Lowlands. A concentration of lakes consisting of the Laguna Perdida, Laguna Sacpuy, the Lago Petén Itzá, the Laguna Sacnab, and the Lago Yaxha lies at the southern border of the EIR (see Figure 2.7). Another cluster of smaller lakes, Laguna Misteriosa and Laguna Silvituc, lies at the western border of the EIR. The Mirador Basin exhibits three larger lakes: Lago Chuntuqui, Lago Paixban and Lago Puerto Arturo (Hansen *et al.* 2002: 275; Parry 2007: 12; see Figure 2.7). The third cluster is represented by the Laguna San Felipe and the Laguna Bacalar of Quintana Roo (see Figure 2.7). In contrast, the only still bodies of water in the Northern Lowlands are cenotes (see blue circles in Figure 2.7), which are densely distributed north of the EIR (see chapter 2.1.4.1). In summary, Figure 2.7 clearly illustrates that still-water bodies, just like river-systems, are almost nonexistent within the Elevated Interior Region of the Maya Lowlands.

While lakes are rare in the Maya Lowlands, thousands of aguadas speckle the landscape. These represent the most abundant and important sources of water in many regions throughout the Maya Lowlands (Nondédéo 2003).

2.1.4.3.1 Aguadas

(a) Definition of aguadas

The origin of the word is the Spanish term *aguada*, which denotes "watering place" (Akpinar 2011: 1).[11] As research has progressed, scholars have introduced a wide range of descriptions for aguadas (Akpinar and Dunning 2011: 107). Among others, these include:

(1) "less permanent pools that are ancient cenotes with sloping sides" (Cole 1910).

(2) "surface water pools" (Higbee 1949).

(3) "ponds" (Dunning *et al.* 2015: 105).

(4) "broad, shallow depressions" (Flores-Nava 1994; Matheny 1976; Monroe 1970).

(5) "sinkholes and shallow water deposits" (Cervantes-Martinez *et al.* 2002; Geovannini Acuña 2008; Lundell 1937).

(6) "a water body that is isolated from the underlying aquifer by an organic clay basin seal" (Hodell *et al.* 2005; Schmitter-Soto *et al.* 2002).

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[11] The Yucatecan term *akal*, can also refer to aguadas. However, it is a relatively broad term that can also be applied to seasonal swamps (*bajos*).

Figure 2.7: Map of still bodies of water in the Maya Lowlands (Map: N. Seefeld, modified from Connors et al. 1996; Figure 3. Reproduced with kind permission of Martin Connors; modified from Pope and Dahlin 1989: Figure 1. Reproduced with kind permission of Kevin O. Pope. Base map was modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Wischey.

(7) “small ponds associated with topographic depressions” (Wahl *et al.* 2007).

(8) “small dissolution dolines” (Akpinar 2011: 10; Beach *et al.* 2008).

(9) “depressions that hold water today” (Lohse 2004: 128).[12]

In the remainder of this study, the author will define aguadas as water holding ponds. In most publications, the term “aguada” refers to both natural and anthropogenic reservoirs (Beach *et al.* 2015b: 258). In order to give the reader a deeper understanding of the origin and characteristics of these features, the next paragraph will illustrate the formation process of aguadas.

(b) Formation of aguadas

In general, aguadas can be divided into the two basic groups of natural aguadas (1), and artificial aguadas or reservoirs (2). As artificial aguadas and reservoirs are in fact anthropogenic landscape modifications, they will be presented in greater detail along with the other hydraulic features in Chapter 5.5.4.

Natural aguadas originate from collapse or dissolution features (Akpinar *et al.* 2012: 85; Chmilar 2005: 19; Monroe 1970). The size and origins are subject to variation both between and within the different regions of the Maya Lowlands (Akpinar and Dunning 2011: 107). The formation of aguadas can be attributed to two general geologic processes:

(1) In some instances, aguadas originate from dolines or karst sinkholes that partially filled with sediment (Akpinar and Dunning 2011: 107; Beach *et al.* 2015b: 260).

(2) In other cases aguadas are the result of tectonic activity (Akpinar and Dunning 2011: 107). Limestone dissolutions and sinkhole formations show a concentration of aguadas along fractures in the parent material (Beach *et al.* 2003; Dunning and Beach 2004). In areas without fractures, limestone dissolution processes show a more random and less concentrated distribution (Akpinar 2011: 9).[13]

(c) Classification of aguadas

For this dissertation, the author is partially adapting the classification of aguadas defined by Arredondo-Figueroa and Flores Nava (1992), who group natural aguadas in two different categories:

1) Permanent sinkhole aguadas, and

2) Seasonal shallow basin aguadas

Type 1: Permanent sinkhole aguadas

Permanent sinkhole aguadas are the result of the same geomorphic processes as cenotes. In contrast to cenotes however, they were never in direct contact with the groundwater level, or they were isolated from the aquifer due to the accumulation of sediment or organic matter (Akpinar 2011: 11, see Figure

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[12] Natural landscape features between 500 and 60,000 m^2 in surface area that have undergone extensive ancient modifications and today hold water for most time of the year (Folan *et al.* 2001: 63; Lohse 2004: 128; Weiss-Krejci 2013: 87).

[13] In this relation, it should be pointed out that anthropogenic modifications of natural aguadas tend to blur the traces that would enable the determination of the geologic forces that formed them.

2.8). Due to these circumstances, they are only fed by means of direct rainfall or surface runoff from their immediate local catchment areas (Cervantes-Martinez *et al.* 2002; Flores-Nava 1994; Schmitter-Soto *et al.* 2002). They become impervious by the deposition of organically rich and less permeable clayey sediments on their bottom (Dunning *et al.* 2015b: 7; Flores-Nava 1994).

Permanent sinkhole aguadas can have both steep walls and tapering sides. Their surface area may reach up to several hectares (Foster and Turner 2004; Schmitter-Soto *et al.* 2002) and because they can reach depths of up to 15 meters, they seldom go dry (Akpinar and Dunning 2011: 108, Monroe 1970).

Since permanent sinkhole aguadas and cenotes share the same origin, they are often located in the same location and are consequently confined to the northern Maya Lowlands and the western and eastern coastal regions of the central Maya Lowlands (Dunning 1998). The inaccessibility of the aquifer in the central portion of the Yucatán Peninsula (see Chapter 2.1.4.1) impedes the formation of permanent sinkhole aguadas (Akpinar and Dunning 2001: 109).

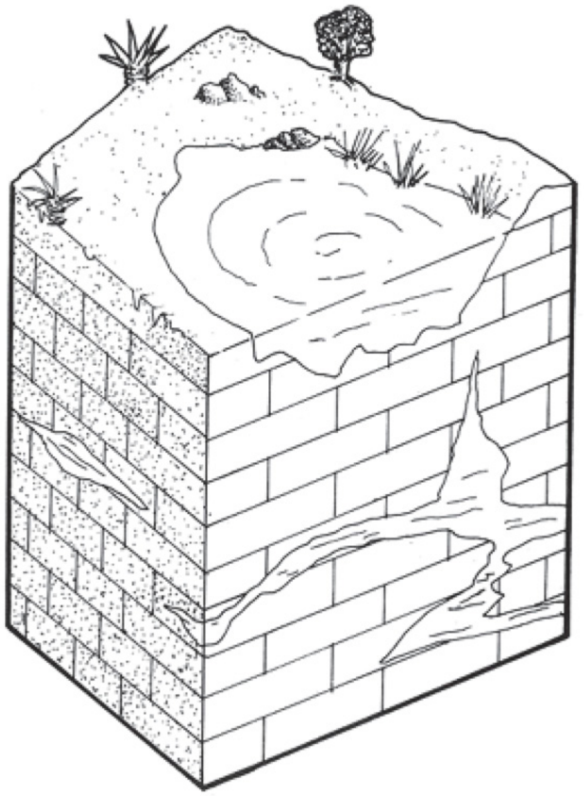

Figure 2.8: Illustration of a permanent sinkhole Aguada (source: Flores-Nava *et al.* 1989: Figure 2). Reproduced with kind permission of Alejando Flores-Nava.

Type 2: Seasonal shallow basin aguadas

The formations of seasonal shallow basin aguadas, sometimes defined as dissolution dolines (e.g. Ford and Williams 1989), are typical features of karst landscapes and are formed by the direct dissolution of the surface rock (Akpinar and Dunning 2011: 109; Beach *et al.* 2015b: 260; Dunning *et al.* 2015b: 10; Monroe 1970; Siemens 1978). Due to the inaccessible depth of the aquifer, almost all aguadas in the Central Maya Lowlands represent seasonal shallow basin aguadas. Similar to permanent sinkhole aguadas, seasonal shallow basin aguadas are refilled exclusively by direct precipitation or the runoff from their immediate catchment areas. Over time, they became waterproof through the assemblage of clays and sediments emerging from the limestone (Dunning *et al.* 2015b: 7; Flores-Nava 1994; Nondédéo 2003: 27). In order to systematize their development, Arredondo-Figueroa *et al.* (1982), defined two ecological phases: Dilution (1) and concentration (2).

During the early dilution phase, rainy season precipitation results in the sudden release of nutrients like phosphorus and nitrogen causing an increase in the aguada's primary productivity and successive links in the trophic chain. These processes result in limnetic fauna and zooplankton (Akpinar 2011: 13).

During the concentration phase (the dry season), nutrients supplement the dry sediment at the bottom of the aguada and lead to vegetation cover that remains until the following wet season (Arredondo-Figueroa and Flores Nava 1992, Flores-Nava 1994).

This ongoing process of dilution and concentration phases forms a mixture of clay and organic debris that constitutes the impervious layer at the bottom of the aguadas (Akpinar and Dunning 2011: 111; Ancona 1889; Adams 1981; Beach and Dunning 1997; Gill 2000; Mathewson 1977; Scarborough *et al.* 1995; Siemens 1978). Recent discoveries seem to indicate that some impervious layers at the bottom of aguadas are composed of smectite clays[14] that originate from the degradation of volcanic ash (Dunning *et al.* 2015a: 100; Grim and Grüven 1978: 128; Tankersley *et al.* 2015: 190). These ashes are residues of volcanic eruptions in Guatemala and Mexico that were deposited in the Southern Maya Lowlands over long periods of time (Ford and Rose 1995: 159; Tankersley *et al.* 2015: 211). Near La Milpa, Weiss-Krejci *et al.* (n.d.) carried out an XRD analysis of the thick clay layer at the bottom of the Aguada Lagunita Elusiva (see Chapter 5.6.5.3.8.3). The analysis showed that the material was a bentonite clay 100% impermeable to water. Future research might indicate that the deposition of volcanic ash was a major factor in forming the impermeability of the sediment layers at the bottom of seasonal shallow basin aguadas. In this context, it should also be noted that only archaeological investigations may prove if these impervious layers are of cultural origin, or if they accumulated through natural processes (Anselmetti *et al.* 2007; Beach *et al.* 2003, 2015b: 260; see also Chapter 5.6.4.1).

The need for more intensive investigations is also demonstrated by an interesting finding in karst studies (see Ford and William 1989) that showed that clay sediments accumulating in depressions are able to seal existing cracks in sinkholes (Akpinar and Dunning 2011: 111). Similarly, X-ray diffraction analysis of sediment samples from the Aguada Santa Ana Vieja (central Petén) showed different types of chloride minerals, revealing that the sealing clay layer was obviously the result of geomorphic and geologic processes (Akpinar and Dunning 2011: 111; Cowgill and Hutchinson 1966). Nondédéo (2003: 27) defined a small subcategory of seasonal shallow basin aguadas. According to him, aguadas situated within seasonal streams (e.g. within the Río Desempeño) or bajos can function as small absorption reservoirs.

(d) Geographic distribution of aguadas

Altogether, thousands of aguadas have already been located in the Maya Lowlands and new features are being discovered each year (Beach *et al.* 2015a). Because they are the results of the geomorphologic transformation described in Chapter 2.1.2, aguadas are most abundant along the edges of bajos (Dunning *et al.* 2015: 10). In rarer cases, they are located along the fractured bedrock of karst uplands and in patches of relatively low elevation in upland areas (Akpinar-Ferrand *et al.* 2012: 85; Beach *et al.* 2003; Bullard 1960: 363, 1969; Carr and Hazard 1961: 13; Dahlin *et al.* 1980; Dunning and Beach 1994; Siemens 1978, 1979: 380; Wahl *et al.* 2007). South of the Sierrita de Ticul, the elevation, precipitation and soil depth increases. At the same time, permanent sinkhole aguadas become less frequent, while the shallow basin aguadas become more frequent (Akpinar 2011: 12; Flores-Nava 1994).

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[14] According to Tankersley *et al.* (2011: 2925) "Smectite is a group of expanding-lattice clay minerals that include biedellite, hectorite, montmorillonite, natronite, saponite, and sauconite, and is the principal component of bentonite clay deposits." Most bentonites form from volcanic ash and were not deposited through dissolution of the surrounding bedrock (Cowgill and Hutchinson 1963: 41; Tankersley *et al.* 2015: 191).

2.2 Climate of the Maya Lowlands

Climatically, the Maya area has a seasonal wet and dry pattern. The hybrid tropical/subtropical climate generates "severe disparities in rainfall" (Dunning *et al.* 2015b: 10). Depending on the location, the region falls into the Köppen climate zones of Am (Tropical Monsoon) and Aw (Tropical Wet) (Akpinar 2011: 6). Generally, the climate becomes more humid towards the east and south[15] (Golden and Scherer 2012: 68; Magaña *et al.* 1999, 2003; Nondédéo 2003: 28; Wilson 1980: 23). This trend is associated with the fact that the Maya Lowlands are located at the northern edge of the inner-tropical convergence zone within the Pacific Ocean – a broad area, where the northeastern and southeastern trade winds clash and ascend (Beach *et al.* 2015a: 8; Chmilar 2005: 16; Wilson 1980: 23). Another influential factor is the location of the Guatemalan Highlands and the Maya Mountains. These direct the clouds towards the Petén and the foothills of the highlands (Nondédéo 2003: 28). Daily temperature variations are primarily due to changes in cloud-cover: Only 63% of the possible solar insolation reaches the ground due to cloud interception, a major inhibitor of high temperatures (Miller 1996: 100). In the winter months, cold air fronts, locally known as *Nortes,* produce thick cloud layers and are accompanied by heavy rainfalls and drastic temperature drops of up to 10° C (Miller 1996: 100; see Chapter 2.2.2).

The amount of rainfall in the Maya Lowlands varies between 500 mm in the northwest coast and 4,000 mm in the highlands (Beach *et al.* 2015: 8; Weiss-Krejci 1999: 134; Wilhelmy 1981: 101). Between these two extremes, the latitude, elevation and rain shadow largely determine the amount of precipitation (Beach *et al.* 2008). The following paragraph illustrates the characteristics and geographic locations of the respective climate zones.

2.2.1 Climate zones of the Maya Lowlands

The climate zones of the Maya Lowlands are highly localized (Yaeger and Hodell 2009: 197) and it is hardly possible to extrapolate data from one region to another (Golden and Scherer 2012: 69). However, some general distinction can be made:

The Northern Maya Lowlands can be attributed to the climate type of tropical savannas (Aw in the Köppen Classification) or to tropical wet-dry (BS in the Köppen Classification). These are marked by annual precipitation of less than 500 mm (Foster and Turner 2004; Nondédéo 2003: Figure 5).

The Central Maya Lowlands feature either seasonally dry or moist climate (Aw in the Köppen Classification). The rainy season extends from June to October, while the dry season extends from November until May (Nondédéo 2003: 28).

The southern Maya Lowlands can be assigned to the tropical monsoon climate type (Am in the Köppen Classification) (Akpinar *et al.* 2012: 85; Parry 2007: 11; Wahl *et al.* 2007: 214). In this zone, the majority of rainfall occurs between late May and December, while the dry period extends from January until May (Dunning *et al.* 2003; 2015: 10; Gallopin 1990: 11; Puleston 1973: 49; Rosenmeier *et al.* 2002; Wahl *et al.* 2007). The rainfall varies between 900 and 2,500 mm, with a regional average of 1,600 mm (Rosenmeier 2002; Scarborough 1991: 125; Wilson 1980: 25; see Figure 2.9). In years of exceptionally high rainfall, the precipitation can measure up to 5,000 mm per year (Parry 2007: 1; Wahl *et al.* al. 2007: 214). The rates of evapotranspiration are 95% with a mean annual temperature of 25° C (Parry 2007: 11).

The southernmost areas however, with annual precipitation of around 2,500 mm and without a distinctive dry season, are assigned to the climate zone of rainy tropics (Af in the Köppen Classification) (Wilson 1980: 25). In the area around Yaxchilan and Piedras Negras, the annual amount of precipitation

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[15] Owing to this phenomenon, the meteorological station of Civiltuc, recorded average annual precipitations of 1161 mm between 1959 and 1969. The meteorological station of Zoh Laguna documented average annual precipitations of 1240 mm between 1953 and 1969. The station of Nicolas Bravo, which is situated even further to the east, recorded an average annual precipitation of 1257.8 mm between 1958 and 1995 (Nalda *et al.* 1997; Nondédéo 2003: 28; Turner 1983: 54).

lies at 2,200 mm (Aliphat 1994: 44), while the area of Palenque receives an average of 3,044 mm of annual precipitation (Golden and Scherer 2012: 70). The Usumacinta floodplain also shows some of the highest precipitation rates of the entire Maya Lowlands (Golden and Scherer 2012: 68; see Figure 2.9). So far however, the climatic studies in this region have remained scarce (Dunning *et al.* 1998: 94; Golden and Scherer 2012: 68).

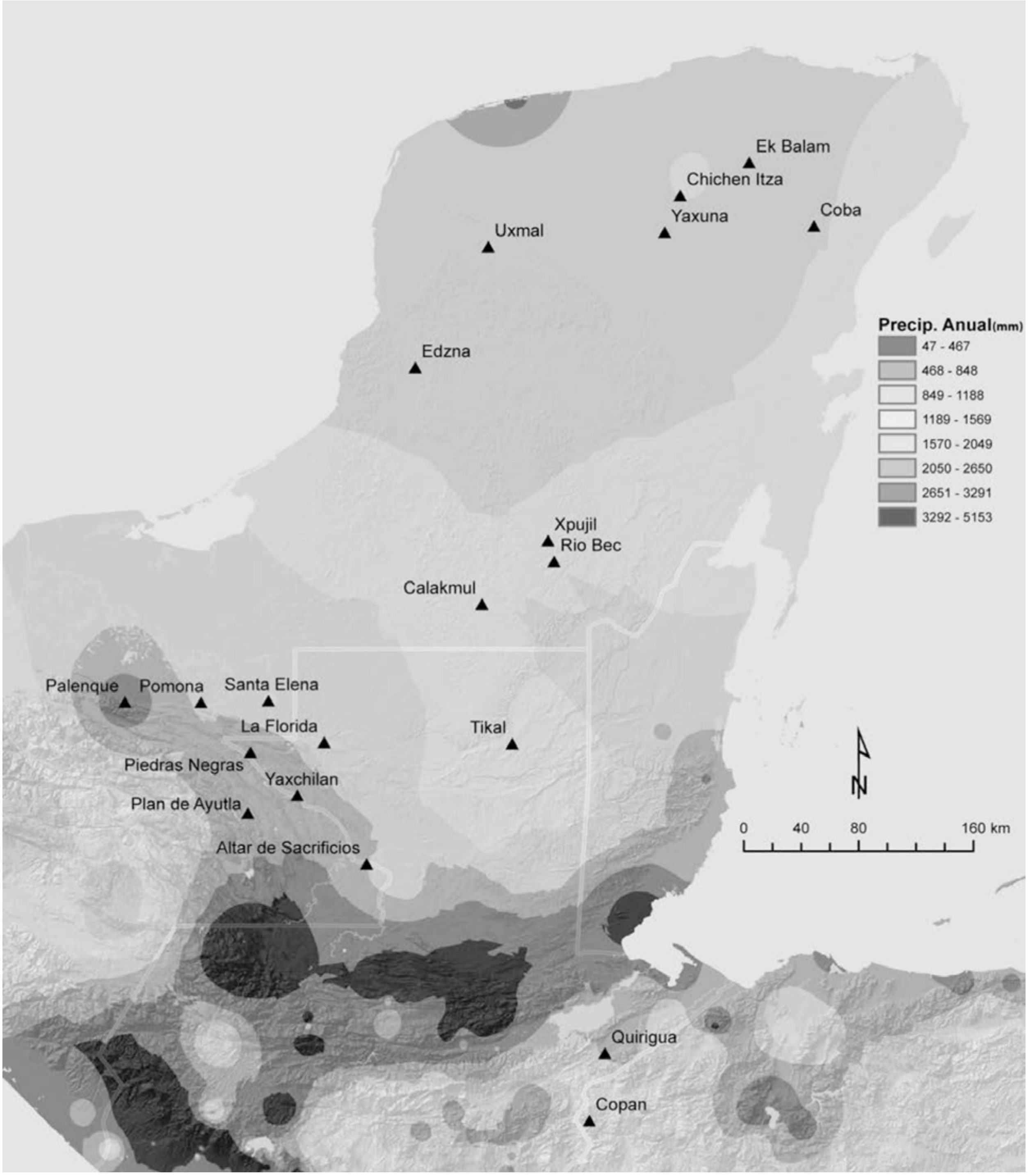

Figure 2.9: Map of the Maya area indicating the amount of annual mean rainfall (source: Golden and Scherer 2012: Figure 2). Reproduced with kind permission of Charles Golden.

As Dunning and Beach (2000: 181) point out, the Maya Mountains form an important climate boundary, because more orographic precipitation and rainclouds occur to the west of this formation. Apart from this general climatic shift from the north to the south, the east and west of the Central Maya Lowlands can be further distinguished. The east receives some precipitation during the winter months due to the beneficial influence of winds from the Caribbean Coast, known to bring rainclouds into the Xpujil region (Nondédéo 2003: 28).

Logically, it follows that these harsh differences in rainfall lead to different forms of agricultural productivity. While peasants of southern Mexico have suffered from severe drought over the last two decades (Seager *et al.* 2009; Stahle *et al.* 2009), peasants of the middle Usumacinta region have enough water to yield two annual harvests of maize, beans and other crops (Golden and Scherer 2012: 68).

2.2.2 Seasonal phenomenology of the climate in the Maya Lowlands

Although the annual precipitation cycle can generally be described as the dry season extends from January to May and the rainy season from late May until December, there are two peaks of rainfall in the rainy season worth noting:

The first peak occurs in June and the second peak in September, both of which are interrupted by a brief dry period of severe droughts, the so-called *veranillo* or *canícula,* which usually occurs between the middle of June and early August (Hester 1954; Puleston 1973; Wahl *et al.* 2007: 214). It is important to note however that the timing of the *canícula*/*veranillo* are variable. When the *canícula* persists for an extended period, it can cause massive consequences for agricultural production (Dahlin 2005: 234-235).[16]

The rate of precipitation is highest in September and October. In the same period, hurricanes and other tropical storms in the Caribbean Sea may bring heavy winds and torrential rainfall causing heavy devastation along the way (Nondédéo 2003: 28; Wilson 1980: 21-23). As these tropical storms and hurricanes frequently occur during the harvest seasons, they often have serious influences on the extent of agricultural production (Dunning and Houston 2011; Dunning *et al.* 2015b: 10).

During the dry season, only 10% of the annual precipitation occurs (Chmilar 2005: 17). Although the dry season usually extends from January until May, the months of March and April are the driest. In order to provide a better understanding of these phenomena, it is crucial to present the meteorological processes causing them: At the onset of the dry season, high-pressure areas move over the Atlantic towards the southwest, where they gather over the Yucatán Peninsula and impede the formation of clouds (Wilson 1980: 24).

During the rainy season, these conditions are reversed and rainclouds release precipitation over the Maya Lowlands (Nondédéo 2003: 28). In this process, the north migration of the Inter-Tropical Convergence Zone (ITCZ) and the Bermuda-Azores-High pressure systems stimulate heavy rains. In November and December, dry weather conditions return, as the ITCZ and the Azores-Bermuda move towards the Equator and cause strong trade winds.

In contrast to this strict annual seasonality of rainfalls, precipitation can also occur during the dry season. This happens when cold fronts from the United States collide with the moist and hot air masses of the Yucatán Peninsula (Nondédéo 2003: 28). These cold air fronts are locally known as *nortes* and produce a thick layer of clouds accompanied by heavy rainfall and drastic temperature drops (Escoto 1964: 193: Wilson 1980: 23).[17] In some cases, nortes may also cause high waves in the Gulf of Mexico and, in the process alter the beaches and islands along the north and west coasts (Wilson 1980: 23).

Despite these drastic seasonal variations in precipitation, it is interesting to note that the temperature differences over the course of the year are surprisingly low (Brewer 2007: 14; Gill 2000; Nondédéo 2003:

[16] Hester (1954: 27-28) described a *canícula* drought in the town of Lechaquillo in the year 1953, which affected 90% of the peasants and led to a crop failure of 80% (Silverstein *et al.* 2009: 49).

[17] Nondédéo (2003: 28) noted that while the annual average temperature in the southern Campeche state was around 26° C, temperatures could suddenly drop to 18° C and less during *nortes*.

28). Far more pronounced are the climatic fluctuations that occur from one year to the next – an aspect presented in the following paragraph.

2.2.2.1 Interannual climatic variations in the Maya Lowlands

While the scientific interest in the climatic variations within the Maya Lowlands previously focused on the more or less regular fluctuations between dry seasons and rainy seasons, several scholars of the 1980s observed that some years were marked by very pronounced dry seasons of four to five months (Wilk 1985: 49).[18] However, it was the study by Gill (2000) that brought these interannual climatic fluctuations into light for the scientific community and general public. In the subsequent years, this increased interest led to a series of new publications (e.g. Gunn *et al.* 2002: 80).

Generally, annual precipitation can vary more than 30% from the long-term average (Wilson 1980: 24), a fact that has caused serious issues for the agricultural production in recent years (Dunning and Beach 2004; Dunning *et al.* 2015b: 10). Based on the present understanding, the wide array of interannual climatic variations in the Maya Lowlands are caused by regional and global climatic dynamics, shifting atmospheric pressure belts and prevailing winds (Beach *et al.* 2008; Brenner *et al.* 2003; Hodell *et al.* 2001: 1368; Kueny and Day 2002; Mueller *et al.* 2009; Piperno and Pearsall 1998). The interannual variations of rainfall are highly unpredictable because the seasonal migration of the ITCZ and the Azores-Bermuda high-pressure system varies on both short-term and long-term scales (Mueller *et al.* 2009).

A very important aspect of Gill's (2000) results included the hypothesis that pronounced droughts would have been one of the main causes for the collapse of Classic Maya civilization, a theory discussed in greater detail in Chapter 4. Another important aspect of Gill's (2000) work was the notion that severe droughts might not have affected all areas equally. Furthermore, Gill (2000) noted that some cities and regions would have been affected more so than others in a single drought period and that different patterns of severity often occurred in the next period (Brewer 2008: 15). In this context, Brewer (2007: 15) remarked that "to a large extent across the region, the following years are not dependent upon the previous, the resulting pattern of rainfall and drought is random".

In this respect, Nondédéo (2003: 28) justifiably refers to the lack of older precipitation data from southeastern Campeche and points out that the seemingly random fluctuations of precipitation might be explained satisfactorily if more climate data could be evaluated (Lundell 1934: 262; Wilson 1980: 28).[19] Nondédéo's (2003) observation conforms of Wilson's (1980: 21) remark that precipitation data would only be reliable if collected for at least 20 years.

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[18] These variations have a wide range and do not only occur from year to year. Thus, longer enduring changes such as droughts lasting for years may also occur. Climatic variations can occur quite differently in space, so that they only affect small fractions of the Lowlands, while neighboring regions remain unaffected (Gunn and Adams 1981: 80).

[19] As Lundell (1937: 262) already remarked during his residence in southern Campeche, there is an extremely high inconstancy and irregularity of precipitations from one year to another (Nondédéo 2003: 28). Consequently, several dry years can be followed by a humid year.

2.3 Soils of the Maya Lowlands

> *„Yucatán is the country with the least earth that I have ever seen, since all of it is one living rock"* (de Landa 1978; Wilson 1980: 5).

As soils are the product of the parent rock material and the climate, the geomorphic processes (see Chapter 2.1.1) that resulted in the different geologic subregions of the Maya Lowlands (see Chapter 2.1.3 and Figure 2.3) are also reflected in the spatial allocation of soils (Dunning and Beach 2000: 183).Generally, the inorganic component of the soils is determined by the mineralogy of the decomposed and dissolved parent material (Wilson 1980: 32). As the limestone parent material of the Maya Lowlands decomposes and dissolves, the remaining inorganic soil minerals mostly consist of small amounts of insoluble residues usually resting directly upon the parent rock and rarely feature transition zones (Wilson 1980: 32).

Underneath the hard surface layer lies the decomposition front, a zone where the original character of the limestone bedrock undergoes a chemical alteration. In this process, a softer, mostly brittle and almost pure calcium carbonate forms, locally known as *sascab* (Wilson 1980: 11). Essentially, sascab is a type of soil or lime-sand made up of particles with diameters of less than 0.065 mm. These particles are comprised of clastic or mixed sedimentary rocks of a calcareous-pelitic class created by lacustrine or oceanic processes (Mottana *et al.* 1978: 330; Nondédéo 2003: 29; Parry 2007: 80). According to Rapp and Hill (1998: 27), the fine-grained texture and clastic nature of the marl are characteristic of low-energy processes created in aquatic conditions (Parry 2007: 80). Sascab is distributed irregularly throughout the landscape and can reach thicknesses of several meters (Wilson 1980: 11).

The majority of the soils found in the Maya Lowlands are of calcareous origin (Nondédéo 2003: 29). In most cases, they are young, shallow, base-rich and clayey soils with a high calcium carbonate content (Dunning *et al.* 2015b: 8; Nondédéo 2003: 29). Additionally, the mineral composition can be further defined by the drainage characteristics of the soils. As a general rule, if the soils are well-drained, they are rich in kaolinite, while if they are water-saturated, they are rich in montmorillonite.Because these soils feature only low amounts of the minerals needed for breeding crop plants, such as potassium phosphate and iron, they are generally considered unsuited for agricultural use (Stephens 1962: 303; Turner 1983: 53-55; Wilson 1980: 33). As Nondédéo (2003: 28) stresses, this low mineral content motivated both pre-Hispanic and modern-day farmers to practice slash-and-burn agriculture, which enriches these natural sediments with ash. According to Nondédéo (2003: 29) and Dunning *et al.* (2015: 8), the soil types of the Maya Lowlands can be divided into the three main orders of lithosols (1), mollisols (2) and vertisols (3), all of which include typic, lithic, cumulic, and vertic subgroups.

(1) Lithosols referred to by the Maya as *tsek'el* or *chenche*, are recently formed and shallow (maximum thickness of 10 cm) soils that feature a similar chemical composition to their original substrate. As they form in decomposition processes near the surface, lithosols generally contain many stones. They are well-drained, black and mostly covered by dense vegetation (Gliessman *et al.* 1983: 94). However, according to Nondédéo (2003: 29), lithosols are not well suited for agricultural use.

(2) Mollisols, also referred to as "calcimorphous soils" or "rendolls", belong to the rendzina soils, which are widespread and typical for karstic region (Dunning and Beach 2000: 183; Nondédéo 2003: 20). Although they only represent 1% of the world's tropical soils, they are the predominant soil type of the Maya Lowlands (Brewer 2007: 18). Their color ranges from gray to black (Brewer 2007: 18). Characteristically, they are unripe soils with a shallow depth of 30-50 cm, rich in organic matter and usually well-drained (Brewer 2007: 18). Their texture ranges from brittle clay to clay suitable for pottery (potter's clay) and their pH-values range from neutral (pH-7) up to low alcalic (pH-8) (Brewer 2007: 18; Buol *et al.* 2003; Fedick and Ford 1990: 20; Silverstein *et al.* 2009: 50; Wilk 1985: 48). Despite their shallow depth, they can be highly productive in non-mechanized cultivation systems. Fedick and Ford (1990: 20) emphasized that mollisols belong to the most important and naturally productive soil types in the world. Their harvests exceed those of any other non-draining soil-types (Brady 1974: 327). Only irrigated areas achieve a higher agricultural productivity (Brewer 2007: 18; Dunning and Beach 2002). However, as they are usually situated on hillslopes, erosion processes frequently affect them (Dunning *et al.* 2015b: 8; Fedick and Ford 1990: 20). Modern Maya farmers consider them to be most productive for swidden ("slash and burn") cultivation in the form of *milpas* (Brewer 2007: 18; Fedick and Ford 1990).

(3) Vertisols or **hydromorphous soils**, belong to the soil type of gleys. They develop in water-saturated depressions where they can reach thicknesses of several meters and contain montmorillonite (Wahl *et al.* 2007: 214). Montmorillonite clays are sheet silicates, and can swell due to the absorption of water and other substances. Used as an additive in soils and stones, montmorillonite can decelerate the filtration of water. For example, this has been used in order to bridge extended dry periods in agriculture (Dudal and Eswaran 1988: 16). The vertisols of the Maya Lowlands may consist of to 80% montmorillonite (Gunn *et al.* 2002: 304). Due to the high amount of montmorillonite, these clays may swell depending on the moisture content during the rainy season, and become moldable and sticky (Dunning *et al.* 2015b: 9; Fedick and Ford 1990: 21). During the dry season, they contract, become hard as concrete and form fissures of up to 120 cm in depth (Brewer 2007: 18; Buol *et al.* 2003; Turner and Harrison 1983b: 3). Despite their high content in organic matter, they are unsuitable for agricultural uses due to their inability to drain, which causes them to be extremely hard to process (Silverstein et al 2009: 53). Their color varies between gray and black and the Maya refer to this soil type as *ek' lu'um* ("dark soil").

2.3.1 Geographic distribution of soil types

Due to less faulting, the soils in the northern Maya Lowlands are shallow, well-drained, clayey, and rich in lime content (Brewer 2007: 17; Chmilar 2005: 18; Dunning and Beach 2000: 183).

The soils of the southern Maya Lowlands, on the other hand, reflect the limestone material, drainage characteristics and specific climatic conditions of the area (Chmilar 2005: 18; Dunning *et al.* 1998b: 142; Dunning and Beach 2000). Generally, the soils of the southern Maya Lowlands tend to be deeper than those in the Northern Lowlands. They are also poorly drained, rich in lime, and fertile (Dunning and Beach 2000: 183; Dunning *et al.* 1998: 93). In the southwestern Lowlands, e.g. in the region of Piedras Negras, the soils may reach thicknesses of several meters (Fernández *et al.* 2005; Golden and Scherer 2012: 71; Johnson *et al.* 2007).

The soils of the highlands are generally fertile, but as they represent clay mollisols or rendzinas, which are mostly located in steep slopes, erosion is a constant threat (Dunning and Beach 2000: 192; Dunning *et al.* 1998a; Siemens 1978).

2.4 Landscape forms of the Maya Lowlands

In general, the landscapes of the Maya Lowlands can be subdivided into four different types of habitats, each with their own characteristic vegetation-communities (Fedick and Ford 1990: 20; Wahl *et al.* 2007: 214).

(1) Well-drained uplands

(2) Slowly draining lowlands

(3) Seasonally inundated lowland areas (bajos), and

(4) Permanently moist depressions

According to Fedick and Ford's (1990: Table 1) assessment, these landscape forms are distributed in a mosaic-like pattern throughout the Maya Lowlands. Each of them has different characteristics and implications for agricultural development, which is presented in greater detail in the following (Wahl *et al.* 2007: 214).

2.4.1 Well-drained upland areas

The landscape form of well-drained upland areas consists of gentle limestone hills and summits covered by thin layers of fertile mollisols. These soils are able to support broad-leaved, thick and closed semi-deciduous forests with canopies that can reach heights of more than 50 meters (Binford *et al.* 1987: 117; Brewer 2007: 18; Lucrecia de Mac Vean 2003: 3; Lundell 1937: 27; Parry 2007: 8; Silverstein *et al.* 2009: 50; Villa Lobos 2000; Wagner 1964; Wilk 1985: 48).The characteristics of the vegetation-communities in the well-drained upland areas are determined by the local amount of precipitation. The vegetation types in well-drained upland areas range from lowland humid tropical mesophytic, semi-deciduous forests to tropical evergreen forests (Dunning and Beach 2000: 183; Wahl *et al.* 2007).[20] "The most frequent and dominant tree-species in these vegetation communities are *Manilkara zapota* (Engl. sapodilla), *Brosimum alicastrum* (Engl. Ramón or breadnut tree), *Pouteria reticulata* (Engl. Eyma), *Drypetes brownie*, *Sabal mauritiiformis, Blomia prisca*, *Sambal mauritiiformis*, *Blomia prisca*, *Trichilia minutiflora,* and *Pseudomedia oxyphylaria*" (Dunning *et al.* 2015b: 11). In the northern Petén and southern Campeche, the semi-deciduous rainforests still experience a relatively long dry season (Dunning and Beach 2000: 183).

2.4.2 Slowly draining lowland areas

Slowly draining lowland areas represent those areas where the limestone dissolution processes were most active. These areas are mostly found at low elevations within chains of hills and generally represent transitional zones between well-drained highland areas and the various swamp forms (Fedick and Ford 1990: 21, Table 1). Generally, these habitats are quite extensive and represent the predominant landscape type in many areas (Fedick and Ford 1990: 21). The soils of these low-lying areas are a mixture of poorly drained vertisols and mollisols (Brewer 2007: 18). Areas dominated by vertisols feature the typical argilloturbations called *Gilgai* (Brewer 2007: 18; Buol *et al.* 2003; see Figures 2.10a and 210b).

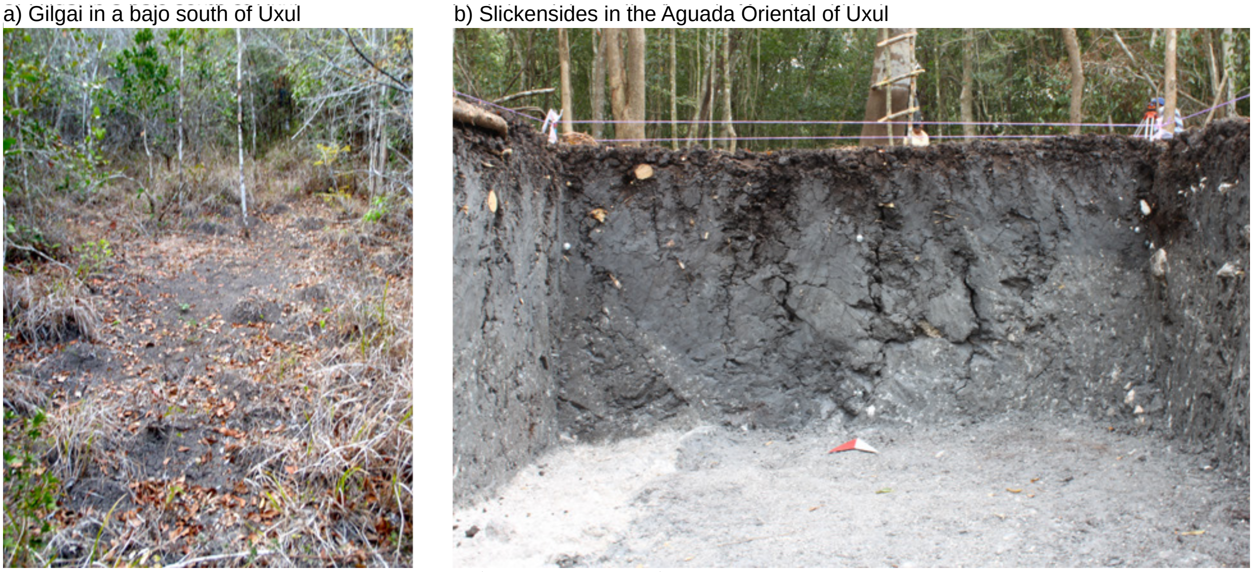
a) Gilgai in a bajo south of Uxul
b) Slickensides in the Aguada Oriental of Uxul

Figure 2.10: Examples of gilgai and slickenslides (Photos: N. Seefeld).

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[20] Other denominations for this vegetation-type are "upland forest" (Brokaw and Mallory 1993; Dunning *et al.* 2015b: 11; "climax forest" (Lundell 1937) and deciduous seasonal forests" (Wright *et al.* 1959).

The areas dominated by mollisols support marsh forests with an open canopy and various palm species (Fedick and Ford 1990: 21; Wright *et al.* 1959). In many ways, these forests have a similar structure to those in the well-drained upland areas. However, they have a lower canopy and a different composition of plant species (Dunning *et al.* 2015: 10). The remaining parts are covered with grass-savannas (Brenner *et al.* 1990; Cowgill and Hutchinson 1966; Lundell 1937). On rare occasions, seasonal shallow-basin aguadas can be located in slowly draining upland areas, mostly along escarpments (Bullard 1960: 363, 1969; Wahl *et al.* 2007).

2.4.3 Seasonal inundated lowland areas and permanently moist depressions

The two landscape types of seasonally inundated lowland areas (bajos) [3] and permanently moist depressions [4] are actually two subdivisions of a landscape type generally referred to as bajos. The Spanish term *bajo* (Maya: *akalche'*, Siemens 1982: 207) was usually applied rather loosely and broadly in the archaeological literature to refer to any karstic depression with poorly drained and generally swampy soils (Culbert *et al.* 1991: 118; Dunning *et al.* 2006: 81, 2015: 9; Harrison 1977: 469). Although definite figures are lacking, bajos cover an estimated 40-60% of the land surface in the Maya Lowlands (Chmilar 2005: 18; Culbert and Rice 1990; Dunning *et al.* 2006: Figure 5.1; Sever and Irwin 2003: 114; Weller 2006: 21).[21] Individual bajo landscapes have areas ranging from tens of meters to several square kilometers (Beach *et al.* 2009: 1713). Bajos are widely used as a source of raw materials. For instance, they provided clay for the production of pottery and chert for tool production by the pre-Hispanic Maya (Beach *et al.* 2003; Chmilar 2005: 18; Harrison 1999; 45; Jacob 1995; Nondédéo 2003: 27). In fact, bajos are the principal sources of raw chert in the Maya Lowlands. This concentration of chert was caused by natural erosion processes where it appears as a secondary inclusion in the limestone-matrix (Akpinar 2011: 25; Chmilar 2005; Kunen 2004; Tourtellot *et al.* 2003: 44; Weiss-Krejci and Brandl 2011: 154).

The vegetation within each bajo environment is highly specific and mainly determined by its geographic elevation (Dunning *et al.* 2006: 81; Pope and Dahlin 1989: 91; Turner and Harrison 1983a: 250). Throughout the history of research, there have been several attempts to categorize this broad range of vegetation communities (e.g. Culbert *et al.* 1991: 116). Because of the great variety of habitats, the many types of wetlands were classified using different terminologies. However, the past two decades has shown that the most obvious and practical characterization is the differentiation between outer and inner bajos mainly based on elevation differences (Dunning *et al.* 2006: 81). These are seasonally inundated lowlands areas (inner bajos) and permanently moist swamps (outer bajos).

Formation processes of inner bajos and outer bajos

According to Beach *et al.* (2009: 1711), bajos appear to be poljes that developed within grabens. Because many formed in areas with gypsum-rich substrates, they may show a preferential dissolution of gypsum (Perry *et al.* 2009). The soils forming these bajo landscapes are the result of two geomorphic processes. On the one hand, these soils result from erosion in the sloped terrain of the "well-drained upland area" landscape type (Beach *et al.* 2009: 1713). On the other hand, the weathering process of the limestone bedrock produces montmorillonite clays, which wash into the lower lying inner bajos, where they can form deep and impermeable vertisol layers with thicknesses of up to several meters (Fedick and Ford 1990: 23; Nondédéo 2003: 27; Silverstein *et al.* 2009: 50; Wahl *et al.* 2007: 214). After their deposition these vertisol clays are exposed to argilloturbation (Akpinar 2011: 7). In general, deeper depressions are marked by wetter conditions and the formation of organic soils (Dunning *et al.* 1998a). Recent investigations indicate that just like in aguadas, significant portions of the bentonite clays in bajo environments of the Central Maya Lowlands are derived from eolian volcanic ash (Dunning *et al.* 2015a: 100; Tankersley *et al.* 2011, 2015; see Chapter 2.1.4.3.1).

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[21] During his early visits in the 1930s, Cyrus Lundell (1934: 276) determined a much lower percentage of bajos and claimed that only 15% of southeastern Campeche would be covered with bajos during some portions of the year (Nondédéo 2003: 27).

Gates (1999: 31) and Beach *et al.* (2009: 1713) also proposed the idea that bajos might have a connection with old streambeds or intermittent streams. In conjunction with this idea however, Nondédéo (2003: 28) correctly observed that the more elevated locations of riverbeds do not coincide with the locations of bajo landscapes. Consequently, Gates' (1999) concept was not widely distributed in the literature.

2.4.3.1 Seasonally inundated lowland areas / inner bajos

Inner bajos, a landscape habitat also referred to as "*closed depression seasonal swamps*" (Fedick and Ford 1990: 23), "wooded swamps" (Puleston 1971: 332), "logwood bajos" (Puleston and Puleston 1971: 335), or "upland bajos" (Puleston and Puleston 1971: 335) are generally located between 80 and 250 m above sea level (Dunning *et al.* 2006: 81; Turner and Harrison 1983a: 250; see Figure 2.11). Inner bajos are a very dominant landscape element of the southern Maya Lowlands (Wahl *et al.* 2007: 214). As they are not connected to rivers, they are not perennially inundated. One of the few exceptions to this general rule is the region of the Lago Petén Itzá and its environs (Fedick and Ford 1990: 23).

During the rainy season, these swamps absorb great amounts of standing water and desiccate once again during the dry season (Dunning *et al.* 2015b: 9; Fedick and Ford 1990: 23; Turner and Harrison 1983a: 250). Consequently, they represent seasonal wetlands. Inner bajos feature a wide range of vegetation complexes that result from the local soils and characteristic inundation and desiccation processes in the respective area (Brokaw and Mallory 1993; Culbert *et al.* 1996: 52; Dunning *et al.* 2006: 82; Lundell 1937; Pope and Dahlin 1989: 93; Siemens 1978). Due to the highly variable soil moisture however, they are mainly marked by woody and herbaceous vegetation (Dunning *et al.* 2015b: 8). Permanently water-bearing layers are generally situated more than 100 meters below the surface and consequently do not influence the hydrology of the respective wetland (Pope and Dahlin 1989: 93). Currently, it is still being discussed as to whether each individual bajo represents an independent system or if they are interconnected. Fialko (1999: 688) proposed the idea that an interaction exists between the basins and sub-basins of the Río Holmul and some of the larger bajos of the northeastern Petén at the borders of Holmul and Nakum (Pope and Dahlin 1989: 98; see Figure 2.11). According to Hansen *et al.* (2002: 288), the water of the Mirador Basin seems to flow mostly towards the north and consequently drains into the Candelaria Basin via the Río Paixban. Furthermore, some streams at the western border of the Mirador Basin seem to drain into the San Pedro-Usumacinta system (Hansen *et al.* 2002: 288). More detailed regional studies of bajo landscapes might clarify these open questions. Currently however, it should be stressed that the hydrology of inner bajos remains "little understood" (Wahl *et al.* 2007: 214).

As Dunning *et al.* (2015b: 9) noted, studies over the last decade[22] have shown that bajos have experienced considerable environmental transformations over past several millennia (Beach *et al.* 2003, 2008, 2009; Dunning *et al.* 2002, 2006; Hansen *et al.* 2002). Due to the increased content in montmorillonite, the vertisol type clays, which dominate these inner bajos, swell and contract dramatically according to the seasonally changing hydrographic conditions (Dunning and Beach 2000: 192; Parry 2007: 169). Typically, these contractions occur during the dry season from January to May, while the soil expansions take place with the onset of the dry season from June to August. After September, the clays reach their saturation point and surface pools begin to form until December (Beach *et al.* 2009: 1713). These contraction and expansion cycles can form a superficial pattern of elevations and depressions, which have been described as *gilgai* (Hansen *et al.* 2002: 281). The typical attributes of the gilgai microtopography are a wedge-shaped, parallel flat soil structure, protruding slickensides and chimney-like extrusions (Dudal and Eswaran 1988: 10; Jacob 1995: 184). In profiles of bajo sediments, these gilgai are easily observed due to the characteristic undulations and stratigraphic upheavals (Parry 2007: 176).

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[22] As these studies have mostly focused on the development of bajo landscapes in reaction to the climatic conditions in pre-Hispanic times, they will be presented in the framework of Chapter 4.

These gilgai, and the constant contractions and expansions limit the agricultural productivity and workability of these vertisol clays (Dunning *et al.* 2006: 84; Fedick and Ford 1990: 23; Hansen *et al.* 2002: 273; Pope and Dahlin 1989: 93; Silverstein *et al.* 2009: 53). Furthermore, the moisture is stored in these heavy clays in a hygroscopic state. Owing to this effect, the clays absorb existing moisture like a sponge (Fedick and Ford 1990: 23; Lundell 1937: 28). As Fedick and Ford (1990: 23) noted, the ability to work this soil by hand is restricted to short periods between the cycles of moisture during the rainy season and hardness during the dry season.[23] Another factor for the limited agricultural potential of inner bajos is the acidity of the soils. Vertisols in the Bajo de Santa Fe feature pH levels ranging from moderately acidic at the surface (pH 5.1) to extremely acidic (pH 3.2) at a depth of 46 cm (Brewer 2007: 19; Fedick and Ford 1990: 23; Ford 1981: 171). According to Gunn *et al.* (2002: 301), the agricultural potential is further decreased by the salinity of the soil (Hansen *et al.* 2002: 275; Parry 2007: 12).[24] Some recent studies (Dunning *et al.* 2015b: 9) however, indicate that histosols (organic muck) occur where there is perennial soil-moisture in some of the larger bajos. According to Dunning *et al.* (2015: 9), histosols may have been more widespread in bajos at "some time in the past".

The vegetation communities within inner bajos vary considerably according to the specific microtopographic situation (Dunning *et al.* 2015b: 11). Nevertheless, the vegetation-types of inner bajos are usually defined as xerophytic forests[25], which are adapted to the strong fluctuations in moisture. The most common tree species in these depressions are the "palo de tinto" (*Haematoxylum campechanium*, mostly used as logwood[26]) and the "chechem" (*Metopium Brownei)* (Dunning *et al.* 2015b: 10; Pope and Dahlin 1989: 93; Wright *et al.* 1959). These trees are frequently twisted and thorny and as a result of the annual argilloturbation process, they are typically 3-10 m in height (Akpinar 2011: 8; Dunning *et al.* 2015b: 10; Wahl *et al.* 2007). As aguada habitats feature more humid conditions than the surrounding "inner bajo" habitats, the vegetation communities are more similar to those usually located in the well drained upland areas landscape type (Lohse 2004; Wahl *et al.* 2007). Matheny *et al.* (1983) describe the presence of water dependent species like *Nymphea* (water lilies) and *Pisita stratiotes* (water lettuce) in the aguada habitats of Edzná. Wahl *et al.* (2007) carried out an intensive study of plant communities in bajo habitats, which showed the coexistence of numerous aquatic species, herbs, cultigens and arboreal species (Akpinar 2001: 9; Brenner *et al.* 1990; Cowgill and Hutchinson 1966).

Important sources of water within the inner bajos are aguadas and *civales* (Hansen *et al.* 2002; Jacob 1995; Scarborough 2003b). Aguadas can be located at both the margins and interior zones of inner bajos (Weiss-Krejci and Sabbas 2002: 343). As Dunning *et al.* (2015: 10) noted, inner bajos are "the most common location for *aguadas*". The soils in the direct vicinity of aguadas range from thin, highly erodible and agriculturally productive soils to heavy impervious clays (Chmilar 2005; Dunning and Beach 1994; Dunning *et al.* 2007; Higbee 1948; Lundell 1937). Although they may be located in the middle of "inner bajos" with dry xerophytic vegetation communities, they represent islands of micro-habitats that highly differ from the immediate landscape type. The fact that soils and vegetation communities of aguada habitats differ so drastically from the surrounding "inner bajo" habitat might be considered a reason to define aguada habitats as an independent landscape type. However, it should be stressed that natural aguada habitats are landscape features limited to the slowly draining lowland area and inner bajo landscape types. Owing to this obvious geographic distribution, the author would like to define them as a subtype of the slowly draining lowland areas and inner bajos landscape types.

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[23] In fact, these vertisols are very fertile, but their agricultural use by hand is restricted due to their poor workability and poor drainage (Fedick and Ford 1990: 22). Many of those regions dominated by vertisols in other parts of the world remain underdeveloped due to the lack of heavy machines for plowing.

[24] Parry (2007: 88, with table 4.2) however highlights that while most bajo sediments proved to be acidic (pH reading between 5.1-3.1) the sediments within the bajo and reservoir of Naachtun would have been neutral to alkaline.

[25] Other terms used for this forest assemblage include "bajo forests" (Lundell l937), "low marsh forests" (Wright *et al.* 1959) and "tintal bajo" (Ford 1986) (Dunning *et al.* 2015b: 11).

[26] The frequent occurrence of *Palo de tinto* trees becomes obvious in one of the definitions of inner bajos as „logwood bajos" (Puleston and Puleston 1971: 335; see above).

Additionally, aguadas yield important animals species including mammals, birds, fish, gastropods and zooplankton (Akpinar 2011: 9; Flores-Nava 1994; Goulden 1966; Harrison 1977, 1999: 45; Hubbs 1935; Matheny *et al.* 1983; Moholy-Nagy 1978; Murie 1935). Therefore, in the current landscape, aguadas represent important sources of animal protein such as Pomacea[27] snails, mollusk species (e.g. *Pomacea flagellata*) or fish[28] (Goulden 1966; Hubbs 1935; Murie 1935).

Civales are treeless, permanent wetlands, which are much less common than aguadas. They can be located at both the margins and interior areas of inner bajos (Chmilar 2005: 19; Dunning *et al.* 2002: 272, 2006: 274; Hansen *et al.* 2002: 277; Hodell *et al.* 2000; Jacob 1995; Scarborough 2003b; Weller 2006: 349). Civales are covered with thick layers of peaty histosols (peaty mucks) and vertisols that support rich herbaceous vegetation communities (Castaneda 1995; Dunning and Beach 2000: 183; Dunning *et al.* 2006: 84, 2002: 286; Hansen *et al.* 2002: 277; Lundell 1937; Parry 2007: 12; Wahl *et al.* 2007: 217). Dunning *et al.* (2002: 272) also define civales as an independent landscape type that shows many similarities to the permanently moist outer bajos described in the upcoming paragraph.

2.4.3.2 Permanently moist swamps - outer bajos

In contrast to inner bajos, the permanently inundated outer bajos, also referred to as "permanent wetlands" and "riverine swamps", are situated less than 80 meters above sea level (see Figure 2.11). Although some of the outer bajos are only seasonally flooded, the majority are permanently wet throughout the entire year, as their soils are continously saturated with moisture (Dunning *et al.* 2006: 82; Gliessman *et al.* 1983: 104; Wilk 1985: 48). Consequently, they can be defined as permanent wetlands. Outer bajos are sometimes connected to rivers, but may also represent independent water systems (Pope and Dahlin 1993: 381; Turner and Harrison 1983a: 269). Due to regional changes in the water level of coastal tributaries, their water table varies between one and two meters from the rainy season to the dry season (Pope and Dahlin 1989: 91, 96). In both cases, the water table lies less than two meters below the surface, causing the soils to remain moist for the entire year except for the uppermost layer (Pope and Dahlin 1993: 381).

The soils of these outer bajos are mostly sticky, moist clays with a high content of montmorillonite (Darch 1983a; Turner and Harrison 1983a: 250; Wright et al 1959). Despite their high clay content, these soils do not tend to form gilgai formations, since they only develop with high fluctuations in moisture (Gliessman *et al.* 1983: 104; Jacob 1995: 184). The soils of inner bajos are a wetland variety of mollisols (see Chapter 2.3.1) and are suitable for the cultivation of various crops in ditched field systems (Brewer 2007: 18; Fedick and Ford 1990). The almost neutral pH values of these soils, their fertility and workability and the described stable hydrological conditions create a suitable environment for wetland cultivation. Usually, three different vegetation zones can be defined in the periphery of outer bajos (Jacob 1995: 177; see Figure 2.11):

(1) The upper border areas of bajos are dominated by hill country vegetation in the form of secondary, tropic moist rainforests with cohune palms and deciduous hill area trees (Ficus, Ceiba, Pouteria, etc.).

(2) The swamp habitats themselves are surrounded by a bog forest belt (*bañado*) consisting of a mangrove mixed forest (Darch 1983b; Lundell 1937: 27-32; Miranda 1958: 243-245; Miranda and Hernández 1963; Siemens 1982: 207; Wright *et al.* 1959).

(3) Marshes dominated by sedges (*Cladium jamaicense*) lie within the bajos (Fedick and Ford 1990: 22; Jacob 1992: 191-194, Siemens 1982: 210). Palms and other mixed forest species are found upon low "bajo

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[27] As Pomacea snails prefer wet environments, they can frequently be found in aguadas (Matheny 1980: Dunning *et al.* 2010).

[28] Murie (1935) observed that an aguada in Uaxactun was filled with fish that died as soon as the water evaporated during the dry season (Akpinar-Ferrand and Dunning 2011: 120). In the Aguada Oriental of Uxul, a similar phenomenon was observed in the course of several consecutive field seasons.

islands" (Siemens *et al.* 2002: 206). Sometimes, permanent lakes (*esteros*) can be located within these sedge marshes, which are marked by a low oxygen content (Siemens *et al.* 2002: 207). The size of these lakes varies between a few square meters and several square kilometers (Pope and Dahlin 1989: 91).

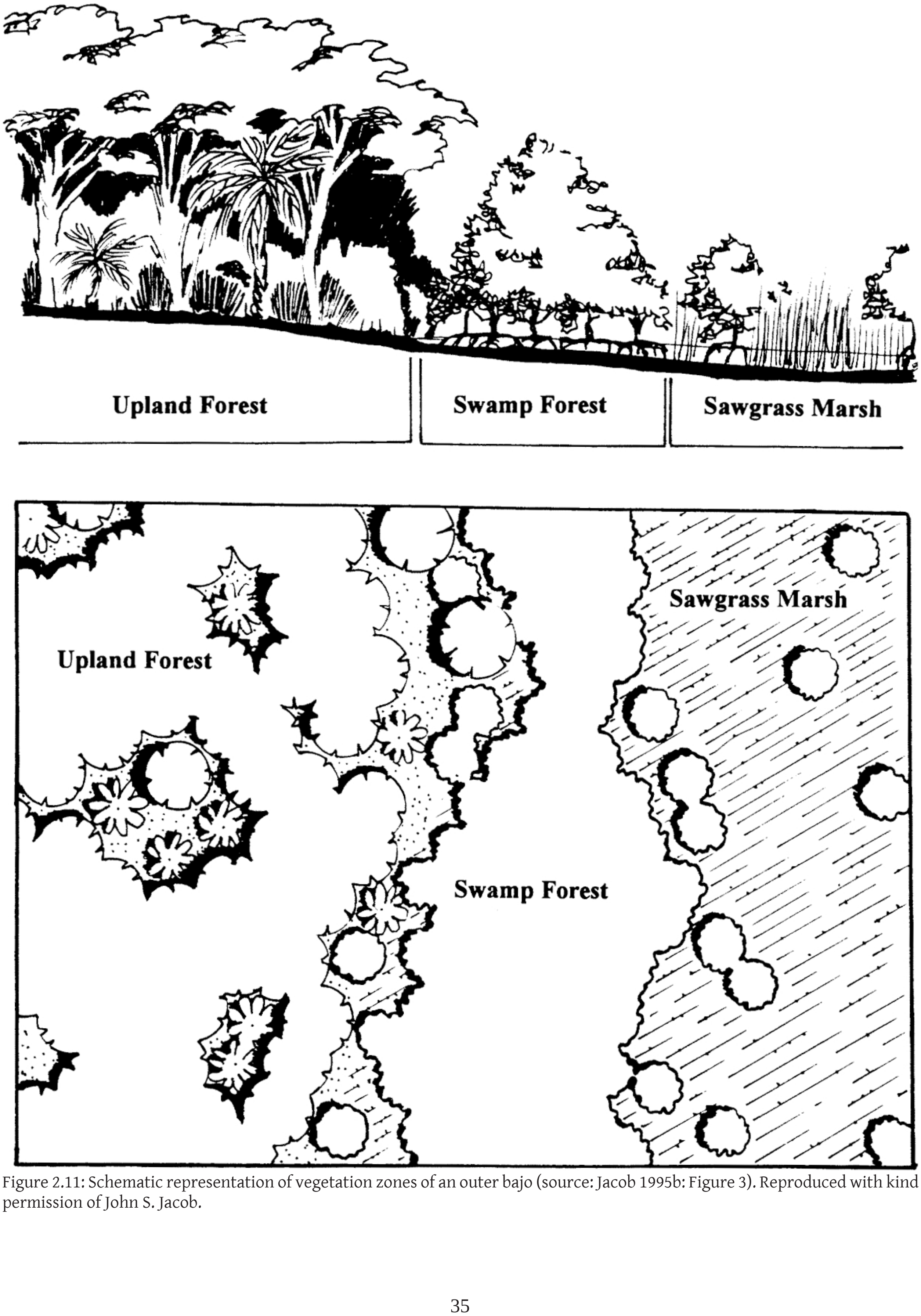

Figure 2.11: Schematic representation of vegetation zones of an outer bajo (source: Jacob 1995b: Figure 3). Reproduced with kind permission of John S. Jacob.

2.4.3.3 Geographic distribution of inner and outer bajos

As Figure 2.12 shows, the majority of the outer bajos are located close to the northern coast of Belize (e.g. Pulltrouser Swamp), at the Caribbean Coast of Belize (e.g. Cobweb Swamp), in southeastern Quintana Roo (e.g. Bajo Morocoy) and along the riverbed of the Río Candelaria (Dunning *et al.* 2006: 82; Turner and Harrison 1983: 250). The largest inner bajos, such as the *Bajo de Santa Fe* east of Tikal, the *Bajo de Juventud* northeast of Uaxactun or the *Bajo la Justa* near Yaxha, are situated in the southeastern and southwestern corner of the big Karst Plateau of the Petén and the Mirador Basin (Dunning *et al.* 1998, 2006: 82; Siemens 1982: 207). According to Dunning *et al.* (2015: 10), these large bajos are drained by the Río Azul and the Río Holmul, which also drain several other small bajos.

As this review of the geological history has shown, the development of the limestone block and its dissolution and fragmentation into several subunits had a tremendous effect on the distribution of surface water and the depth of the water table. As the distribution of the river systems (see Figure 2.6), still bodies of water (see Figure 2.7) and the depth of the aquifer (see Figure 2.4) has shown, the Elevated Interior Region (EIR) exhibits the fewest number of sources of water. The most decisive factor for this pronounced water scarcity in the EIR is its slightly elevated location between 200 and 500 m above sea level and the associated lack of accessibility to the groundwater-table (see Chapter 2.1.4.1). Curiously, the distribution of inner bajos coincides largely with the extension of the EIR (compare Figures 2.7 and 2.11). Natural aguadas are a common element in these inner bajos. As permanent river systems were only distributed outside of the EIR, the Classic Maya inhabitants of this core area could only access two forms of natural sources of water, scarp-foot-springs and natural aguadas:

Although scarp-foot-springs have been located in some areas of the Maya Lowlands (see Chapter 5.6.3), they have not yet been extensively investigated (see Johnston 2004a: 278). Based on the current state of knowledge, the author would like to put forward the hypothesis that the natural aguadas were the most common and important source of water for the inhabitants of the EIR – a core area for the Classic Maya. Outside of the EIR, the access to sources of water is significantly easier. To the west and the east, the amount of collected runoff resulted in a denser distribution of river systems. North of the EIR, the low elevation and flat contour of the natural landscape led to a shallower depth of the groundwater table, which favored the formation of natural sources of water (e.g. cenotes) and the construction of artificial wells. To the south of the EIR, the high amount of precipitation and the widespread distribution of river systems, which are mostly fed by runoff-water from the Highlands, resulted in an abundance of water resources.

While this chapter provided an overview of the geologic history and the distribution of sources of water and climatic conditions in current times, the main issue of this dissertation is the implications of the natural landscape for the development of the Classic Maya society. As the prehistoric climate and the natural landscape do not necessarily coincide with the current conditions, it is important to develop a realistic scenario of the natural landscape and the climatic conditions in the Maya Lowlands during pre-Hispanic times.

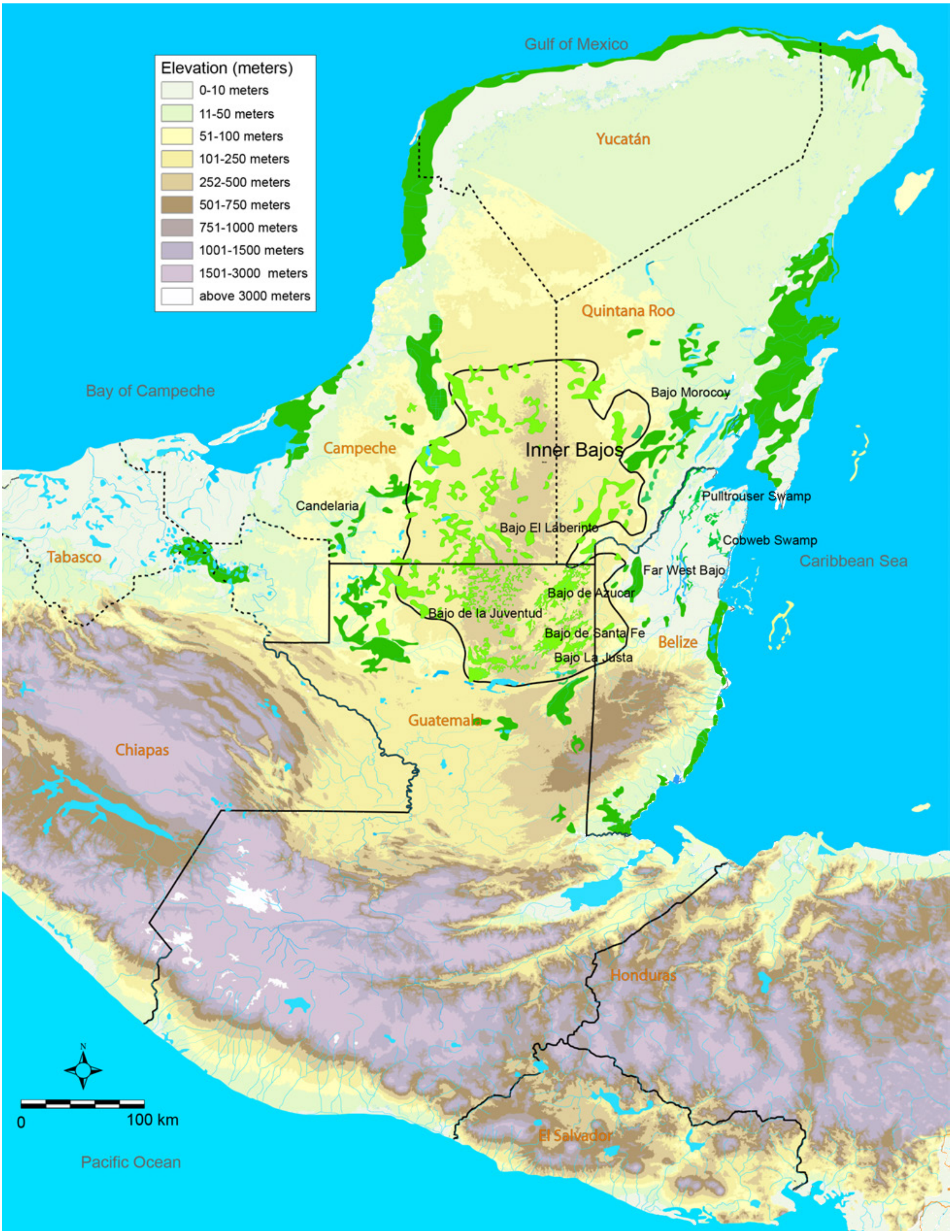

Figure 2.12: Geographic distribution of inner and outer bajos in the Maya Lowlands. Inner bajos are indicated in light green. Outer bajos are indicated in dark green (Map: N. Seefeld, redrawn after Jacob 1995: Figures 1 and 2. With kind permission of John Jacob; Pope and Dahlin 1989: Figures 1 and 7. Reproduced with kind permission of Kevin O. Pope; Quintana and Wurster 2001: Figure 1. With kind permission of the Commission for Archaeology of Non-European Cultures / German Archaeological Institute; Base map was modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

3 History of research on the hydrology of the Maya Lowlands

The following chapter will identify the key points in the history of research on the hydrology of the Central Maya Lowlands. As Dunning *et al.* (2006: 85) correctly observed, a complete survey on the entire history of research could fill an entire monograph. Therefore, this chapter only points out the main lines of development in the investigations of agricultural features, hydraulic features, climate history and the interplay between the results and theories gained from these different fields of research.

At the same time, this chapter is confined to a brief description of the groundbreaking fieldwork projects and the general lines and positions of discourse over the course of time. However, this presentation will not foreshadow the more detailed discussion of these theories, which are presented in Chapter 8. As will become apparent in the upcoming review of the research history, the scientific debate on the hydrology of the Central Maya Lowlands was always closely interlinked with the theories on climatic conditions, demographic situations and agricultural practices in the Classic Period. Therefore, the main goal of the following overview is to illustrate the close relationship of these fields of study to the current state of research and the current theories on water management practices in the Classic Maya society.

As outlined in Chapter 2, the geologic composition of the Yucatán Peninsula and the climatic conditions in the Maya Lowlands cause pronounced water scarcities during the dry season – a condition that currently makes survival in this habitat highly challenging. The problems deriving from this water scarcity were already recognized at the beginning of the scientific examination of pre-Hispanic Maya society.In the mid 19th century, John Lloyd Stephens (1843; II: 165) already observed that,

"Among the wonders unfolded by the discovery of these ruined cities, what made the strongest impression on our minds was the fact that their immense population existed in a region so scantily supplied with water"

Surprisingly, Stephens (1841: 455) paid particular attention to the issue of water supply in the Northern Maya Lowlands. After a primary inspection of Uxmal, he even interpreted the *chultunes* of the site as cisterns (Stephens 1843: 105). Furthermore, accounts of stone slabs at the bottom of Uxmal's aguadas convinced him that these sources of water had been constructed by the original inhabitants (Stephens 1833: 284; Weiss-Krejci 1999: 137). During the second half of the 19th century, Brasseur de Bourbourg (1984: 20) produced a map showing the location of aguadas in northern Yucatán (Barrera Rubio and Huchim Herrera 1989: 279). At the end of the 19th century, Thompson (1897) carried out a number of focused archaeological excavations of the chultunes of Labná. The location and form of these chultunes and the documentation of waterproof layers convinced him that they had been used as reservoirs (Weiss-Krejci 1999: 137). Apart from these pioneering efforts however, the second half of the 19th century saw few noteworthy scientific results. It was not until the early 20th century that pioneering scholars such as Maler (1908, 1911: 5), Cole (1910), Ricketson and Kidder (1930) and Lundell (1933) undertook the effort to expand the scientific understanding in this budding field.

Even during these first expeditions and reconnaissance surveys, all of these scholars noticed the close spatial association of aguadas with pre-Hispanic settlements. During this period, the scientific expeditions followed the trails that had been established by chicleros and loggers in the 19th century. Due to the practical use of these trails, chicleros established them in such a way that they would pass near aguadas. As Weiss-Krejci *et al.* (n.d.) point out, the early explorers inevitably passed by these aguadas "like travelers in a desert" (see also Weiss-Krejci 1999: 138) and consequently took notice of the obvious correlation between the remains of pre-Hispanic settlements and aguadas. Many accounts of these early explorations even emphasized the role of aguadas in the colonization of this region (e.g. Bullard 1960: 364; Folan *et al.* 1995: 330; Morley 1938[1]: 25-29; Quintana and Wurster 2001: 9-10; Scarborough 1993: 26; Smith 1950: 84). This interest grew even more when Ricketson and Kidder (1930) surprisingly realized during a collaborative expedition of Pan American Airways and the Carnegie Institution of Washington that most of the landscape features designated as lakes in their contemporaneous maps turned out to be aguadas (Akpinar and Dunning 2011: 106). In hindsight, the earliest phase of Maya archaeology (until the 1930s) showed a very extensive interest in the landscape of the Maya Lowlands and the living conditions of its pre-Hispanic inhabitants.

When Lundell (1937:10) visited the Maya area in 1932, he remarked that the larger and older trees in the forest had an apparent age of approximately 1,000 years – an observation leading him to the conclusion that the forest he observed was largely the result of manipulation by its former Maya inhabitants (Parry 2007: 7). Although this observation was not given proper attention during the time of publication, it was later on proved in several studies. Generally, this observation shows the different quality of research and the different perspectives with which the ancient Maya society was studied at that time.

In 1931, the geographer Charles Wythe Cooke published the momentous article "Why the Mayan Cities of the Petén District Guatemala, were abandoned". In this article, Cooke (1931) claimed that the contemporary seasonal bajos (inner bajos) would have once constituted perennial swamps, shallow lakes or large reservoirs during the Preclassic and Classic Period. Although none of these assumptions had been confirmed by empirical data, this vision was widely accepted (Turner and Harrison 1983: 265). Regrettably, it was even actively spread among the scientific community causing it to be considered almost as though it were a common consensus (Adams 1980: 211; Dunning *et al.* 2002; Leyden 2002: 93; Parry 2007: 170; Siemens 1982: 216). The far-reaching effect of Cooke's early theories still reverberates in recent discussions. Due to this wide distribution, the ideas of Charles Wythe Cooke can be considered the most influential model of Maya Lowlands hydrology in the research history. After the apparent early interest in subsistence strategies that lasted until the 1930s, Cooke's (1931) theory subdued the earlier humanistic approaches (Seefeld 2013a). In 1936 however, Smith (1950: 61) carried out an archaeological excavation of two reservoirs in Group B of Uaxactun, which resulted in the discovery of horizontal stone slabs that served to seal the basin of the smaller reservoir (Weiss-Krejci 1999: 138). In the larger reservoir, Smith (1959: 61) even observed a small dam feature "blocking the head of a shallow ravine". Based on these discoveries, Smith (1950: 84) even concluded that "in the absence of lakes, springs, or rivers in the dry season, the population must have depended entirely upon reservoirs, natural or artificial". However, as these pioneering discoveries were not published before 1950, their implications were only recognized in later decades.

Once the scientific community had agreed on the convenient assertion that the Maya Lowlands would have had a much more humid climate in Preclassic and Classic times, no scholar made a serious effort to investigate the subsistence strategies of the pre-Hispanic Maya population before the 1970s. While Morley (1946: 141) and Thompson (1968: 253) focused on the achievements of the elites, the issue of water supply remained neglected (Weiss-Krejci 1999: 139). As it was widely acknowledged that the water supply would have been entirely unproblematic in Preclassic and Classic times, the (limited) scientific interest was directed to the "reconstruction" of agricultural production techniques in pre-Hispanic times.

To this end, the Maya scholars of the 1940s and 1950s simply transferred the results of ethnographic studies to the Classic Maya civilization. Morley (1946: 141), for instance, developed the idea that milpas, swidden-agriculture and other extensive agricultural systems would have characterized Maya settlements in pre-Hispanic times – just like today. As most scholars believed that the (alleged) more humid conditions would have enabled copious agricultural production, the idea that there was a general prevalence of extensive agricultural production systems was largely maintained throughout the rest of the 20th century (Chase and Chase 1998: 60; Harrison and Turner 1978; Reina 1967; Steggerda 1941). According to this concept, the pre-Hispanic Maya would have preferably cultivated highland soils (Scarborough 2006: 234). Thus, this concept was later on defined as the "highland paradigm" (Pope and Dahlin 1989: 87).

As Chase and Chase (1990: 60) correctly observed, the general perceptions of the 1940s and 1950s were a classic circular argument: As long as scholars considered swidden agriculture as the predominant subsistence strategy, they could argue that the pre-Hispanic Maya society would have featured relatively low population densities and a decentralized social structure. Despite this general lack of interest in agricultural and hydraulic features, some scholars continued to comment on the ubiquity of these features. Thus, Higbee (1948) noted the "ancient relationship" between pre-Hispanic settlements and aguadas because he realized that contemporary chicleros oriented their paths along these sources of water (Akpinar 2011: 22). In a similar manner, Scholes and Roys (1948) continued to observe that many aguadas of the Southern Lowlands were still used for their resources or chosen as residential areas by the contemporary Maya communities (Akpinar 2011: 22).

By the 1950s however, Maya archaeology was influenced by two new scientific approaches:

(1) The introduction of systematic settlement surveys, and

(2) The investigation of seasonally inundated habitats along streams.

In his pioneering explorations in the Petén, Bullard (1960) followed the trails of chicleros and discovered previously unknown "secondary centers" and a wide range of settlement remains, which showed the omnipresence of residential structures. Furthermore, he noted a "marked tendency for these house ruin areas to occur in the vicinities of present-day, and possibly former, water sources" (Bullard 1960: 364). Based on these observations, Bullard (1960: 364) calculated that "the maximum distance from a water source to the next was probably less than two kilometers" (Akpinar 2011: 22, 23). Following the groundbreaking studies of Carl O. Sauer (1952), Palerm (1955) carried out the first archaeological investigations of wetlands in Central Mexico (Puleston 1977: 450; Wolf 1962: 78). In Tikal, Edwin Shook (1958: 18) discovered several hitherto unknown aguadas and reservoirs and tried to use their storage capacity for an estimation of the city's population in pre-Hispanic times (Weiss-Krejci 1999: 140).

Ironically, these discoveries of the 1950s demonstrated both a potential problem in the subsistence of the Classic Maya society, while also providing a potential solution. By the onset of the 1960s, the growing scientific interest in subsistence strategies of the pre-Hispanic Maya would lead to the first critical remarks on the "highland paradigm" and the predominant concepts of agricultural production of the time (Scarborough 2006: 234).

> *"If we assume that the Maya of the Petén possessed only slash-and-burn cultivation how do we explain the numerous ceremonial centers of the area?* [...]. *It is more than likely that the Maya too possessed some system of intensive cultivation, supplementary to their slash-and-burn practices* [...] *Perhaps it was a system of chinampas, or a related system, which made use of the many lakes and swamps of the Petén"* (Wolf 1962: 78).

> "*„Even if the subsistence requirements of the populations can be shown never to have demanded anything other than swidden agriculture, this still does not mean, that no other forms were ever practiced. It would be quite interesting to know whether any more productive methods were workable – particularly whether any methods might have been used which could have demanded some substantial degree of socio-political integration and development of managerial class"* (Cowgill 1962: 279).

By the mid 1960s, three parallel developments led to the first serious scientific discussion of the climatic conditions, the agricultural production techniques and the management of water supply in pre-Hispanic times:

(1) Owing to the continuation of systematic settlement surveys (e.g. Willey *et al.* 1965), the scientific community had to acknowledge that the density of settlements during the Late Classic Period was greater than previously expected. For some scholars, the results indicated that this densely populated area could not have been supported by a system consisting of purely swidden agriculture (Chase and Chase 1998: 60; Coe and Haviland 1982; Culbert *et al.* 1990; Haviland 1970; Puleston 1983).

(2) While the investigation of the natural environment and the geology had been confined to a handful of studies (e.g. Bartlett 1935; Lundell 1937, 1945; Miranda 1959; Simmons *et al.* 1959; Wright *et al.* 1959), the 1960s saw the first attempts at the scientific reconstruction of paleoclimatic conditions. In 1966, Tsukada and Deevey (1967) extracted the first pollen diagram of the Maya Lowlands from the Lago Petenxil. These initial data indicated an apparent increase in tree pollen, which Tsukada and Deevey (1967: 328) interpreted as a regeneration process of the forest after the Maya Collapse (Beach *et al.* 2015a: 11; Cowgill *et al.* 1955; Wahl *et al.* 2007: 213). Moreover, some environmental investigations in aguada habitats (Aguada Santa Vieja [Cowgill and Hutchinson 1966]) and several excavations of aguadas in Tikal[29] (Carr and Hazard 1961; Goulden 1966) were carried out during the 1950s and 1960s.

(3) On a theoretical level, the mid 1960s also experienced a rising interest in the historical development and social consequences of water management in Mesoamerica (Scarborough 2006: 224). This interest was initiated by the research of William Sanders and Barbara Price (Sanders and Price 1968; see also Price 1971), who developed a number of field methods partially based on Karl A. Wittfogel's (1957) model of hydraulic societies (which again was based on Marx, see Chapter 8.1) and Julian Haynes Steward's (1955a, 1955b) Culture Ecology (Parry 2007: 22; Scarborough 2006: 224).

In his main work, "Oriental Despotism: A Comparative Study of Total Power", Wittfogel (1957) defined his extended theory of hydraulic societies by primarily studying large hydraulic systems on a regional basis (Scarborough 1991: 123). According to Wittfogel, despotic bureaucracies were the consequence of large-scale irrigation systems in arid or semiarid regions, which had to be supplied with water from remote springs through the construction of artificial canals. According to this theory, these efforts of irrigation led to a centralization of resource control and became the trigger for an unequal relationship between managers and users, which would later manifest in a strictly defined social stratification (Scarborough 1991: 123). Although Wittfogel (1957) had developed his model for the first successful hydraulic societies in southern Mesopotamia, China, Egypt and the Indus Valley, some elements of the concepts were already adopted by Sanders and Price (1968).

At the onset of the 1970s, the three different theories and approaches of the 1960s ultimately led to an extensive awareness in the entire scientific community of the issues of agricultural production and water supply. As in the previous decade, the increasing interest in these issues came to light with three different approaches: Settlement studies (1), the investigation of intensified agriculture in pre-Hispanic times (2), and the application of Wittogel's (1957) hydraulic societies to Mesoamerica (3).

(1) In the field of settlement studies, the ongoing research consolidated the observations of the previous decade (Beach *et al.* 2009: 1714). By the end of the 1970s, the results of these regional surveys showed that the population density of the Maya Lowlands had obviously been much higher than previously expected. These discoveries sparked the interest of many scholars who wanted to understand the usage of the landscape and explain the subsistence strategies of the pre-Hispanic population. Some of these population estimates (e.g. Turner 1974) indicated that the population would have been so high that it could not have been solely supported exclusively on the basis of extensive swidden agriculture in the well-drained upland areas (Beach *et al.* 2006, 2009: 1714; Culbert and Rice 1990). Inevitably, these considerations led to more systematic studies of features for intensified agriculture in the Maya Lowlands.

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[29] Even though the results of the investigations in Tikal were never officially published, the reports of these excavations are stored in the Tikal Archives of Philadelphia and have been mentioned in a number of publications (e.g. Harrison 1970).

(2) The investigation of intensified agriculture initially concentrated on wetland cultivation and subsequently extended to agricultural terraces later on. Apart from the potential demographic pressure indicated by the results of settlement surveys, the ethnohistorical and archaeological studies on *chinampa*-agriculture in the Basin of Mexico and the drained field systems of the Puebla-Tlaxcala Basin were important influences for these first investigations in the Maya Lowlands (Armillas 1971; Beach *et al.* 2009: 1714; Coe 1964; Fowler 1987). As a reaction to these observations from other regions of Mesoamerica, some scholars speculated that the pre-Hispanic Maya also might have practiced intensified agriculture in wetland habitats (Beach *et al.* 2009: 1714). The discovery of various wetland patterns and evidence for wetlands fields in South America (e.g. Parsons and Bowen 1966) also aroused the interest of Mayanists such as Siemens and Puleston (1972). While the existence of intensified wetland cultivation had previously been based solely on assumptions, Siemens and Puleston (1972) organized flights over southern Campeche by the end of the 1960s, which led to the groundbreaking discovery of rectangular patterns in wetlands (Beach *et al.* 2009: 1714; Jacob 1995: 175; Luzzadder-Beach and Beach 2006; Weller 2006: 33; see Chapter 5.2.1). Based on archaeological investigations, Siemens and Puleston (1972: 229) could factually verify that these patterns were residues of drained and raised fields.

As expected, the identification of these features led to further studies based on aerial-photography and resulted in an animated discussion on the intensity and the geographic distribution of intensified agriculture in the Maya Lowlands (Pope and Dahlin 1989: 87; Scarborough 2006: 224; Siemens 1978, 1982, 1983a, 1983b, 1996, 1998, Siemens *et al.* 1987; 1977, 2002). During the 1970s, these studies factually led to the discovery of further latticed forms in southeastern Quintana Roo and northern Belize defined as “wetland fields” or elevated fields (see Chapter 5.2.4) (Turner and Harrison 1983b; Weller 2006). Throughout this process, numerous publications on ancient wetland agriculture were published (e.g. Harrison and Turner 1878; Turner and Harrison 1981). Based on these discoveries, the scholars who had studied these wetland cultivation features formed a new concept that critics would later define as the so-called “New Orthodoxy” (Pope and Dahlin 1989). In succession, some members of the “New Orthodoxy” voiced the opinion that raised fields would have represented the most important component in the agriculture of the pre-Hispanic Maya (Armillas 1971: 651; Denevan and Turner 1974: 24). In this period, Turner (1976: 78; 1978a: 172; 1978b, 1979) even arrived at the conclusion that the high population densities of the Maya Lowlands, which were only just being revealed in the 1970s, would be quite realistic in the light of the newly discovered cultivated areas. Despite the widespread and systematic surveys of wetland fields, archaeological excavations of these features were still limited. Due to this limited amount of excavated features, the critics of the “New Orthodoxy” fundamentally negated the agricultural relevance of wetland areas (Pope and Dahlin 1989: 87).

In addition to these studies on wetland agriculture, some scholars searched for more potential alternatives to extensive swidden agriculture. This process led to the identification of agricultural terraces in the Río Bec region (Donkin 1979; Patrick 1979: 103; Turner 1974, 1979). However, despite a general widespread acclaim, the initial results did not encourage further investigation of terrace features in the 1970s.

(3) On a theoretical level, the 1970s also experienced the application of Wittfogel’s (1957) concept of *hydraulic societies* to Mesoamerica. After the monograph published in 1957 had referred to the first successful hydraulic societies in southern Mesopotamia, China, Egypt and the Indus Valley, Wittfogel developed a model tailored to Mesoamerica, “the Hydraulic Approach to Pre-Spanish Mesoamerica” (1972), which never achieved the publicity and impact of his main work. In fact, the influence of Wittfogel’s concepts on the theories and models of water management in Mesamerica remained rather limited. During the late 1970s however, some scholars expressed the idea that the development of social and political complexity in the pre-Hispanic Maya society would have been primarily triggered by water management. This is apparent in the following citation:

“it appears evident to me that water controls in the lowland Maya area played an important role in the development of Preclassic and Classic civilizations” (Matheny 1976: 646).

Although the influence of Wittfogel's (1957) concept is clear in these statements, he was almost never openly cited for those ideas. A more influential and widely adopted concept of the 1970s was Julian Haynes Steward's *Culture Ecology.* This is apparent in the fact that the research questions of the time aimed to define patterns of land-use and settlement, and to identify the cultural adaptations to the natural environment (Boserup 1965; Parry 2007: 33; Sanders 1978). During the 1970s, Ray Matheny (1976) also carried out the first surveys of the "hydraulic system" of Edzná. Although Matheny was the first scholar to use the term "hydraulic feature" in Maya archaeology and also carried out the first systematic research of an extensive hydraulic system, the scientific attention of the 1970s was still largely focused on the issue of agricultural production and mostly ignored the issue of water supply.

At the onset of the 1980s, the scientific discussion was mostly centered on the agricultural potential of wetlands. Simultaneously, a small group of scholars resumed research on the climatic conditions of pre-Hispanic times. After the initial results from the 1970s, the arguments from the members of the "Highland paradigm" and the "New Orthodoxy" had evolved into a fierce debate, which, unfortunately, was not always problem-oriented.

The precise catalyst of this debate was a publication by Richard Adams (1980: 221) on a set of radar images from the Maya Lowlands, which led him to the conviction that canal systems had not only been prevalent along the Río Candelaria, northern Belize and Quintana Roo, but also in the entire landscape of the Petén, the Petén Campechano and western Belize (Adams 1982, 1991: 6323; Adams *et al.* 1981: 1458; Turner and Harrison 1983b: 250). Furthermore, Adams (1980) considered his limited observations as proof for the agricultural relevance of wetlands, which he identified as the subsistence base for urban and rural settlers (Fedick and Ford 1990: 19). As none of the "canal systems" had been checked on the ground before the publication, the opponents of the "New Orthodoxy" reacted with vehement criticism (Pope and Dahlin 1989: 94).

As a reaction, the members of the "New Orthodoxy" actually organized a number of systematic archaeological investigations in wetland areas, which had previously only been studied in surveys (Turner and Harrison 1981: 399). With these systematic investigations, the advocates of the "New Orthodoxy" sought to convince their critics of their legitimacy by supporting their earlier theories with a broad empirical foundation. The results of these excavation projects in the wetland areas of Belize and Quintana Roo were published in an astonishing number of publications. Among the most influential publications were the documentation of drained and/or raised fields in Pulltrouser Swamp (Turner and Harrison 1983), the Bajo Morocoy (Gliessman *et al.* 1983), Nojmul (Hammond *et al.* 1985, 1987), Albion Island (Antoine *et al.* 1982; Bloom *et al.* 1983; Siemens 1982), Lamanai (Lambert and Arnason 1983) and the Belize River Valley (Kirke 1980). Owing to the wide circulation of these publications, even the earlier critics of the New Orthodoxy had to abandon their strict stance of rejection. By the mid 1980s, the notion that the pre-Hispanic Maya had built canals in order to cultivate wetland areas was generally accepted. However, many controversies still prevailed (Pope and Dahlin 1989: 89).

After this sudden increase of investigations in wetland areas, the mid 1980s marked both the climax and turning point in the scientific interest of wetland agriculture in the Maya Lowlands. Once the critics of the "New Orthodoxy" had accepted the general existence of wetland agriculture, the number of archaeological investigations in outer bajo habitats markedly dropped. Due to the intensive investigation of outer bajos in the early 1980s, only a small number of new raised field features were found in later decades.

In exchange, the ongoing search for subsistence strategies finally led to more detailed investigations of large-scale terrace systems (Chase and Chase 1987: 53; 1990, 1994; Healy *et al.* 1980, 1983), small-scale terrace systems (Dunning and Beach 1994; Fedick 1994) and fields and gardens within sites (Chase and Chase 1998; Killion *et al.* 1989). Furthermore, the settlement studies began to take interest in the hinterland areas of larger urban centers. In this research field, Anabel Ford (1981) conducted a groundbreaking intersite settlement survey between Tikal, Yaxhá and Uaxactun.

After concentrating on outer bajos, the scientific interest shifted towards the habitats of inner bajos by the mid 1980s. As Cooke's (1931) theory that there were generally more humid conditions in Preclassic and Classic times was still widely accepted, the advocates of the "New Orthodoxy" reasoned that under more humid conditions, even inner bajo habitats would have featured a higher agricultural potential. By the mid 1980s, the advocates of the "New Orthodoxy" claimed that inner bajos would have featured a high agricultural potential and, consequently, would have been an essential element of pre-Hispanic agriculture and even an essential factor for the evolution of Classic Maya civilization (Adams *et al.* 1981, 1990). According to their idea, the inner bajos originally would have constituted perennial lakes and housed a greater ecological diversity and productivity (Harrison 1978; 1990). Turner and Harrison (1983b: 265) even claimed that the deforestation of the landscape by the pre-Hispanic Maya would have caused heavy erosion resulting in these open water surfaces filling up to such an extent that they would have desiccated and transformed into the current landscape type of inner bajos (Dunning *et al.* 2006: 81; Harrison 1978, 1990; Scarborough 1991: 125; Turner 1978).

With regard to this scenario, the critics of the "New Orthodoxy", who had already accepted the general agricultural usage of outer bajos for cultivation with elevated fields, expressed the concern that the ecologic qualities of inner bajos (see Chapter 2.4.3.1) would have prevented an agricultural use (Jacob 1995: 175). Consequently, the critics of the "New Orthodoxy" insisted that swidden agriculture in the highland areas would have been the central cultivation method and that wetlands would have only been used on rare occasions (Pope and Dahlin 1989: 89). In the heat of the debate, the advocates of both schools started to gain interest in the results of paleoclimatic studies in the hope to find evidence for their respective theories. While the fields of archaeology and paleoecology had previously not influenced each other, archaeologists progressively started to incorporate results from paleoclimatic studies.

After paleoclimatic studies had largely been abandoned during the 1970s, the seminal studies of Deevey *et al.* (1979) on the environmental impact of the pre-Hispanic Maya and the ensuing soil erosion ("Maya clay", see Chapter 4.2.2) led to an intensification of research in this field (Beach *et al.* 2015a: 11). While this development caused an obvious increase of pollen diagram analyses, the results were largely ignored by Maya archaeologists until the end of the 1980s (Beach *et al.* 2015: 11; Dunning *et al.* 2006: 85; Turner and Harrison 1983: 251). A pioneering publication of this period was Binford's *et al.* (1987) study on the interaction between the Maya and their environment (Beach *et al.* 2015a: 11). In this publication, Binford *et al.* (1987) produced a diagram correlating population density, deforestation events, soil erosion and sedimentation-processes and thus impressively demonstrated the potential of paleoecological data for the community of Maya archaeologists.

Throughout the entire 1970s and 1980s, which saw a tremendous increase of scientific understanding on the cultivation techniques of the pre-Hispanic Maya, the scientific community mostly ignored the issue of water supply (Scarborough 2006: 224). In hindsight, the renunciation of Wittfogel's "Marxist" ideas in North American archaeology during these decades could be interpreted as a phenomenon of the Cold War. After the fall of the Iron Curtain, Scarborough (2006: 224) lamented that the discussion of Wittfogel's *hydraulic societies* and its potential applicability had never moved beyond a "polemic" both from the advocates and from the critics. According to Scarborough (2006: 224), the scientific interest of the 1970s and the 1980s had focused too heavily on irrigation and agricultural intensification while few efforts had been undertaken in order to study the effects of water manipulation on the socioeconomic and sociopolitical organization (Scarborough 1993). Indeed, it is striking that none of the studies on agricultural production and subsistence investigated the manner in which the pre-Hispanic Maya cities were supplied with water. This attitude can be largely explained by the fact that the scientific community had agreed on the convenient assertion that the Maya Lowlands would have shown a much more humid climate in Preclassic and Classic times.

The beginning of the 1990s finally brought about a set of new research fields and theories. On the one hand, the increasing corpus of paleoclimatic data had enabled more precise statements on pre-Hispanic climatic conditions. On the other hand, the early 1990s saw the first archaeological investigation of hydraulic features by larger research groups.

In the field of paleoclimatic studies, the research of the early 1990s considerably refined the information base covering the development of the climate and landscape in pre-Hispanic times (Dunning and Beach 1994; Dunning *et al.* 1998; Jacob 1995b; Leyden 1994). Soon, the results indicated that the pre-Hispanic Maya had been affected by two extreme drought conditions. The first occurred during the transition from the Late Preclassic to the Early Classic and the next during the Terminal Classic (Hodell *et al.* 1995: 391). As soon as the potential consequences of these drought periods for the development of the Maya civilization had been realized by the scientific community, many scholars started to consider the issue of water supply for the first time. Inevitably, this process also led to the first serious archaeological investigations of hydraulic features.

The first in a long line of projects was the investigation of Tikal's hydraulic features (Scarborough and Gallopin 1991). Although Scarborough and Gallopin (1991: 661) did not carry out any archaeological excavations, their analysis of the landscape led them to the belief that water management would have been one of the "centralizing triggering effects for the development of central political power" (Akpinar 2011: 15). This interpretation bears witness to the fact that Wittfogel's concept of *hydraulic societies* was once again applied in North American archaeology after the fall of the Iron Curtain.[30] The next essential step in the development of models of water management in pre-Hispanic Maya society came with the introduction of adaptive models during the 1990s (Lucero 2002: 818). According to these models, the sociopolitical control and the religious leaders were part of an integrated system in which political and religious authorities collaborated in order to consolidate the centralization of power (Joyce 2004; McAnany 2004: 151; Parry 2007: 36).

In subsequent years, a reanimated interest in hydraulic features caused focused archaeological investigations of hydraulic systems in urban settings. Examples of these projects are the investigations in Kinal (Scarborough *et al.* 1994), Calakmul (Folan *et al.* 1995a; Domínguez Carrasco and Folan 1996), Tikal (Scarborough 1994; Fialko 1999), La Milpa (Dunning *et al.* 2002, 2006 ; Scarborough *et al.* 1995), and Copán (Davis-Salazar 2001, 2003). Simultaneously, many archaeological projects also undertook more systematic surveys and excavations of agricultural terraces. During the 1990s, new terrace features were documented in the upper Belize Valley (Fedick 1994), in Xunantunich (Neff *et al.* 1995), Caracol (Chase and Chase 1998) and in the Petexbatun-region (Beach and Dunning 1995; Dunning and Beach 1994).

Since the beginning of the 1990s, some archaeologists also speculated that the development of hydraulic systems would have been caused by prehistoric climatic transformation processes (Folan *et al.* 1995: 312; Gunn et al 1994). In this period, scientific interest was largely focused on the interplay between the natural environment and its pre-Hispanic inhabitants. Apart from a few notable exceptions (e.g. Baker 2003; Berr and McAnany 2007; Pohl *et al.* 1996; Pyburn 2003), the issue of wetland agriculture, which had dominated the scientific discussions of the 1970s and 1980s, had largely abated. Instead, scholars tried to develop a deeper understanding of the ecological variability of inner bajos and their relevance for the pre-Hispanic population (e.g. Culbert *et al.* 1991, 1996; Dunning *et al.* 2002, 2006; Kunen 1999, 2000, 2001, 2004).

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[30] Since the onset of the 1990s, Vernon Scarborough has been the most prominent advocate of Wittfogel's concept (Kunen 2006: 100).

After the fall of the Iron Curtain and the associated (partial) reintroduction of Wittfogel's *hydraulic societies* in Maya archaeology, the 1990s also experienced the introduction of the term "built environment". Lawrence and Low (1990: 454) defined the *built environment* as follows.

"...Any physical alteration of the natural environment, from hearths to cities, through construction by humans. Generally speaking, it includes built forms, which are defined as building types (such as dwellings, temples, or meeting houses) created by humans to shelter, define, and protect activity. Built forms also include, however, spaces that are defined and bounded, but not necessarily enclosed, such as the uncovered areas in a compound, a plaza, or a street."

Fortunately, the concept of the built environment encompassed all cultural modifications of the natural landscape. Therefore, its introduction into Maya archaeology caused an increasing awareness of landscape features that were not residential or religious stone structures. To a certain extent, this extended view enabled the more integrated approaches of Maya archaeology that have taken place since the end of the 1990s, when the investigations of hydraulic features were extended beyond the central reservoirs in urban contexts for the first time. Exemplifying this approach are the pioneering studies of small depressions in hinterland areas within northwestern Belize (Weiss-Krejci and Sabbas 2002). Based on these investigations, Weiss-Krejci and Sabbas (2002: 343) argued that alternative and decentralized water sources must be taken into consideration before claiming the predominance or even necessity of centralized water resource control. In the first step, this study, which defined "small depressions" as a new set of hydraulic features, increased the general awareness for the existence of hydraulic features in hinterland areas. In the second step, this awareness led to more thorough surveys of settlement landscapes, recognition of the various scales of hydraulic features and an increase in archaeological investigations. Generally, the first decade of the 21st century was marked by an increased interested in paleoclimatic studies (1), a reevaluation of existing theories and published hydraulic features (2), a sensitization for the ecological and cultural variability of the different regions of the Maya Lowlands (3), and an increase in archaeological investigations of hydraulic features at all scales (4).

At the onset of the 21st century, the awareness for the existence of extreme drought periods, which had grown since the middle of the 1990s, had now become a focus of scientific interest. In 2000, Richardson Gill (2000) published his popular monograph "The Great Maya Droughts", in which he compiled the available data of pre-Hispanic climatic conditions. Soon afterwards, the theories of "The Great Maya Droughts" were published in a TV documentary and aroused the widespread interest of the public. In hindsight, the first decade of the 21st century can be identified as the period in which the issue of climate change reached public awareness for the first time. The zeitgeist of this decade also becomes apparent in the fact that documentaries such as "an inconvenient truth" (2006), written by former US vice president Al Gore were screened in major cinemas. In this period, Jared Diamond (2006) also published his popular book, "Collapse: How societies choose to fail or succeed", in which he developed the deterministic idea that most of the word's leading early civilizations had fallen victim to their unsustainable management of the environment. This book also listed the Classic Maya civilization as an example. While the quality of these publications may be questionable, they nevertheless led to a dramatically increased interest in the pre-Hispanic climatic conditions and the hydraulic features of the Classic Period – both by the academic community and the general public.

In succession, many archaeological projects increasingly tried to combine and compare the archaeological results with datasets from geography and paleoclimatology. Once these interdisciplinary interpretations had shown their potential, many subsequent archaeological projects in the Maya Lowlands started to cooperate with geologists, palynologists and geographers in the field. Fortunately, studies on the subsistence strategies of the pre-Hispanic Maya did not only have a more pronounced focus on the issue of water management (see Beach *et al.* 2008; Brewer 2007; Chmilar 2005; Crandall 2009; Dunning *et al.* 2010; Geovannini Acuña 2008; Johnston 2004; Thomas 2010), but also integrated the most recent discoveries of paleoclimatic studies. Luckily, the experiences of the previous decades motivated scholars towards inquiries regarding resource procurement and subsistence strategies in large urban centers.

The incorporation of environmental information thus provided a more profound understanding of the organization of a greater cross section of pre-Hispanic settlements and pre-Columbian society (French 2002; Johnston 2004a, 2004b; Lucero 1999, 2002; Parry 2007; Primrose 2003). A perfect example for the successful and useful combination of archaeological, epigraphic and environmental data is a publication by Garrison and Dunning (2009), which vividly explains the dynamic interactions of human activities, environmental transformations and human adaptation strategies in the history of San Bartolo.

Another trademark of the studies during the first decade of the 21th century was a growing awareness for the specific topographic characteristics of the different sub-regions in the Maya Lowlands. The awareness for the heterogeneity of these micro-habitats enabled a more problem-oriented discussion on the social relevance of intensified agriculture and water management. Consequently, the newly developed agricultural models noted the importance of the mosaic of special micro-habitats and the coexistence of various strategies of production, which were formed as a reaction to the ecologic, social and demographic factors of a specific location (Gunn *et al.* 2002: 298; Kunen 2004). This awareness of the specific conditions of the respective micro-habitats also led to a more differentiated evaluation of the sociopoliticsl relevance of water management. Owing to this development, the observations from one location were no longer transferred to another. In the first decade of the 21st century, the investigations of hydraulic features in hinterland areas continued (Brewer 2007; Chmilar 2005; Weiss-Krejci 2013; Weiss-Krejci and Brandl 2010; Weiss-Krejci and Sabbas 2002; Weiss-Krejci *et al.* n.d.).

As Weiss-Krejci and Sabbas (2002: 343) remarked, the studies of the early 1990s had repeatedly emphasized the necessity of water management for the florescence and emergence of Maya civilization (Adams 1991: 632; Dunning *et al.* 1999; Scarborough 1994). Since the onset of the 21st century however, the reinforced interest in the water supply of pre-Hispanic settlements finally moved beyond the strict dichotomous arguments of the 1980s and 1990s and enabled a significant progression in the evaluation of the social relevance of water management. In this process, some authors (e.g. Hageman and Lohse 2003: 121) developed new theories moving in the direction of a cooperative organizational structure of water management. Other scholars began to interpret the existence of hydraulic features as an expression of the specific requirements of the population in pre-Hispanic times.

At the current state of research, it is hard to characterize the present interpretation of water management in Maya archaeology. Nevertheless, the previous studies from the second decade of the 21st century indicate that hydraulic features are being investigated with the same intensity as in the first decade. Fortunately, the publications of recent years have not only increased in quantity but also in quality. This becomes apparent in the recently published works on the hydraulic and agricultural features of Tikal (Lentz *et al.* 2015; Scarborough *et al.* 2012), San Bartolo and Xultun (Akpinar-Ferrand *et al.* 2012), Yaxnohcah (Brewer 2017, Brewer *et al.* 2017)and special issues on water management in *Contributions in New World Archaeology* (Źrałka and Helmke 2013) and *Investigadores de la Cultura Maya* (2012).

4 Climate history and landscape history of the Maya Lowlands

In the absence of abundant surface water, the pre-Hispanic Maya inevitably had to rely on precipitation. As indicated in the previous chapter, the climatic conditions and landscape in pre-Hispanic times has been a matter of a lively debate. Therefore, the investigation of the climate and landscape history is an important factor for a more precise assessment of the social and economic processes in the pre-Hispanic Maya society. As Beach *et al.* (2015a: 9) claimed, many scholars have speculated on the relevance of periods of extreme drought for the cultural transition between the Classic and the Postclassic periods (Luzzadder-Beach *et al.* 2012). In order to provide the reader with a general understanding of the foundation of data regarding this discussion, the upcoming chapter will outline the general development of climatic conditions, the human impact on the natural environment and the resulting landscape transformation. In this context, the reader will acquire an understanding of which developments in the landscape history were caused by natural factors, and which developments were supposedly caused by cultural activities.

4.1 Methods for the reconstruction of past climates

All statements concerning paleoclimatic conditions are mostly based on the investigation of climatic phenomena. In contrast to archaeological data, these climatic phenomena usually depict far more complex relationships (Gunn *et al.* 2002b: 79; Rice 1996). For more than a century, scholars have tried to understand and describe the climatic conditions of the Maya Lowlands and to shape these insights into models. These models can be subdivided into retrospective and prospective climate-models (Gunn *et al.* 2002b: 80):

Retrospective models make use of the physical remains of the past in order to explain the relationship between climate and cultural change. Prospective models, on the other hand, are based on both historic and recent processes. They investigate patterns on global and regional levels, which can be used to define a causal chain of processes ranging from local and regional to global scales (Gunn *et al.* 2002b: 80). The results of prospective models can be applied not only into the past and future, but also from one location to another (Gunn *et al.* 2002b: 80). Furthermore, they can be connected to models of local cultural processes (Seefeld 2008: 92).

Paleoclimatic investigation methods include the analysis of pollen or charcoal from lacustrine-sediments (palynology), paleo-limnological samples, the investigation of riverine sediments[31], solar and volcanic activity (Hodell *et al.* 2001: 167), atmospheric pressure (Gill 2000), ice cores from glaciers, dendrochronology (Stahle *et al.* 2011), isotope analysis[32] and El Niño events (Gunn *et al.* 2002: 8). From these different methodologies, only dendrochronology and palynology will be outlined.

4.1.1 Dendrochronology

In Mesoamerica, the application of dendrochronology is still a very infrequently used method for the reconstruction of pre-Hispanic climatic conditions. The first and only application of dendrochronology was carried out in old Montezuma baldcypress trees (*Taxodium mucronatum*) in Barranca de Amealco, Queretaro and Los Peroles, San Luís Potosí (Mexico), which provided a 1,238 year tree-ring chronology (Stahle *et al.* 2011: 1). This dataset enabled the first absolutely dated climate reconstructions that spans over a millennium (Stahle *et al.* 2011: 2). This chronology could be correlated with precipitation, temperature,

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[31] The intention of investigating riverine sediments aims to detect the water flow, which is used to gain references on prehistoric precipitation rates (Gunn *et al.* 1994, 1994, 2002b: 82; Robichaux 2002: 341).

[32] The earliest isotopic values were extracted by Covich and Stuiver (1974) in the Lago Chichancanab (Akpinar 2011: 14). According to Akpinar (2011: 14), recent improvements in mass spectrometry will allow a finer resolution of isotope-based climate reconstructions in the near future (Brenner *et al.* 2003).

drought indices, and crop yields (Stahle *et al.* 2011: 1). The final numeric chronology was based on 74 cores from 30 trees (Stahle *et al.* 2011: 1). As in all other regions of the world, the dendrochronology project carried out in Central Mexico enabled the detection of moisture-levels based on the width of growth rings. While humid years are marked by thicker growth rings, drier conditions result in thinner growth rings (Stahle *et al.* 2011: 1). In order to refine the informative value of these datasets, the tree rings of the recent years were correlated with precipitation and temperature data recorded during an overlapping period of time (1973-2003) (Stahle *et al.* 2011: 2).

4.1.2 Palynology

Of all the methods used for investigating paleoclimatic conditions within the Maya Lowlands, pollen analyses experienced the widest application (Seefeld 2008: 92). Consequently, most hypotheses of paleoclimatic conditions are based on results acquired with this method. In principle, pollen analyses are rather simple (Leyden 2002: 86): Plants and ferns produce pollen and spores, which are dispersed by wind, insects and animals (Seefeld 2008: 92). This process produces a "pollen-rain" that scatters in the broader environment on land and water surfaces, and becomes preserved in anaerobic and dry settings (Leyden 2002: 86; Seefeld 2008: 92). These remains are dated with radiometric investigations of single samples and/or the entire stratigraphic context (Leyden 2002: 86). Lacustrine sediments and permanently water-bearing aguadas feature the best conditions for the long term-conservation and storage of pollen and spores (Akpinar-Ferrand *et al.* 2012: 98; Seefeld 2008: 92). As the sediment in lakes and aguadas was mostly deposited in standing water with low oxygen conditions, the pollen and other microfossils stored in these contexts are well preserved (Beach *et al.* 2015b: 259). Furthermore, the permanent inundation of these contexts makes them less vulnerable to natural and cultural interference (Leyden 2002: 86). On the other hand, seasonally dry aguadas have a greater chance of post-depositional disturbances, which may cause problems during the collection of pollen (Akpinar 2011: 15). Although sediments from anthropogenic contexts frequently allow for dating, they do not promote the conservation of pollen due to frequent interference (Leyden 2002: 86). After the extraction, all documented pollen are divided into the biological subgroups (*Taxa*) such as trees, herbs and aquatic plants and depicted in diagrams (Leyden 2002: 87 with figure 2). For every taxon, a diagram is produced in which the age and amount of particular pollen species are displayed (Leyden 2002: 87, with figure 2).

As Leyden (2002: 87) emphasizes, the interpretation of these pollen diagrams cannot answer all questions concerning climatic conditions. This is due to the inherent limitation in the fact that interactions between climate and vegetation are too complex (Seefeld 2008: 93). A common principle in pollen analysis is the assumption that "the present is the key to the past" (Seefeld 2008: 93). If the modern habitat requirements of the respective plant or vegetation combination is known, bygone climate changes are determined through statistical and qualitative methods (Leyden 2002: 87; Seefeld 2008: 93). If prehistoric plant forms do not have modern counterparts, interpretations become less assured. Results can also be affected by extremely small pollen concentrations. Therefore, rarer pollen species are frequently not identified and are consequently not included in calculation (Leyden 2002: 87, Seefeld 2008: 93). Besides this, cultural inferences in pollen diagrams can be misinterpreted as climatic signals (Leyden 2002: 87).

Due to these limitations, Leyden (2002: 85) demands multiple approaches from interdisciplinary investigations[33] for a thorough interpretation of bygone climatic conditions. This is because all studies of prehistoric climatic conditions draw on indirect climatic clues, which are incomplete in their precision and preservation. Therefore, an accurate dating of lacustrine sediments is almost impossible. This issue causes comparisons between pollen-sequences of different lakes to be even less secure (Brenner *et al.* 2002: 141; Seefeld 2008: 93). According to Akpinar (2011: 15), pollen studies carried out in the Maya Lowlands mostly reflect the anthropogenic modification of the environment rather than natural events such as climate change. Furthermore, they mostly show the vegetation disturbances caused by the

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[33] In order to prevent observations from being attributed to the wrong mechanisms, Leyden (2002: 85) demands that all involved factors, including those which are not necessarily connected with the investigation inquiry, are clearly intelligible.

earliest settlers and subsequent agricultural activities (Beach *et al.* 2008; Brenner *et al.* 2003; Leyden 2002; Rosenmeier *et al.* 2002). Another promising method for the reconstruction of paleoclimatic conditions pertains to the El Niño Southern Oscillation events (ENSO) (Akpinar 2011: 14). As Beach *et al.* (2008) noted, the frequency of these ENSO events fluctuated drastically during the Holocene (Akpinar 2011: 14).

4.2 Models of pre-Hispanic climatic conditions

The wide range of theories on the prehistoric conditions in the Maya Lowlands can be divided into three main theses:

Theory 1: The prevalence of generally more humid conditions during the Preclassic and Classic period.

Theory 2: The conversion of permanent wetlands into seasonal wetlands.

Theory 3: Pronounced droughts of the Late Preclassic and the Terminal Classic caused the collapse of Classic Maya civilization.

4.2.1 Theory 1: Prevalence of generally more humid conditions during the Preclassic and Classic periods

Investigation into the prehistoric climatic and hydrological conditions within the Maya Lowlands began in the 1970s (see Chapter 3) (Seefeld 2008: 90). Among other factors, the catalyst for this increase in investigations was Cooke (1931), who speculated that many of today's seasonal swamps would have constituted permanent swamps, large shallow lakes or large modified reservoirs during the Preclassic and Late Classic Periods (Pope and Dahlin 1989: 100). According to Cooke's (1931) hypothesis, these permanent bodies of water would have been so heavily filled up with sediments due to massive, human induced erosions that they would have dried up and transformed into the seasonal wetlands of today (Olson 1979: 26; Turner and Harrison 1983b: 265). Many supporters of this theory expanded on it and reasoned that the inner bajos of today would have originally constituted much more fertile habitats and, consequently, could have been used for intensive cultivation with elevated fields (see Chapter 5.2) (Dunning *et al.* 2006: 92; Harrison 1977: 471; Turner and Harrison 1983b: 250, 265).

Based on this theory, which by that time was still based on mere assumptions, their supporters further speculated that the cultivation of wetlands would have represented the basis of food production during the Late Classic Period and an essential factor for the evolution and florescence of Classic Maya civilization (Adams 1980: 221; Turner 1983: 49). This scenario even led Siemens and Puleston (1972: 399) to the assumption that a generally higher water table would have enabled an extensive water-based transport system throughout the entire Maya Lowlands (Seefeld 2008: 91; see Figure 4.1). Although the empirical foundation of Theory 1 and the theories building on it were lacking in many regards, the prevalence of generally more humid conditions was accepted by the majority of the scientific community.

4.2.2 Theory 2: The conversion of permanent wetlands into seasonal wetlands

Theory 2 was established in the mid 1980s when a wave of investigations showed that irrigated fields were confined to outer bajos (Adams 1980; see Figure 4.1). It is in fact an extension of Theory 1 and implies that today's seasonal wetlands would have actually been permanent wetlands during the Preclassic and Classic periods. In order to verify the importance of wetland agriculture in pre-Hispanic Maya society, the advocates of the "New Orthodoxy" speculated that "the canal systems of the inner bajos" were unable to be located as they had been buried beneath thick layers of "Maya clay" (Scarborough and Valdez 2003: 12; Scarborough *et al.* 1995: 115; Seefeld 2008: 91; Weller 2006: 34).

In this context, Turner and Harrison (1983b: 251) surmised that the differences in the geographic allocation of canal features could be ascribed to the topographic differences between inner bajos and outer bajos. Hence the inner bajos of the Petén would have been potentially subject to a much higher rate of erosion and sedimentation than the outer bajos of the eastern peripheral area (Belize and Quintana Roo) (Turner and Harrison 1983b: 251, 265). Turner and Harrison (1983b: 251) reasoned that the outer bajos would have been less affected by sedimentation as they were surrounded by shallower slopes. They also claimed that this connection would explain the better state of preservation of canal systems in Belize and the Candelaria Basin (Seefeld 2008: 91).

4.2.3 Theory 3: Pronounced droughts as catalysts for the Collapse of Classic Maya civilization

Theory 3 was developed during the 1990s when an increasing amount of paleoclimatic data indicated that the Maya Lowlands had experienced two pronounced drought periods: one during the transition from the Late Preclassic to the Early Classic and another during the Terminal Classic (Hodell *et al.* 1995: 391; Lentz *et al.* 2015). According to this theory, the first severe drought period at the end of the Late Preclassic caused the abandonment of the Preclassic sites in the Mirador Basin (Hansen *et al.* 2002: 289). The second drought would have been one of the factors that led to the downfall of the former kingdoms and the abandonment of urban centers, a process frequently described as the collapse of the Classic Maya civilization during the Terminal Classic (Brenner *et al.* 2003; Gill 2000; Gill *et al.* 2007; Golden and Scherer 2012: 67; Hansen *et al.* 2002: 289; Lucero 2002; Willey 1973; Yaeger and Hodell 2009).

In order to support this theory, some scholars argued that stable isotope and trace-element analysis of human skeletons indicate that animal proteins had not been sufficiently available during the Late Classic (Dunning and Beach 2000: 190). However, because most reconstructions of pre-Hispanic climatic conditions are based on Palynology, the upcoming overview mainly focuses on pollen cores. Reconstructions based on other methods are marked as such.

4.3 Current state of knowledge on pre-Hispanic climatic conditions

As pointed out in the previous chapter, serious investigation of paleoclimatic conditions began in the 1980s. While these studies were initially very scarce and confined to isolated areas, the increase of interest since the mid 1990s led to an extensive corpus of pollen cores (Folan *et al.* 1995: 312; Gunn *et al.* 1994, 1995). It is however important to highlight that these pollen studies have still not covered the entirety of the Maya Lowlands. While the central, northern and eastern Petén and Belize have been studied rather intensively, relatively few land use studies have been executed in the Western Maya Lowlands (e.g. the Usumacinta Basin), Campeche and Quintana Roo (Golden and Scherer 2012: 68). It is important to note that the natural landscape of the Maya Lowlands and the living conditions of the pre-Hispanic Maya were determined by two basic factors:

(1) The climatic conditions, which directly determined the availability of water, the productivity of soils and the vegetation, and

(2) The culturally induced modifications of the natural landscape.

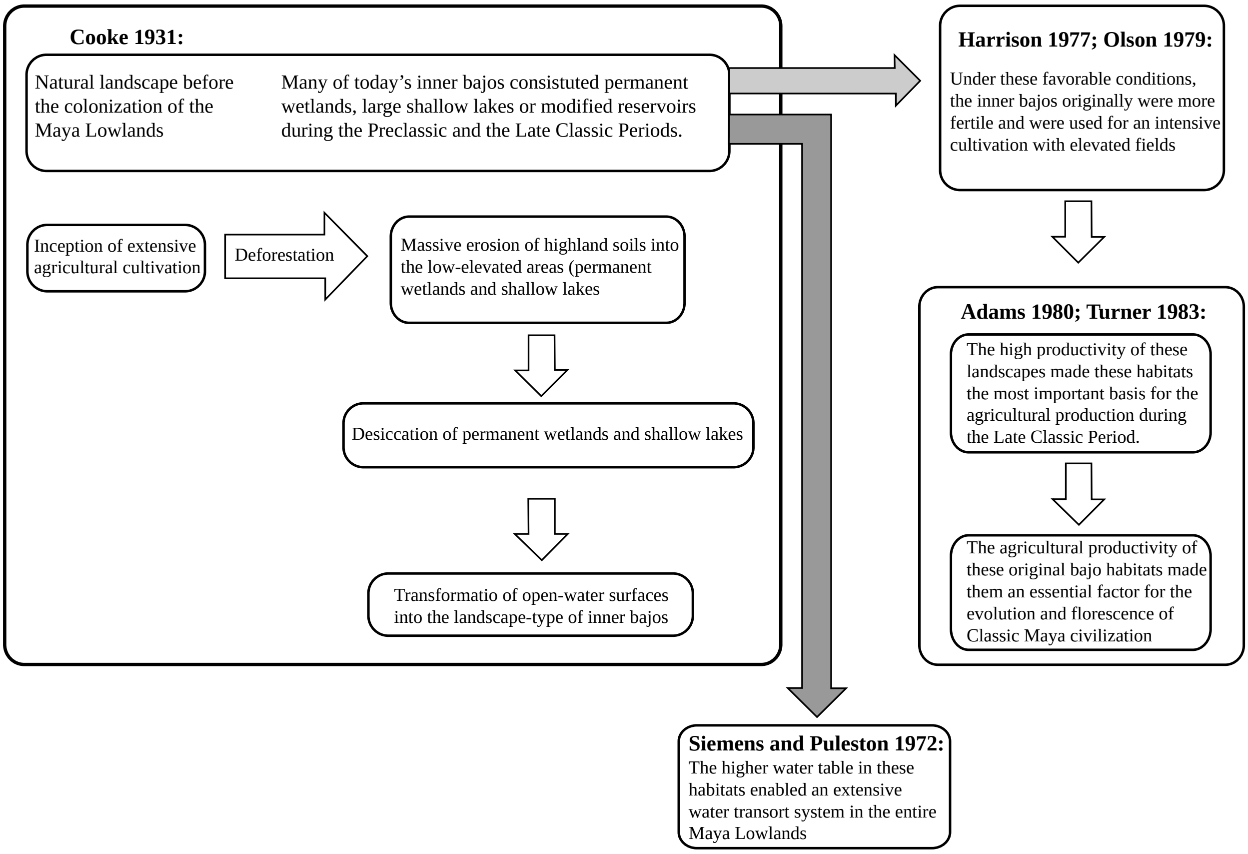

Figure 4.1: Schematic representation of climate theory No. 1.

During the Holocene, the climatic conditions around the globe experienced a number of dramatic changes. These also affected the Maya Lowlands (Dunning *et al.* 2006: 91, 2015: 10; Hodell *et al.* 2005). In this process, global and pan-Caribbean mesocycles of climatic fluctuations caused several cool and dry periods, followed by warmer and more humid periods (Brenner *et al.* 2002). These periods could last several hundred years (Haug *et al.* 2002; Mueller *et al.* 2009). In addition to these longer trends, shorter climatic cycles also affected rainfall patterns, most notably a 208-year cycle of solar energy pulses (Dunning *et al.* 2015b: 10; Hodell *et al.* 2011; Wahl *et al.* 2006). The following summary will provide a general overview of the history of climatic conditions (Factor 1) and the culturally induced modifications of the landscape (Factor 2) over time and their effect on the pre-Hispanic Maya society. This chronological survey will present the specific conditions of each region and identify the differences.

4.3.1 Early environmental history of the Maya Lowlands

The earliest records from sediment cores of the Maya Lowlands date back to the early Holocene (9500-1500 BC) (Dunning and Beach 2000: 188). In this period, climatic conditions were slightly drier and the ecosystem was defined by savannas (Beach *et al.* 2009: 1713; Leyden 1984). Pollen studies prove that tropical forests began to appear throughout the Central Maya Lowlands around 8600 BC (Akpinar 2011: 15). Pollen diagrams indicate the diffusion of vegetation that closely resembles current conditions (Dunning *et al.* 2006: 87; Seefeld 2008: 18). Leyden (2002: 93) saw these results as an indication that the precipitation and temperatures of this epoch would have approximated contemporary ones (Seefeld 2008: 18). During this time, the communities of deciduous dry forests seem to have emerged in northwestern Yucatán (Seefeld 2008: 18). In the Eastern and Southern Lowlands however, more humid tropical semi-deciduous and deciduous (evergreen) forests appeared (Leyden 2002: 85). Around 5500 BC, the Petexbatun region was completely covered by tropical deciduous forest species such as Moraceae, Combretaceae and Burseraceae (Dunning and Beach 2000: 188).

The colonization of the Central Lowlands by the Maya between 3200 and 1700 BC, a process that Hammond and Tourtellot (2004: 294) described as the "Maya landnam", led to widespread establishment of agriculture and the expansion of permanent human settlements (Beach *et al.* 2009: 1712; Dunning *et al.* 2006: 87; Seefeld 2008: 18). The traces of these organized forest clearances and the expansion of agriculture are clearly reflected in the pollen record. The earliest traces of these "human disturbances" can be dated to 3000 BC (Beach *et al.* 2015a: 7; Jones 1994; Pohl *et al.* 1996). Pollen cores indicate that these human influences had spread over the entire Lowlands by 2000 BC (Dunning *et al.* 1999: 658; Leyden 2002: 94; Pohl *et al.* 1996). In the case of Lago Salpetén for instance, the pollen core indicates that only a small amount of forest had remained in the vicinity by around 2000 BC (Gunn *et al.* 2002: 31; Leyden 2002: 94, with Figure 6).

4.3.2 Middle Preclassic

By the Middle Preclassic Period, small rural populations in the Maya Lowlands started to practice swidden agriculture, expand their settlements and increasingly colonize new areas, which lead to extensive forest clearances (Beach *et al.* 2009: 1712). Interestingly, some areas, such as the region of Copán, already experienced the highest rates of deforestation during the Middle Preclassic (McNeill *et al.* 2012: 13). The current understanding however suggests that in most other regions of the Maya Lowlands, clearances were just beginning to appear during the Middle Preclassic (Garrison and Dunning 2009: 537). The deforestation processes are clearly reflected in the palynological records by more open vegetation (i.e. savanna species[34]), the appearance of maize pollen and high amounts of eroded upland soils in bajo habitats (Beach *et al.* 2009: 1712; Dunning and Beach 2000: 188; Seefeld 2008: 18). The pollen recovered from the Aguada Tintal (vicinity of San Bartolo) indicate that maize, cotton, and manioc were being cultivated in the vicinity between 780 and 410 BC (Garrison and Dunning 2009: 538).

Another catalyst for clearances, apart from the creation of agricultural and residential spaces, was lime burning, which was necessary for paving patios and plastering of facades (Garrison and Dunning 2009: 540; Schreiner 2002; Seefeld 2008; Wahl *et al.* 2007: 217; Wernecke 2008: 207). In the soil cores, these activities are indicated by burned organic sediments (Rice 1996: 201; Shaw 2003: 163). These forest clearances inevitably caused increased soil erosion (Dunning and Beach 1994: 56; 2000: 188), a process that can nowadays be archeologically documented in depressions and inner bajos in the form of washed-in highland sediments or "Maya clay" (Binford *et al.* 1987: 119; Curtis *et al.* 1998; Garrison and Dunning 2009: 538; Dunning and Beach 1994: 52; Dunning *et al.* 1997, 1998a: 143, 2006: 87; Jacob 1995b: 186; Scarborough 1991: 125; Seefeld 2008: 19 with Figure 11). A very drastic example of these erosion processes was documented in the Aguada Catolina (Petexbatun-region), which was clogged by a meter-deep layer of clay during the Middle Preclassic (around 2000 BC) (Beach *et al.* 2015b: 259). Pollen cores indicated that a severe drought period had occurred during the end of the Middle Preclassic (475-250 BC) (Akpinar 2011: 14; Brenner 2003; Curtis *et al.* 1998; Hodell *et al.* 2001; Mueller *et al.* 2009; Wahl *et al.* 2007).

4.3.3 Late Preclassic

By the Late Preclassic Period, the intensity of land use increased by several times and the deforestation processes had already led to widespread erosion in most regions of the Maya Lowlands (Akpinar 2011: 15; Curtis *et al.* 1998; Leyden 2002; Leyden *et al.* 1998; Islebe and Sanchez 2002). According to Beach *et al.* (2009: 1712), the culturally induced soil erosion reached its peak during the Late Preclassic because the extensive form of swidden agriculture required the deforestation of vast areas (Abrams and Rue

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[34] According to Johnston *et al.* (2011), the expansion of savanna-species can be interpreted as an indicator of both anthropogenic clearances and climatic aridity (Akpinar 2011: 17).

1988: 392; Adams *et al.* 2004: 329; Anselmetti *et al.* 2007; Seefeld 2008: 94; Shaw 2003: 163). In the pollen cores, these deforestation processes are indicated by high concentrations of charcoal fragments, which were interpreted as indicators for swidden agriculture (Akpinar 2011: 17; Johnston *et al.* 2011). In a few locations, some scholars were even able to document that some of today's inner bajo landscapes originally were perennial lakes (Beach *et al.* 2009: 1714). Evidence for the existence of lake habitats buried under a thick layer of Late Preclassic "Maya clay" could be documented in the Bajo Donate and the Bajo Majunche near San Bartolo (Beach *et al.* 2009: 1713; Garrison and Dunning 2009: 538). According to Beach *et al.* (2009: 1714), many bajos had mid to Late Holocene phases in which at least portions of the depressions were filled with shallow lakes or perennial herbaceous wetlands. However, these wetlands have long since disappeared due to both anthropogenic erosion and periods of regional climatic drying (Beach *et al.* 2009: 1714; Castañeda Salguero 1995; Dunning *et al.* 2002, 2006; Jacob 1995; Métailié *et al.* 2003; see Figure 4.2).

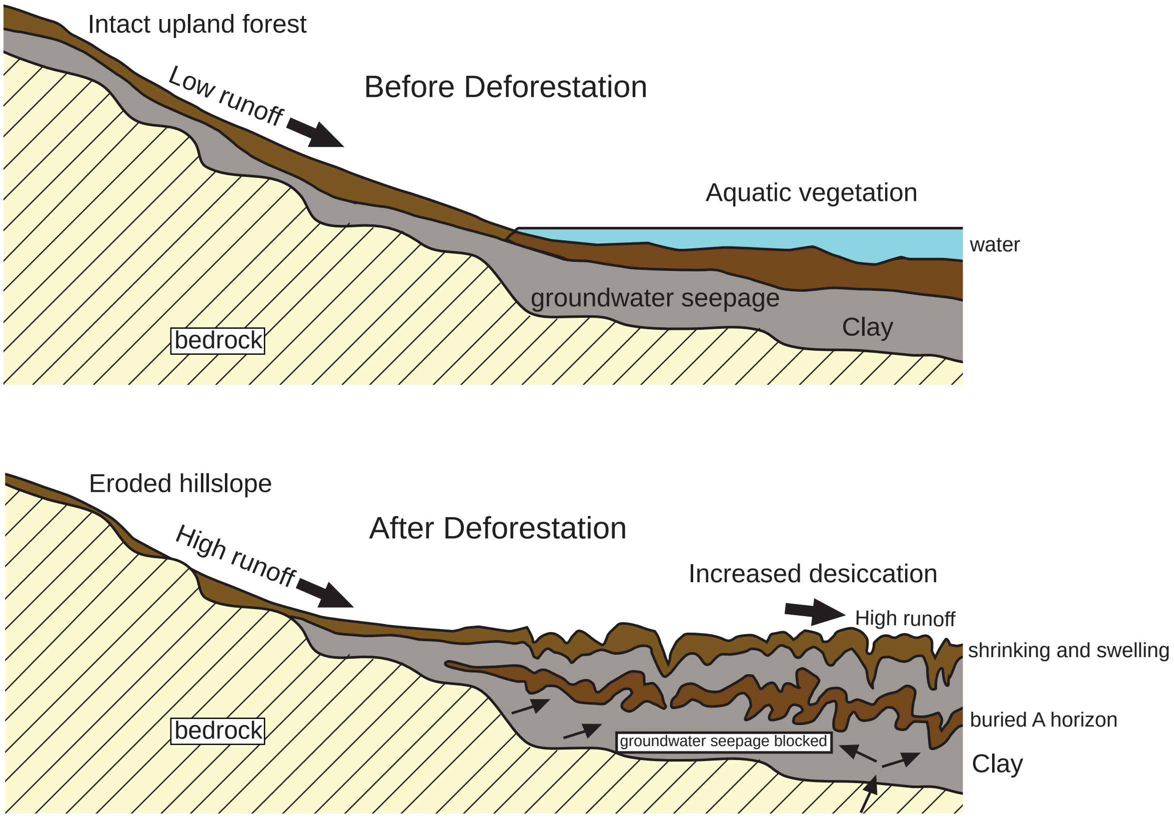

Figure 4.2: Schematic representation of the effects of deforestation processes (redrawn after Dunning *et al.* 2002: Figure 8). Reproduced with kind permission of Nicholas P. Dunning and Taylor & Francis Group.

Indeed, the model of soil erosion caused by deforestation is one of the few theories on pre-Hispanic climatic conditions that can be observed almost anywhere in the Maya Lowlands.[35] The existence of upland sediments can be observed in many seasonal and perennial wetlands of the southern lowlands (Beach *et al.* 2006: 175; Binford *et al.* 1987: 119; Deevey *et al.* 1979: 298; Dunning and Beach 1994: 52; Dunning *et al.* 2002: 269, 2006: 87; Hansen *et al.* 2002: 289; Jacob 1995b: 186; Parry 2007: 32; Scarborough 1991: 125, 1994: 43). Deevey *et al.* (1979: 302) were the first to observe this phenomenon and designated these calcareous, grey clay layers as "Maya clay". They can be seen in basins in the form of dense layers of anthropomorphic sedimentary clays with thicknesses of up to several meters (Binford *et al.* 1987: 117; Jacob 1992; Leyden 2002: 93; Rice 1996: 198). Generally, deforestation and agricultural practices that lead to accelerated soil erosion have been identified as the causes of this deposition (Islebe *et al.* 1996: 269; Rosenmeier *et al.* 2002). Since anthropogenic activities may have very different effects from one region to another, the thickness of the documented "Maya clay" layers varied drastically from one location

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[35] In this respect, it should be pointed out that according to Siemens (1982: 210), the sedimentation of inner bajos could have been caused, at least partially, by natural factors (see Chapter 4.4).

to another (Dunning and Beach 1994: 52; Dunning *et al.* 2006: 92). At the current state of research, no regularity can be observed in the density of these depositions (Seefeld 2008: 95). So far, the depositions of Late Preclassic upland sediments ("Maya clay") could be documented in the following locations (see Figure 4.3 and Table 1):

Generally, these forest clearances lead to the expansion of herbaceous plant species and increased the distance over which pollen could be transported by the wind (Leyden 2002: 93). In the pollen record, these effects can be identified by an increase of maize, grasses and herb pollen (Seefeld 2008: 94). In addition to the issues caused by the erosion of upland-soils, the Maya of the Late Preclassic were apparently confronted with a period of increased aridity (25-210 AD) (Abrams and Rue 1988: 392; Akpinar-Ferrand *et al.* 2012: 98; Curtis *et al.* 1998; Dunning *et al.* 2012; Hodell *et al.* 1991: 791; Leyden 2002: 94; Leyden *et al.* 1994: 4857; Scarborough *et al.* 2012: 12412). Many authors believe that the combined effect of increased soil erosion and pronounced droughts would have made the transitional phase between the Late Preclassic to the Early Classic a time of environmental stress, which would have resulted in a sharp cultural decline (Dahlin and Dahlin 1994; Dunning and Beach 2000: 184, 188; Dunning *et al.* 2015: 10; Hansen *et al.* 2002: 278).[36] Indeed, evidence for dramatic transformation processes in the form of site abandonments or shifts in settlement patterns are reflected in the archaeological records of various sites:

Location	**Source**
La Milpa, La Milpa Aguada	Scarborough *et al.* (1995: 113).
Caracol	Healy *et al.* (1983: 404).
Calakmul, Bajo El Laberinto. In this location, sedimentation can already be observed after the middle Holocene.	Gunn *et al.* (2002a: 313).
Laguna Yaxha	Deevey *et al.* (1979: 302); Hansen *et al.* (2002: 289); Rice *et al.* (1985: Figure 22); Shaw (2003: 160); Turner and Harrison (1983b: 265).
Laguna Sacnab	Deevey *et al.* (1979: 302); Hansen *et al.* (2002: 289); Rice *et al.* (1985: Figure 22); Shaw (2003: 160); Turner and Harrison (1983b: 265).
Far West Bajo	Dunning *et al.* (2006: 92).
Bajo La Justa	Dunning *et al.* (2006: 92).
Bajo de Santa Fe	Cowgill and Hutchinson (1963); Olson (1982: 20).
Bajos of the Mirador-Basin	Castañeda and Castañeda Cerna (1994: 142); Dahlin *et al.* (1980); Fairley *et al.* (2002: 207); Romero Zetina and Schreiner (2000).
Laguna Oquevix, Lago Chimaj and Lago Chilonche	Brenner *et al.* (1990).
Albion Island (Belize)	Pohl *et al.* (1990); Wiseman (1985, 1990).
Copán	Abrams and Rue (1988); McNeill *et al.* 2010, 2012; Paine and Freter (1996: 37).
Nakbe, Aguada Zacatal	Wahl *et al.* (2007: 219).
Cobá, Site-center	Leyden (2002: 96).
Laguna Tamarindito (Petexbatun-region)	Dunning *et al.* (1997: 262).
Laguna Petenxil (Petén)	Tsukada (1966: 63).
Cobweb Swamp (vicinity of Colhá). Here, the washed-in clay is 50-100 cm thick.	Jacob (1995b: 179).
Aguada Lagunita Elusiva	Akpinar 2011: 16; Weiss-Krejci *et al.* n.d.
San Bartolo, Bajo Donate, Bajo Majunche, Aguada Tintal	Beach *et al.* 2009: 1713; Garrison and Dunning 2009.

Table 1: Sites with evidence of "Maya Clay".

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[36] According to other scholars, additional factors for these transformation processes might have been economic collapses (Reese-Taylor and Walker 2002) or the early failures in the institution of kingship (Garrison and Dunning 2009: 545; Schele and Freidel 1990: 127-128).

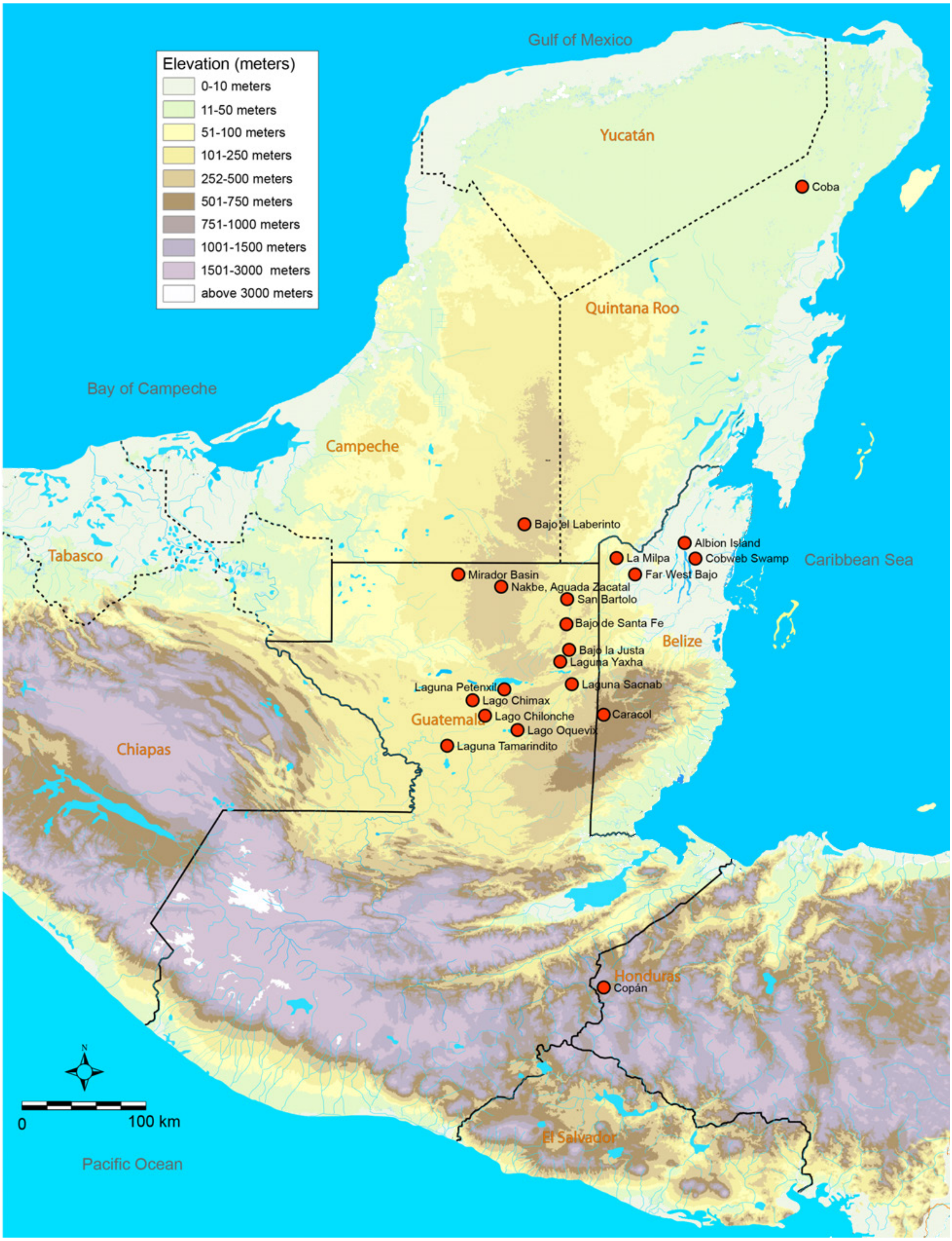

Figure 4.3: Map of sites with evidence of "Maya clay" (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

In the region of San Bartolo and Xultun, paleoclimatic data suggest a severe drought during the Late Preclassic[37] Period, which could have caused the temporary abandonment of San Bartolo (Akpinar and Dunning 2011: 111; Garrison and Dunning 2009: 545). Garrison and Dunning (2009: 537) reasoned that the low density of water storage features in San Bartolo might have weakened the resilience of the settlement, and ultimately would have been a catalyzing factor for its abandonment. In the Holmul Basin, (particularly in the sites of Cival and T'ot), the archaeological data also indicated a transformational period at the end of the Late Preclassic (Estrada-Belli 2002, 2006; Garrison and Dunning 2009: 545). In Río Azul, the transition from the Late Preclassic to the Early Classic was marked by the abandonment of rural settlements (Adams 1995, 1999; Garrison and Dunning 2009: 545). In the soil profiles of El Mirador, Dahlin (1983: 254) also observed the occurrence of a severe drought period around AD 250 (Gunn *et al.* 2002b: 81). Parry (2007: 32) and Scarborough (1993: 43) speculated that the environmental stress had caused the abandonment of El Mirador and Nakbe. Adams (1991: 632) even suggested that the underdeveloped hydraulic systems of the Mirador Basin would have been a key factor for the low resilience of these sites (Akpinar 2011: 21; Brenner *et al.* 2003; Dunning *et al.* 2002; Hodell *et al.* 1995; Shaw 2003). In Copán, the transitional period from the Late Preclassic to the Early Classic also experienced the highest deforestation rates after the Middle-Preclassic (McNeill *et al.* 2012: 13).

4.3.4 Early Classic

Most scholars believe that during the Early Classic, the pre-Hispanic Maya had to struggle with a heavily eroded landscape, which would have forced them to invent techniques for the prevention of soil erosion, e.g. the construction of terraces along bajo margins (Beach *et al.* 2009: 1722; Dunning and Beach 2000: 196; Jacob 1995; Rice 1993). Due to these landscape modifications, soil erosion in the Maya Lowlands was successfully decreased in several areas (e.g. in Chan Cahal and in Xultun; see Beach *et al.* 2009: 1722; Garrison and Dunning 2009: 542). Other areas however, such as the region of Tikal,[38] were still heavily affected by human-induced soil erosion and deforestation (Beach *et al.* 2015b: 270).

4.3.5 Late Classic

Even though the demographic stress and deforestation had doubtlessly reached its peak during the Late Classic Period, the experience of earlier ecological disasters motivated the Maya to carry out techniques aimed at protecting slopes and reducing erosion. As Beach *et al.* (2009: 1712) pointed out, the Late Classic brought about the most intensive use of land and the highest population densities. Despite these developments, the processes of soil erosion actually declined in several locations after the peak of erosion in the Late Preclassic (Anselmetti *et al.* 2007; Beach *et al.* 2008).

Nevertheless, pollen data suggest that some areas, such as the Petexbatun region[39] or the area around Tikal,[40] still suffered significant soil erosion during the Late Classic Period (Dunning and Beach 2000: 188; Parry 2007: 32). Soil samples from the Aguada Lagunita Elusiva 5 km east of La Milpa (see Chapter 5.6.4.3.8.3) indicated that during the Late Classic Period, the surrounding landscape was heavily affected by human disturbances and was used intensively for agricultural production (Weiss-Krejci *et al.* n.d.).[41]

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[37] The indication of a severe drought during the Late Preclassic period is based on the coring and excavations at the bottom of Aguada Tintal and the Aguada Terminos (see Chapter 5.6.4.3.7), where Akpinar and Dunning (2011: 111) documented hard, oxidized layers. According to Akpinar and Dunning (2011: 111), the phases of extreme droughts had "baked the clay floors of these aguadas into an adobe like state".

[38] Human disturbances are clearly visible in the soil samples of the Aguada El Zotz (Beach *et al.* 2015b: 270).

[39] According to Dunning and Beach (2000: 188), the sediment core extracted from the Aguada Tamarindito clearly indicates two main waves of deforestation: The first during the Late Preclassic and the second during the Late Classic period.

[40] Soil samples from the Aguada El Zotz clearly indicate high levels of disturbance during the Late Classic (Beach *et al.* 2015b: 270). In these samples charcoal particles indicate regional and local burning.

[41] In this case, the human disturbances were determined on the basis of Poaceae, Asteraceae and *Zea mays. Zea mays* percentages range as high as 5-6 %, indicating the cultivation of large quantities of maize close to the aguada (Dunning and Beach 2010: 381-382; Weiss-Krejci *et al.* n.d.).

Furthermore, the sediment core indicates that the soils in the area were exhausted (Dunning and Beach 2010: 381) – an observation that could also be documented in pollen cores from several other aguadas in the Lowlands (Akpinar-Ferrand *et al.* 2012; Dunning *et al.* 2005; Wahl *et al.* 2007; Webster *et al.* 2005). Dunning and Beach (2000: 190) reason that these processes resulted in a scarcity of productive "highland soils", which would have favored conflicts between members of neighboring residential groups and different sites. Furthermore, they claimed that the Late Classic and Terminal Classic defensive structures of the Petexbatun region would constitute archaeological evidence for this theory (Dunning and Beach 2000: 190). Paleoclimatic data from Copán however indicate very different conditions. In a pollen core extracted from the Aguada Petapilla, McNeill (2012: 13) did not observe any overexploitation of the environment (high deforestation rates) during the Late Classic Period (McNeill 2006, 2012: 13; McNeill *et al.* 2010; Rue 2002; Webster *et al.* 2005).[42]

4.3.6 Terminal Classic

Around AD 800, numerous soil cores[43] indicate that the climate became considerably dryer in many regions of the Maya Lowlands, a process which many scholars[44] identified as a potential cause for the collapse of Classic Maya civilization. Even the dendrochronology datasets indicated that the worst droughts of the first and second millennium AD occurred between AD 810 and 860 and AD 897 and 922 (Stahle *et al.* 2011: 3).

By AD 900, almost all Maya cities had been abandoned (Webster 2003; Guderjan 2007; Beach *et al.* 2009: 1713). Some authors (e.g. Demarest 2004: 501; Parry 2007: 186) reasoned that this environmental stress would have also been a factor that increased military conflicts, as has been documented in the Petexbatun region (Demarest *et al.* 1997).

Recent studies indicate that precipitation rates had dropped by 30-50% during the Terminal Classic (Beach *et al.* 2015b: 275; Medina-Elizalde and Rohling 2012). Other studies (Cook *et al.* 2012; Georgescu *et al.* 2012) indicate that, apart from soil erosion, the extensive forest clearances might have also negatively affected the rainfall patterns (Lentz *et al.* 2015b: 283). This theory is backed up by the fact that modern forest clearances in the tropics dramatically affect transpiration rates and hydrological cycling (Lentz *et al.* 2015b: 283). In this process, the extensive forest clearances led to a drying and warming of the climate, which may have decreased rainfall as a feedback effect (Dahlin 1983: 248; Shaw 2003: 161).[45] This effect is caused by the rate of insolation that is reflected by the vegetation matter (*Albedo-Effect*; Seefeld 2008: 97; Shaw 2003: 161; O'Brien 1996: 313; see Figure 4.4):

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[42] Instead, the data suggested that the highest levels of deforestation had occurred during the Middle Preclassic and during the transition from the Late Preclassic to the Early Classic period (McNeill *et al.* 2012: 13; see above).

[43] 1) The occurrence of an extreme drought at the transition from the Late Classic to the Terminal Classic could be documented in a pollen core from the Aguada Petapilla near Copán (McNeill *et al.* 2012: 13). The Lago Chichancanab near Cobá apparently experienced its driest period of the last 8000 years in the timespan between 800 and 1020 AD. (Gunn *et al.* 2002: 82; Shaw 2003: 160). The drastic drought-period can be observed in an increased deposition of gypsum over carbonate and a volume drop of approximately 30% (Beach *et al.* 2009: 1716, 2015b: 275; Hodell *et al.* 1995). Webster *et al.* (2007) described a similar process in southern Belize.
2) According to Shaw's (2003: 159) belief, all data from cenotes and lakes within and at the margin of the Lowlands indicate a climatic change from a more humid period towards a dryer period, which took place around 900 AD

[44] Akpinar-Ferrand *et al.* 2012: 98; Brenner *et al.* 2003; Curtis *et al.* 1998; Denton and Karlén 1973: Figure 1; Dunning *et al.* 2015b: 10; Eddy 1977: 88; Fialko *et al.* 2005: 489 with Figure 8; Folan *et al.* 1983: 458, Gill 200; Gunn *et al.* 1994, 1995, 2002b: 81; Haug *et al.* 2003; Hodell *et al.* 1995: Figure 9, 2001, 2005: 1413; Kennett *et al.* 2012; McNeill *et al.* 2010, 2012; Medina-Elizalde and Rohlin 2012; Parry 2007: 186; Robichaux 220: 341; Scarborough and Grazioso Sierra 2015:19; Seefeld 2008: 19; Shaw 2003: 159, with Table 1; Weiss-Krejci and Sabbas 2002: 353; Yaeger and Hodell 2008.

[45] Such processes can currently be observed quite clearly in the Maya Lowlands in the form of climatic transformations on a local level (Seefeld 2008: 97). As an example, the Río Holmul, which gradually disappears from year to year due to forest clearances and the construction of new improvised roads, can be considered a moribund river (Fialko 1999: 688). In this process, it becomes very clear that precipitation rates decrease and soil erosions rise in all of those locations where no forest areas are available any longer (Seefeld 2008: 97). This leads to a slow desiccation of the riverbed (Fialko 1999: 688). Likewise, Dunning and Beach (1994: 55) experienced the processes of modern soil loss and sedimentation due to recent forest clearances and cultivation in the Petexbatun region.

The components of a cleared system consist of soil, grasses and the pockets of air in between (Seefeld 2008: 97). A forested system on the other hand includes the soils (and their humus-covering), the tree trunks, branches and leaves (Shaw 2003: 161). The greater amount of matter within the forested system leads to lower temperatures and better storage of moisture (Seefeld 2008: 97). In this context, the wind is a crucial factor.

Within the forested system, the wind can only mix the air to a limited extent due to leaves. In cleared systems on the other hand, the wind blows immediately over the surface causing a constant exchange of saturated air with dry air, which thereby increases evaporation on the surface (Shaw 2003: 161). The supremacy of forested systems is apparent in the fact that, as opposed to cleared systems, the air is replenished with humidity during the night resulting in morning fog or dew. However, humidity rates drop to almost zero when the temperatures rise over the course of a day (Shaw 2003: 161). In cleared forests, such oscillations are far less extreme since some level of humidity remains in the air throughout the entire day (Shaw 2003: 161). Moreover, the rainfall in cleared systems impacts the soil at a much higher speed since they are not slowed down by the canopy. This leads to a more rapid eluviation of sediments (Shaw 2003: 164; see Figures 4.4 and 4.5).

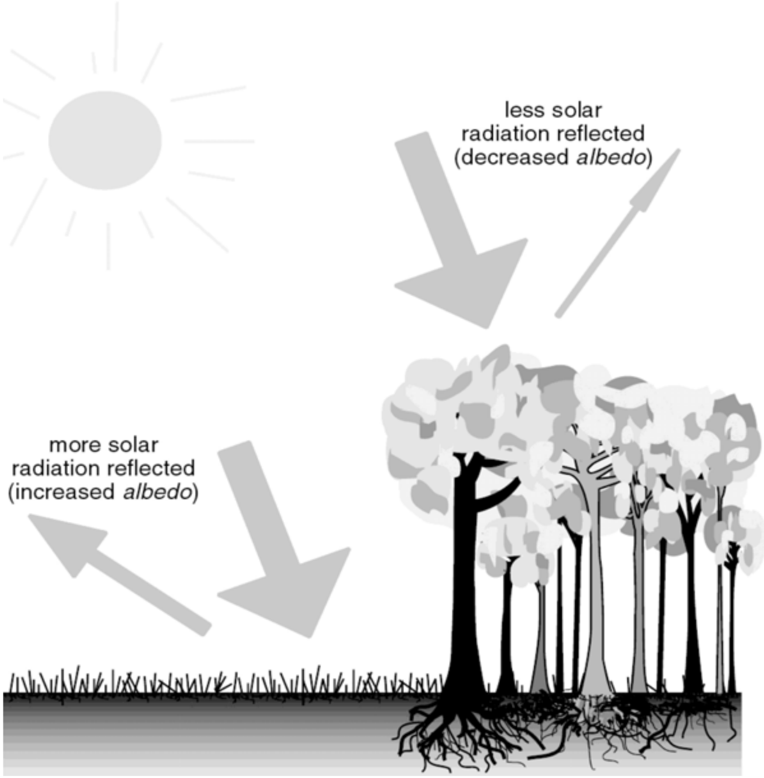

Figure 4.4: Surface *albedo* in forested and cleared areas (source: Shaw 2003: Figure 2. Reproduced with kind permission of Justine M. Shaw and Cambridge University Press).

Lentz *et al.* (2015b: 283) speculated that the pre-Hispanic Maya, such as the inhabitants of Tikal "who cleared about 60 percent of their upland forest, may have unknowingly contributed to the devastating droughts of the Late Classic Period". Curiously, the pollen diagrams indicated that the abandonment of Maya cities in the Late Classic and the Terminal Classic led to a relatively quick recurrence of tropical forests and a decrease in erosion rates (Anselmetti *et al.* 2007; Beach *et al.* 2009: 1712, 2015a: 7; Brenner *et al.* 1990: 250; 2002, 155; Leyden 2002: 94; Leyden *et al.* 1994: 4858; Luzzadder-Beach and Beach 2009; Shaw 2003: 163-164; Vaughan *et al.* 1985: 74).

Among other locations, these processes could be documented in a pollen core extracted from Aguada Lagunita Elusiva near La Milpa (Dunning and Beach 2010: 382). At 50 cm into the core (AD 800-900), there is a large spike in fern spores, followed by an increase in high forest arboreal species and mangroves (e.g. *Combretaceae*). This could be interpreted as an abandonment of the settlement and a regeneration of the rainforest (Weiss-Krejci *et al.* n.d.). The core from Aguada Lagunita Elusiva also indicates that residential areas in the vicinity of the aguada were abandoned by AD 900 and subsequently replaced by upland forests (Dunning and Beach 2010). Interestingly, these data correlate quite precisely with the archaeological records, which also document an abandonment process during this period (Akpinar 2011: 16; Dunning 2003). Furthermore, the significant decrease of soil erosion after the collapse indicates a widespread reforestation after the abandonment of the sites (Akpinar 2011: 8; Dunning and Beach 1994; Mueller *et al.* 2010). Nevertheless, some areas did not fully recover until the Spanish conquest of the Americas (Hodell *et al.* 2000: 32).

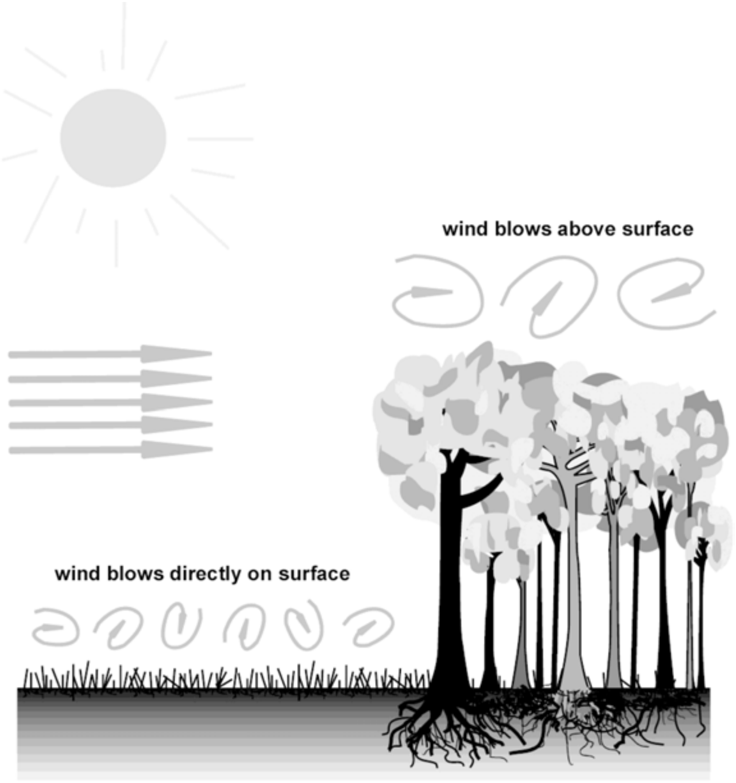

Figure 4.5: Wind effects in forested and cleared areas (source: Shaw 2003: Figure 3. Reproduced with kind permission of Justine M. Shaw and Cambridge University Press).

4.3.7 Postclassic

As various studies have shown, the long-term presence of the Maya and their transformation of the natural landscape had a persisting effect on the vegetation of the Maya Lowlands (Lundell 1937). During his early explorations of the Maya area, Lundell (1937: 10) observed that the larger and older trees in the forest showed an apparent age of approximately 1,000 years, leading him to the conclusion that the forest was the result of environmental manipulations by the pre-Hispanic Maya (Parry 2008: 7). Consequently, Lundell (1937: 10) inferred that the low population density of the northern Petén during the Postclassic Period would have encouraged the development of a "climatic climax forest" (Parry 2007: 7). Furthermore, Lundell (1937: 10) recorded the preferential growth of species such as ramón (*Brosimum alicastrum*), zapote (*Achras zapota*) and chico zapote (*Manilkara zapota*), which he interpreted as the result of climatic variables and human selection (Binford *et al.* 1987; Parry 2007: 7; Wagner 1964). Later researchers also observed this "preferential growth" in comparison to the general variety of vegetation, and also concluded that the vegetation communities would have developed over the last 1,000 years as a result of pre-Hispanic anthropogenic environmental manipulation (Binford *et al.* 1987: 119-120; Parry 2007: 7; Wagner 1964).

In the Petexbatun region, pollen cores indicated that forest cover regenerated rather quickly after the abandonment of the local sites (Dunning and Beach 2000: 189). For Dunning and Beach (2000: 189), this result indicated that the forests in this region might have been more resilient compared to those of other regions. Furthermore, the remaining Postclassic populations in sites such as Lamanai demonstrably only had a moderate impact on the natural landscape (Graham *et al.* 1989).

Together, the collected pollen data indicate that the pre-Hispanic Maya were a dominant factor in the transformation of their environment after 2000 BC (Gunn *et al.* 2002a: 314; Leyden 2002: 93, 98). The data sets show that extended forest clearances have the potential to heavily modify the structure and composition of plant communities and induce regional climate changes as a consequence (Leyden 2002: 93; Seefeld 2008: 95).

4.4 Discussion of models on pre-Hispanic climatic conditions

While the general trends in the development of models regarding the climate and transformation of the landscape over time have been reconstructed to a satisfying extent, many scholars are still debating the more specific models of pre-Hispanic climatic conditions presented in Chapter 4.2. Therefore, the upcoming subsection discusses the plausibility of these models by comparing them with the palaeoecological data. The following three theories will be discussed:

(1) The prevalence of generally more humid conditions during the Classic Period

(2) The sedimentation of the inner bajos transformed permanent wetlands into seasonal wetlands, and

(3) The theory that droughts caused the collapse of Classic Maya civilization.

4.4.1 Theory 1: The prevalence of generally more humid conditions during the Classic Period

By comparing the corpus of available paleoclimatic data, it becomes apparent that the evidence for a local climatic drying during the Late Preclassic and the Terminal Classic are highly ambiguous (Dunning and Beach 2000: 190; Dunning *et al.* 2006: 92; Turner and Harrison 1983b: 251). Whereas no evidence for a local drying could be documented in the Petexbatun region (Dunning and Beach 2000: 190), other regions of the Maya Lowlands experienced very distinct droughts during the Late Preclassic and the Terminal Classic (Curtis *et al.* 1996; Hodell *et al.* 1995; Leyden *et al.* 1998; Whitmore *et al.* 1996). In fact, the only distinct and general pattern in the soil cores is the evidence of drought periods during the Late Preclassic and the Terminal Classic (Akpinar-Ferrand *et al.* 2012: 98; Brenner *et al.* 2003; Curtis *et al.* 1998; Dunning and Beach 2000: 190; Dunning *et al.* 2006: 90, 2012; Hodell *et al.* 2001; Scarborough *et al.* 2012: 12412; Seefeld 2008: 96). Although strong drought periods occurred in different regions of the Maya Lowlands during different periods, they do not form a general pattern and, accordingly, would have only had consequences on a regional level (Beach *et al.* 2015b: 279). However, the two pronounced drought periods at the end of the Late Preclassic and during the Terminal Classic coincide very well with the social and political transformation of these periods (Beach *et al.* 2015b: 279; Hansen *et al.* 2002: 278; Gill 2000; Leyden *et al.* 1998).

4.4.2 Theory 2: The sedimentation of the inner bajos transformed permanent wetlands into seasonal wetlands

Generally, the theory of a transformation process of permanent wetlands into seasonal wetlands (Cooke 1931) cannot be verified or falsified because the sum of available paleoclimatic datasets is too ambiguous (Hansen *et al.* 2002: 278; Seefeld 2008: 98; Turner and Harrison 1983b: 251). This becomes apparent in the investigations by Garrison and Dunning (2009: 537), who documented that before the colonization of the Maya Lowlands, even bajo landscapes located near to one another, featured very different conditions: The Bajo Majunche was marked by a herbaceous, perennial wetland and a shallow lake, the Bajo Donato was a shrubby grassland that evolved into a mixed wetland forest, and the Bajo Itz'ul was originally a swamp forest (Dunning *et al.* 2009; Garrison and Dunning 2009: 537). Within the Far West Bajo[46], Bajo La Justa[47] and Pulltrouser Swamp[48], paleoclimatic investigations indicated more humid conditions. These results were later interpreted as evidence for the existence of shallow lakes and perennial wetlands during the Late Preclassic and the Late Classic (Dunning *et al.* 2006: 92).

In other wetlands on the other hand, climatic conditions seem to have been worse than today. Soil samples from the Bajo el Laberinto dated to 550 BC even indicate the existence of a shallow, gypsous salt lake (Gunn *et al.* 2002a: 313). Such an environment would have almost certainly been unfit for agricultural use (Dunning *et al.* 2006: 88). Today's landscape also features comparable salt lakes (Dunning *et al.* 2006: 88). One example is the Lago Salpetén, which probably provided similarly poor living conditions in the past as it does today (Brenner 1994: 377-378; Gunn *et al.* 2002a: 313).

According to Cowgill and Hutchinson (1963: 30), investigations within the Bajo de Santa Fe did not produce any indications that these wetlands would have once been pools of standing water (Seefeld 2008: 96).[49] Consequently, it cannot be claimed that today's seasonal bajos would have suffered less from water scarcity or possessed better soils in the past (Dunning *et al.* 2006: 90). Although Beach *et al.* (2009: 1713) argued that "many" bajos originally represented perennial wetlands, examples for the conversion of permanent wetlands into seasonal wetlands could only be documented in three cases: La Milpa (Dunning and Beach 2000: 193), the Bajo Donato (see Figure 4.6), and the Bajo Majanche (Beach *et al.* 2008: Figure 6) near San Bartolo (Beach *et al.* 2009: 1713; Castañeda Salguero 1995; Jacob 1995; Dunning *et al.* 2002, 2006, Métailié *et al.* 2003):

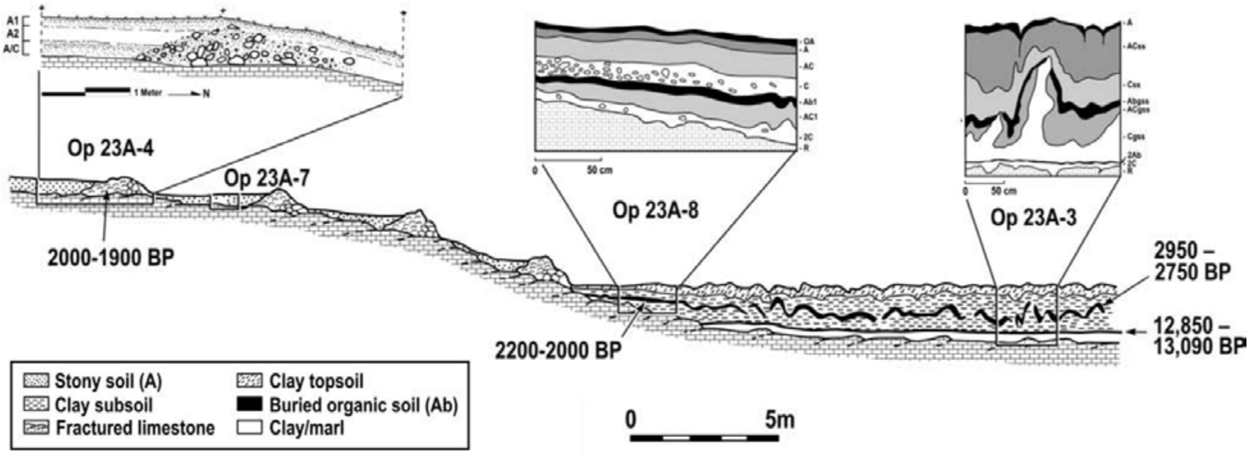

Figure 4.6: Bajo Donato, Soil profile indicating the presence of paleosols (source: Beach *et al.* 2009: Figure 3). Reproduced with kind permission of Timothy Beach and Elsevier.

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[46] Investigations indicate that the Far West Bajo was a perennial wetland during the Protoclassic (*c.* 150 AD) (Dunning *et al.* 1999, 2000; Kunen 2001: 342; Scarborough 2006: 229; Scarborough and Valdez 2003: 11).

[47] Within the Bajo La Justa, a herbaceous vegetation could be identified, which, according to Dunning *et al.*'s (2006: 87) belief, is an indicator for perennial wetlands with cattails and sawgrasses.

[48] According to Turner and Harrison (1983b: 251), findings of mollusks indicate that this outer bajo had been permanently filled with water during the Late Classic Period.

[49] To the contrary, Hansen *et al.* (2002: 288) devoutly believe in more humid conditions.

In Drainage 3 of La Milpa (see also Chapter 5.7.9.1), Dunning and Beach (2000: 193) documented a buried, peaty soil horizon of the Preclassic containing pollen from wetland and lake plants. According to Dunning and Beach (2000: 193), the buried layer of soil proved that the current bajo originally would have been a shallow lake, which was later filled up with eroded sediment (Dunning 1999). The presence of such singular findings demonstrates once more that the microtopography and, in some circumstances, also the microclimatic conditions would have played an important part for the availability of water (Seefeld 2008: 96). As Beach *et al.* (2009: 1722) correctly emphasize, "the few available studies on inner bajos do not allow to characterize the region's complicated hydrology, ecology, cultural history and geology" as these issues would require a more thorough consideration in future investigations.

According to Dunning *et al.* (2006: 98), today's ecologic conditions do not facilitate reliable inferences into the past. Moreover, he and his colleagues also stressed that it is still unclear as to the extent that purely climatic processes were responsible for these transformations (Dunning *et al.* 2006: 97). Leyden *et al.* (2002: 98) on the other hand highlight that the research results clearly demonstrate the human capability to cause dramatic transformations of their environment (Seefeld 2008: 97). In a similar manner, Shaw (2003: 161) believes that all regional transformations of the climate are caused by the cumulative effects of earlier changes in surface precipitation. Beach *et al.* (2009: 1714) emphasize that inner bajo landscapes were apparently closely tied to demographic developments. In a few cases, sediment deposits in bajos indicated flooding events that most likely took place during major hurricanes (Beach *et al.* 2009: 1714). These observations indicate that the pre-Hispanic Maya suffered from climatic conditions similar to those the current Maya experience.

So far scholars have not observed inner bajos featuring layers of clay thicker than those of the outer bajos (Seefeld 2008: 95). Consequently, Turner and Harrison's (1983b: 265) hypothesis that canal systems once existed, but could no longer be documented due to strong overlap with "Maya clay" must be regarded as disproved (Seefeld 2008: 95). This conclusion should not exclude the fact that future archaeological investigations in inner bajos may still document canal features buried under Maya clay. However, without explicit proof it has to be stated that canal systems were apparently not built within seasonal wetlands (Seefeld 2008: 95). Moreover, it should also be pointed out that according to Siemens (1982: 210), the sedimentation of swamps can be partially explained by natural factors (Seefeld 2008: 98). According to Richard's (1966: 283) findings, it is typical that swamps are continuously, but irregularly filled with sediment in a process called *Verlandung* (Seefeld 2008: 98). The fact that aquatic plants impede the movement of water accelerates the deposition of sediments (Richards 1966: 283). The plants also consolidate sediments and accumulate detritus (Siemens 1982: 210). This results in forested or at least seasonally dry land (Siemens 1982: 210).[50]

It should be emphasized that wetlands are generally highly dynamic habitats with extremely diverse ecological conditions that change over time (Beach *et al.* 2003; Dunning *et al.* 2006: 84; Pope and Dahlin 1989: 89; Rejmankova *et al.* 1995: 34). Furthermore, the consequences of land use appear to be very different from one region to the next. This issue makes it even more difficult to develop a universal model for the ecological conditions and the usage of wetlands in pre-Hispanic times (Turner and Harrison 1983b: 251). However, Dunning *et al.* (2006: 96) believe that the hydrological conditions of some bajos changed in such a way as to simultaneously advantage and disadvantage the Maya (Seefeld 2008: 98).

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[50] Clues for such *Verlandung* processes seem to emerge in the Mirador Basin. Hansen *et al.* (2002: 279) observed that the current flora within the vegetation-covered bajos is in the process of replacing these perennial wetlands. They interpreted this observation in the form of a prospective climate model, as an indication of a current transformation from marsh to forest, which they attributed to the sedimentation of civales (Hansen *et al.* 2002: 278, with fig. 8; Siemens 1978: 143).

4.4.3 Theory 3: Droughts as catalysts for the collapse of Classic Maya civilization

The end of this chapter appears to be an appropriate place to comment on the popular hypothesis that cycles of extreme drought were responsible for the collapse of the Classic Maya society. In general, the amount and the density of paleoclimatic data is still too limited to make a definite statement on this highly complex issue. It is commonly acknowledged that the Maya had to adjust to both annually changing patterns of rainfall and climatic periods lasting several decades (Akpinar 2011: 14; Brenner *et al.* 2003; Hodell *et al.* 2001; Mueller *et al.* 2009).

Although some scholars (e.g. Demarest 2004; McAnany and Gallareta Negrón 2010) have previously dismissed the "drought-hypothesis", current researchers are able to refer to a vastly greater amount of paleoclimatic data:[51] Datasets collected with improved research methods all indicate an extensive drought spanning several decades in the mid-ninth century (Lentz *et al.* 2015b: 283). The severity of this drought is also reflected by evidence of drier climates in parts of Mexico, Central America and the Sahel-zone during this time (Akpinar 2011: 14; Beach *et al.* 2008; Hodell *et al.* 2001; Stahle *et al.* 2011). In many areas of the Maya Lowlands, this period coincides with the abandonment of the urban centers (Houston *et al.* 2010; Lentz *et al.* 2015b: 283).

Despite these readily apparent analogies, it should be kept in mind that the political collapse of Classic Period Maya society was the cumulative result of social and political processes over several centuries (Golden and Scherer 2012: 74). Therefore, environmental changes should only be considered an additional factor that would have aggravated previously existing political problems (Golden and Scherer 2012: 74). According to Stahle *et al.* (2011: 3), droughts played a rather "contentious" role in the collapse of Classic Maya civilization and could not explain the complex chronology of regional cultural changes identified in the archaeological records during the Late and Terminal Classic (Demarest *et al.* 2004). As Golden and Scherer (2012: 72) pointed out, a drop in precipitation rates does not necessarily cause the decline of agriculture. In order to support this objection, they refer to the fact that while maize and beans require 500 mm of precipitation during the growing phase, they can also be grown with as little as 150 mm at a reduced harvest (Gentry 1969; 60; Shaw 1988: 6111; Singh 1989: 40).

4.5 Concluding remarks

Three central aspects of the presented paleoclimatic studies are of special importance for the research question of this study:

(1) The deposition of highland sediments ("Maya Clay"), primarily during the Preclassic.

(2) The occurrence of severe droughts at the end of the Late Preclassic and the end of the Late Classic, and

(3) The understanding that climatic conditions during the Late Classic were either comparable, or drier than today.

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[51] The prevalence of extended drought cycles was recently also supported by new data sets based on speleothem data (e.g. Kennett *et al.* 2012; Medina-Elizalde *et al.* 2010).

(1) Widespread deposition of highland sediments ("Maya clay")

Archaeological excavations of surface depressions of the Maya Lowlands revealed that highland sediments were subject to widespread erosion, particularly during the Preclassic, with some areas continuing into the Late Classic (Seefeld 2008: 97). All datasets indicate that this erosion was caused by the widespread deforestation of the landscape through extensive cultivation (Beach *et al.* 2009). This finding is of particular relevance for the topic of this dissertation as it proves that the pre-Hispanic Maya were able to cause drastic transformations to the natural landscape, which apparently triggered the development of specific adaptation strategies in later periods (Leyden *et al.* 2002: 98; Shaw 2003: 161).

(2) Occurrence of severe droughts at the end of the Late Preclassic and the Terminal Classic

With our current understanding, most scholars agree that the pre-Hispanic Maya were affected by pronounced cycles of drought at the end of the Middle Preclassic (475-250 BC), during the Late Preclassic (AD 25-210), and in the Terminal Classic (AD 800-1000) (Akpinar 2011: 14; Beach *et al.* 2003; Brenner *et al.* 2003; Curtis *et al.* 1998; Gunn *et al.* 2002: 298; Hodell *et al.* 2001; Lentz *et al.* 2015b: 283; Mueller *et al.* 2009; Shaw 2003: 160; Wahl *et al.* 2008). The extended drought of the Terminal Classic is even reflected in dendrochronology data (Stahle *et al.* 2011). Although the effects of these extreme droughts for the development of Classic Maya civilization are still under debate, they do coincide quite precisely with the social and political transformations that took place during these periods (Beach *et al.* 2015b: 279; Gill 2000; Hansen *et al.* 2002: 278; Leyden *et al.* 1998).

(3) The understanding that the climatic conditions during the Late Classic were comparable to today

In this dissertation, the most essential realization is undoubtedly that the climate conditions during the Late Classic, the period of the highest demographic stress, are comparable to contemporary climatic conditions (Beach *et al.* 2003, 2009; Gunn *et al.* 2002: 298; Shaw 2003: 160). Furthermore, Beach *et al.* (2015b: 279) highlighted that the periods of drought during the Late Classic did not form any general pattern. Thus, they only would have had consequences on a regional level (Beach *et al.* 2015b: 279). The resulting scenario indicates that the task of supplying water within the Central Maya Lowlands during the Late Classic held similar challenges to today (Dunning *et al.* 2006: 85). In order to found, extend and maintain permanent settlements despite these challenges, the pre-Hispanic Maya were consequently forced to invent adaptation strategies and establish artificial water sources. The physical remains of these adaptation strategies are the hydraulic features of the Maya Lowlands, the topic of the upcoming chapter.

5 Review of hydraulic features in the Maya Lowlands

The following review attempts to explain of the functionality, technical design and geographic distribution of the different forms of hydraulic features. In order to achieve this, the author processed the available publications on hydraulic features in the Maya Lowlands and developed a comparative overview. As pointed out in Chapter 1, this dissertation analyzes the published hydraulic features with three different approaches (see Figure 5.1). The following chapter will only analyze the first approach: the technical design and functionality of hydraulic features. The two higher levels of interpretation are presented and discussed in Chapter 8. Before presenting the particular form of hydraulic features in great detail, the upcoming section first provides a general definition of water management in the literature.

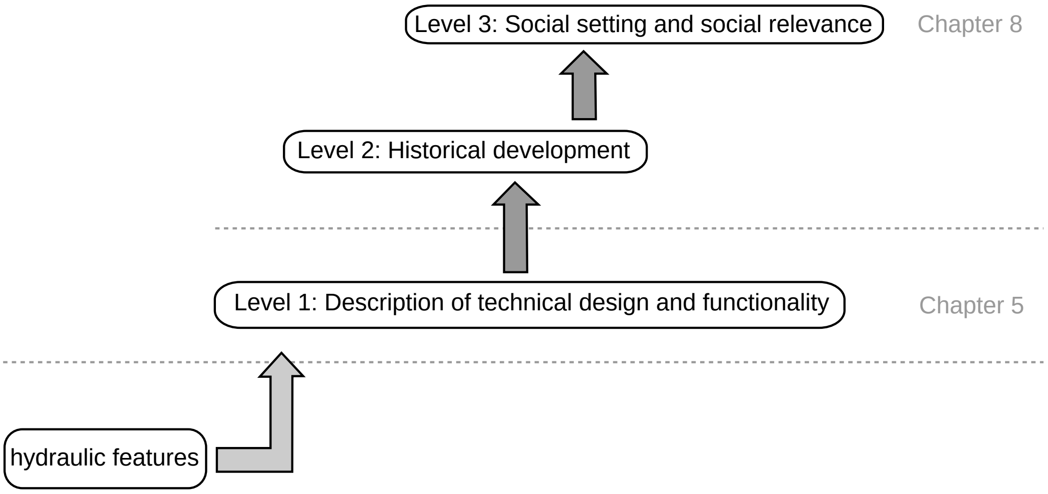

Figure 5.1: Schematic representation of the analysis of hydraulic features.

5.1 Specific technical requirements for hydraulic features in the Maya Lowlands

5.1.1 Definition of water management

Although several scholars have developed various definitions of water management for specific applications,[52] the author follows Brewer's definition, who defines it as "the collection, interruption and redirection of water and water flow by society" (Brewer 2007: 1). This collection, interruption and redirection of water was achieved through the implementation of hydraulic features.[53] As Ray Matheny (1978: 185-186) correctly emphasized, the hydraulic features of the pre-Hispanic Maya do not only refer to "reservoirs, canals and drains, but also to terraces, raised fields, including *chinampas*, embankments, garden beds and other constructions designed to alter the normal flow of water in soil". In the author's opinion, this early definition is still very adequate because it covers all constructions that alter the normal flow of water including those with a potential agricultural purpose.

5.1.2 Technical requirements for a constant water supply in the Maya Lowlands

Because the pre-Hispanic Maya were able to survive and flourish for several centuries in the Central Lowlands, they had evidently developed effective strategies to ensure water supply (Seefeld 2013a: 60). However, in addition to the geological and climatic factors concerning water scarcity (see Chapter 2), access to sources of water was further complicated by a number of ecological and cultural factors.

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[52] Thus, Harrison (1993) defined two major functions for Maya water management:
1) The collection and storage of water for daily use, consumption and household uses, and
2) The usage of water for intensified agriculture (Brewer 2007: 1; Scarborough 1991, 2003: 78).

[53] Definition: Landscape modifications or constructions for the storage, transport and/or redistribution of water which are either visible in the landscape or can be identified by means of archaeological methods (see Chapter 1).

5.1.2.1 Challenges for a constant supply of water in the Maya Lowlands

Typically, the tropics have a high level of biodiversity, but low concentrations of single species in a particular area (Chmilar 2005: 5; Scarborough 2000, 2003). In this respect, the pre-Hispanic Maya had to cope with very different challenges in comparison to most early societies in the Old World. In addition to this low concentration of single species and the restraints of the landscape presented in Chapter 2, the tasks of agricultural production and water supply were further complicated by the fact that this habitat was lacking animals that could be used as beasts of burden (Seefeld 2013a: 61). Furthermore, the Maya never used wheels. Due to these additional restraints, water could not be transported over long distances since all loads needed to be carried by human carriers (Seefeld 2013: 60). For trading lighter goods, such as jade, obsidian, and even food crops, transport by human carriers was demonstrably practiced (see Figures 5.2a and 5.2b), even over great distances (Drennan 1994: 210; Lentz *et al.* 2015b: 283; Pyburn 1998; Tourtellot and Sabloff 1972: 132; Webster 2002).[54]

a) Calakmul, Chihk Naab, Wall painting of bearer, Photo

b) Calakmul, Chihk Naab, Wall painting of bearer, Drawing

Figure 5.2: Calakmul, Chihk Naab, Structure 1-Sub. 1-4, Wall painting of bearer. The depicted bearer is carrying a large pot and a rope-tied bundle, which he bears with a tumpline over the forehead (source: Carrasco Vargas *et al.* 2012: Figure 3). Reproduced with kind permission of Simon Martin and Precolumbia Mesoweb Press.

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[54] Lentz *et al.* (2015b: 283) however, correctly emphasized that even under perfect conditions, food imports by human carriers would have been impossible to maintain for longer periods of time (Drennan 1984; Webster 2002). In this context, Gill (2000: 79) also reasoned that in times of drought, the import of foodstores would have been impossible as the carriers would have been "overwhelmed by famished inhabitants along the way" (Lentz *et al.* 2015b: 283).

In contrast, the import of water would have quickly become inefficient after a few kilometers, because the carriers had to consume considerable amounts of the transported water themselves (Drennan 1985: 891). Therefore, water imports from sources further than a few kilometers from the settlement center would have become ineffective (Seefeld 2013: 61). The applicability of this rule of thumb becomes apparent in an account by Bullard (1960), who claimed that the likely maximum distance between aguadas and larger Maya settlements would have been less than 2 km. Furthermore, Ricketson (1933) described that during longer travels in the Maya Lowlands in the dry season, a day's journey would have been 19 to 24 km, or the distance from one aguada to another (Akpinar-Ferrand and Dunning 2011: 117).

Consequently, Maya polities could not be supplied by sources of water from the hinterlands. Accordingly, regional models of water supply, which were developed for the ancient civilizations in the Old World as well as the New World, surely cannot be applied to the Maya civilization (Prasad *et al.* 1987; Scarborough 2003a: 145; Wheeler 1969). In fact, it is the author's opinion that it is mandatory to develop a local model, since the water supply of each settlement inevitably had to be locally guaranteed. Each settlement needed to ensure that the local water sources sufficiently provided for each inhabitant over the entire year (Seefeld 2013a: 61). In order to use the natural landscape effectively, the pre-Hispanic Maya first had to modify it according to their needs and then gain control over the most essential resources (Chmilar 2005: 5; Fedick and Ford 1990; Ford 1990; Tourtellot 1993).

Because the central Maya Lowlands landscape did not feature sufficient surface water (see Chapter 2.1.4), the Maya were scarcely able to practice irrigation water management in the classic sense (Akpinar 2011: 20). Instead, they understood that the key to such a provision lay in the application of rainwater harvesting. Through the usage of the landscape and by collecting some amount of the rainy season downpours, the pre-Hispanic Maya practiced rainwater harvesting and aimed to develop water storage systems for the dry season (Dunning *et al.* 1999: 656; Geovannini Acuña 2008: 87). These landscape modifications and the construction of hydraulic features required time, labor, materials and an essential knowledge of land development (Donkin 1979: 33; Doolittle 1990: 94; Kunen 2001: 327).

Rainwater harvesting aims to collect the maximum amount of precipitation before it drains into the bedrock (Seefeld 2013a: 61). Within the landscape of the Central Maya Lowlands, the pre-Hispanic Maya therefore had to make use of natural surface depressions and extend their natural surface area. For this purpose, they would artificially increase the capacity of existing natural aguadas and alter the course of seasonal streams (*corrientales*) (Scarborough *et al.* 1995: 100). Essentially, rainwater harvesting involved landscape modifications on varying scales. Artificial reservoirs could be created either through increasing the size or impermeability of natural depressions or through more labor intensive constructions of new reservoirs (Seefeld 2013a: 61). Over several centuries, the pre-Hispanic Maya transformed the landscape in such a way that it had a much higher carrying capacity than what is observable today (Akpinar 2011: 20; Scarborough 1995). Furthermore, the increased interest in the water management practices of the pre-Hispanic Maya resulted in the documentation of numerous new hydraulic features, which showed that they were highly diverse and in each case adapted to the particular local topographic conditions of a specific site (Akpinar 2011: 19). The self evident application of these techniques was even observed by Fray Diego de Landa, who described that,

> *"those Indians who are living close to the mounds tend to dig cavities into the bedrock, in order to collect precipitation, because of the low-lying groundwater-level"* (de Landa 1993: 155).

The practicality of the local landscape for the creation of an "artificial watershed" was mainly influenced by the surface runoff (Silverstein *et al.* 2009: 50). The surface runoff is based on several factors including the amount, intensity and duration of rainfall, the slope gradient of the respective catchment basin, the evapotranspiration, infiltration, the seepage and extension of the catchment area above the slope, percolation and soil piping (Carson and Kirkby 1972; Silverstein *et al.* 2009: 50; White 1988: 149-172).

In order to quantifiably estimate the effectiveness of these landscape modifications, some scholars attempted to determine the storage capacity of archaeologically documented hydraulic features. In doing so, they sought to determine the number of people that these features could supply. This endeavor led to the reconstruction of daily water consumption in the pre-Hispanic Maya Lowlands – a process described in detail below.

5.1.2.1.1 Calculation of daily water consumption

Over the last two decades, several scholars have suggested very different assumptions on the daily requirements of water in pre-Hispanic times (Beach *et al.* 2015b: 276). The estimations per (adult) person ranged between:

1.9 liters (Brewer 2007; Akpinar-Ferrand *et al.* 2012).

2 to 3 liters (White *et al.* 1972: 252).

2.4-4.8 liters (McAnany 1990: 269).

4.8 liters (Weiss-Krejci and Sabbas 2002: 354), and

2 to 5 liters (Beach *et al.* 2015b: 276).

As Maldonado *et al.* (2012: 51) emphasized, urban centers did not only require water for consumption, but also for the preparation of mortar during the construction of architectonic structures. Furthermore, Beach *et al.* (2015b: 276) correctly asserted that most calculations do not consider the required water for cooking, washing, bathing, irrigation and rituals. Due to the economic and social importance of irrigation agriculture, this process required a number of technological adaptations.

5.1.2.2 Technical requirements for agricultural production

As is widely known, plant growth depends on a combination of sufficient but not excessive amounts of insolation, heat, carbon dioxide, soil nutrients, space, time and moisture (Downing 1974: 113; Parry 2007: 22). Depending on the specific geographic conditions, systems of intensified agriculture attempt to increase the agricultural production and/or extend cultivation into naturally "marginal", "infertile" or generally unsuitable areas by means of landscape modifications (Kunen 2001: 327). As the nutrient content of soils reduces over time due to cultivation, a central purpose of agricultural intensification was the protection of the agricultural potential of existing acreages (Turner 1979: 106). This purpose led to the development of strategies for pest and weed control[55] (1), forms of fertilization (2) and, most notably installations for the detention and/or redistribution of water (3) [hydraulic features] (Scarborough *et al.* 1995: 99).

Although the Maya apparently seemed to possess some understanding of pest control (Gliessman *et al.* 1981: 182), and may have even practiced composting in house gardens during the Classic Period (Turner 1983b: 49), biological additives were apparently not applied at any noteworthy extent (Scarborough *et al.* 1995: 99). In most of the studied prehistoric features for intensified cultivation, the majority concentrated on soil moisture.

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[55] In this context Reina and Hill (1980: 77) stressed that maize, for example, when not stored and conserved adequately is destroyed by insects within three months.

For effective irrigation agriculture, runoff had to be diverted during heavy rainfall throughout the rainy season, while during the dry season, an adequate water content of the soils had to be maintained (Kunen 2001: 326). Consequently, the consideration of drainage patterns and the general microtopography was essential during the selection of acreages (Wilk 1985: 48). If the pre-Hispanic Maya managed to apply the right amount of water to the field at the right time, they could increase the plant growth dramatically (Lohse and Findlay 2000: 177). The possibility of controlling the soil moisture was hence a central element for a successful intensified agricultural system of any size[56] (Lohse and Findlay 2000) and required different forms of hydraulic constructions for the detention and diversion of water. The most effective forms of intensive agricultural production in the pre-Hispanic Maya Lowlands were elevated fields (see Chapter 5.2) and terrace systems (see Chapter 5.3), both of which implied large amounts of labor and planning (Beach *et al.* 2002, 2008, 2009, 2015a: 20). In order to illustrate the different technological approaches the Maya applied to ensure a constant supply of water and/or intensified agriculture in their particular living environments, the following section explains the different types of hydraulic features.

5.1.3 Technical approaches for water management in the Maya Lowlands

The wide range of hydraulic features that have been described or published so far can be subdivided into five different categories based on their structural composition and desired function:

- Canals (Chapter 5.2),

- Terrace complexes (Chapter 5.3),

- Dam systems (Chapter 5.4),

- Drainage features (Chapter 5.5), and

- Reservoirs (Chapter 5.6).

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[56] Consequently, a consideration of the drainage and the microtopography was essential during the selection of a field for the dry seasons (Wilk 1985: 48).

5.2 Canals

Since the development of Karl Wittfogel's (1957) theory of hydraulic societies (see Chapters 3 and 8.2.2), canals have been considered one of the most important indicators for the identification of complex societies. Due to the theoretical and ideological importance of this research question, controversy developed during the 1970s and 1980s as to whether or not canal systems existed in the Maya Lowlands. Of all features indicating the existence of agricultural intensification, canals were therefore studied most intensively (Healy *et al.* 1983: 399).

5.2.1 Functions of canal systems

In the past, many scholars developed various theories on the development and function of canal systems. In general though, they be can summarized into three main theses (Jacob 1995b: 184):

(1) Natural landscape formations without any traces of human modification,

(2) Results of human construction projects, and

(3) Anthropogenic modifications of natural landscape formations.

According to Jacob (1995a: 53; 1995b: 184), the "ubiquity of natural processes" would make it advisable to always assume a natural origin of these landscape features as long as no cogent evidence hints toward an anthropogenic influence.[57] Through the use of aerial photos in the 1970s, many observable patterns in wetlands were identified as networks of fields. However, Puleston (1978: 234) later speculated that these patterns could actually be the result of gilgai formations (Turner and Harrison 183b: 249; see Chapter 2.4.3). According to Puleston, the fissures created through desiccation processes would have filled up with gravel and sediment over time. As soon as these clays swelled due to the return of moisture, bulging and regularly formed surface elevations would have developed and were likely misinterpreted as cultural features (Guderjan *et al.* 2003a; Turner and Harrison 1983a: 3).

However, most scholars argued in favor of the second and/or the third thesis and were convinced that the documented "linear landscape features" represent cultural features or modifications of natural landscape formations. The author is convinced that they are at least cultural modifications of natural features, since natural features rarely reach such regularity in form. According to established theories, the canal features of the Maya Lowlands served either as water transportation routes (1), fish farming tanks (2), or devices for intensified agriculture (3).

(1) Interpretation as water transport routes

Due to their considerable width and length, many scholars interpreted the documented canal systems as hints for the existence of a pre-Hispanic water transport network that had connected the Central Lowlands to the Caribbean Coast (see Chapter 8.2.2; Guderjan *et al.* 2003a: 88). Siemens and Puleston (1972: 229) noted that such a transport network also would have been useful as an escape route in case of an invasion. The theory promoted by Siemens (1982: 214) stated that such waterways were used for the exploitation of firewood (in this case, *Haematoxylum campechanium*) and other forest products. This led Camara (1984: 325) to the assumption that the majority of the recently rediscovered canals could have also been constructed in historic times in order to harvest *palo de tinto* for export to Europe and for the fabrication of textile fibers (Pope and Dahlin 1989: 99). In order to confirm this theory, Siemens (1982) cited several examples of canal constructions and uses in Campeche's coastal areas (especially Candelaria

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[57] Jacob (1995b: 184): "*In other words, a landform should not automatically be considered anthropogenic until natural causes can be credibly discounted*" (see also Pope *et al.* 1996: 165-166).

and Chumpán) during the 18th and 19th centuries. In a similar manner, Millet (1984) claimed that some of the canals along the Río Candelaria had been constructed in the 19th and 20th centuries in order to extract *Palo de tinto* with canoes (Vargas 2012: 195).

However, this theory was not accepted in the scholarly debate (Pope and Dahlin 1989: 99). Turner and Harrison (1983b: 248) assumed that acreages abandoned after the collapse might have offered a new niche for swamp forests. Over the centuries, these forests would have developed so properly that they would have attracted loggers ranging from colonial times up to the 20th century. It is possible that these loggers would have used the old canals built by the Maya as an access route to the bajos in order to exploit the local tree species (Turner and Harrison 1983b: 248). At the same time, local residents had continued to use the swamps for hunting and fishing (Turner and Harrison 1983a: 248).

(2) Interpretation as artificial fish ponds

Thompson (1974: 298) was the first to publish the hypothesis that the canals of the Candelaria Basin (Campeche) might have been used as fish farms. He came to this conclusion due to these canals being situated in low elevation areas directly connected to rivers that would have become flooded during the rainy season and swampy during the dry season. According to him, these floods would have flushed fish into the canals as well (Siemens 1982: 221). During the retreat of water in the dry season, fish would have searched for refuge in natural, or in this case, artificial bodies of water within the swamps and, according to Thompson (1974: 298), would have been easy to catch. Although Thompson (1974: 300) admitted that some waterways of the region would have been usable for canoe transport, he believed that the majority of them served as fish farms. Puleston (1977a: 456) assumed that the fish excreta added important nutrient content to the canal sediment. In addition, Scarborough (1983a: 741) pointed out that such fish populations might have impeded an excessive expansion of insect populations in such stagnant waters (Cooke 1931: 287). Finally, Thompson (1974: 301) declared these natural and artificial “basins” as a simple solution for the question of subsistence and advocated to give them more attention, since he believed they would have played a central role for local nutrition and maybe even trade (Puleston 1977a: 449). This thesis is supported by the fact that the canals Puleston (1977: 457) made while constructing an experimental elevated field on Albion Island already housed a noteworthy fish population after only four months.

(3) Interpretation as constructions for intensified agriculture

For the problems analyzed in this book, the interpretation of canals as installations for intensified agriculture is doubtlessly of paramount interest. The advocates of intensified wetland cultivation interpreted these elevated surfaces and “linear depressions” as remains of intensified hydraulic cropping systems developed by the Maya in order to improve the relation between harvests, soils and water levels and to extend the cultivation period further into the dry season (Siemens 1982: 221; Turner and Harrison 1983b: 259). Several different approaches were developed in order to classify these canal systems according to the function attributed to them:

At a fundamental level, Scarborough (1991: 113) distinguishes between canals that are either fed by springs, reservoirs or seasonal streams (1) and those fed by permanent rivers (2). This distinction is based upon classification approaches developed for Old World canal systems.

The first form, which Scarborough (1991: 113) also described as “stillwater canalization”, aims to manipulate runoff and to control the seasonally adjusted emptying of filled reservoirs for the purpose of irrigation. For the second form, so-called “running water” canalizations were used in connection with slowly flowing permanent rivers and served as drainages (Scarborough 1991: 114).[58] Due to the geological conditions described in Chapter 2.1.4, the majority of the canal systems documented in the Maya Lowlands constitute stillwater canalizations. Therefore, Scarborough's (1991) differentiation is of minor relevance for Maya archaeology. A more useful approach, on the other hand, is the differentiation between drainage canals and irrigation canals – something far more pertinent to the ongoing discussion (Turner and Harrison 183b: 256). The differentiation between drainage canals (a) and irrigation canals (b) is usually based on the construction of a feature:

(a) Drainage canals were constructed to create drained fields[59] (Culbert *et al.* 1991: 116; Pope and Dahlin 1989: 100). They consist of parallel ditches in fields and served to divert excess water to a lower lying location (Turner and Harrison 1983a: 256). An essential requirement for this technique was for the canals to have a specific inclination. However, such inclinations were rare in the canal constructions of the Maya Lowlands (Culbert *et al.* 1991: 116) (see Figure 5.3).

(b) Irrigation canals are also defined by ditches running parallel to each other. However, they are also marked by perpendicular ditches that result in the characteristic latticed patterns denoted as "raised fields" (Culbert *et al.* 1991: 116; see Figure 5.4). Although most scholars strictly separate drainage canals from irrigation canals/raised fields, the precise technical differentiation is still a matter of debate.

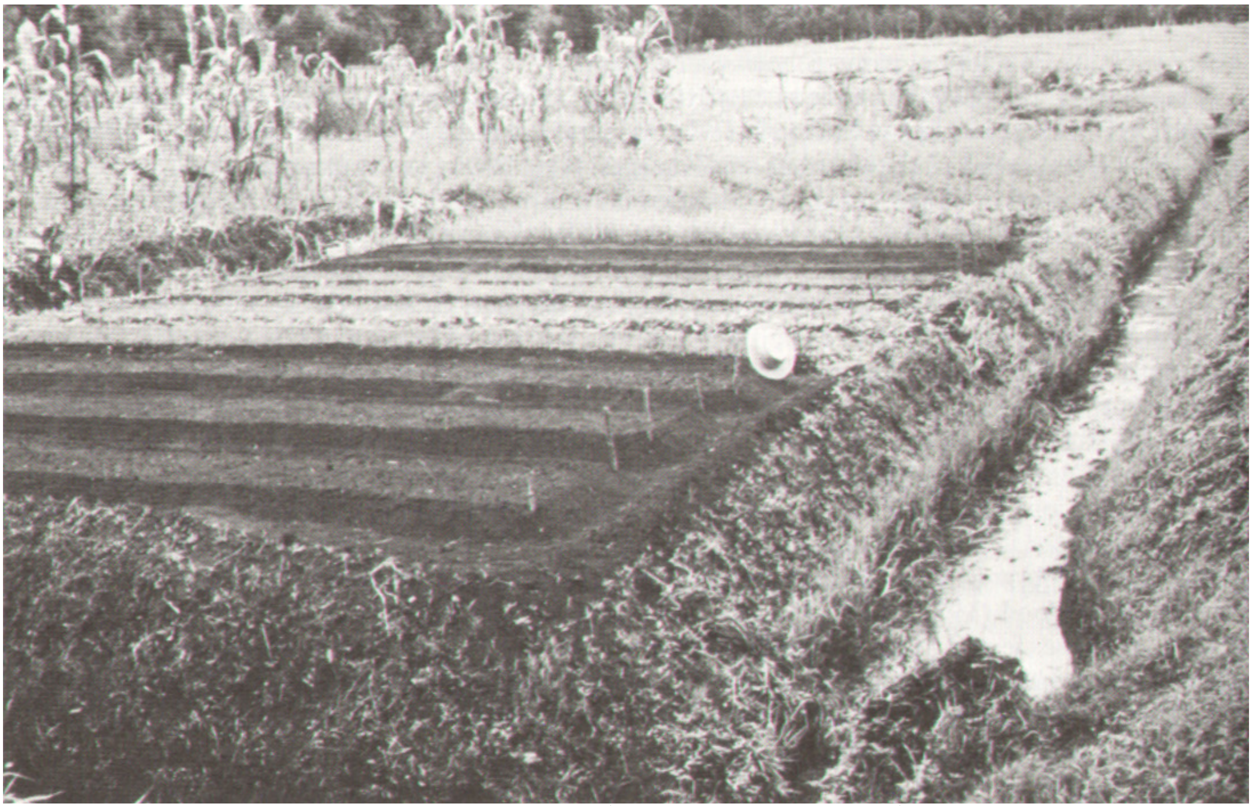

Figure 5.3: Drained fields in the department of Sacatepéquez (source: Wilken 1971: Figure 5). Reproduced with kind permission of Cambridge University Press.

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[58] Scarborough (1991: 114) related the canal system of Pulltrouser Swamp to this type. He also described that the local water-levels of a giant backflow near the New River would have been controlled by floodgates during the Classic Period, serving to lead this water away from the rivers. Interestingly, Scarborough did not describe the exact design of these "floodgates". They are not described by Turner and Harrison (1983a, 1983b) either.

[59] Synonymous terms for drained fields are "channelized fields" and "ditched fields" (Fedick and Ford 1990: 22).

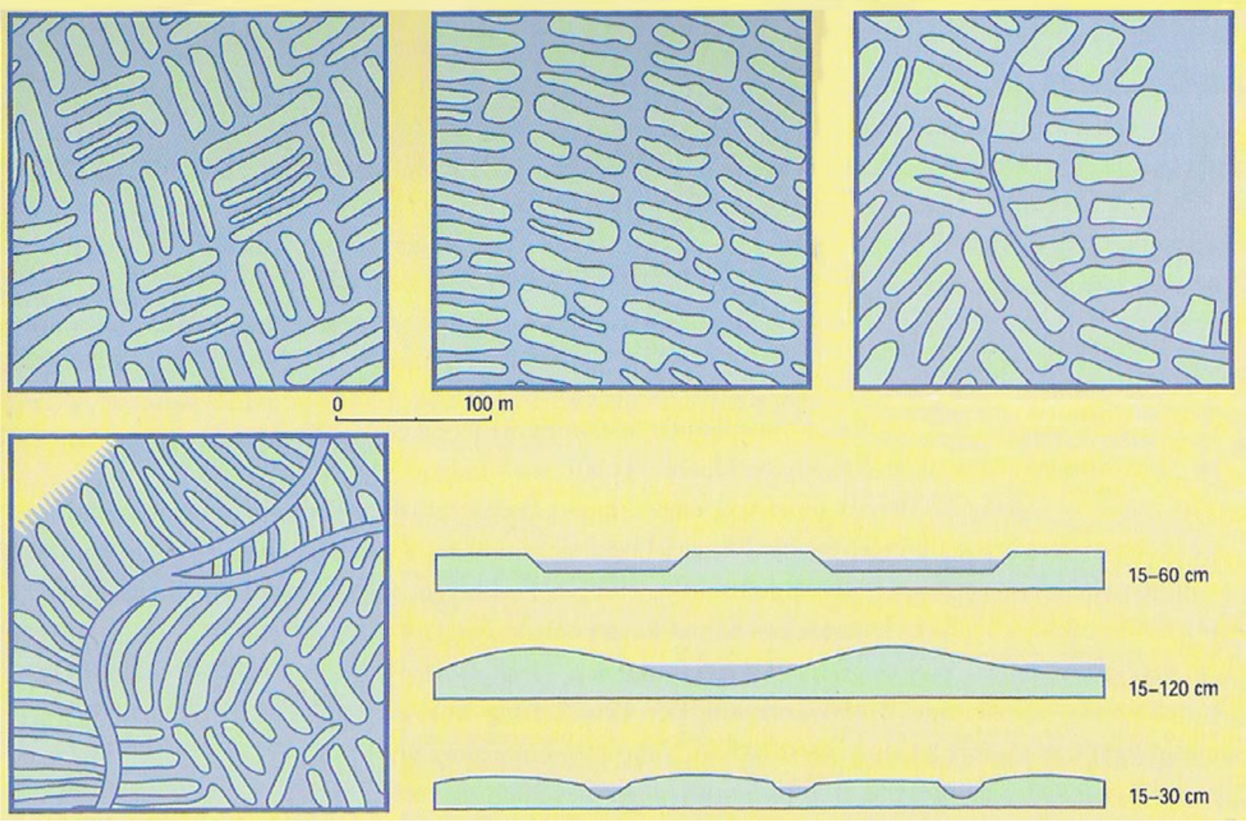

Figure 5.4: Schematic representation of elevated fields (modified from Harrison 2000: 77, Figure 115). Original graphic was produced by Peter Frese. Reproduced with kind permission of Peter Frese.

5.2.2 Design and functionality of canal systems

Physically, the function of a canal is heavily influenced by the inclination and permeability of soils (Scarborough 1991: 113).[60] Therefore, the documentation of consistent canal declination may indicate an intended flow direction (Jacob 1995b: 188). However, measurements such as these have only been carried out in very rare cases. While the precise functionality of particular canal systems is still a matter of debate, the construction of canals has been studied in greater detail.

5.2.2.1 Construction process of canal systems

As Turner and Harrison (1983b: 258) noted, it is generally difficult to determine the planning and construction process of canals. Furthermore, Jacob (1995b: 185) recommended questioning the notion of a purely anthropogenic origin of these features as he believed many features might be modifications of natural landscape features. The extent of these modifications apparently varied to a large degree and could range from widening, straightening or deepening of already existing (possibly natural) canals to the construction of drainage canals or the sophisticated construction of truly elevated fields (Jacob 1995b: 188). Due to lacking data, Turner and Harrison (1983b: 259) referred to ethnographic observations in the highlands of Papua New Guinea where residents managed to construct complex networks of elevated fields with stone tools and baskets (objects that the Classic Maya also possessed).

Owing to the small number of archaeologically documented profiles, it is hard to make reliable or general statements regarding the structural composition of the documented canal systems. As already

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[60] It should be noted that elevated fields may deter easily if they are poorly constructed or affected by extreme weather conditions (Beach *et al.* 2015a: 20).

pointed out in Chapter 3, the potential structural composition of canal systems has been a matter of a controversial debate (Antoine *et al.* 1982: 234; Olson 1974; Puleston 1977a: 455, 1977b, 1978). Nevertheless, some similarities can be identified in the published features: drained fields are more frequently located in the transition zone between bajos and the *tierra firme*, and were therefore constructed by the excavation of canals in the *tierra firme* (Turner and Harrison 1983b: 247). By contrast, elevated fields are commonly situated along the edges of outer bajo habitats (Siemens 1982: 221; Turner 1983b: 45). In most cases, the natural bajo soils were removed prior to the construction of canals so that the underlying sascab (see Chapter 2.3) or bedrock was exposed (Turner 1983b: 46). Afterwards, the canals were apparently dug directly into the underlying sascab, clay or limestone bedrock (see Figure 5.5).[61]

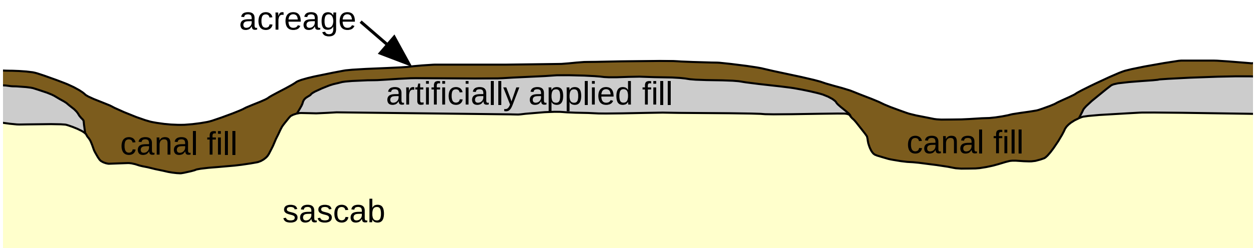

Figure 5.5: Schematic profile of a raised field complex (redrawn after Turner 1983b, Figure 4-9) Reproduced with kind permission of Billie Lee Turner and the University of Texas Press.

In some cases, such as the drainage canals near Río Azul, the canal's inner surface was apparently covered with an intentionally applied clay layer, which would have reduced water seepage and stabilized the lateral walls (Culbert *et al.* 1991: 120). In most cases, these canals were created at the margins of bajos, with the apparent purpose of draining excess water from more elevated acreages into the wetlands (Turner 1983b: 43). Presumably, these procedures would have been sufficient for the creation of a drained field. The construction of elevated fields, which showed a more complex structural composition, would have required more complicated procedures. In addition to the small canals that framed the sides of raised fields in lattice patters, many canal systems included large canals with widths of more than 10 m and lengths spanning several hundred meters (Pope and Dahlin 1989: 93). In some cases, these large canals were constructed in order to connect the large outer bajos with rivers (Pope and Dahlin 1989: 95). From a technological angle, raised fields are defined as a cultivation method marked by the transfer and elevation of soils above the natural terrain or water level of the wetlands (Turner 1983b: 45).[62] These procedures were extremely important as inundations during the rainy seasons would have flooded the acreages and caused the rotting of crops due to stagnant moisture (Siemens 1982: 218). Therefore, it is generally thought that the soil extracted during the excavation of the canals was deposited on their sides in order to form elevated fields (Puleston 1977a: 450; Siemens 1982: 219; Turner 1983b: 46; Turner and Harrison 1983b: 247, Weller 2006: 33). Some scholars suggested that additional materials[63] were applied to these surfaces as well (Siemens 1982: 218).

The few published studies indicate that the surfaces of the raised fields within Pulltrouser Swamp (Turner 1983b: 46) and the Bajo Morocoy (Gliessman *et al.* 1983: 101) once represented 60-65% of their entire respective field networks. Thus, the remaining 35-40% of the surfaces were covered by canals. The height difference between the elevated surfaces of the fields and the seasonally flooded canals can hardly be reconstructed today as the piled up sediments have since eroded and filled the adjacent canals. Turner (1983b: 46) assumed that the maximum height difference between the bottoms of canals and the elevated fields in Pulltrouser Swamp might have added up to more than 2.50 m in some areas. The shape of raised

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[61] This process could be observed in Río Azul (Culbert *et al.* 1991: 119); in the bajos around Yaxhá (Grazioso Sierra *et al.* 2000: 208); within the Bajo Morocoy (Gliessman *et al.* 1983: 101), Cerros (Freidel and Scarborough 1982: 142); Dos Hombres (Lohse and Findlay 2000: 181) and Pulltrouser Swamp (Turner 1983b: 39; see Chapter 5.2.4).

[62] "the transfer and elevation of earth beyond the natural terrain" ... (Denevan and Turner 1974: 24).

[63] For instance, Puleston (1977b: 450) suggested the not-so accepted theory that a base layer of sascab was piled on these platforms. In fact, this theory is not based upon documented features, but rather on Puleston's (1977a: 455) own ideas of a stable design of an elevated field, which he implemented during an experimental construction of such a compound in San Antonio/Albion Island, Belize (Antoine *et al.* 1982: 288; Puleston 1977a: 456).

fields can greatly vary: They range from irregular forms such as those in Cawak, to cobweb forms, such as those in Cobweb Swamp (Jacob 1995) and Chan Cahal, to rectangular forms, such as those at Birds of Paradise (Beach *et al.* 2015a: 13).

5.2.2.2 Theories on the functionality of canal systems

In general, most scholars tend to identify the documented canal systems as elevated fields (Culbert *et al.* 1991: 116). Due to this circumstance, there are disproportionately more theories on the functionality of elevated fields than on the more "simple" and less productive drained fields.

5.2.2.2.1 Drainage canals

Jacob (1992: 87, 1995b: 188) remarked that within very clayey soils, drainage canals need to be constructed more closely to one another than in normal soils due to the lower hydraulic conductivity. For this reason, an effective distribution of drainage canals would have played a very important part (Trafford 1975: 336). With this in mind, Jacob (1995: 188) calculated that drainage canals built with distances of more than 8-10 meters between them would not have been effective in the successful drainage of the clay varieties of outer bajos (Smedema and Rycroft 1983: 78). In some cases, modern inundations of areas classified as drained fields indicated that drainage canals with the precipitation rates of today could not have entirely impeded the flooding of acreages.[64] However, Culbert *et al.* (1991: 122) remarked that a total drainage might not have even been necessary, since the bajos near Río Azul, for example, would have been free of water during nine months of the year anyway. From this observation, they deduced that these drainage canals might have served to extend the cultivation period of these seasonally inundated areas. Pope and Dahlin (1989: 100) speculated that even these subtle artificial prolongations of the dry periods both before and after it might have enabled two harvests per year (Siemens 1982: 221; Turner and Harrison 193b: 259). Furthermore, the periodic inundations would have prevented an excessive dispersal of grasses and insects and provided acreages with eutrophic sediments (Culbert *et al.* 1991: 122).

Jacob (1995:b: 188) went even further and promoted the idea that even simple canals (drainage canals) would have enabled irrigation during the dry season. To this end, the pre-Hispanic Maya only would have needed to deepen the canals in order to adjust them to the lower water table of the permanent wetlands. With such a layout, irrigation might have been realized through "subirrigation" (capillary action causing water to rise to the root zone) or through forms of surface irrigation, such as calabash "splash irrigation" or "pot irrigation", as it was practiced in the Highlands of Guatemala until the 1970s (Jacob 1995b: 188; Wilken 1987; see Figure 5.6).

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[64] According to statements of local informants, the compounds of drained fields along the Río Candelaria were completely inundated during the rainy season (Siemens and Puleston 1972: 233). Culbert *et al.* (1991: 122) made similar observations in the Bajo Pedernal near Río Azul and Jacob (1995b: 188) also observed this in the Cobweb Swamp near Colha.

Figure 5.6: Splashwater irrigation with calabashes in the Guatemalan Highlands (Photo: Kent Mathewson). Originally published by Denevan (1982: Figure 4). Reproduced with kind permission of Kent Mathewson.

5.2.2.2.2 Elevated fields

Commonly, elevated fields are considered the most productive form of wetland agriculture[65] and have therefore been subject to far more detailed studies and publications (Culbert *et al.* 1991: 116) than drainage canals. Providing that the canals had been filled with water year-round, permanent cultivation of the fields would have been possible, and, theoretically, one could have bred fish in the canals simultaneously (Thompson 1974: 298; Turner 1983: 50). Although only few studies were carried out concerning the productivity of wetland fields in the past, Jacob (1995b: 117) claimed that the natural fertility of most wetland soils (Jou and Hossner 1992: 161) would leave little reason to doubt their productivity. At the same time, elevated fields also represent the most labor-intensive wetland modification, since the excavated trenches were continuously silted by washed-in sediments (Matheny 1978: 204; Siemens 1982: 223). If maintenance operations are neglected, sediments may accumulate and disturb the flow of water, which could have resulted in flawed drainage and ultimately the rotting of roots (Scarborough 1991: 119). Based on ethnographic observations, numerous scholars (e.g. Antoine *et al.* 1982: 234) remarked that these washed-in sediments could be placed directly on the fields as fertilizers (Lambert and Arnason 1983: 118; Siemens 1982: 219). Another reason for the labor-intensive maintenance of these cultivation systems was the risk of destruction by the annually recurring rainfall (Gómez-Pompa *et al.* 1982). However, they were frequently the only option since cultivation without the construction of elevated fields would not have been possible in permanently flooded areas (Culbert *et al.* 1991: 116).

The exact function of elevated fields is still a matter of debate. As already mentioned, a central problem in the investigation lies in the fact that almost all of the documented canal systems are usually designated as elevated fields in a rather undifferentiated manner (presumably due to the agricultural potential ascribed to them) (Culbert *et al.* 1991: 116). Due to this circumstance, the classification of a ditch as a drainage-canal or irrigation canal is unfortunately determined quite subjectively (Siemens *et al.* 2002: 120). Therefore, the author agrees with Siemens *et al.* (2002: 120), who noted that it is generally difficult to determine the exact function of a specific canal system. As mentioned above, most scholars believe that elevated fields were irrigated by a grid of smaller canals. On the other hand, Turner and Harrison (1983a: 3, 1983b: 256) supposed that canals appearing in conjunction with elevated fields could perform the function of both drainage and irrigation. This would have enabled the manipulation of the water levels within the canals for the water supply of the field surfaces and the root zone.

In order to determine the function of a canal, the most important indicator is its inclination. Even though only few authors make any statements as to the inclination of the canals they document, it still becomes apparent that the majority of the canals documented within the Maya Lowlands present a surprisingly low deviation (Scarborough 1983a: 737). Due to this fact, especially during the rainy season, it would have been quite difficult to find non-inundated areas to which one could have diverted the excess water (Siemens 1982: 219; Siemens *et al.* 2002: 120; Turner and Harrison 1983b: 256). These observations led Siemens *et al.* (2002: 120) to the belief that many canal features might have also had water retention functions due to seasonal changes and the highly varying precipitation rates.[66] It is therefore quite plausible that many of the published canal systems fulfilled drainage, irrigation or water retention functions according to seasonal or more long-term climatic variations. Consequently, they could have fulfilled and combined all of these three functions and may have been used for a variety of agricultural purposes as well (Jacob 1995b: 188; Siemens *et al.* 2002: 120; Turner and Harrison 1983a: 3, 1983b: 257).[67] In the author's opinion, canal systems could therefore be classified as constructions that counterbalanced the strongest effects of water scarcity and water excess according to the respective season.

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[65] Turner and Harrison (1983b: 260, Table 13-2) estimated that the approximately 311 ha acreage of Pulltrouser Swamp might have supported more than 3,500 persons according to a "conservative estimate". They referred to calculations by Sanders (1976: 147, Table 10), who estimated that the chinampa cultivation of Mexico (an agricultural system which, according to the opinion of the advocates of an intensive wetland cultivation, worked similar to those of elevated fields) had resulted in an annual maize harvest of 3,000 kg per hectare, with each hectare able to feed 199 persons.

[66] As will become obvious in the description of published canal features, functions such as "water-retention" have already been observed on several occasions (Freidel and Scarborough 1982). Scarborough (1983b: 725) also assumed that the canal system of Cerros served another function in the rainy season than in the dry season.

[67] Such functionality can be observed in the canals of the hydraulic system of Edzná (Gunn *et al.* 2002: 298).

As some pollen samples indicate, the same plant species had been cultivated on both drained and elevated fields. Besides, Lambert and Arnason (1983: 257) and Siemens (1989: 73) noted that some plants in the Maya Lowlands thrive not only in the dry season, but during seasonal inundations as well. These species include: Maize (*Zea mays*), beans, cocoyam (*Xanthasoma sagittifolium*), cassava (*Manihot esculenta*), canna (*Canna edulis*) and cacao (*Theobroma).* Although it has been frequently suggested that elevated fields were used for the cultivation of cacao (Dahlin 1979: 80; Siemens 1989: 73), no actual proof of cultivation has been published so far. In most studies, only maize could be verified (Puleston 1977a: 451; Turner 1983a: 48). Along with this, some scholars documented sporadic evidence for cotton (*Gossypium*) and amaranth (*Amaranthus*) (Puleston 1977a: 453; Turner and Harrison 1983b: 258).

5.2.3 Geographic distribution of canal systems

As the mapping of the canal systems clearly illustrates, all of the published features are concentrated around outer bajos and permanent streams (see Figure 5.7). As already mentioned in Chapter 3, the existence of agricultural canal systems in the Petén, which several scholars had observed in SAR imagery, have never been confirmed by ground inspections (Adams *et al.* 1981: 1457; Harrison 1977: Puleston 1978; Siemens 1978; Turner 1974, 1978, 1979; Turner and Harrison 1981). Despite numerous studies (Adams 1993: 393; Adams *et al.* 1990: 241; Dahlin 1979; Puleston 1978), not a single verified canal system has been documented and published within inner bajos so far (Culbert *et al.* 1991: 122; Dunning *et al.* 2006: 91; Siemens 1982: 207). Nevertheless, numerous scholars have continuously reported on observations of such features. However, all the information concerning potential canal systems in inner bajos are based upon unverified descriptions of such installations.[68]

At the current state of research, the verified existence of canals for intensified agriculture could only be documented in the wetlands of northern Belize, southern Quintana Roo, along the Usumacinta River and in the basin of the Candelaria River (Beach *et al.* 2015a: 13; Liendo-Stuarto 1999; Pope and Dahlin 1989: 100; Turner and Harrison 1983b: 249; see Figure 5.7). In order to provide a better understanding of the technical layout and the functionality of these verified canal systems, the upcoming chapter will present a detailed description of these published features and their integration into the respective settlement landscape.

5.2.4 Published canal features from the Maya Lowlands

Due to the problems determining the function of canal systems being largely ambiguous, all of the documented canal features are presented in a single group.

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[68] Thus, Weller (2006: 33) claimed to have identified remains of elevated fields within the Bajo La Justa and the Bajo de Santa Fe on Landsat satellite images. Fialko (1999: 688) likewise described drainage canals in the Bajo Zocotzal and the Bajo Ixtinto, 10 km to the southeast of Tikal, which would have drained fields and diverted water into adjacent aguadas. Grazioso Sierra *et al.* (2000: 208) reported canal structures near Yaxha. Gunn *et al.* (2002: 300) identified elevated fields at the border of the Bajo El Laberinto near Calakmul during the examination of satellite images. Unfortunately, all of this information is not traceable, since the Landsat images mentioned by Gunn *et al.* (2002: 300), Fialko 1999: 688) and Weller (2006: 33) have never been published. Apart from that, no mappings or results of field documentations (survey, profile drawings, etc.) have been presented. According to some advocates of intensive wetland cultivation, this allocation is caused by the fact that the canal features of the inner bajos had been too heavily covered with sediments due to drastic erosion processes to be visible today (Scarborough and Valdez 2003: 12; Weller 2006: 34). However, as demonstrated in Chapter 4.4, the current state of research does not support the hypothesis that erosion processes would have caused a widespread destruction and/or obliteration of canal features in the Petén.

Figure 5.7: Geographic distribution of canals in the Maya Lowlands (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

5.2.4.1 El Tigre

In 1968, prehistoric drained fields and canals were observed during a flight along the Río Candelaria in Campeche near the site of El Tigre[69] (Siemens and Puleston 1972: 228). In the north, the settlement of El Tigre was delimited by the Río Candelaria, to the west and east by bajos,[70] and to the south by the Laguna del Patio.[71] A ground inspection indicated that these fields had been used for intensive cultivation for a long period (Siemens and Puleston 1972: 229).

Drained fields were more frequently documented along the higher and dryer shores of woodless meadows at a relatively great distance to floodplains (Siemens and Puleston 1972: 233). Another concentration was located opposite of El Tigre along the inland slope of the river embankment and in an adjacent bend of the Candelaria (Siemens and Puleston 1972: 233; see Figure 5.9b). More recent investigations by Vargas (2012: 195) indicated that the elevated fields were not only confined to El Tigre, but in fact extended until the border of the town of Candelaria. According to Vargas (2012: 195), additional raised fields are located towards the west and near a big meander formed by the Candelaria (see Figure 5.8b).

The total surface area of these cultivation systems was between 1.5 and 2 km^2 (Siemens and Puleston 1972: 233).[72] Excavations in a field complex of El Tigre revealed a piece of wood (*Bucida buceras*) that provided a ^{14}C-dating of 50 BC – 250 AD (Siemens 1989: 73; Siemens and Puleston 1972: 229). According to Gunn *et al.* (1994: 185), paleoclimatic studies indicate that these elevated fields were built during a period of severe drought, which resulted in extremely low water levels of the Río Candelaria (Vargas 2012: 196).

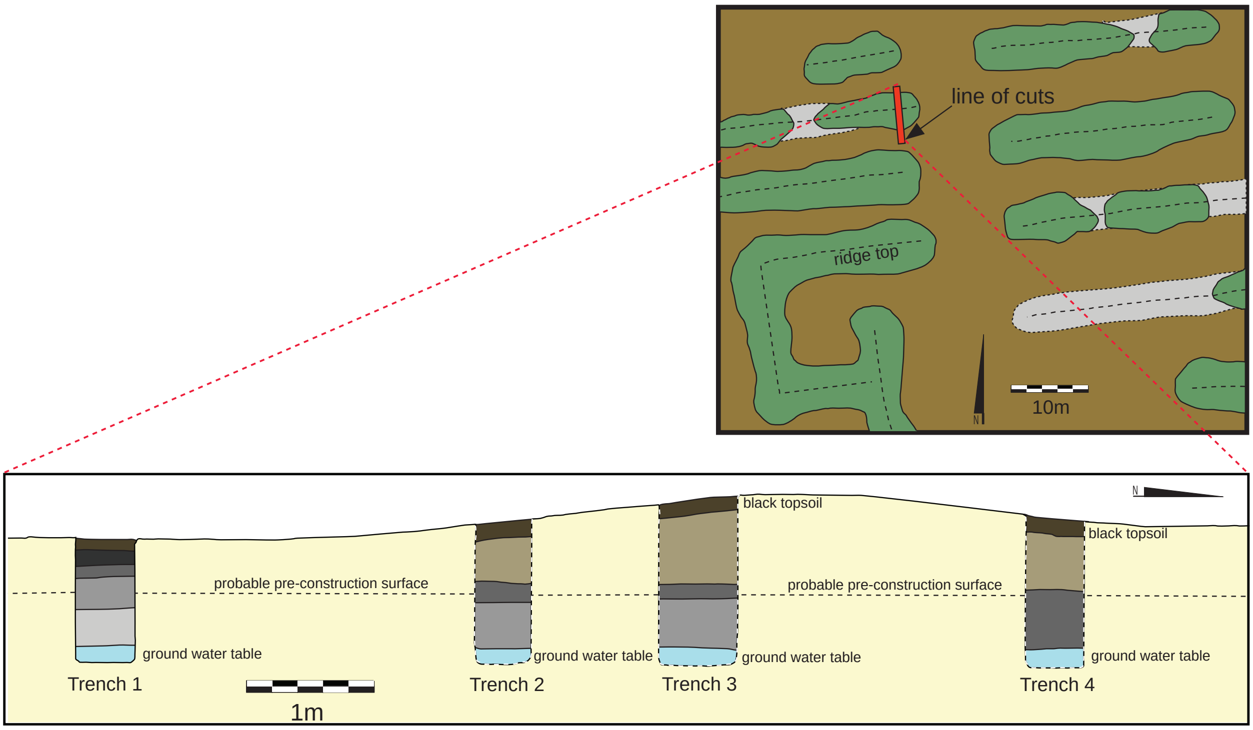

Figure 5.8: Canal features of El Tigre (redrawn after Siemens and Puleston 1972: Figure 5. Reproduced with kind permission of Alfred H. Siemens and Cambridge University Press).

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[69] Scholes and Roys (1968: 160) had identified this site as the settlement of Itzamcanac, capital of Acalan, one of the indigenous provinces of the Yucatán Peninsula during the Conquista (Puleston 1977a: 450).

[70] According to Vargas (2012: 195), these bajos would have represented important areas of cultivation, enabling the Maya to have two annual harvests of maize.

[71] According to Vargas (2012: 196), these topographic conditions would have forced the pre-Hispanic inhabitants to build *sacbe'ob* (causeways) over the bajos. Currently, three sacbe'ob have been documented within the site.

[72] Palerm and Wolf (1972: 28) even calculated a total extension of 3 km^2 (Vargas 2012: 195).

From the air, a network of hundreds of narrow, almost straight, mostly 1-2 km long canals crossing the center of El Tigre could be recognized that had apparently been connected to remains of elevated fields (Siemens and Puleston 1972: 235; see Figure 5.9c). The extended canal system seem to have provided these fields river access and allowed shortcuts and bypasses along the actual river, e.g. between settlements and milpas (Siemens and Puleston 1972: 229, 235). According to Siemens and Puleston (1972: 238), these many bypass routes might have also been advantageous for defense during wars fought in the rivershed. The various field plots were separated by canals with widths ranging between 1 and 2 m (Palerm and Wolf 1972: 28; Vargas 2012: 195, see Figures 5.9a and 5.9b).

a) Complex of elevated fields and canals in the floodplain of the Río Candelaria

b) Aerial photo of elevated fields near El Tigre

c) El Tigre, Aerial photo of the modern settlement and the complex of elevated fields

Figure 5.9: Aerial photos of raised fields in El Tigre and the Candelaria floodplain (Source: Photo collection of A. Siemens. Reproduced with kind permission of Alfred H. Siemens).

5.2.4.2 Bajo Morocoy

The Bajo Morocoy is located immediately to the northeast of the city of Nicolas Bravo/Quintana Roo, at an elevation of 80-85 m above sea level and features an area of 150-200 km^2 (Gliessman *et al.* 1983: 92). It forms part of a complex extending from Nicolas Bravo to Ucum and has remains of fields and canals with a total surface area of 34.4 km^2. In total, this bajo has a mild slope of around 0.3% (Gliessman *et al.* 1983: 94). The depression is dominated by haplaquoll soils that support a semi-deciduous forest with canopies spanning 4-8 m (Gliessman *et al.* 1983: 92).

During the surface mapping of the bajo, several elevated fields systems and canals, some of which were large enough to run through the entire bajo, were documented (Turner and Harrison 1983b: 95). The extensions of the field systems are quite variable as they included round and rectangular forms, while their widths typically ranged between 10 and 25 m (Gliessman *et al.* 1983: 97). In the same manner, the surface areas of these elevated fields vary, but have an average between 400 and 600 m^2 and more or less correlate with the fields of Pulltrouser Swamp (Gliessman et al 1983: 97, 101). The larger canals are up to 20 m wide, while the interconnected secondary canals are only 8-12 m wide (Gliessman *et al.* 1983: 97). All secondary canals were connected to main canals. It is apparent that the canals were cut into the sascab in order to create a greater height difference between the canals and acreages (Gliessman *et al.* 1983: 101; see Figure 5.10). The larger canals only seem to cover 10% of the total surface, while the platforms make up 60% of the bajo surface (Gliessman *et al.* 1983: 101). According to Gliessman *et al.* (1983: 101), the flatness of the bajos does not allow for drainage of this system.

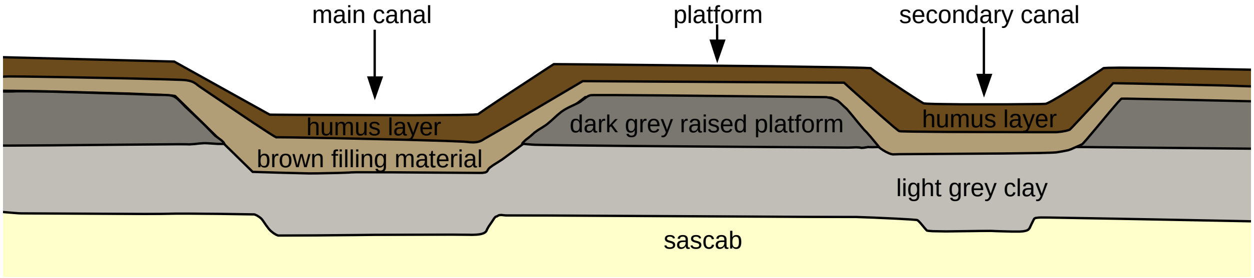

Figure 5.10: Schematic profile of elevated fields within the Bajo Morocoy (redrawn after Gliessman *et al.* 1983: 103, Figure 5.2). Reproduced with kind permission of Steve Gliessman.

5.2.4.3 Cerros

The site of Cerros is situated in northern Belize at the northern leeward coast of Lowry's Bight and features structures of which apparently 90% were built during the Late Preclassic (Freidel and Scarborough 1982: 133). The hydraulic system of Cerros consists of a 1,200 m long main canal[73] that curves around the 36 ha central portion of the settlement. The canal has a very mild slope and resembles the Preclassic ditch of Becán[74] (Scarborough 1983a: 721). This 3.2-6.0 m wide and 1.6-2.10 m deep main canal featured a flat, U-shaped cross section and was cut into the limestone bedrock (Freidel and Scarborough 1982: 142). It appears the canal's western side had steps that may have facilitated water recollection during the dry season (Scarborough 1983a: 731). In six positions, the main canal was traversed by dam-like *sacbe'ob*, located more or less uniformly around the canal's course (Freidel and Scarborough 1982: 133). Seven broader and flatter canals cut into the limestone bedrock radiate out in different directions from the main canal, some of which go towards the aguadas (see Figure 5.11a). One of these lateral canals drained into a 30 m wide reservoir in the boundary area of a complex of elevated fields to the north. These fields form four narrow rectangular platforms with areas of 14 x 28 m up to 22 x 40 m and were surrounded by

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[73] According to Pope and Dahlin (1993: 380), this main canal is the only canal feature which can be observed in the Radar images of Adams *et al.* (1981) (see Chapter 3).

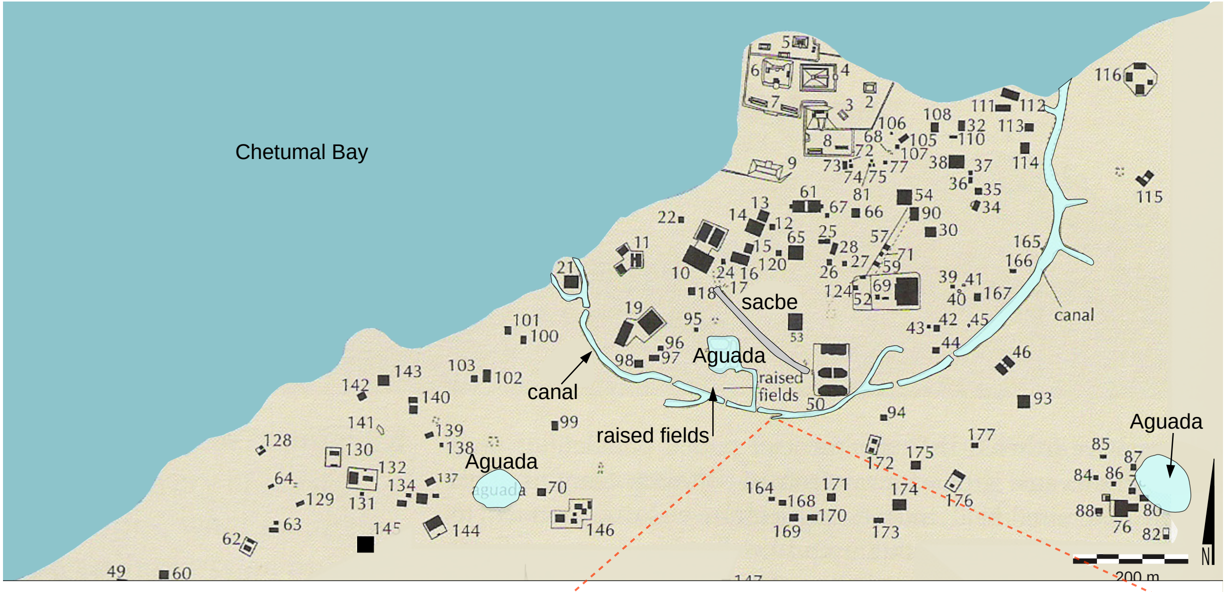
[74] The site core of Becán, which has a surface of 0.18 km^2 was encompassed by a 5 m deep and 16 m wide ditch from the Late Preclassic (Ball and Andrews 1978; Folan *et al.* 1995: 311; Webster 1976a; see Chapter 5.6.4.3.11). According to Freidel and Scarborough (1982: 145) the main canal of Cerros, if it had a defensive function, which seems to be the primary aim of Becán's main canal, it was only a secondary function.

additional reservoirs and interconnected by canals (see Figure 5.11a) (Freidel and Scarborough 1982: 143). For Freidel and Scarborough (1982: 147), the existence of limestone blocks in this section and especially their position within it indicated that they reinforced the sides of the fields. Based on these limestone blocks they also reconstructed the width of the smaller connecting canals (Scarborough 1983a: 725).

In the eastern section of the settlement, Scarborough (1983a: 731) documented a drainage network of low moats. In the western-central portion, a 2 m deep and 6 m wide U-formed canal used for intensified agriculture was also documented. During the Early Classic, this canal was modified by a check-dam and a stone-bordered collection pond (see Figure 5.11c) (Scarborough 1983a: 732).

Freidel and Scarborough (1982: 145) interpreted these features as a "water management system". Due to the extremely high salt content documented within the site, especially in the fields, this water management system declined prematurely (Scarborough 1980: 345; 1983a: 741). However, when the system was still active, the water that presumably came during heavy rains was diverted into the main canal and led into retention basins by smaller canals. According to Scarborough (1983b: 128), these smaller canals, despite their poor state of preservation, could still be detected in contour maps. According to Scarborough's (1983a: 725) model, this system would represent a "stillwater-system". During the dry season, the stone flanked basin/canals, reservoirs, and the water retained in the main canal would have allowed for irrigation. During the rainy season on the other hand, the many smaller canals would have served a drainage purpose, while the water-filled main canal would have been used as a water transport route (Scarborough 1983a: 741). Scarborough (1982: 148) also pointed out the possibility that the entire system would have once possessed a connection to the New River and, therefore, may have been irrigated year-round. In this respect, it should be noted that the existence of such a connection was never documented and thus, the hypothesis for a potential year-round irrigation cannot be verified.

a) Map of the site Cerros



b) Main canal, isometric section

c) Main canal, East profile

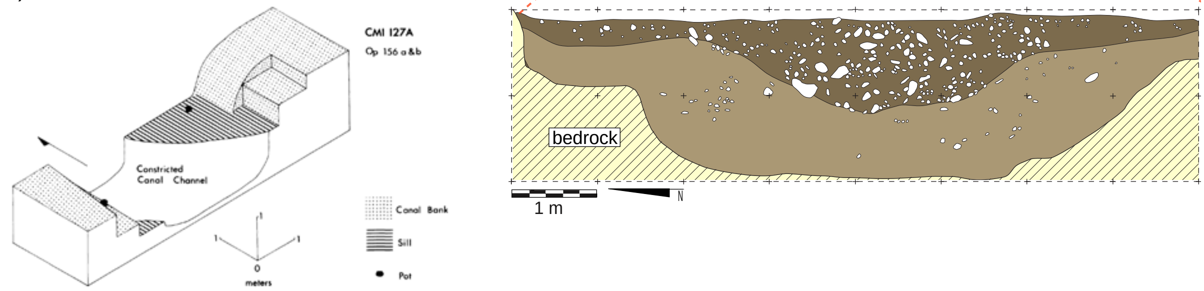


Figure 5.11: Cerros, Canal system in the site center. (a) (redrawn after Scarborough 1983: Figure 2); (b) (source: Scarborough 1983b: Figure 10); (c) (redrawn after Scarborough 1983: Figure 9). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.

5.2.4.4 Río Azul (Bajo Pedernal)

During a landscape survey of the Bajo Pedernal near Río Azul, Culbert *et al.* (1991: 119, Figure 7.19) documented north-south running linear features identified as canals. Archaeological excavations revealed that these canals had depths of up to 1.5 m and had been carved out from the bedrock and sascab (Culbert *et al.* 1991: 119). The cross-section drawing of these canals showed that they were U-shaped along their widths and that their interior walls were covered with a clay layer, which Culbert *et al.* (1991: 119) believe served to stabilize the later walls, control erosion and seal the canal floor. Due to the absence of east-west running canals, these north-south running canals were interpreted as drainage canals (Culbert *et al.* 1991: 119; Pope and Dahlin 1989: 98). Based on the surface survey, Culbert *et al.* (1991: 121) concluded that almost all of the bajos near Río Azul had once been drained, which would have resulted in more land for dry-season cultivation.

5.2.4.5 Río Bravo Region

5.2.4.5.1 Far West Bajo

The Far West Bajo has an area of approximately 3 km^2 and lies 3 km to the west of La Milpa at the end of a natural seasonal stream. This stream begins at a reservoir in the core of the site of La Milpa and flows to the west until it reaches the bajo (Kunen 2001: 333; Scarborough and Valdez 2003: 11). Due to its small size, this bajo was studied by means of various transects and survey-blocks (Kunen 2001: 333). According to Scarborough (2006: 22), excavations within the Far West Bajo revealed 18 drainage canals with depths of 3 to 4 m. Unfortunately, the documentation of these canals has not yet been published.

5.2.4.5.2 Blue Creek

The core area of Blue Creek is located on the summit of the Río Bravo escarpment (Baker 2016: 115; Guderjan *et al.* 2003: 84). The Río Bravo, Booth's River, and the swamps surrounding the confluence of these rivers are all located to the east of this core area. The 40 km^2 "Dumb Bell Bajo" lies to the west and features a high agricultural potential (Guderjan *et al.* 2003: 77). Towards the north, the Blue Creek (Río Azul) forms the modern frontier between Belize and Mexico (Guderjan *et al.* 2003: 77). To the south lies a small canyon that may have been an old river course of the Blue Creek. These elements delimit an area of 150 km^2, of which 20 km^2 were mapped during a survey (Guderjan *et al.* 2003: 77).

Within the Río Bravo depression, there is a low-lying area consisting of several wetlands[75] and meandering drainages with scattered "islands" of dry mainland, and at least five complexes of drained fields (Guderjan *et al.* 2003: 78; see Figure 5.12). Three of these systems were documented near the rural settlement of Chan Cahal (Guderjan *et al.* 2003: 79). The field systems had different sizes, forms and orientations and were constructed at some point during or after the Late Classic (Guderjan *et al.* 2003: 79). Guderjan *et al.* (2003: 87) estimated that the 40 km^2 area between the Río Bravo escarpment and the Río Bravo was once covered with a system of drained fields adding up to a surface area of 6 km^2.[76] Apart from this information, Guderjan *et al.* (2003) did not provide further statements regarding the form and composition of the documented canal systems.

In addition to these systems, numerous wetland fields were documented in northern Belize. In the Chan Cahal wetlands located east of Blue Creek's site center (see Figures 5.13a and 5.13e), Beach *et al.* (2009: 1716) excavated 22 different systems of elevated fields (Guderjan 2007). Near the site of Sierra de Agua,

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[75] According to Guderjan's *et al.* (2003: 80) observation, some wetlands were not used for agricultural purposes but for the exploitation of resources such as apple snails (*Pomaceae*), birds, reptiles, insects, grasses, reeds or sedge (Guderjan *et al.* 2003: 87).

[76] In fact, Guderjan *et al.* (2003: 87) consider a surface of 12 km^2 more plausible. They consider these systems of drained fields as a potentially larger and economically important component of Blue Creek's community.

Baker (2003: 185) located two complexes of "ditched fields" (see Figure 5.12c). Besides this, additional systems of wetland fields were located in Chawak, Birds of Paradise and Lamanai (Beach *et al.* 2009a, 2011, 2013, 2015a: 13; Luzzadder-Beach *et al.* 2009a, 2002).


a) Blue Creek, Map indicating the location of canal systems

b) Blue Creek, Map of raised fields near the site core

c) Blue Creek, Aerial photo of elevated fields

d) Irish Creek Marsh, Aerial photo of elevated fields

e) Chan Cahal, Aerial photo of elevated fields

f) Birds of Paradise, Aerial photo of elevated fields

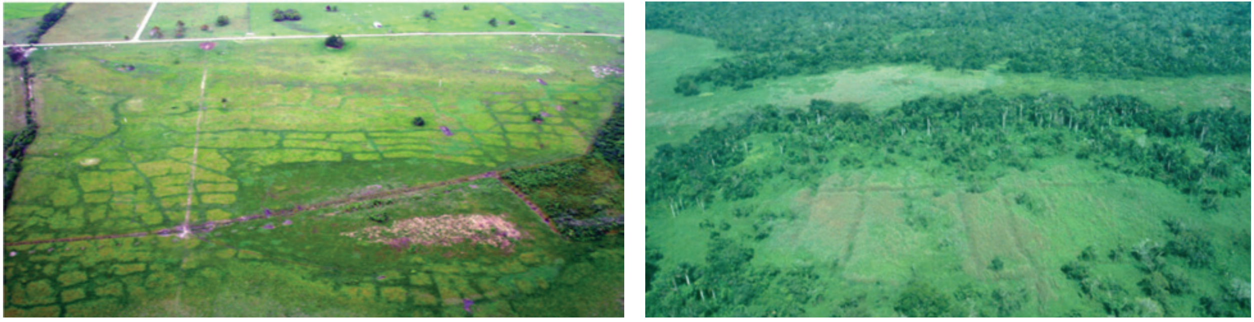

Figure 5.12: Blue Creek, Overview of elevated fields. (a) (source: Guderjan *et al.* 2003: Figure 7.2. Reproduced with kind permission of Thomas Guderjan); (b) (source: Guderjan 2007: Figure 5.2. Reproduced with kind permission of Thomas Guderjan); (c) (source: Baker 2003: Figure 8-11. Reproduced with kind permission of Jeffrey Baker); (d) (source: Baker 2003: Figure 8-1; reproduced with kind permission of Jeffrey Baker); (e) (Photo: A. Padilla. Originally published in Luzzadder-Beach et al. 2012: Figure 1. Reproduced with kind permission of Sheryl Luzzadder-Beach and PNAS); (f) (Photo: S. Luzzadder-Beach. Originally published in Luzzadder-Beach et al. 2012: Figure 1. Reproduced with kind permission of Sheryl Luzzadder-Beach and PNAS).

5.2.4.6 Nohmul

The site of Nohmul sits on a limestone hillcrest to the east of the Río Hondo and features a mild topographic relief with obvious traces of alluvial depositions (Pyburn *et al.* 1998: 43). The eastern foothills of this hillcrest descend to the western arm of the Pulltrouser Swamp (Hammond *et al.* 1987: 258). To the west of Nohmul, in the Douglas North Zone, there is a bajo landscape where a number of elevated fields were identified in aerial photos (see Figure 5.14). In order to determine the chronology and function of these features, Hammond *et al.* (1987: 259) carried out several test excavations and one larger excavation trench. These excavations showed that the canals sloped from southwest to northeast and thereby drained into the wetlands. Furthermore, Hammond (1985) observed that the fields had a lattice pattern forming a mosaic of small acreages (see Figure 5.13). The size of most acreages varied between small fields with areas of approximately 10 x 10 m and mid-sized fields with areas of approximately 20 x 20 m. However, some distinctively rectangular fields reached extensions of up to 40 x 20 m (Hammond *et al.* 1985: Figure 7). Based on their excavation results, Hammond *et al.* (1987: 259, 280) claimed that the documented fields represented both drained and elevated fields, and would have been constructed during the Late or Terminal Classic.

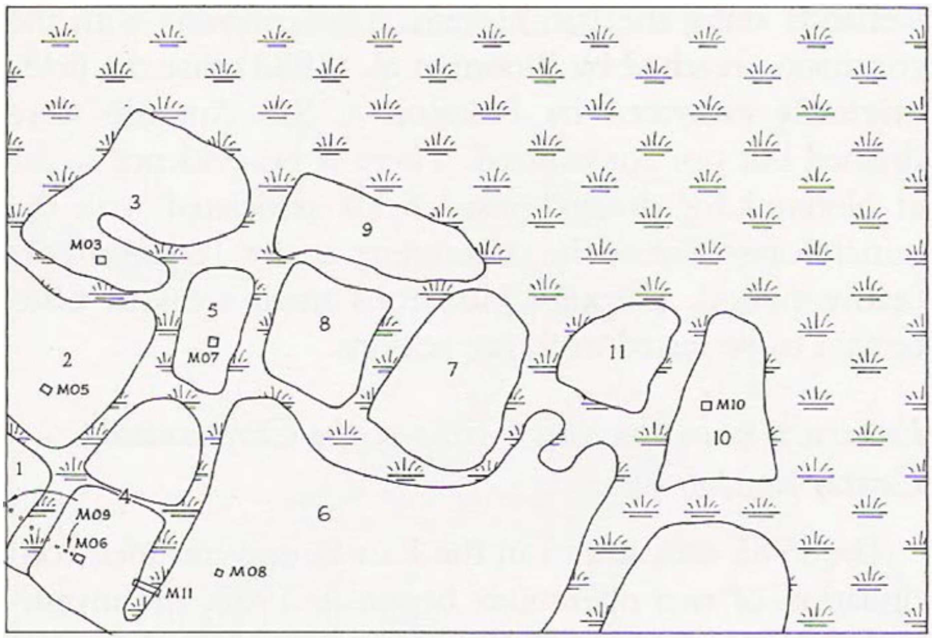

Figure 5.13. Nohmul, Douglas North Zone, Sketch of raised fields (source: Hammond et al. 1987: 259, Figure 2. Copyright Nojmul Project, by courtesy of Dr. Norman Hammond).

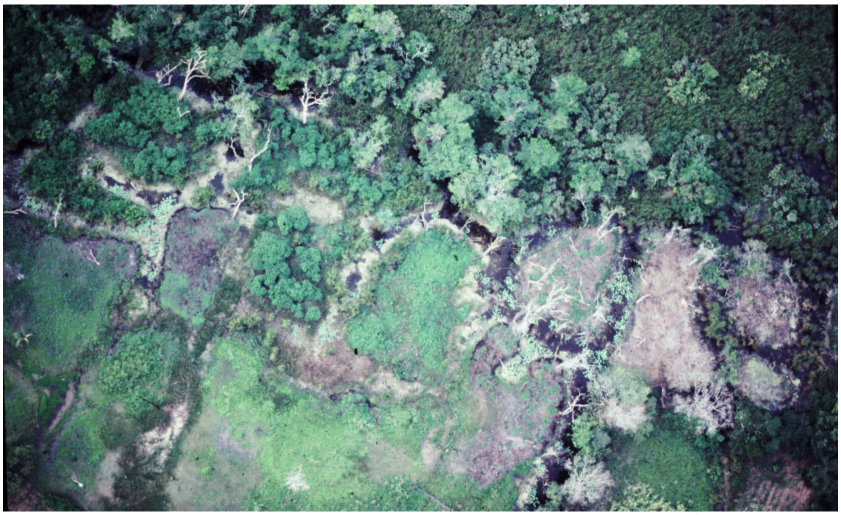

Figure 5.14: Nohmul, Douglas North zone, Aerial photo of raised fields (Photo: Courtesy of Norman Hammond. Reproduced with kind permission of Norman Hammond.

5.2.4.7 Pulltrouser Swamp

The excavations and survey of 1979 and the monograph on Pulltrouser Swamp published in 1983 were of such great importance for the study of wetland cultivation that they can be considered a turning point in the investigation of wetlands (Culbert *et al.* 1991: 116; see Chapter 3). However, according to Turner and Harrison's (1983b: 246), these studies could "only scratch the surface of the landscape features and settlement structures". Pulltrouser Swamp consists of three interconnected depressions between the New River and the Río Hondo in northern Belize: Pulltrouser West, Pulltrouser East and Pulltrouser South (Fedick and Ford 1990: 22; Turner 1983: 33, see Figure 5.15). At the western shore of Pulltrouser South lies the small rural site of Kokeal (Turner and Harrison 1983b: 264). The annual fluctuation of water within Pulltrouser Swamp is minimized by the slow and steady flow of the New River whose water level varies by less than one meter over the course of a year (Fedick and Ford 1990: 22). The soils of Pulltrouser Swamp are a variety of mollisols (haplaquolls), which are well-suited for the cultivation of a variety of fruits on elevated and drained fields (Darch 1983: 22).


a) Pulltrouser Swamp, Map of raised field site 3

b) Map of Pulltrouser Swamp showing the distribution of canals and excavation units

c) Pulltrouser Swamp, Map of raised field site 2

d) Pulltrouser Swamp, Map of raised field site 1

Figure 5.15: Pulltrouser Swamp, Maps of Raised field sites 1, 2, and 3. (a) (redrawn after Turner 1983b: Figure 4-8. Reproduced with kind permission of Billie Lee Turner and the University of Texas Press); (b) (redrawn after Turner II and Harrison 1983: Figure 4-4); (c) (redrawn after Turner II 1983b: Figure 4-7); (d) (redrawn after Turner II 1983b: Figure 4-6). Reproduced with kind permission of Billie Lee Turner and the University of Texas Press.

Along the three arms of Pulltrouser Swamp and in the adjacent New River Zone, groups of different scholars documented a network of canals and raised fields with a surface area of at least 311 ha (possibly up to 688 ha) (Harrison and Fry 2000; see Figure 5.15b). The local hydrology is clearly reflected in the distribution of canal constructions (Turner 1983: 32). Because the immediate margins of the swamp show higher seasonal fluctuations of water levels, they were rarely used for cultivation (Turner and Harrison 1983b: 247). Due to their relatively constant water levels, even the interior sections of Pulltrouser South and Pulltrouser West showed underdeveloped canal patterns (Turner 1983: 33). Well-defined patterns only occurred in those areas where seasonal fluctuation in water levels were great, but desiccations scarce (Turner 1983: 33; see Figure 5.15). The widths and lengths of the ditches documented by Turner (1983: 33) vary notably.

The ditches leading into the depression's interior are arranged at near-regular intervals from one another at the transition from the bajo edge to the forest, and are relatively short compared to their 8-10 m width (Turner 1983: 33). Longer and narrower (3-5 m wide) ditches tend to be located at the border between the mainland and the bajo (Turner 1983: 33). However, apart from these two types of ditches, there are a multitude of additional canals forming a network between the acreages (Turner 1983: 33). During the survey, two additional main ditches were documented that connect Pulltrouser Swamp with the New River (Turner 1983: 33; Turner and Harrison 1983b: 247). According to Turner (1983: 49), these might have once been used as a means of water regulation and/or water transport, which would have possibly enabled canoe travel through the entire system of Pulltrouser Swamp, the New River and more distant destinations (see Chapter 8.2.2). In order to better understand the structural composition of these features, Turner (1983: 33) defined three sections for excavations (raised field site 1, 2, and 3; see Figure 5.15b). These excavations led to the documentation of numerous complexes of drained and elevated fields. The drained fields were mostly rectangular and usually located at the natural border to the mainland (Turner 1983: 45). The drainage canals were cut two meters deep into the natural surface of the terrain and extended inland (Turner 1983: 45). Within the bajo, elevated fields formed linear compounds and followed the orientation of the drainage canals (Turner 1983: 45). According to Turner (1983: 46), the field surfaces originally constituted between 60 and 65% of the entire field network. Turner and Harrison (1983b: 247) assumed that the primary function of the documented system was not drainage since the depression's extremely mild slope and the New River's low discharge rate would have hindered this.

In their view, these complexes could have been used both for drainage and irrigation (Turner and Harrison 1983b: 247). Since the fields would have been permanently supplied with water in most years, year-round cultivation would have been realistic (Turner and Harrison 1983b: 247). Although the majority would have been built during the Classic Period, according to Turner and Harrison (1983b: 247), the construction of this system began before 200 BC. By the Terminal Classic, constructions for intensified agriculture were abandoned together with the settlement of Kokeal.

5.2.4.8 Albion Island

Albion Island is a 20 km long and 5 km wide island located at the northern border of Belize. It is formed by the main channel and a backwater of the Río Hondo (Antoine *et al.* 1982: 228; Stein 1990: 323). The island is marked by a long, central and rocky hillcrest surrounded by floodplains and bajos (Coffin 1990: 79; Pyburn *et al.* 1998: 40). Since the karst topography of the drainage basin acts like a buffer for superficial discharge, the river's water level stays more or less consistent throughout the entire year (Antoine *et al.* 1982: 228; Siemens 1978). Based on survey results, Lewenstein and Dahlin (1990: 352) calculated that the entire island had a density of 197 structures or 700 persons per square km (Siemens 1982: 217).

During the 1970s, a network of canals in a floodplain near the village of San Antonio was discovered through the analysis of aerial photographs (see Figure 5.16). Later archaeological investigations showed that these drainage canals formed a rectangular pattern and encompassed a complex of elevated fields with a surface area of 0.1-0.3 hectares (see Wiseman 1990: Figure 11.1). Each field lies 30-40 cm above the level of the canals and the river (Antoine *et al.* 1982: 228; Pohl 1990a). Even today, some of these canals are still waterlogged for most of the year (Stein 1990: 324). Stratigraphic observations revealed that the fields were presumably built during the Preclassic,[77] and had to be continuously raised due to the general ascent of the water level (Bloom *et al.* 1983; Puleston 1977b: 41). When the rise of the water table could no longer be compensated for through these later modifications, the fields were abandoned (Turner and Harrison 1983b: 269). During the Classic Period, the high water level of the Río Hondo only enabled cultivation during the dry season when water levels were lowest (Stein 1990: 335). Therefore, the canals of San Antonio presumably served to drain these elevated fields in such a way that they could be used agriculturally (Antoine *et al.* 1982: 234).

Figure 5.16: Albion Island, Aerial photo of elevated fields (source: Siemens 1982: Figure 4). Reproduced with kind permission of Alfred Siemens and Elsevier.

5.2.4.9 Colha/Cobweb Swamp

Cobweb Swamp is located near the site of Colha and represents a permanent wetland that drains into the Caribbean Sea via the Northern River (Jacob 1995b: 177). Owing to this topographic location, cultivation was presumably quite limited due to the high salt content of the soils (Jacob 1995b: 188). At the margin of Cobweb Swamp, some islands with widths between 4-6 m and lengths between 12-17 m were documented. The canals that separated these islands ranged between 3 and 4 m in width. Jacob (1995: 185) assumed that natural canals or island patterns along the swamp's margin already existed prior to the initial colonization of the area. The basis of this hypothesis is the profile of an excavated canal (see Figure 5.17). As Jacob (1995b: 185) noted, this canal was much wider than would have been necessary for the purpose of drainage or irrigation – in fact, it was at least as wide as the adjacent fields. Therefore, the cultural modification of this natural landscape feature would have taken place later through the creation of ditches and the straightening of already existing canals. In this process, both drained fields and more sophisticated modifications such as elevated fields would have evolved (Jacob 1995b: 195; Figure 8).

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[77] In Stein's (1990: 324) opinion, Turner and Harrison's (1983b: 263) assumption that the first canal construction on Albion Island came about during the Late Preclassic, is hard to prove since all (datable) sediments which would have accumulated during the agricultural activity would have been removed due to the canals' maintenance.

According to Jacob (1995b: 187), these modifications began during the Late Preclassic, at a time when Colha experienced a population expansion marked by the deposition of Maya clay (Jacob 1995b: 187; see Chapter 4.3). Although these sediments were no longer as fertile as the underlying "Cobweb-Clay",[78] their agricultural potential still would have been sufficient to make the laborious digging of the canals profitable for the peasants of that time (Jacob 1995b: 187).

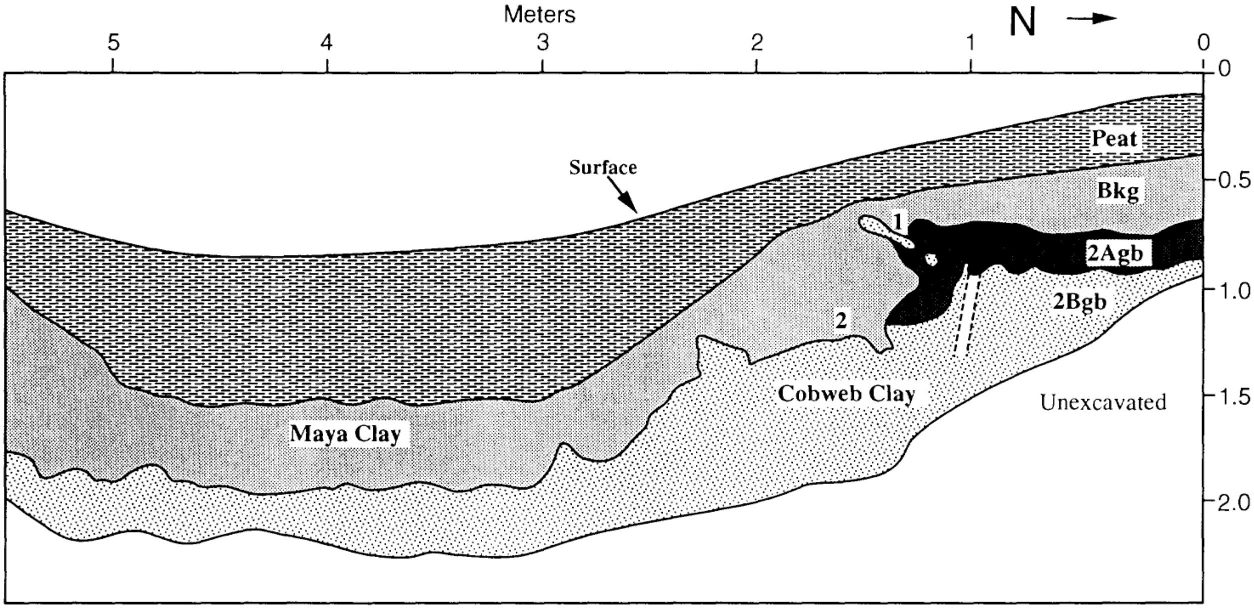

Figure 5.17: Colha, Cobweb Swamp, Canal, Operation 1, Subop. 2, West profile (source: Jacob 1995b: Figure 6). Reproduced with kind permission of John Jacob.

Jacob (1995b: 187) suggested that the documented canals were used for both drainage and irrigation. Although the field's position at a swamp's margin would best indicate a drainage function according to prevalent ideas, Jacob (1995b: 187) noted that the water level dramatically dropped during the dry season. Therefore, deeply excavated canals could have been used to divert water from the moister sedge grass marshes into the fertile belt of the swamp margin during the dry season (Jacob 1995b: 187). The canals might have been constructed in order to improve drainage at the beginning of the dry season and to facilitate agriculture during the rainy season (Jacob 1995b: 187). Given the current climatic conditions, cultivation during the rainy season seems improbable as many of today's peasants claimed that the field is flooded during the majority of the rainy seasons (Jacob 1995b: 188). Instead of assuming a massive modification of the wetland's bank, the data from Cobweb Swamp, according to Jacob (1995b: 188), rather indicate more moderate modifications of already existing landscape features. This also becomes apparent in the fact that systems with more than four or five parallel canal could be documented at all position along the shore (Jacob 1995b: 179).

5.2.4.10 Lamanai

The site of Lamanai or Indian Church was presumably occupied from 600 BC to 1675 AD and is located at the western shore of the New River Lagoon, near the estuary to the New River (Lambert and Arnason 1983: 112). To the west, the New River Lagoon is bordered by 60,000 hectares of undulating land with very fertile and agriculturally productive soils (Lambert and Arnason 1983: 113; Pyburn 2003: 123). At the eastern shore of the New River Lagoon, in the adjacent Blue Creek and in the New River's riverbed, several scholars (Lambert and Arnason 1983: 116; Siemens 1982: 223; Turner and Harrison 1983b: 249)

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[78] According to Jacob (1995b: 182, 186), the "Cobweb-Clay" situated underneath the "Maya Clay" developed in situ through the weathering of the underlying sascab. The Maya clay on the other hand, was presumably washed in from adjacent upland areas due to soil erosion.

located canals that they interpreted as indicators for wetland cultivation. Unfortunately, more detailed information of these features has not been published.

5.2.4.11 Belize River Valley

In the Belize River Valley, Kirke (1980: 28) documented a number of "linear features" between Nordlands Farm and Barton Creek (Cayo District). These features were located at a distance of 1-3 km from the river and were situated above the actual level of the river. Additionally, they appear to show a partial connection to pre-Hispanic settlements with a high density of structures (see Kirke 1980: Figure 2). Apart from very flat and narrow canals with depths between 4 and 20 cm, and maximum widths of 1 m, Kirke (1980: 284) also documented canals that formed a rectangular pattern. Presumably, these latter canals represented drainage canals used to divert water from the highland into the Belize River (Kirke 1980: 282).[79]

5.3 Terraces

Terrace systems are constructions built for intensified agriculture and have not always been interpreted as "hydraulic features". By some scholars, they were defined as demarcation lines for the definition of or the facilitated access to specific acreages (Kunen 2001: 342). In Maya archaeology literature, terraces were first described in the 1920s and 1930s (Lundell 1940; Ower 1927; Thompson 1931) and were suggested to be constructions for intensified agriculture (Beach *et al.* 2015a: 20; Chase and Chase 1998: 60; Donkin 1979; Turner 1974). Although the importance of pre-Columbian terrace systems had always been undisputed, according to Healy *et al.* (1983: 399), this form of intensified agriculture received quite limited attention from scholars between the 1930s and 1980s (Donkin 1979: 33; Patrick 1979: 769; Turner 1979: 103). In general, the theory that terraces had agricultural relevance within the Maya Lowlands was criticized quite explicitly (Chase and Chase 1998: 60). Sanders (1979: 495) for instance, negated the importance of the terraces, which Turner (1979) had studied in the Río Bec region. Neverthelesss, in the past 30 years, numerous terrace systems from the Maya Lowlands have been studied and published.

5.3.1 Functionality of terraces

As ethnographic observations (Wilken 1987: 259) indicate, terraces constitute a "natural" consequence of cultivating slopes (Donkin 1979: 2; Dunning and Beach 1994: 58). They catch and preserve soils that would otherwise be washed away through alluvial or colluvial (erosion) processes (Hageman and Lohse 2003: 116; Healy *et al.* 1983: 404; Wilken 1987: 99-100). Furthermore, they regulate and distribute water and enhance the nutrient content of soils (Beach *et al.* 2002: 379; Macrae and Iannone 2011: 186; Treacy and Denevan 1994: 93). The effectiveness of a terrace system is immediately connected to its design, maintenance and the rate of precipitation (Dunning and Beach 1994: 56). Similar to elevated fields, terrace systems can easily break down or become ineffective if they are poorly built or affected by excess flowing water or soil erosion (Beach *et al.* 2015a: 20).

The central and most important element of any given terrace system is the terrace wall itself. Terrace walls canalize and evenly dispense the rainy season torrents (Healy *et al.* 1983: 405). Quite frequently, these flows of water are diverted in such a way that they aggregate immediately behind the terrace walls (Kunen 2001: 326). Water flows causing erosion can be avoided in this manner (Healy *et al.* 1983: 405).[80] The porous fill material of terrace walls enables the discharge of water and hence impedes the

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[79] According to Kirke (1980: 284), these resembled the canals of Edzná to a great extent. Furthermore, he presumed that the features of Nordlands Farm once formed a moat similar to the "fortress" of Edzná (see Chapter 5.7.4).

[80] If terraces are not constructed and maintained extraordinarily well, they are not able to lower soil erosion by more than 50%

vegetation-harming flooding of the acreages (Healy *et al.* 1983: 404; Treacy and Denevan 1994: 93; Turner 1983). Consequently, terraces enable the regulation of soil moisture, one of the fundamental goals of intensified agriculture.

Over time, the gradual accumulation of soil creates a deeper, more fertile and level acreage, which is supplied with new nutrients through the periodically washed in (highland) sediments (Healy *et al.* 1983: 401). For example, this enhanced soil formation can be observed in Caracol where slopes secured by terraces generally feature thicker layers of soil than cleared slopes. In contrast, the slopes without terraces were highly eroded and only featured very thin soil layers (Healy *et al.* 1983: 401). In turn, these deeper soils enabled the development of deeper roots (Treacy and Denevan 1994: 95). In some terrace systems of the Maya Lowlands, sediments from the valley environments were imported to enhance the soils with nutrients and were piled up behind terrace walls (Turner 1979: 109). Chase and Chase (1998: 72) further speculated that the people using these terraces would have fertilized them with human and animal excreta and plant waste (Coultas 1994: 28). The effects of deeper, more humid and adequately drained soils would have enabled additional harvests,[81] increased annual yields and the cultivation of more demanding plants (Chase and Chase 1998: 72; Dunning 1996; Dunning and Beach 1994; Kunen 2001: 326; Turner 1979; Rice 1996). Although in some areas of Mesoamerica terraces were constructed to support residential structures (Blanton 1978; Sanders and Nichols 1988: 44-45), the pre-Hispanic Maya seem to have mostly built terraces to obtain more secure and productive acreages (Chase and Chase 1998: 72). Apart from protecting highland soils, the construction of terraces would have also created watersheds (Crandall (2009: 14). Dunning and Beach (1994: 57) assumed that the slope management of the Maya would have been sufficient to keep the loss and regeneration of soils at equilibrium.

Apart from terraces, the pre-Hispanic Maya also used constructions that are harder to trace archaeologically, such as soil or plant ridges (Beach *et al.* 2015a: 20; Dunning and Beach 1994: 57). Terrace systems mostly occur in combination with field walls, which apart from diverting and draining water also might have been used for the demarcation of property, the creation of elevated walkways or as stone storage facilities (Fedick 1994: 121; Hughbanks 1998: 112; Tourtellot *et al.* 1994: 120). Field walls are linear rubble structures, which, in contrast to terraces, are not usually built on foundation stones (Kunen 2001: 339). In fact, they are unstratified masses of chert and limestone pebbles in a clayey soil matrix and they are often difficult to distinguish from terraces (Kunen 2001: 335, 339). Frequently, single rows of stone blocks demarcate the front and backside of features, while the space in between was filled with fill-material (Kunen 2001: 339). According to Garrison and Dunning (2009: 543), the Late Classic saw the widespread application of terracing as an agricultural technique. This would have been accompanied by less imposing constructions, such as long, linear features composed of chert cobbles that may have served to prevent soil-runoff or as walkways between gardens of specific economic crops.

5.3.2 Construction forms of terrace systems

While typologies may vary slightly from region to region,[82] most scholars divide the terrace systems of the Maya Lowland into four basic types (Kunen 2001: 326). One criterion is the function. This is usually determined based on the physical location and the way in which the wall is constructed. Healy *et al.* (1983: 405) interpreted these particular forms of construction as individual adaptations to the local flow of water, the slope's inclination and precipitation rates. For this dissertation, the author divided the published terrace systems into the four categories: dry-slope terraces (Chapter 5.3.2.1), box terraces

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(Dunning and Beach 1994: 56; Foster and Highfill 1983).

[81] The possibility of additional harvests through agricultural terraces is based on ethnographic comparisons from Africa (Chase and Chase 1998: 72; Netting 1993: 269, table 9.1).

[82] In a study of terrace-systems in Xunantunich, Neff (2008: 63) defined 5 different types. His typology differs from the categorization presented in this work only in that the definition of dry-slope terraces is separated in two categories: Single-wall terraces and double-wall terraces. Since both of these are a subtype of dry-slope terraces, the author decided to apply a four-tiered typology.

(Chapter 5.3.2.2), footslope terraces (Chapter 5.3.2.3) and check-dam terraces (Chapter 5.3.2.4). The upcoming section will present the function and design of these different types.

5.3.2.1 Dry-slope terraces

Dry-slope terraces usually follow the topography of hill slopes and are therefore frequently defined as "contour terraces" (Beach *et al.* 2002: 386). They are the most common terrace form of the Maya Lowlands (Macrae and Iannone 2011: 186). These constructions aim to enhance the soil depth and improved regulation of moisture (Donkin 1979: 131). They can only be located on mild slopes with grades of less than 10° (Kunen 2006: 109). Even though they generally follow the course of the topography, some examples run entirely straight without any consideration of the hill's contour (see Figure 5.18).

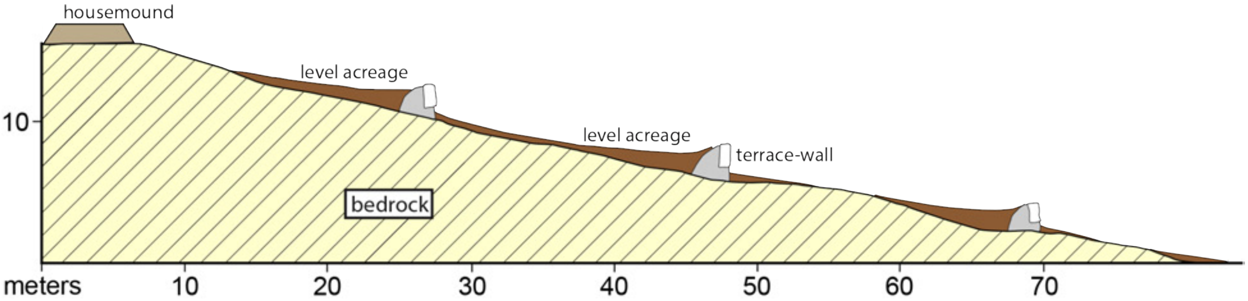

Figure 5.18: Profile of dry-slope terracing along a linear slope (redrawn after Turner 1979: 108, Figure 7.2). Reproduced with kind permission of Billie Lee Turner and the University of Texas Press.

Typical dry-slope terraces have varying lengths and consist of a simple front wall assembled out of unworked, dry-masoned limestone blocks without mortar (Turner 1983: 77). Since these walls were constructed directly on the limestone bedrock, it can be assumed that the old soil was removed before the construction process (Dunning and Beach 1994: 58). In some cases, the front walls were further fortified by large anchor stones set into the limestone bedrock (Kunen 2001: 339). Behind these walls, a thick layer of fill consisting of soil and limestone rubble was piled up (Chase and Chase 1998: 69; Kunen 2006: 109). This rubble layer increased not only the construction's stability, but also its permeability (Kunen 2001: 327) (see Figures 5.19 and 5.20).

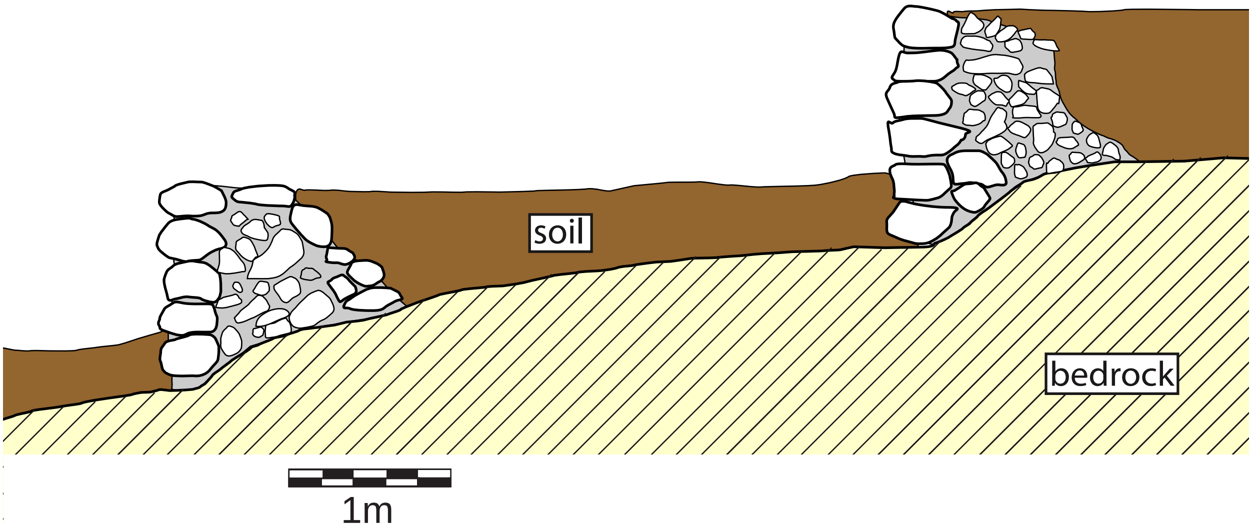

Figure 5.19: Idealized profile of a terrace with single front wall (redrawn after Kunen 2001: 328, Figure 2). Reproduced with kind permission of Julie Kunen.

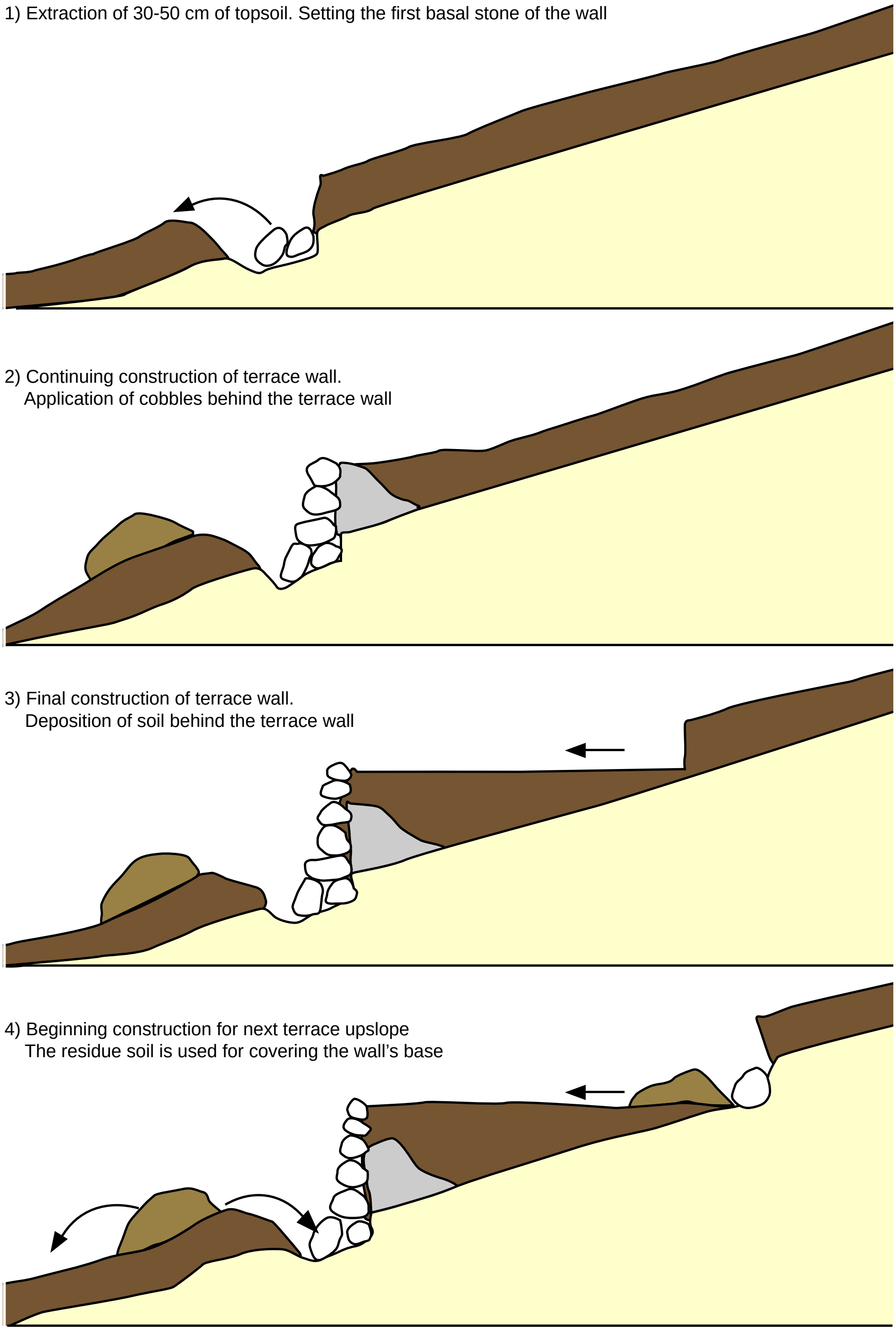

Figure 5.20: Schematic illustration of the construction sequence of terraces (redrawn after Treacy 1994: Figure 5.4). Reproduced with kind permission of the University of Pennsylvania Press.

More elaborate terrace systems were constructed with a double front wall. These consisted of two parallel walls constructed out of large blocks (Healy *et al.* 1983). The space between was filled up with smaller, mostly fist-sized stones (Chase and Chase 1998: 69; see Figure 5.21). In other cases, a rubble bed was piled up behind this double wall to increase stability (Healy *et al.* 1983). This form of construction was documented in almost identical form in the dry-slope terraces of Río Bec, the Upper Belize River Valley, the Río Bravo area, and the Vaca Plateau. The so-called "rock-slab dry-slope terraces" (Kunen 2001: 331) of the Petexbatun region are quite similar to those of Río Bec in their outer appearance.

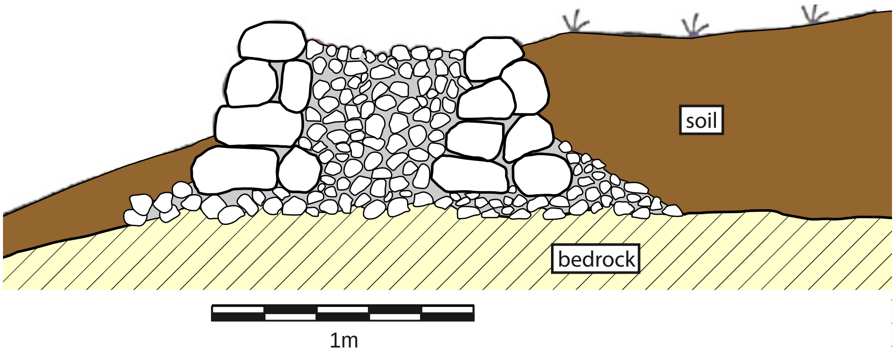

Figure 5.21: Idealized profile of a terrace with a double front wall (redrawn after Kunen 2001: 328, Figure 2). Reproduced with kind permission of Julie Kunen.

However, they actually have a slightly different design (Dunning *et al.* 1998: 258). As Figure 5.22 indicates, they were constructed by piling up loose and upturned boulders and anchoring them to the bedrock with larger blocks (Kunen 2001: 331; see Figure 5.23). In some cases, dry-slope terraces were also placed independent of the topographic contours and formed lattice-like patterns (Demarest 2004: 138; Kunen 2001: 326; Macrae and Iannone 2011: 186; Treacy and Denevan 1994: 98-100).

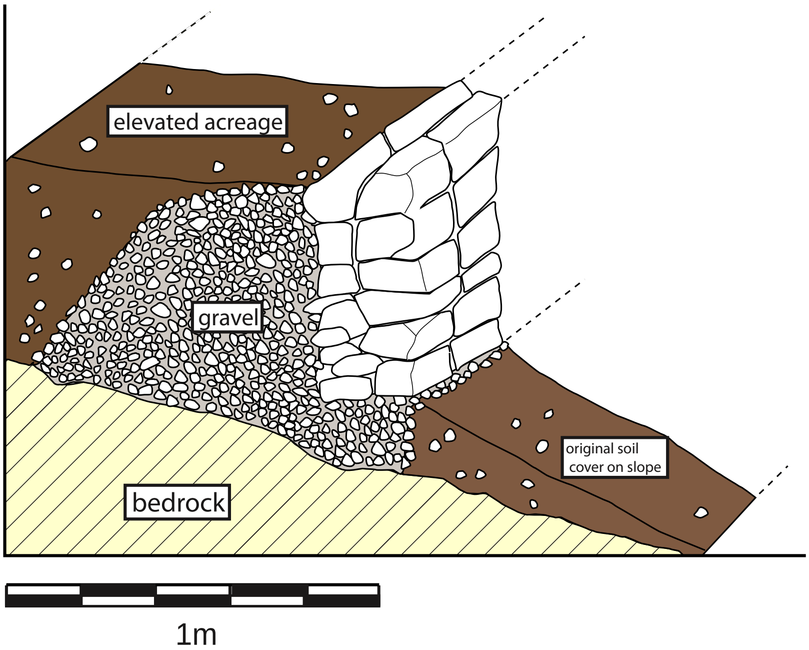

Figure 5.22: Isometric profile of a dry-slope terrace (redrawn after Turner 1979: 108, Figure 7.4). Reproduced with kind permission of Billie Lee Turner and the University of Texas Press.

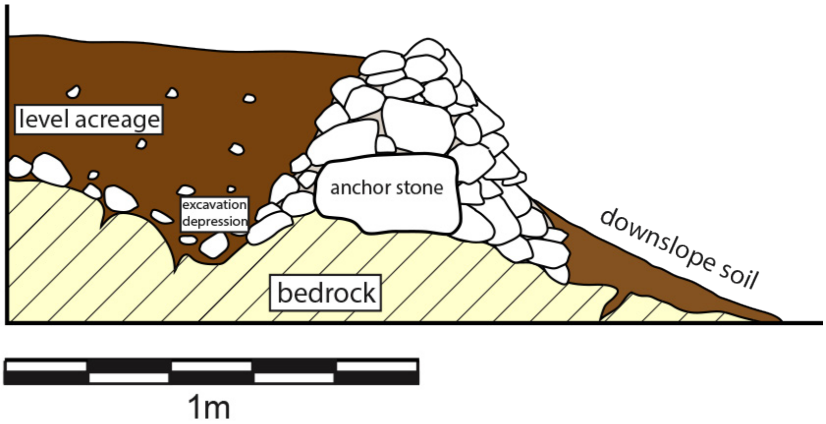

Figure 5.23: Dry-slope terrace of the Petexbatun region (redrawn after Dunning and Beach 1994: 59, Figure 8). Reproduced with kind permission of Nicholas P. Dunning and Cambridge University Press.

5.3.2.2 Box terraces

In most cases, box-terraces are documented in relatively flat terrain (Macrae and Iannone 2011: 186). Since they form independent rectangular patterns and were usually located near residential areas, most scholars interpret them as seedbeds or intensively cultivated gardens (kitchen gardens) such as those of the Petexbatun region (Dunning and Beach 1994: 58; Dunning *et al.* 1997a: 262), the Upper Belize valley (Fedick 1994: 119), and the Three Rivers Region (Beach *et al.* 2002: 386; Hageman and Lohse 2003: 105; Weiss-Krejci *et al.* n.d.; see Figure 5.24).

Hageman and Lohse (2003: 116) presumed that these compounds were used as breeding grounds for plants, which would have been moved to larger fields once they had grown into seedlings. They based these ideas on the results of traditional agronomists (Netting 1993: 52; Wilken 1987: 257-261) who claimed that this cultivation method produced larger harvests and gave peasants the possibility to provide plants special care during early growing stages by means of irrigation, pest-prevention and fertilization. Furthermore, this strategy reputedly reduced the risk of a premature harvest loss (Hageman and Lohse 2003: 116). Although some scholars defined this form of terrace as a sub-class of dry-slope terraces, the author decided to define them as an independent form due to the apparent differences in function and because almost all published box terraces were documented in similar locations.

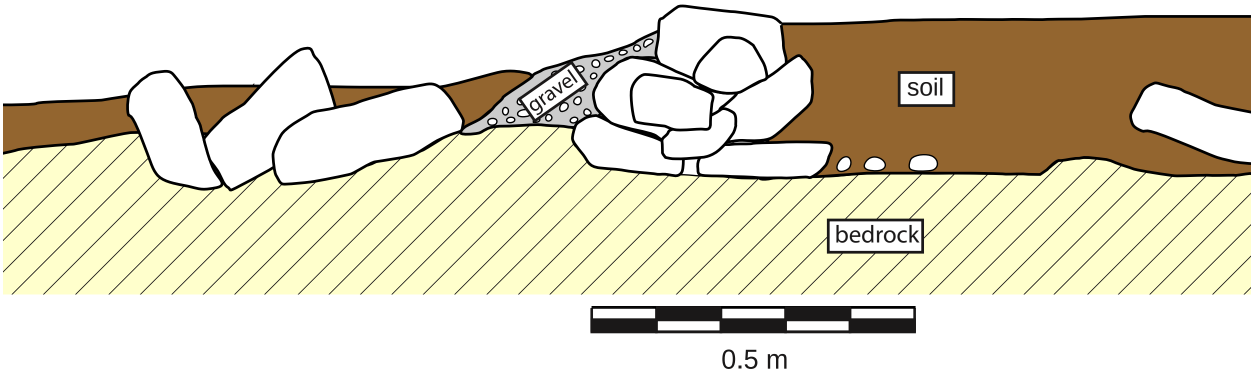

Figure 5.24: Idealized profile of a box terrace (redrawn after Beach and Dunning 1995: Figure 4b). Reproduced with kind permission of Timothy Beach, Nicholas Dunning and the Soil and Water Conservation Society.

5.3.2.3 Footslope terraces

Footslope terraces are located at the foot of long or steep slopes (slope-toe surfaces) that are too steep for the construction of dry-slope terraces (Dunning and Beach 1994: 59). They are designed to control erosion by catching eroded sediments from hillslopes and in doing so form large acreages at the base of hills (Beach *et al.* 2002: 387; Kunen 2001: 326; Macrae and Iannone 2011: 186; see Figure 5.25). The excavation of a footslope terrace near Tamarindito (Dunning and Beach 1994: 60) showed that it had been constructed by erecting two parallel walls of assembled stones and filling the space between with rubble.

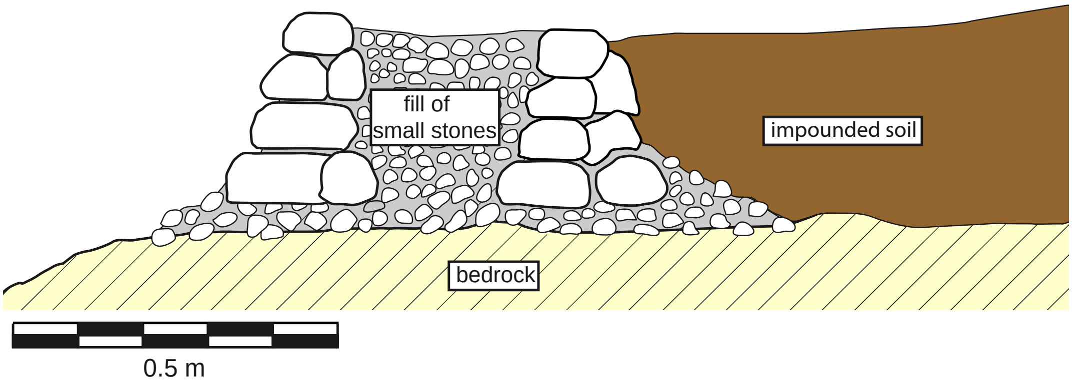

Figure 5.25: Reconstruction of a footslope terrace near Tamarindito (redrawn after Beach and Dunning 1995: Figure 4c). Reproduced with kind permission of Timothy Beach, Nicholas P. Dunning and the Soil and Water Conservation Society.

5.3.2.4 Check-dam terraces

Check-dam terraces are also referred to as “*weir-terraces*” or “*cross-channel-terraces*”. They are usually short in length and height, were constructed across gullies, drainages and other topographic constrictions and served to control the canal discharge (Beach *et al.* 2002: 379; Kunen 2011: 326; Macrae and Iannone 2011: 186). In doing so, water and sediments were more likely to be diverted in such a way that level acreages evolved (Donkin 1979: 131; Dunning and Beach 1994: 59; Wilken 1987: 99; see Figure 5.26). The documentation of check-dam terraces in the Upper Belize River Valley clearly shows several short terrace walls located at regular distances from each other that run perpendicular to the course of the streams between them (Kunen 2001: 329). Near the site of Tamarindito (Petexbatun region), several check-dam terraces assembled out of rubble walls were documented and in each case their centers were anchored with large blocks (Dunning and Beach 1994: 59). In order to facilitate drainages in creeks, check-dam terraces were constructed more frequently on gravel beds than the limestone bedrock (Kunen 2001: 331).

Check-dam terraces are often underrepresented in the archaeological record since the heavy, water-soaked soils behind the walls exerted a greater pressure than other terraces, such as the dry-slope terraces. This results in collapse and being covered with sediment (Dunning and Beach 1994: 59). In the case of the Petexbatun region, it appears that check-dam-terraces that crossed smaller creeks and presumably served the primary purpose of delaying erosions were never cultivated (Kunen 2001: 331).

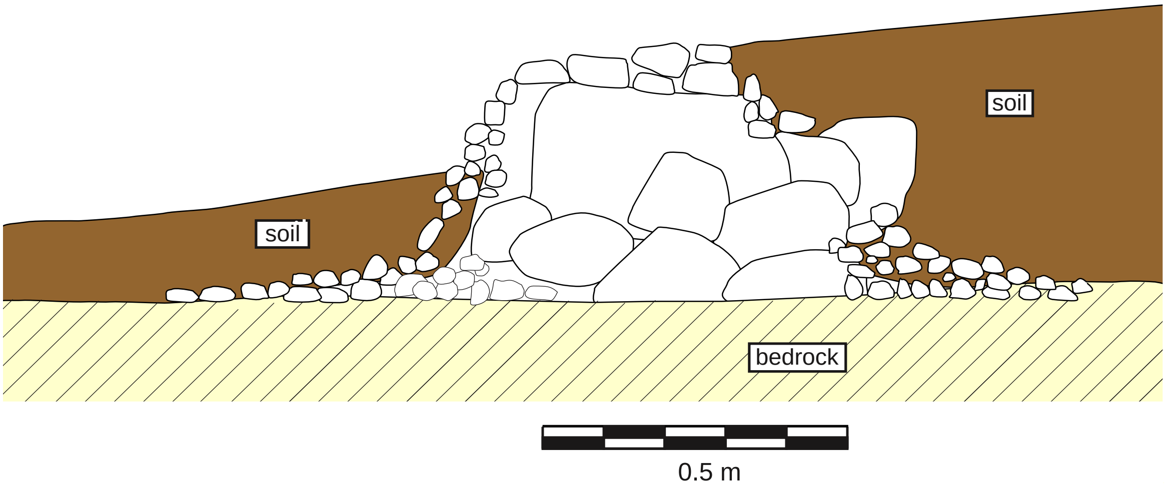

Figure 5.26: Reconstructed check-dam terrace (redrawn after Beach and Dunning 1995: Figure 4a). Reproduced with kind permission of Timothy Beach, Nicholas P. Dunning and the Soil and Water Conservation Society.

These four basic terrace types share some similarities in their composition. Besides the differing construction methods of dry-slope terraces, the compositions of the documented features are quite similar. The main difference lies in their respective location within a cultivated area (Kunen 2001: 326). According to Crandall (2009: 14), the double filling technique, which was applied during the construction of terraces in the Maya region (Murtha 2002), is quite similar to the subterranean water tanks of the Inca (Treacy 1994; see Figure 5.30).

5.3.3 Geographic distribution of terrace systems

So far, terrace systems have only been documented in a very small array of Maya sites, but ongoing research is showing that they originally covered an extensive area of the Maya Lowlands (Beach *et al.* 2015a: 21). In fact, terrace systems are not regularly distributed in the Maya Lowlands because factors such as the slope gradients, soils and subsurface heavily limit their diffusion. As Dunning and Beach (1994: 62 with Figure 12) suggested, this phenomenon is a direct result of the surface geology of the Maya Lowlands (see Chapter 2.1.1). Due to the tectonic movements, which led to considerable foldings and faults (resulting in the Horst- and Graben landscape), terrace systems are confined to the Central and southern Maya Lowlands (Dunning and Beach 1994). However, Dunning and Beach (1994: 51) suggested that the irregular distribution of terrace systems could also reflect the regional population pressure.

Most terraces are located in areas with a relatively moderate slope and especially where slopes are partially broken into natural steps by rock outcrops of the limestone bedrock (Dunning and Beach 1994: 62). Regions with numerous terrace systems typically have moderate slope gradients and a horizontal bedrock structure (Dunning and Beach 1994: 62; see Figure 5.31). On the other hand, terrace systems are less frequent in regions with steep, long, convex and unbroken slopes (Dunning and Beach 1994: 62).[83]

At the current state of research, the Vaca Plateau, the Maya Mountains, Northern Belize, the Petexbatun area, and the Río Bec region have been identified as the main areas for agricultural terraces (Beach *et al.* 2002, 2008, 2015a: 20; see Table 2). It should be stressed that a more focused survey for agricultural terraces would undoubtedly result in the discovery and identification of pre-Hispanic terraces in other parts of the Maya Lowlands. Furthermore, it is surprising that even in areas (e.g. the central Petén) that were thoroughly surveyed, terraces were not documented (Dunning and Beach 1994: 52).[84] Although recent surveys in Tikal (Dunning *et al.* 2015b: 179) might indicate the presence of agricultural terraces, it has to be noted that these systems show a very limited geographical distribution (see Table 2 and Figure 5.27).

No.	Location	Original source
1	Río Bec Region	Healy *et al.* 1983; Kunen 2011; Turner 1978.
2	Mirador Basin	Hansen *et al.* 2002; Mártinez-Hidalgo *et al.* 1998.
3	San Bartolo	Beach *et al.* 2009.
4	Petexbatun-region	Beach and Dunning 1994; Dunning and Beach 1994.
5	Río Bravo Region	e.g. Hageman and Lohse 2003; Kunen 2001; Weiss-Krejci *et al.* n.d.
6	Upper Belize River Valley	Fedick 1994; Healy 1990; Healy *et al.* 2007; Neff *et al.* 1995.
7	Vaca Plateau	Chase and Chase 1998; Coultas 1994; Dunning and Beach 1994; Healy *et al.* 1983; Macrae 2010; Murtha 2002; Macrae and Iannone 2011; Pollock 2006.
8	Maya Mountains	Dunham *et al.* 2009.
9	Copán	McNeil *et al.* 2012; Turner and Johnston 1979.

Table 2: Geographic distribution of terrace systems.

The current state of research indicates that the pre-Hispanic Maya only chose the most ideal areas for slope modifications with terraces. In contrast to the Petén, the Vaca Plateau (a limestone promontory of the Maya Mountains with many granite outcrops), the Maya Mountains and the regions around Río Bec feature ideal conditions for slope modifications in the form of stone terraces (Beach *et al.* 2002, 2008, 2015a: 20; Dunning and Beach 1994: 63). This relationship becomes clear in consideration of the site of Pacbitun, Belize. In Pacbitun, Healy *et al.* (2007: 22) determined that the site's western section, which is marked by smooth slopes and deep soils, featured far more terrace complexes than the east section of the settlement where slopes were steeper, less even and covered with thin and skeletonized soils (Richie 1990: 182). Furthermore, the majority of residential structures were grouped in the periphery of the western terrace areas (Healy *et al.* 2007: 22; Sunahara 1995: 133). In flat terrain, terrace systems are not expected. This pattern is confirmed in the archaeological record from the border area of the Far West

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[83] According to Dunning and Beach (1994: 63) the highly folded bedrock structure in parts of the Petén and Belize lacking horizontal bedrock-outcrops that create natural slope terraces could be the reason why terrace systems were not able to develop in those areas.

[84] According to Dunning and Beach (1994: 60), this phenomenon could partially be contributed to the fact that terrace systems are very hard to discern under dense vegetation (such as in the case of Ceibal, see Tourtellot 1988). According to Dunning and Beach (1994: 61), the possible application of other forms (everything besides from stone terraces), such as slope protections could explain the general lack of similar terrace systems in the central Petén and other hilly regions of the Maya Lowlands.

Bajo, where Kunen (2001: 337) was unable to find a single terrace in an agricultural zone featuring level terrain. This is in stark contrast to the surrounding hillside zones, which featured numerous terraces.

Figure 5.27: Geographic distribution of terrace systems in the Maya Lowlands (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

5.3.4 Published terrace systems from the Maya Lowlands

During the first half of the 20th century, terrace systems were only marginally studied (Dunning and Beach 1994: 52). Important publications and reports on terrace systems were published by Thompson (1931: 228) on Belize, Lundell (1940: 10) on the Petén and Guzman (1958: 400) on Chiapas (Healy *et al.* 1983: 400). So far, terraces and field walls have only been studies in greater detail in nine regions of the Maya Lowlands:

The Río Bec Region (1), the Mirador Basin (2), San Bartolo (3), the Petexbatun Region (4), The Río Bravo Region (5), the Upper Belize River Valley (6), the Vaca Plateau (7), the Maya Mountains (8), and Copán (9). The following chapter will provide an overview of the different ways in which terrace systems were adapted to specific geographic conditions.

5.3.4.1 Río Bec Region

The terraces of the Río Bec region are dispersed along karstic hills and limestone combs (Kunen 2011: 328). During the 1970s, Turner (1983) documented 549 terrace systems. Apart from some occasional check-dam terraces, most of the documented features were dry-slope terraces, which had been constructed in regular and parallel patterns on hillslopes and in drainages (Kunen 2011: 328). On some occasions, Turner (1978: 177) documented field-demarcation walls. In most cases, the terraces were closely associated with residential groups situated above the hilltops, or those that had been integrated into the landscape (Kunen 2001: 329, with Figure 3A). Based on these results, Turner (1983) calculated that the region would have originally featured a density of 314 terraces for each km^2 and claimed that these systems would have been built between the second half of the Early Classic and the end of the Late Classic (Healy *et al.* 1983: 407).

5.3.4.2 Mirador Basin

In the west group of Nakbe, Hansen *et al.* (2002: 283) documented a garden terrace system with an extension of 20 x 120 m (see Figure 5.28). The soils piled up behind the terrace walls had apparently been imported from a nearby bajo. In another terrace construction (Operation 31 X), the pre-Hispanic Maya even piled up a 2.5 m thick layer of imported bajo sediment (Hansen *et al.* 2002: 286; see Figure 5.29). Hansen *et al.* (2002: 286) observed that this sediment had apparently been applied on top of the sascab during the construction process. Sediments imported from bajos were also documented in fields enclosed by stones (Hansen et al. 2002: 287; Mártinez Hidalgo *et al.* 1998: 327). Following these observations, Hansen *et al.* (2002: 288) speculated that wetlands would have been a primary source of fertilizers for upland terraces, which would have dramatically increased the productivity of the terraces fields (Parry 2007: 32).

Figure 5.28: Nakbe, Map of the east- and west groups. The dotted areas in the southern portion of the site were identified as terrace constructions (darker points) and fields with imported bajo sediments (lighter points) (modified from Hansen 2000: Figure 60. Original graphic was produced by Rolf Krause/Rolli Arts). Reproduced with kind permission of Richard D. Hansen and Rolf Krause at Rolli Arts.

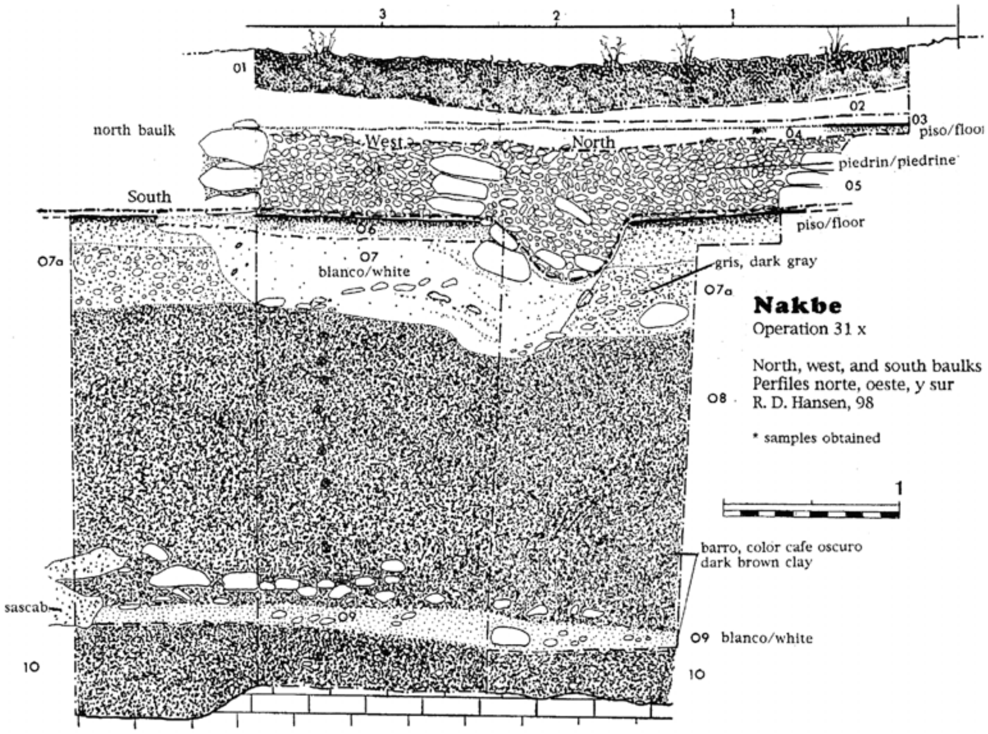


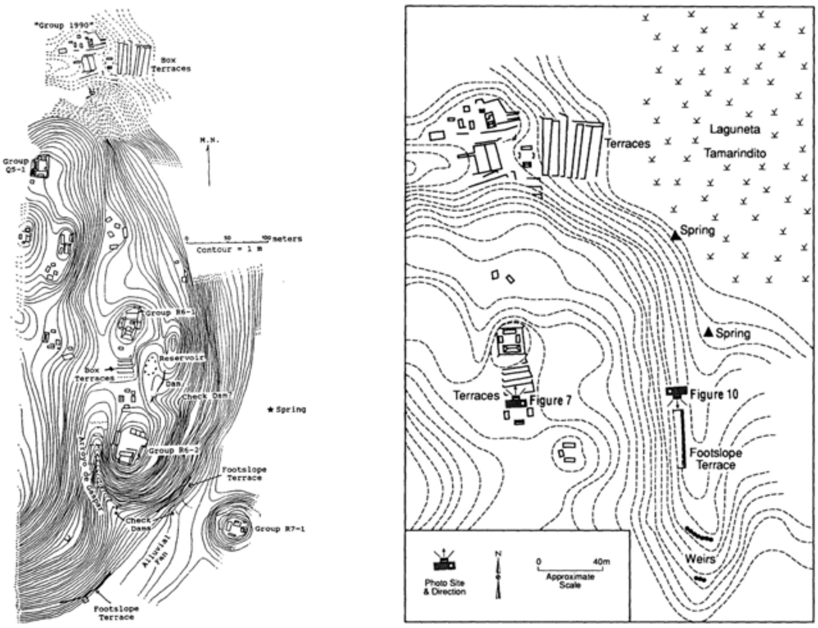
Figure 5.29: Nakbe, Profile of terrace construction (Operation 31) (source: Hansen et al. 2002: Figure 20). Reproduced with kind permission of Richard D. Hansen.

5.3.4.3 San Bartolo

Close to the Bajo Tintal, Beach *et al.* (2009: 1713) documented a number of dry-slope terraces. Excavations at nearby dwellings indicated that these terraces had been built during the Late Preclassic (Beach *et al.* 2008: 1714). Pollen recovered from sediments in the Aguada Tintal further suggested that the Preclassic Maya farmers were cultivating maize, manioc, and cotton around Bajo Donato (Beach *et al.* 2009: 1714).

5.3.4.4 Petexbatun Region

Due to the marked Horst-/Graben topography of the Petexbatun region, terrace systems and field-wall systems were documented in a number of sites such as Tamarindito and Aguada Catolina (Dunning and Beach 1994). Along the broad and gentle slopes of this region, Beach and Dunning (1994: 138) documented numerous dry-slope terraces. Natural drainages on the other hand, had been modified by box terraces, while the base of steep slopes had been fortified by large footslope terraces (see Figures 5.30 and 5.31). In addition to these features, Dunning and Beach (1994: 58) documented field boundary walls that showed a close association with elite residential areas on hilltop locations (Kunen 2011: 331).



a) Tamarindito, Map of eastern settlement area

b) Map of terraces near Laguna Tamarindito

Figure 5.30: Tamarindito, Map of terrace systems. (a) (source: Dunning *et al.* 1997: Figure 5); (b) (source: Dunning and Beach 1994: Figure 6). Reproduced with kind permission of Nicholas P. Dunning and Cambridge University Press.

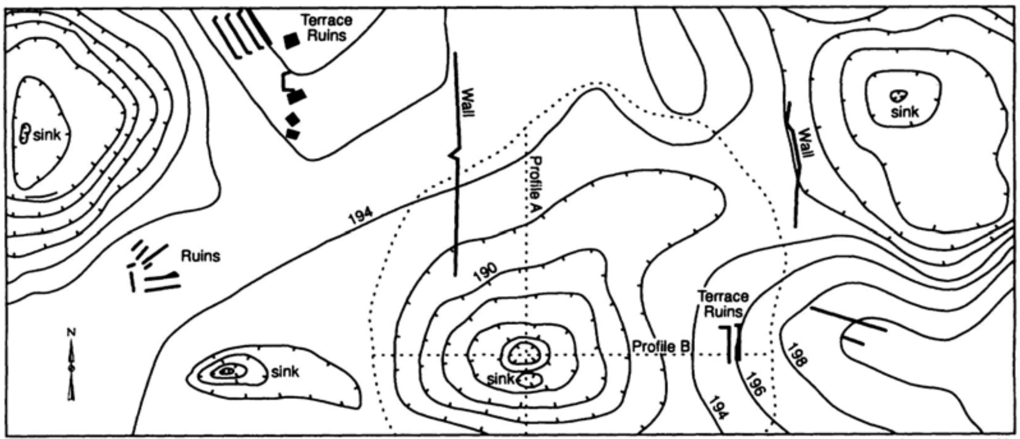


Figure 5.31: Map of Aguada Catolina (source: Dunning and Beach 1994: 55, Figure 4). Reproduced with kind permission of Nicholas P. Dunning and Cambridge University Press.

5.3.4.5 Río Bravo Region/Northwest Belize

The Río Bravo Conservation and Management Area (RBCMA), which is owned and managed by the non-profit organization Programme for Belize (PfB), lies at the eastern edge of the Petén Karst Plateau and is marked by two escarpments: the Booth's Escarpment and the Río Bravo Escarpment (Brokaw and Mallory 1993; Dunning *et al.* 1999: 651; Trachman 2007: 5; Weiss-Krejci n.d.). The slope gradients of these escarpments provided suitable conditions for the construction of agricultural terraces. These have been documented in the Far West Bajo, in the site core and hinterland of La Milpa, near to Dos Hombres, Blue Creek and Chawak But'o'ob, and in Guijarral (see Figure 5.32).

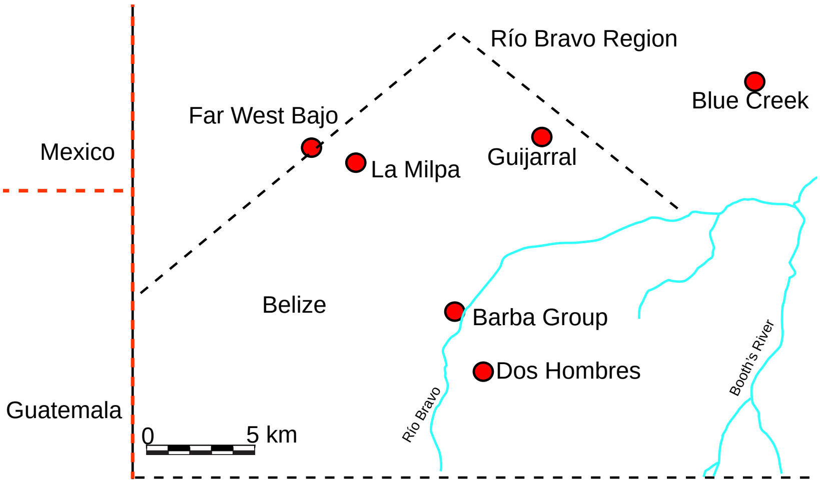


Figure 5.32: Map of terraces in the Río Bravo region (redrawn after Kunen 2001: Figure 4). Reproduced with kind permission of Julie Kunen.

Inside the Far West Bajo (3 km to the west of the La Milpa site center), Kunen (2001: 335) identified four different agricultural zones, in which more than 60 terraces with lengths between 2 and 50 m were mapped (see Figure 5.33). In these four zones, Kunen (2011: 335, 342) mostly identified footslope terraces, many contour terraces, some scattered box terraces and some field walls. These features had apparently been built during the Terminal Classic.[85] In the sloped landscape, Kunen (2001: 335) also located several small reservoirs (*small depressions*, see Chapter 5.6.1). Among these terraces, some small barriers canalized the water of small nearby streams in order to irrigate the terrace plots (Kunen 2001: 337). Behind some terrace walls, Kunen (2001: 342) also discovered sediment that the pre-Hispanic population had extracted from the nearby bajo in order to use as fertilizer.

Just outside of Dos Hombres's site center, Hageman and Lohse (2003: 116) studied three settlement areas (El Barba Group, Caro Zaro and Las Terrazas) (Hageman and Goldstein 2009: 2843). These surveys led to the discovery of numerous footslope terraces and check-dam terraces, which had apparently been built in order to reduce the risk of erosion and lessen the slope gradients from 7-9° to 1-3° (Hageman and Lohse 2003: 116; see Figures 5.39a, 5.39b, and 5.39c).

Near Blue Creek, numerous clusters of dry slope-terraces were documented in the settlement units of Nukuch Mul, the Rosita Group, U Xulil Beh and the La Lucha highland area (Guderjan *et al.* 2003: 85; Hughbanks 1998; see Figure 5.34). In the hinterland of La Milpa, Tourtellot (e.g. Tourtellot *et al.* 2003: 40) located numerous stone piles and small residential structures along the base of a limestone hill that were connected to footslope terraces and field walls. Tourtellot *et al.* (2003: 40) concluded that they were constructed during the Late Classic as a reaction to a massive population increase. Box terraces were also documented in close proximity to the Aguada Lagunita Elusiva (Weiss-Krejci n.d.).

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[85] These field walls were not running parallel to the hill contours, but instead formed convex and V-shaped patterns. Kunen (2001: 335) suggested that these features might have fulfilled the same function as the field walls in the Yalahau region. Here, Fedick *et al.* (2000) reported that these features would have slowed the drainage of heavy rainfall and, consequently would have averted excess soil erosion.

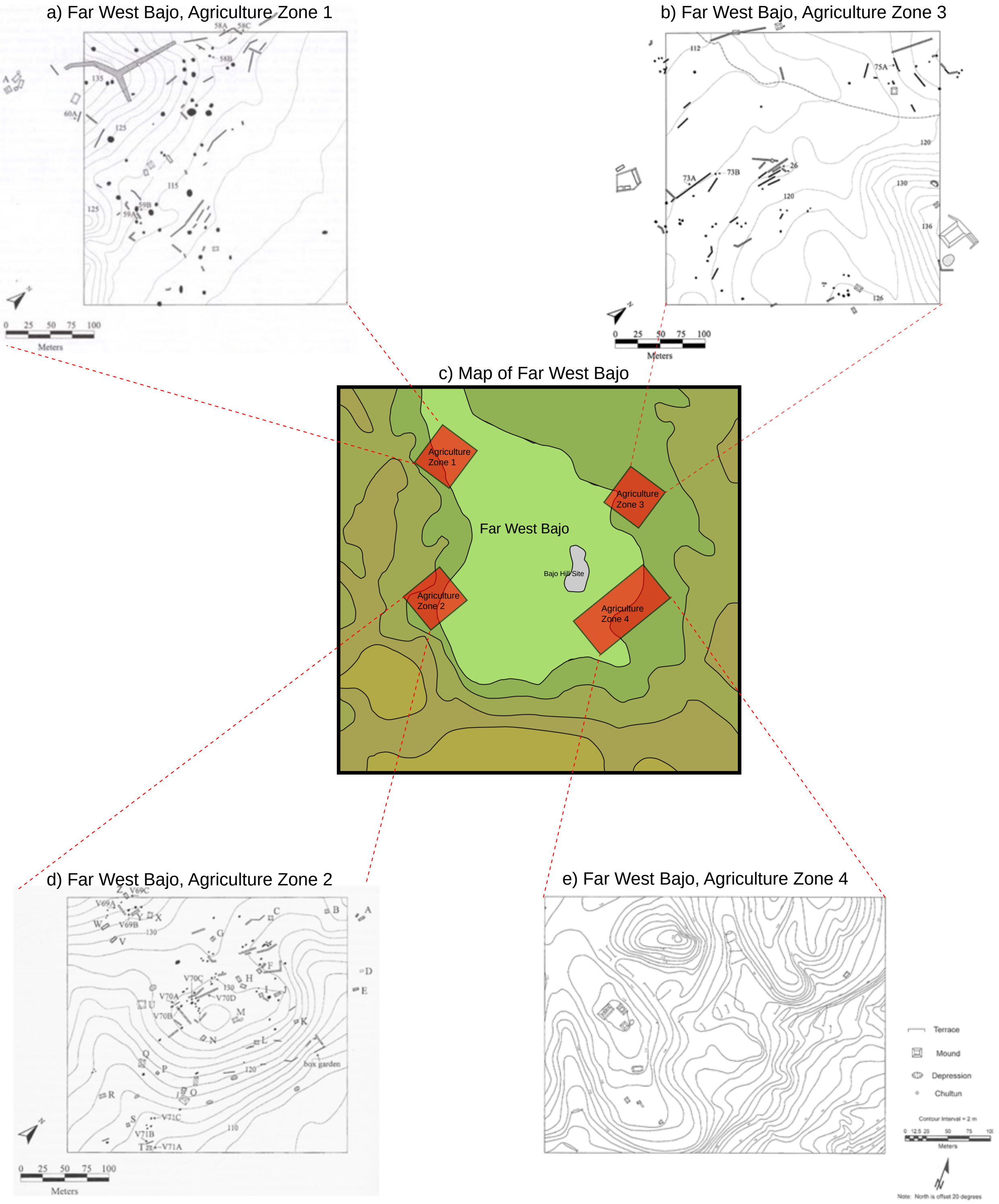
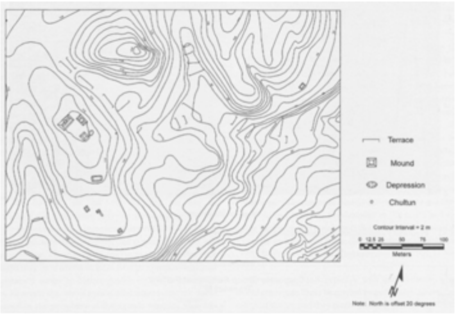


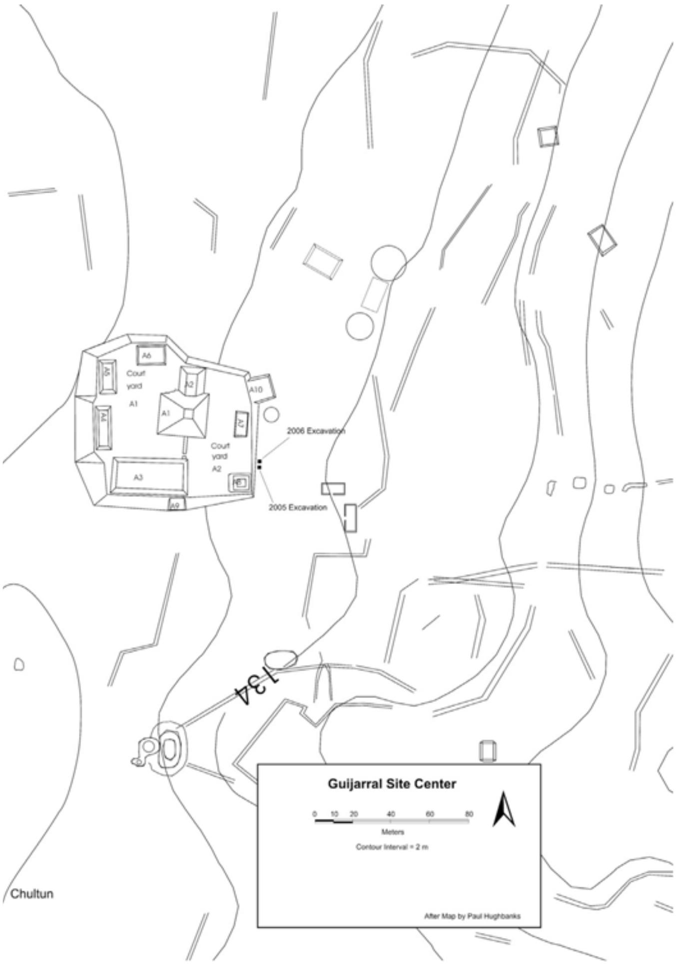
Figure 5.33: Far West Bajo, Map of terrace systems. (a) (modified from Kunen 2001: Figure 5.73); (b) (modified from Kunen 2001: Figure 5.75); (c) (redrawn after Kunen 2001: Figure 5.72); (d) (modified from Kunen 2001: Figure 5.74); (e) (modified from Kunen 2001: Figure 5.76). Reproduced with kind permission of Julie Kunen.

In Guijarral, a rural site located in the Bravo Hills northeast of La Milpa and southwest of Blue Creek, Hughbanks (1998: 107) documented a series of agricultural terraces closely associated with residential areas (see Figures 5.34b and 5.34e). In the site, he located over 140 agricultural terraces built during the Early and Late Classic Period (Hageman and Goldstein 2009: 2843; Hughbanks 1998: 107; Sullivan *et al.* 2008: 100). In Chawak But'o'ob, an escarpment site along the Rio Bravo drainage, Hanna *et al.* (2006) documented several residential terraces, which supported a number of domestic platforms and multi-roomed foundation braces (Hanna and Walling 2011: 2).

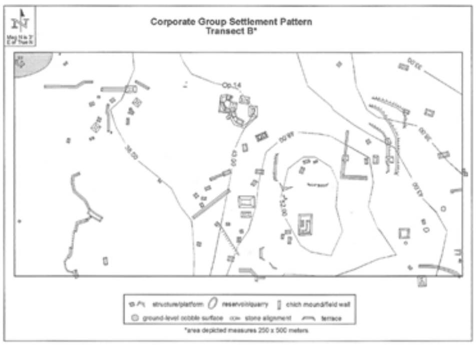
a) Dos Hombres, Terraces in El Barba Group



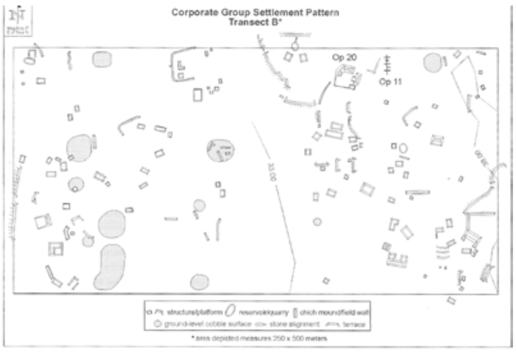
b) Guijarral, Terraces in the site center



c) Dos Hombres, Terraces in Group Cerro Zaro



d) Dos Hombres, Terraces in Las Terrazas Group



e) Guijarral, South profile of terrace construction

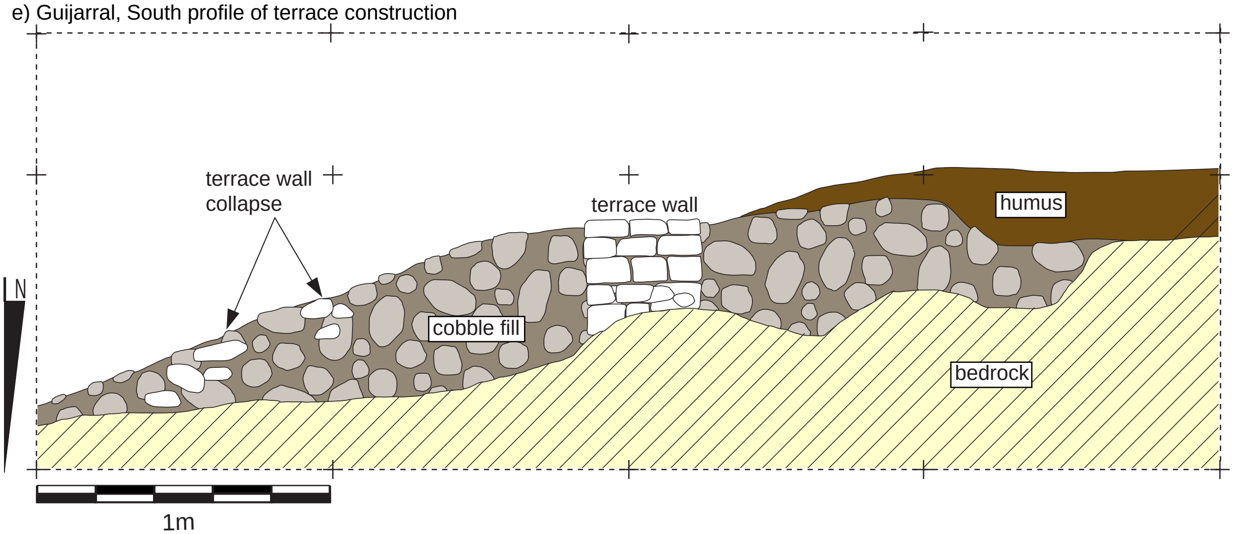


Figure 5.34: Location of terraces in Dos Hombres and Guijarral. (a) (source: Hageman and Lohse 2003: Figure 9.5); (b) (source: Hageman and Goldstein 2009: Figure 2. Reproduced with kind permission of John Hageman and Elsevier); (c) (source: Hageman and Lohse 2003: Figure 9.6); (d) (source: Hageman and Lohse 2003: Figure 9.4). Reproduced with kind permission of John Hageman and the University of Arizona Press; (e) (redrawn after Kunen and Hughbanks 2003: Figure 8.6). Reproduced with kind permission of Julie Kunen and the University of Arizona Press.

5.3.4.6 Upper Belize River Valley

In the territory of the Upper Belize River Valley (West Belize), which is marked by undulating limestone plains, Fedick (1994: 107) mapped the remains of 14 Late Classic terrace systems. These included check-dam terraces, contour terraces and box terraces, all of which featured a distinct connection to residential areas (Kunen 2001: 329; see Figure 5.35).

In Xunantunich, 191 terrace systems were mapped during a settlement survey in an area of 6 km^2 with gentle and moderate slopes (Neff *et al.* 1995: 157). Without conducting any excavations, these complexes were dated to the Late Classic (Ashmore *et al.* 1994: 266).[86]

In Pacbitun, a regional center with an area of approximately 9 km^2 located at the southern border of the Upper Belize River Valley, several terrace systems were documented. These were located along the slopes of the foothills of the Maya Mountains and were apparently not studied in great detail (Healy 1990; Healy *et al.* 2007: 17).

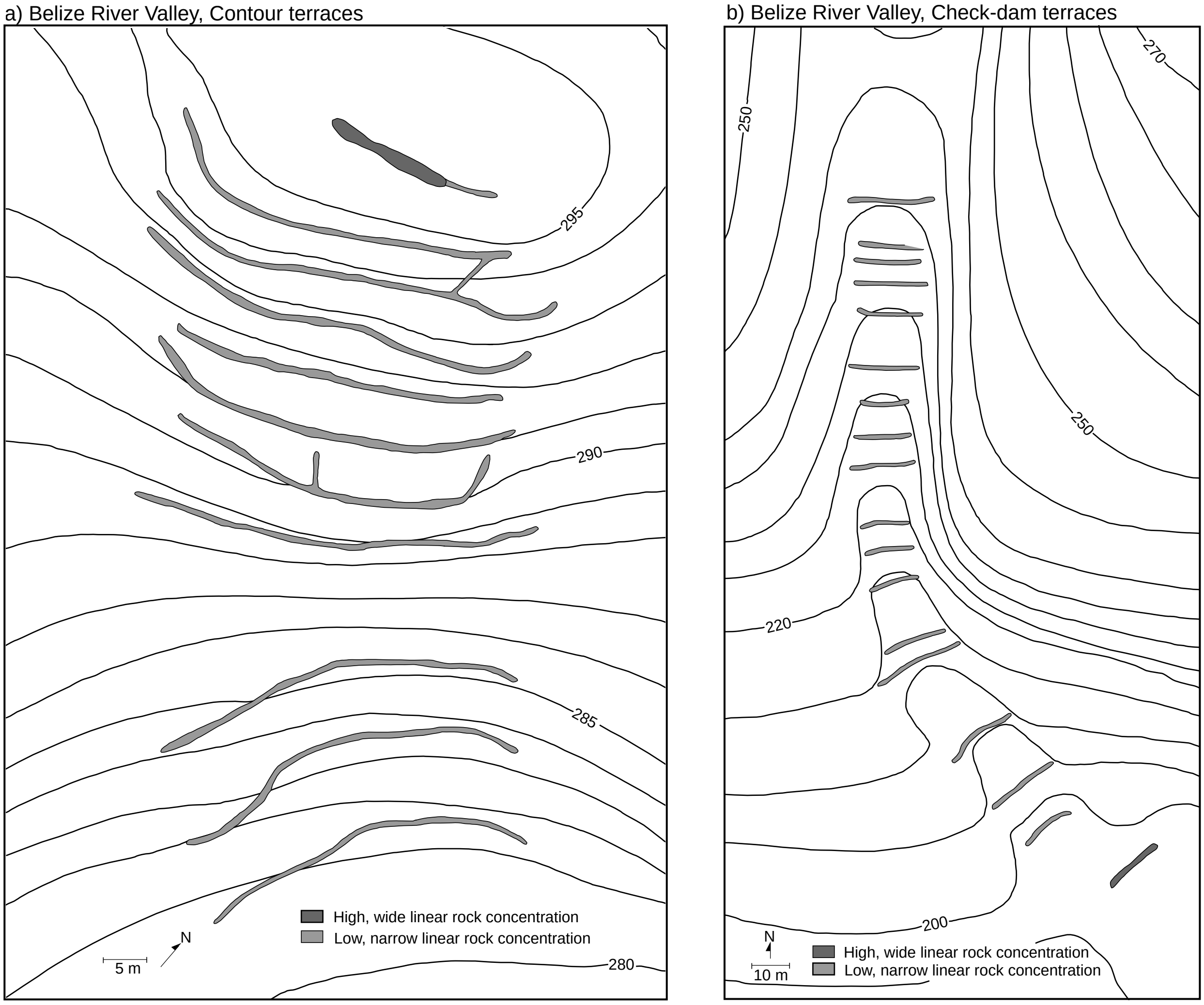


Figure 5.35: Topographic location of terrace-systems in the upper Belize River Valley. (a) (source: Fedick 1994: Figure 12); (b) (source: Fedick 1994: Figure 13). Reproduced with kind permission of Scott Fedick and Cambridge University Press.

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[87] Neff *et al.* (1995) divided these terraces into four categories:
Terraces within fields, which were directly connected to house mounds and hence had a domestic function or were used as house gardens (category 1 and 2). Terraces outside of the fields, which had been constructed parallel or at regular distances from one another and surrounded a singular mound, were interpreted as "field houses" (category 3) and the most common terraces, those outside of the fields showing no connection to domestic structures (category 4).

5.3.4.7 Vaca Plateau

The Vaca Plateau is a limestone promontory of the Maya Mountains with many granite outcrops and is very suitable for the construction of terraces (Dunning and Beach 1994: 63). Therefore, the area has the highest documented concentration of agricultural terraces of the entire Maya Lowlands. In the sites of Mountain Cow and Zayden Creek, Healy el al. (1983: 402) located double wall terraces, (see Figure 5.36a), single wall terraces (see Figure 5.41b) and double wall terraces with an additional supporting layer of gravel (see Figure 5.36c). Curiously, the recovered ceramic material indicated construction during the Preclassic (Healy *et al.* 1983: 402).

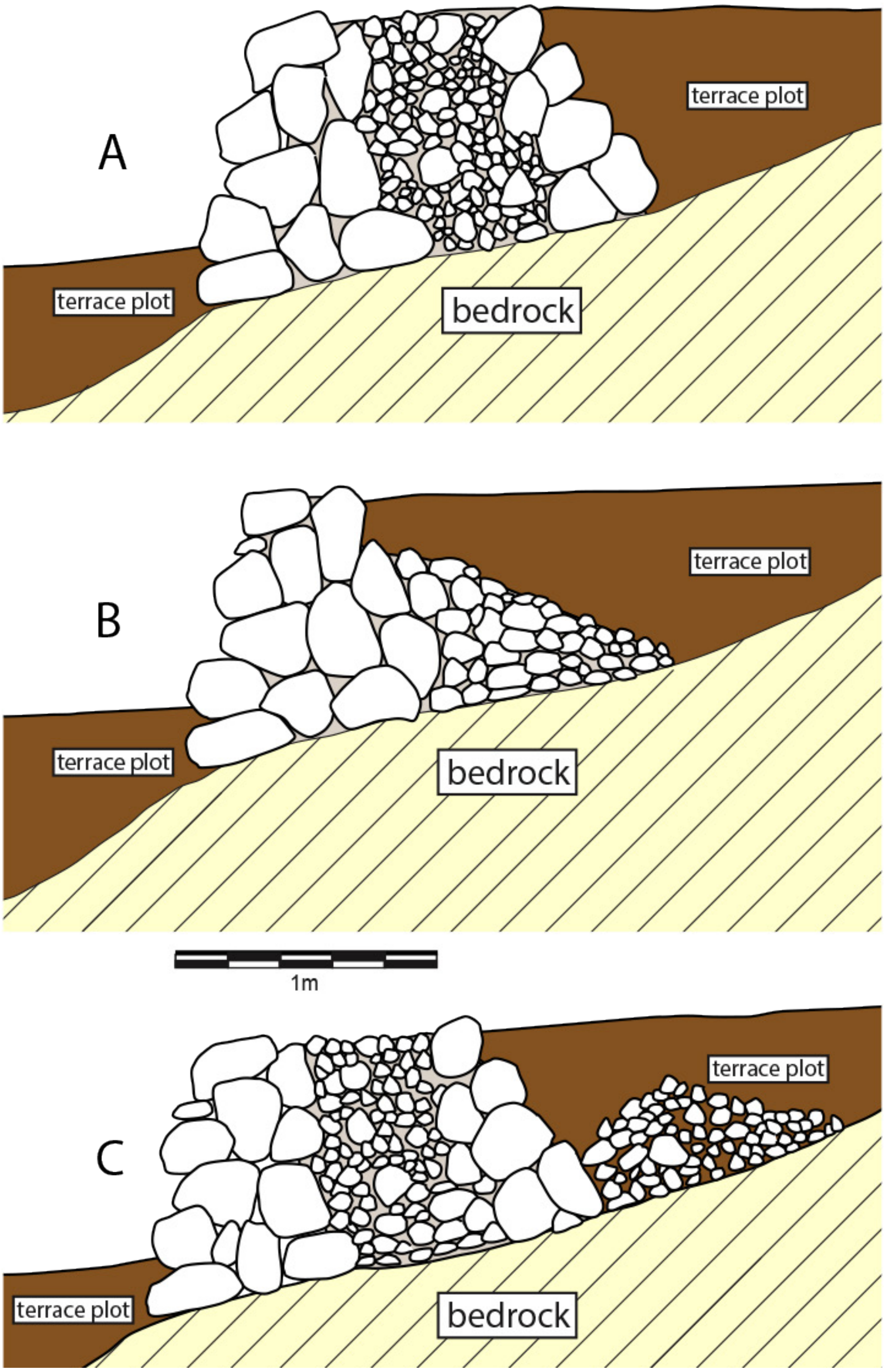

Figure 5.36: Terrace types of the Vaca Plateau (redrawn after Healy *et al.* 1983: Figure 4). Reproduced with kind permission of Paul F. Healy.

5.3.4.7.1 Minanha

In Minanha, Macrae and Iannone (2011: 183) surveyed and excavated several terrace systems located 1.5 km southeast of the site center in the Contreras Valley. Pollock (2006) carried out earlier studies of terrace systems at the site as well (Macrae and Iannone 2011: 185; see Figure 5.38). Altogether, Macrae and Iannone (2011: 186) mapped 133 structures and 730 terrace sections that formed a complex network incorporating several springs (Macrae 2010). Most of these terraces could be defined as dry-slope terraces, which were located along the slopes of the interfluvial hills and the primary valley (Macrae and Iannone 2011: 186). In addition, Macrae and Iannone (2011: 188) documented a small number of footslope terraces.

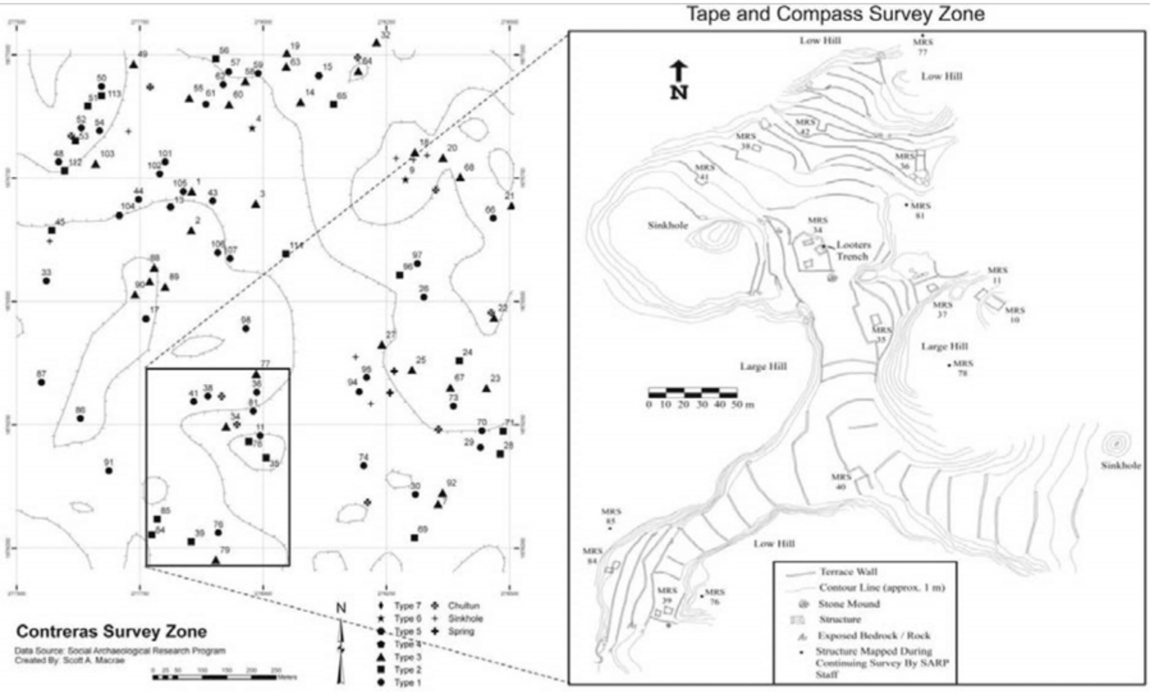

Figure 5.37: Minanha, Contreras Valley, Map of terrace features (source: Macrae and Iannone 2011: Figure 3). Reproduced with kind permission of Scott Macrae and courtesy of the Social Archaeology Research Program (SARP). Courtesy of the Institute of Archaeology, National Institute of Culture and History, Belize.

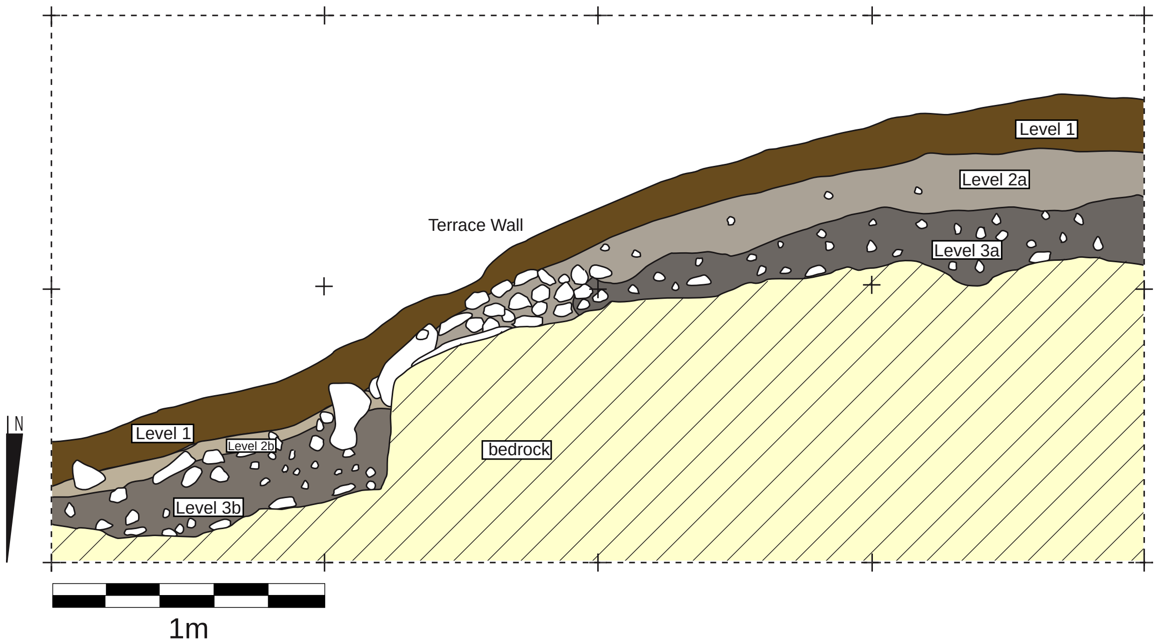

Figure 5.38: Minanha, Contreras Valley, Terrace, OP111-2, South-profile (redrawn after Pollock 2006: Figure 28; reproduced with kind permission of Adam Pollock).

A spatial analysis revealed that the highest quality terraces were located in close proximity to residential structures and/or key agricultural locations that exhibited better access to water and productive soils (Macrae and Iannone 2011: 188). Furthermore, the excavations showed that the pre-Hispanic builders had taken advantage of the step-like nature of the natural bedrock surface (Pollock 2006: 140; see Figure 5.38). In Waybil, a subsidiary site 1.92 km southwest of Minanha, large clusters of agricultural terraces were documented through LiDAR surveys (Macrae and Iannone 2016: 372). Subsequent archaeological excavations indicated that the terraces had mostly been constructed during the Late Classic Period (Macrae 2016).

5.3.4.7.2 Terrace systems of Caracol

The terraces documented in Caracol represent the largest known cluster of terrace systems in the Maya Lowlands and therefore received an intensive investigation. After an initial description by Healy *et al.* (1983), Chase and Chase (1998: 61) carried out an extensive mapping of Caracol's terrace systems with compass and tape. The recent LiDAR Scanning of Caracol's landscape enabled a higher resolution depiction of the pre-Hispanic settlement landscape allowing the identification of numerous previously unknown terrace features (Beach *et al.* 2015: 20; Chase *et al.* 2014). In this chapter, the presentation of Caracol's terrace systems will focus solely on their incorporation into the settlement landscape. The general history and the interaction of the hydraulic and agricultural features will be presented in Chapter 5.7.6. Within Caracol, Kunen (2001: 329) defined five areas of densely arranged terrace systems located at a distance of 1 to 5 km from the site center (Chase and Chase 1998: 64, with Figures 2, 3, 4, 5, 6, and 7):

Terrace Area 1 lies on a prominent hilltop close to Caracol's center and to the south of the southern Acropolis (Chase and Chase 1998: 65). In this area, the terraces are in close proximity to residential areas. Upon this hilltop, the Pajaro Ramonal causeway runs diagonally through the landscape and connects to the southern Acropolis (Chase and Chase 1998: 65). The residential groups of this area contain both large and small structures and the terraces are mostly dry-field terraces.

Terrace Area 2 is located between the Conchita causeway and the Pajaro Ramonal causeway in a low elevation area with little relief energy (Chase and Chase 1998: 65). The documented weir terraces of this area mostly date to the Late Classic (Chase and Chase 1998: 65). The southern section of this area is marked by a lengthy, north-south oriented valley intersected by two low walls that Chase and Chase (1998: 65) interpreted as silt-traps or dams. A third semicircular wall might have served as a sort of dam or bulwark (Chase and Chase 1998: 65). The valley descends towards the north and features a series of very broad weir terraces (Chase and Chase 1989: Figure 5).

Terrace Area 3 is defined by an extremely hilly landscape and features a broad plateau in its eastern portion (Chase and Chase 1998: 65). Within the area, Chase and Chase (1998: 1998: 65) documented weir terraces and linear dry field terraces with lengths of up to 600 m. Many of these terraces were sloped along their length causing the water to seep through laterally (Chase and Chase 1998: 70). In this area, Chase and Chase (1998: 70) also located distinct "guide-walls" running perpendicular or diagonal to the respective slopes and either served to divert or slow the flow of water.

Terrace Area 4 lies between 3.7 and 5 km to the northeast of the site center. In this area, the different applications of the various terrace types can be clearly observed. While the valleys with marked slopes have been modified with weir terraces, the cultivable land between the residential areas is covered with dry-field terraces (Chase and Chase 1998: 65).

Terrace Area 5 (Healy's mapping area) is located 3 km to the east of the site center. Here, the terrace systems were uniform in size and constructed at regular distances from each other, which indicated that their construction was well-planned and coordinated (Kunen 2001: 329; Chase and Chase 1998: 60; with Figure 5).[87]

Due to the good preservation and the extensive study Caracol has experienced, a particular construction pattern of the various terrace types has become apparent. This indicates that the pre-Hispanic Maya chose a specific terrace type based on the particular topographic location. The terraces of Caracol feature front walls constructed out of large, unworked stones stacked several layers high (Coultas *et al.* 1983; Healy *et al.* 1980, 1983: 404).

Their heights varied between 0.20 and 3.00 m (Chase and Chase 1998: 69; see Figure 5.39). The central factor determining the construction form was the slope-inclination. Generally, the highest terrace walls were built along the steepest slopes, whereas lower terraces were concentrated on slopes with lower gradients (Chase and Chase 1998: 69; see Figure 5.39). The gradient of slopes modified with terraces in Caracol ranged between 2° and 27° (Chase and Chase 1998: 70).

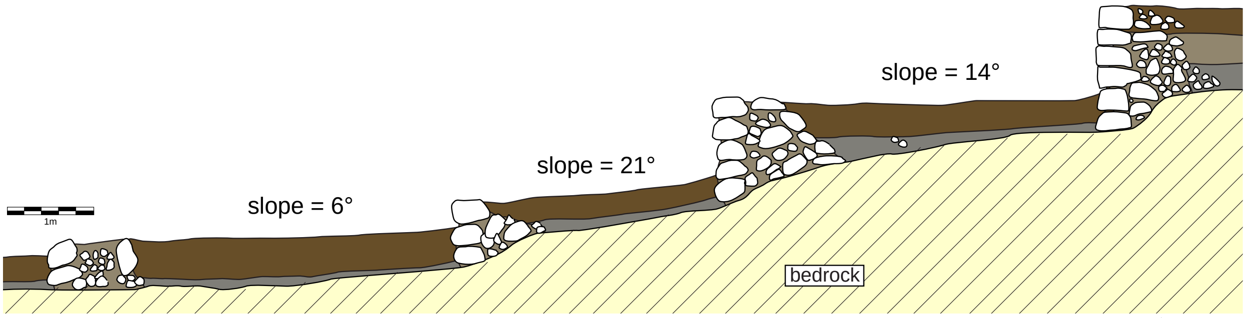

Figure 5.39: Caracol, Schematic profile of terraces indicating the relationship between slope-gradient and wall-heights (modified from Chase and Chase 1998: Figure 8. Reproduced with kind permission of Arlen Chase).

Weir terraces were mostly located in narrow valleys and constructed perpendicular to the gradient, while the linear slope terraces were mostly constructed parallel to the respective slope (Chase and Chase 1998: 70). Furthermore, the terrace constructions can be split into two general categories:

(1) Terrace walls of different heights and widths consisting of piled-up stones found throughout the site along hill slopes and valleys.

(2) Low, double-wall terraces located in valley floors or flat terrain. These terraces had a visible outer stone wall with a relatively low height of up to 50 cm. Behind these walls, the pre-Hispanic Maya piled up stones and rubble (Chase and Chase 1998: 69). According to Chase and Chase (1998: 69), these double-wall terraces were built in order to trap silt and runoff.

As the soil layer behind the studied terrace walls showed no natural soil horizons, Chase and Chase (1998: 69) speculate that they would have been applied artificially after construction (Coultas 1994; Coultas *et al.* 1993; Healy *et al.* 1983: 406). According to Chase and Chase (1998: 69), fertile soils would have been imported and applied to these plots.[88]

Based on the documented features, Chase and Chase (1987: 33) and Tourtellot (1993: 22) described Caracol as a "garden city" because the agricultural terraces would have been a key element in providing food for large populations (Healy *et al.* 1983). Based on their surveys, Chase and Chase (1998: 66, 71) also claimed that "intensive field systems" were located throughout the entire core area of Caracol (a 10 km radius around the center), and that no relatively large portion of the site was devoid of terraces. In fact, Caracol was one of the few Maya centers where all types of terraces (check-dam terraces, dry-slope terraces and box terraces) were tightly interconnected with the residential structures (Kunen 2011:

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[87] The creation of archaeological profiles revealed that the terrace walls of "hill 1" were between 60 and 165 cm high (average of 120 cm), between 150 and 340 cm wide (average of 183 cm) and up to 150 m long (Healy *et al.* 1983: 402).

[88] In making this connection, Chase and Chase (1998: 69) share the theory of Hansen *et al.* (2002).

329). In some cases, these residential areas were entirely surrounded by dry-slope terraces (Kunen 2011: 329). Furthermore, Caracol was the only site where a wide distribution of double-wall dry-slope terraces could be documented (Chase and Chase 1998: 69). Due to these observations, Chase and Chase (1998: 71) concluded that swidden agriculture would have been practiced at a considerable distance of 12 to 30 km from the center. The archaeological investigations of the residential units indicate a development over several construction phases. Chase and Chase (1998: 72) and Healy *et al.* (1983: 407) claimed that the terrace systems would have been built during the Early Classic and in use until the Terminal Classic. However, the vast majority of the terrace systems would have been built during Caracol's strongest expansion between AD 526 and 650 (Chase and Chase 1998: 61, 72).

5.3.4.8 Maya Mountains

While terrace systems had already been documented rather early in the southern Maya Mountains, they were not properly investigated before the late 1990s (Dunham *et al.* 2009: 1). A concentration of Late Classic terrace systems was studied in the site of Muklebal Tzul, located in the upper reaches of the Bladen Branch (Dunham *et al.* 2009: 1). These dry-slope terraces are located on a hillside along a nearby stream, 2 km southwest of the site core. The terrace walls consist of tightly arranged limestone blocks (Dunham *et al.* 2009: 1; see Figure 5.40). Based on the analysis of the recovered soil samples, Dunham *et al.* (2009: 1) determined that the local pre-Hispanic population had used the terrace plots to grow maize (subfamily *Panicoidae)* and bamboo (subfamily *Bambusoidae*).

Figure 5.40: Muklebal, Front-view of terrace wall (source: Dunham *et al.* 2009: Figure 3). Reproduced with kind permission of Todd J. Pesek.

5.3.4.9 Copán

The Copán Valley consists of five different basins situated from east to west: the Basin of Copán, the Basin of Santa Rita, the Basin of El Jaral and the western and eastern Basin of the Río Amarillo (McNeil *et al.* 2012: 12). Contrary to the center of Copán, which had been built at a low elevation along the Río Copán, the site of Río Amarillo is situated on the slopes of the Cerro Canteada in the eastern section of the Copán valley (McNeil *et al.* 2012: 14). The site used to be a residential area of Copán during the Late Classic and was inhabited by a small population (McNeil *et al.* 2012: 11: with Figure 1; Saturno 2000).

Within the Copán Valley, the section of the Río Amarillo receives a higher average amount of annual precipitation than the eastern section.[89] Although the precipitation rates suggest that the Río Amarillo Basin was an ideal location for cultivation, the area suffers from poor drainage (Schumann de Baudez 1983: 200). Consequently, even during the dry season, some parts of the river shore remain inundated (McNeil *et al.* 2012: 15; Schumann de Baudez 1983: 200). Furthermore, the Río Amarillo Basin also exhibits two large bodies of water: The Laguna de las Sierras and the Laguna de las Mesas (McNeil *et al.* 2012: 16).

Excavations in Río Amarillo predominantly concentrated on the site's northern section, a section largely used for residential purposes (McNeil *et al.* 2012: 15, with Figure 4). A good portion of this area was constructed on a hill with a very steep gradient, while the rest sits lower down on a slightly elevated platform (Platform 5), presumably constructed as a means of protection from flooding (McNeil *et al.* 2012: 15). During the rainy season, torrents of water flowed quickly along this area every day. Excavations revealed that a considerable portion of this runoff flowed towards a medium-sized canal or chasm that cuts the site into two halves. To impede the flooding of their dwellings and ritual structures, the inhabitants constructed several drainage canals (McNeil *et al.* 2012).

Furthermore, towards a more elevated section of the site, the pre-Hispanic inhabitants constructed a series of terraces (Terraces 1 and 2) in order to reduce soil loss and create level terrain suitable for the erection of structures or creation of fields (McNeil *et al.* 2012: 15). All of the remaining structures were either protected by or erected upon platforms (McNeil *et al.* 2012: 15). Without these fortifications, these buildings would have quickly eroded out of the hill's slope. In an earlier description, Turner and Johnson (1979: 300) also reported the existence of agricultural terraces in an acreage 5 km northeast of Copán, which according to them was quite fertile. Unfortunately, no documentation material of these features has ever been published.

In conclusion, the pre-Hispanic Maya had only constructed terrace systems in regions with adequate topographic conditions. Therefore, the geographic distribution of these features is limited to very few areas of the Maya lowlands. While terraces and the discussed canal systems had a partially agricultural purpose, the upcoming subtypes of hydraulic features are solely focused on the diversion and impoundment of water. The presentation of their distribution and functionality begins with dam features.

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[89] The basin of the Río Amarillo receives an annual rainfall of 1800-2000 mm, while the Copán Basin receives 1400-1500 mm of annual rainfall (Turner *et al.* 1983: 51-54).

5.4 Dam features

Within the Maya Lowlands, dam systems are an extensive feature type with many variations. The fact that only so few dam features have been documented so far is essentially due to the state of research. In this context, Scarborough (1991: 127) noticed that this type of feature was relatively unimportant for hydraulic systems in comparison to those in other regions of the world (e.g. Mesopotamia). Due to the very few documented features, no classification models for dam features have been published. However, according to the author's opinion, the dam features published so far can be functionally divided into two groups:

(1) Dam system connected to rivers or seasonal streams

(2) Dam systems not connected to streams (see Figure 5.41).

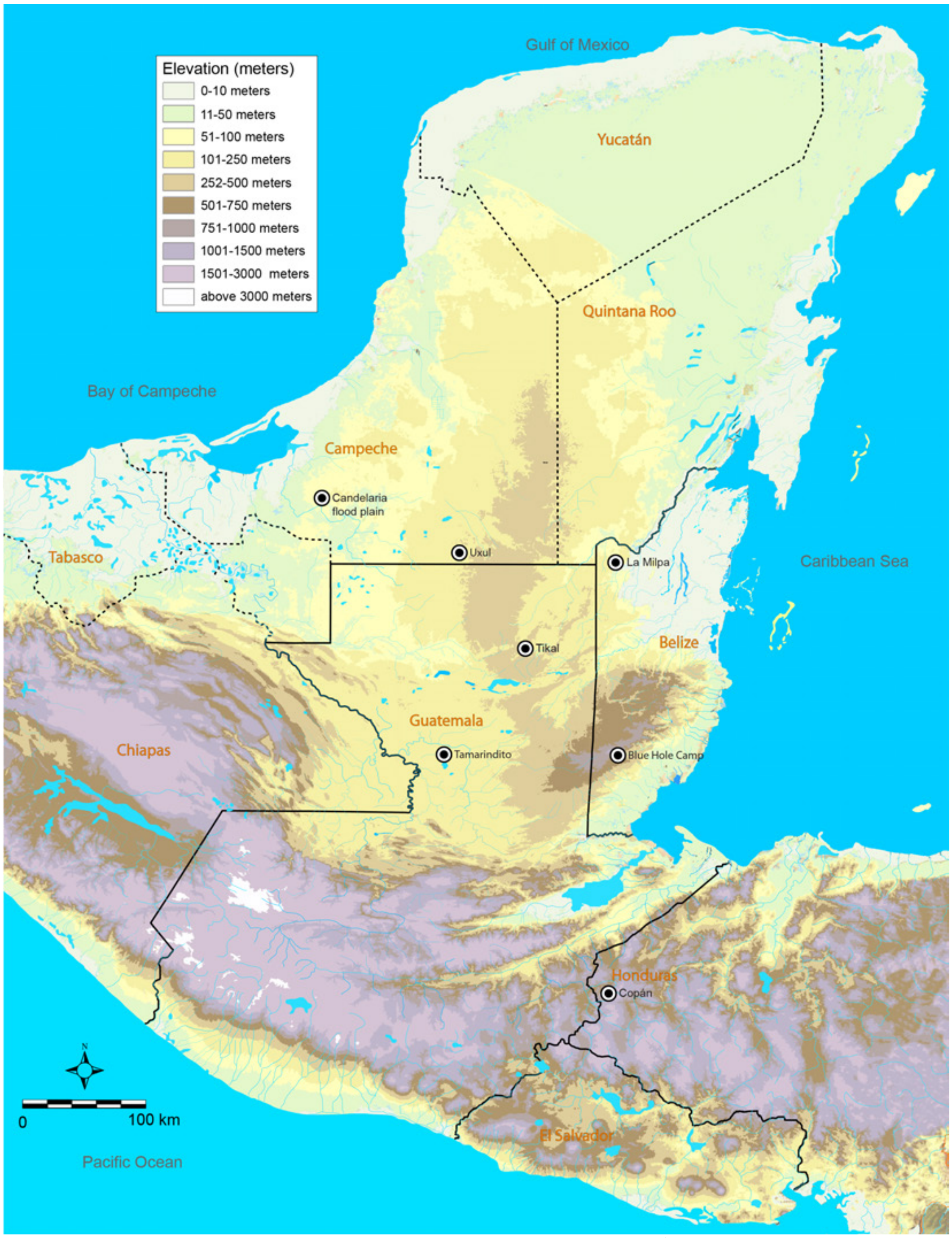

Figure 5.41: Geographic distribution of dam features in the Maya Lowlands (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

5.4.1 Dam systems connected to rivers or seasonal streams

Within this class of features, four structures have been published so far: A dam wall near Blue Hole Camp (1), a number of dam systems in the streambeds of Nakbe (2), a dam wall within the Copán Valley (3), and a number of dam systems in the Candelaria Basin (4).[90]

5.4.1.1 Dam wall near Blue Hole Camp

Near the modern day logging camp of Blue Hole Camp in the Cayo District of Belize, Healy (1983: 148) documented a pre-Hispanic dam wall, which had once overstretched the precipitous 10 m wide canyon of the Congrejo Creek (see Figure 5.42a). During the excavation of a profile trench at the back side of the construction, Healy (1983: 149) observed that the dam wall formed a standing triangle constructed of roughly worked stone blocks (see Figure 5.42e). Its base was directly built on the modified surface of the bedrock material and featured a width of 2.25 m (Healy 1983: 149; see Figures 5.42c and 5.42e). At the wall's central base, Healy (1983: 151) documented a distinctly formed opening 70 x 30 cm wide, which he interpreted as a drain hole for slower and more controlled release of water (see Figure 5.49c). Based on isolated ceramic findings, Healy (1983: 153) assumed that this dam wall had been used between AD 600 and 900. Near this structure, no terrace systems or canals that may have been used as acreages could be documented. Due to these observations, Healy (1983: 153) concluded that the dam was primarily used for the retention of water and not for intensified agriculture. According to Johnston (2004a: 282), this dam was built immediately over an unused and buried spring, which began to flow as soon as it was exposed by the archaeological excavations. Based on the observations of Healy (1983: 143), Johnston (2004a: 292) concluded that the pre-Hispanic Maya had built this wall in order to retain spring water.

5.4.1.2 Dam systems in streambeds of Nakbe

Based on topographic surveys, Hansen *et al.* (2002: 286 with Figure 21) reported that streambeds near the site were modified with check dams resembling the terrace systems near the site center (see Chapter 5.3.4). With regard to the size and other general characteristics of these dams, Hansen *et al.* (2002) do not provide any further details.

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[90] Other sets of dam features connected to streams were documented in Chau Hiix and shall be presented in the context of the hydraulic system of Chau Hiix (see Chapter 5.5.4.6).

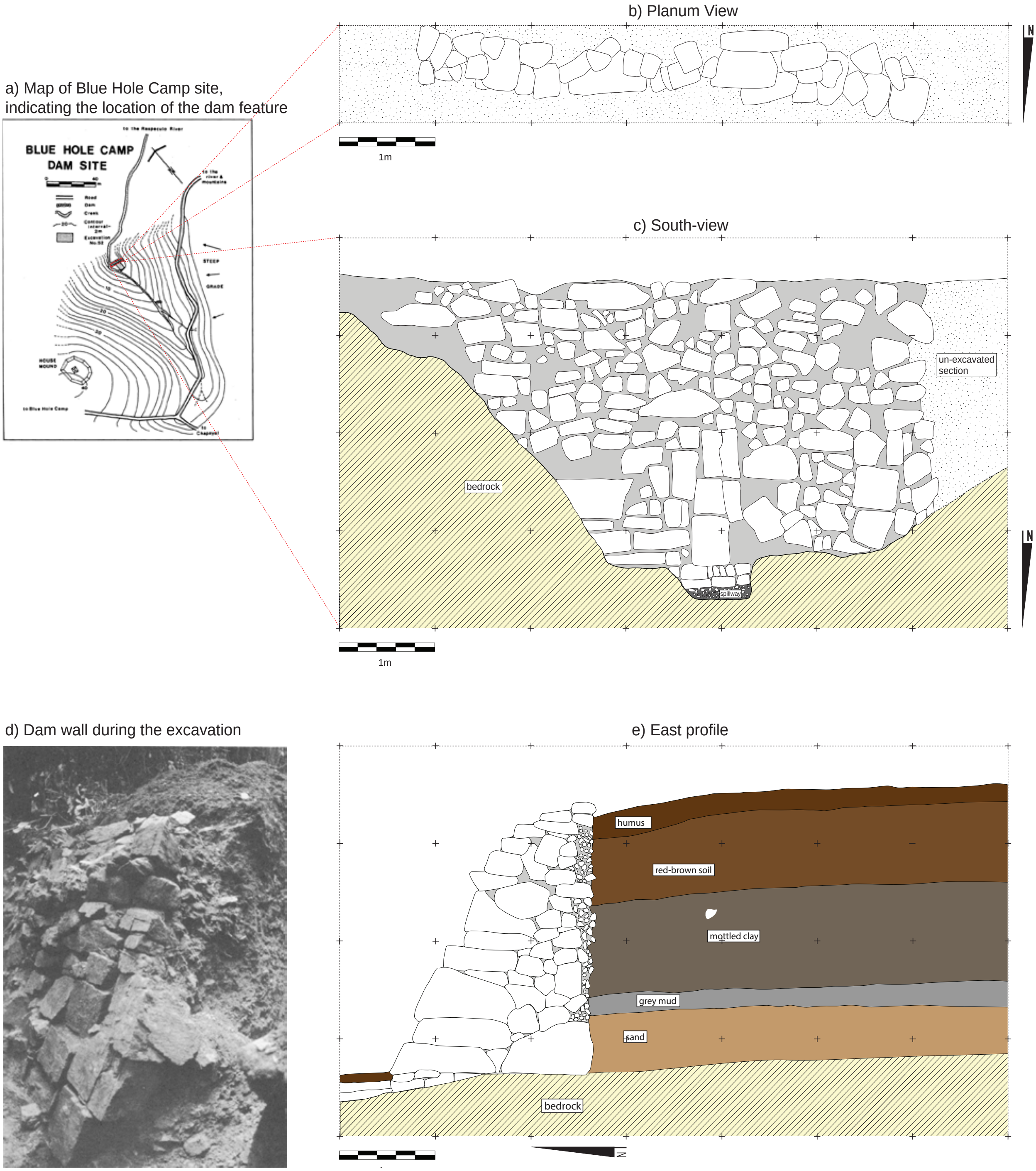


Figure 5.42: Blue Hole Camp, dam feature. (a) (source: Healy 1983: Figure 3); (b) (redrawn after Healy 1983: Figure 5); (c) (redrawn after Healy 1983: Figure 5); (d) (source: Healy 1983: Figure 7); (e) (redrawn after Healy 1983: Figure 6). Reproduced with kind permission of Paul F. Healy.

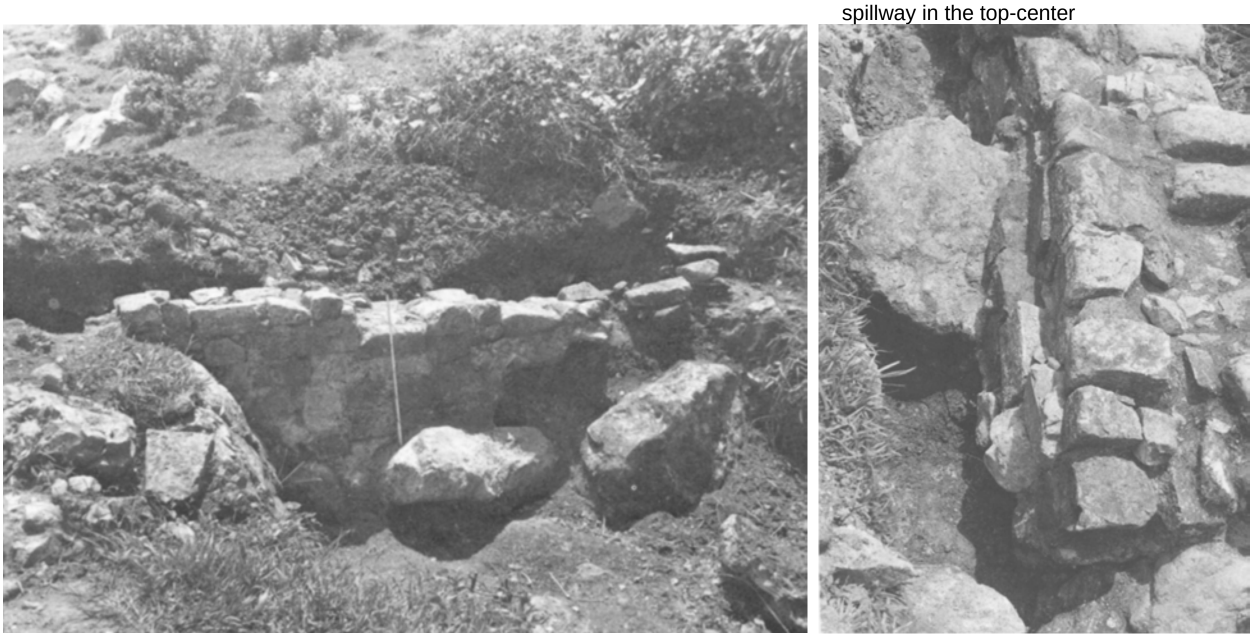
5.4.1.3 Dam wall in the Copán Valley (Honduras)

Within the Copán Valley of Honduras, Turner and Johnston (1979: 299) documented a dam wall that impounded the flow of water of the Quebrada Petapilla, a small tributary of the Río Copán (see Figure 5.43a). The dam featured a length of 4 m and a height of 1.45 m and was constructed out of carefully worked stone blocks with dimensions of 15 x 20-35 cm assembled with mortar (see Figure 5.43b). The wall itself was tightly anchored into cavities in the limestone bedrock. Since this feature was located immediately underneath a spring, Turner and Johnson (1979: 301) concluded that this dam wall would have impounded a pond with a surface area of 32 m^2 and a capacity of 20-25 m^3. A 23 cm deep and 50 cm wide gap in the wall's upper-middle portion was interpreted as a spillway (Turner and Johnson 1979: 301; see Figure 5.43b). Despite the fact that they could not consult any secured sediments or artifact samples for dating, they concluded that it was pre-Hispanic and dated it to the Late Classic. Since a fertile area for cultivation with numerous agricultural terraces and residential structures extended downslope of the dam, Turner and Johnson (1979: 299) assumed that this artificial reservoir created by the dam wall might have been used as an elevated point for irrigation.

5.4.1.4 Dam systems in the Candelaria Basin

Along the course of the Río Candelaria, several possible dams were archaeologically documented or located by local inhabitants and fishermen (Siemens *et al.* 2002: 120; Vargas 2012: 198). Due to their extensive length and the fact that they were composed of carefully set stone blocks placed perpendicular to the current, they were interpreted as anthropogenic structures (see Figure 5.43d). No further specifications were published as to the extension of these walls. Although only speculations can be made as to the function of these features at this point, Siemens *et al.* (2002: 121) assumed that these simple barriers were able to manipulate the flow of sediments carried with the current so that natural terraces would have piled up. Due to the seasonal inundations, this influx of eutrophic sediments could have been incorporated into the river basin agriculture of the Candelaria. According to Vargas (2012: 198), the dams were constructed when the water level of the river was low (see Figure 5.43).

Apart from these documented features, several scholars published additional reports of modified regional streams within the Petén. In most cases, these reports were based on lines detected on Landsat satellite images of the central Petén (e.g. within the Bajo La Justa). Without further ground surveys, Sever and Irwin (2003: 119) interpreted these features as watercourses, which the Maya had possibly modified with dams (Fialko 1999: 688; Grazioso Sierra *et al.* 2000: 206). Fialko (1999: 688) also described the existence of dikes and floodgates within the basin of the upper Río Holmul that would indicate a periodic deviation of the stream in the direction of artificial reservoirs. However, as the satellite images depicting these dikes and floodgates were not published and the alleged watercourses were not verified in ground surveys, the existence of these features cannot be verified.



a) Copán, Dam wall, front view

b) Copán, Dam wall, detail of spillway in the top-center

c) Copán, Dam wall, top-view

d) Aerial picture of a “dam” in the river course of the Río Candelaria

Figure 5.43: Overview of dam features in Copán and along the Río Candelaria. (a) (source: Turner and Johnson 1979: Figure 2); (b) (source: Turner and Johnson 1979: Figure 4); (c) (source: Turner and Johnson 1979: Figure 3. Reproduced with kind permission of Billie Lee Turner and Cambridge University Press); (d) (source: Siemens *et al.* 2002: Figure 4. Reproduced with kind permission of Alfred Siemens and Cambridge University Press).

5.4.2 Dam systems not connected to streams

The group of dam systems not connected to streams features a wide variation in form. Some scholars argued that even causeways (*sacbe'ob*) could be added to this group. According to Dahlin (1984: 19), *sacbe'ob* functioned as dams in many regards and should therefore be considered hydraulic features (Davis-Salazar 2006: 125; Matheny 1980; Scarborough 1991: 111). In order to support his hypothesis, Dahlin (1984: 19) referred to the causeways of Cobá (Fletcher 1983, Folan 1991) and El Mirador, which apparently had been built in order to guarantee the passage through bajo landscapes. Other scholars would later adapt Dahlin's (1984) hypothesis and argue that the causeways of Tikal and Copán would have also served as actual dams, since they would have impounded water and impeded the inundation of residential areas (Scarborough 1991: 127).

In this respect however, Dunning *et al.* (2006: 88) correctly remarked that the state of research could not verify if causeways had ever been used as actual dams. Essentially, this claim was asserted due to the fact that causeways are generally very low and follow the contour of the landscape. Due to this circumstance, they were unsuited for damming greater amounts of water (Dahlin and Dahlin 1994; Dunning et a. 2006: 88). Therefore, Dunning *et al.* (2006: 88) argued that even those causeways traversing bajos would have generally been constructed to secure the wetlands and create reliable walkways during the rainy season.

The only verified examples of *sacbe'ob* serving as dam features are the two main causeways of Copán. Both originate at the main group's central plaza and emanate out to the west and to the east (Fash and Davis-Salazar 2006). Along their course, the heights of the two causeways vary between 0.85 m and 1.7 m to compensate for topographic variation. According to Davis-Salazar (2006: 134), the two causeways would have averted the natural flow of water towards the south. Due to this function, they would have prevented inundation of the residential areas of El Bosque and Las Sepulturas situated to the south (Fash 1983; Fash and Long 1983). Due to the site's hydrologic situation, Davis-Salazar (2003: 277, 2006: 130) interpreted them as water control features and concluded that their layout indicated a "hydrology oriented city planning".

5.4.2.1 Dam wall of Tamarindito

After the Palace dam of Tikal (see Chapter 5.7.3.2.2), the dam wall of Tamarindito is the largest published dam feature of the Maya Lowlands. It is located in the eastern section of the site of Tamarindito in the Petexbatun region and measures 60 m in length, 2 m in width and approximately 3 m in height. As Figure 5.44 indicates, it was also connected to the reservoir, Laguna Tamarindito. According to Beach and Dunning (1997: 20), the collected water was used for pot irrigation of the nearby terraces, while the dam reduced soil erosion and excessive sedimentation of the reservoir (Kunen 2001 331). Although Dunning *et al.* (1997: 262) defined this feature as a dam wall, it could functionally be identified as a check dam or weir terrace instead. Generally, it appears that check dam terraces and actual dam features have few differences in their composition.

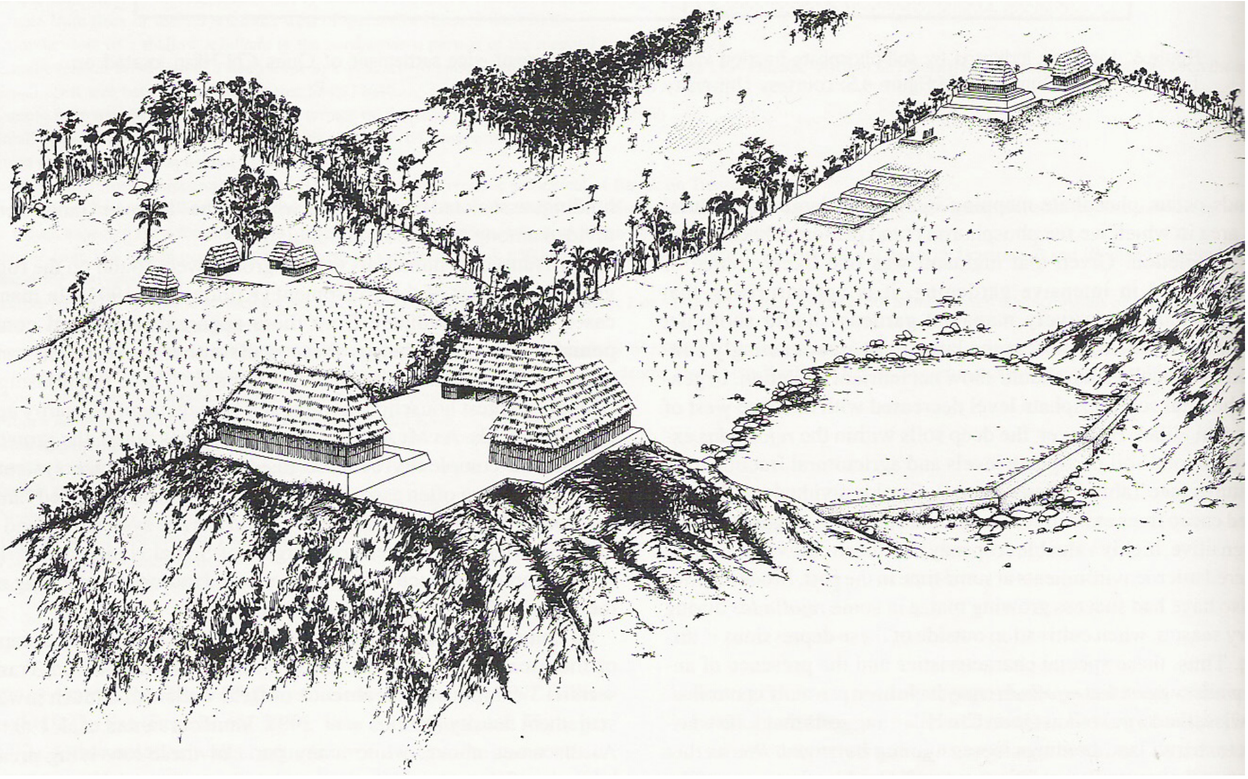


Figure 5.44: Tamarindito, reconstruction drawing of dam and reservoir (source: Dunning *et al.* 1997: Figure 7). Reproduced with kind permission of Nicholas P. Dunning and Vanderbilt University Press.

5.5 Drainage features

In contrast to the previously presented hydraulic features, drainage features were constructed to manage excess water and served to protect residential areas or architectonic structures from inundations. Consequently, they are mostly located in urban contexts. Nevertheless, the function of a specific drainage feature varied considerably according to its geographic location. In sites with abundant water supply, they only served for drainage. In sites with seasonally varying water supply, such as those in the Central Lowlands, the excess water of the rainy season was deflected around the residential areas and led into reservoirs in order to store it for the dry season (Lohse and Findlay 2000: 183).

The most popular and best-published features regarding the regulation of water excess are the hydraulic systems of Copán and Palenque – at the southwestern and the southeastern periphery of the Central Lowlands (Davis-Salazar 2006: 125; see Chapter 5.8.3). The excessive water prevailing in those regions forced the inhabitants to construct hydraulic systems including aqueducts, drainages, canals with side walls, dams and bridges (Davis-Salazar 2006: 124). In Copán, these features primarily served to protect against the erosion of buildings. Hence, drainages and aqueducts served to transport water both above the ground as and below it. In some cases, canals were also installed below plazas. Masoned canals frequently flanked natural streambeds while dams reduced the flow rate and thereby reduced the risk of erosion (Davis-Salazar 2001, 2002, 2003, 2006: 125). In Palenque, bridges enabled the inhabitants to cross the largest rivers flowing through the settlement (French *et al.* 2006: 146).

With regards to this chapter however, the drainage features of the Central Lowlands are of primary interest. Even if the sites in this region suffered from extreme water scarcity during the dry season, the precipitation of the rainy season was still able to produce strong torrents. To protect the architecture, these “seasonal streams” had to be diverted around the residential groups (Lohse and Findlay 2000: 180). As these features not only had to drain water, but retain it for the dry season, the pre-Hispanic inhabitants would have been required to develop adequate water management techniques (Lohse and Findlay 2000: 180).

In the following, three such drainage features from sites in the Central Lowlands will be introduced: The drainage features of Dos Hombres, Yaxhá and Nakum (see Figure 5.45). Other drainage features, such as those documented in Ek’ Balam (see Chapter 5.7.11), Palenque (see Chapter 5.8.3) and Tikal (see Chapter 5.7.3), will be presented along with their respective hydraulic systems.

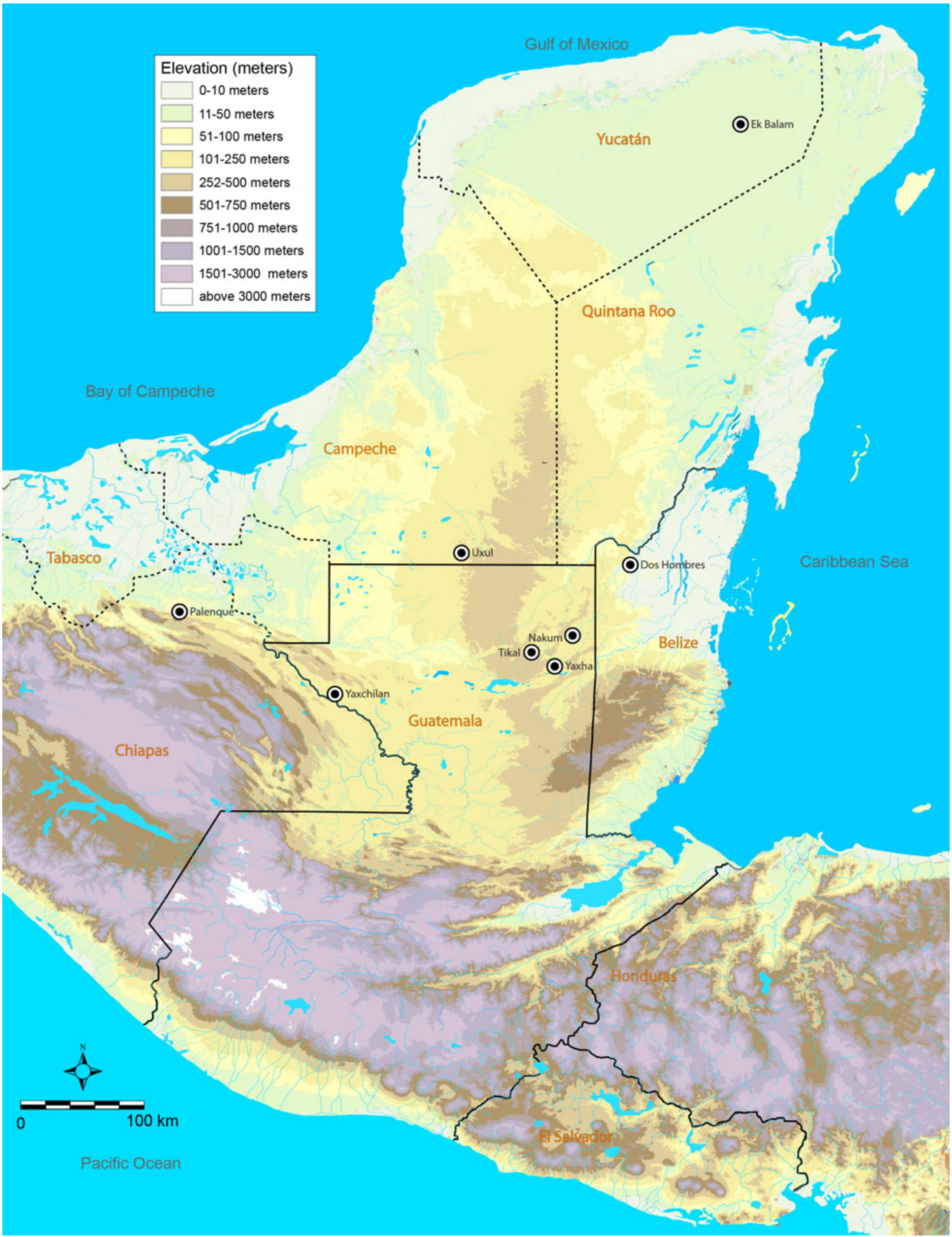


Figure 5.45: Geographic distribution of published drainage features within the Maya Lowlands (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

5.5.1 Dos Hombres

1.5 km to the west of the Dos Hombres'[91] settlement core, Lohse and Findlay (2000: 175) documented a drainage feature in a Late Classic residential group on a slope near the Río Bravo (see Figure 5.46a). This drainage system was cut directly into the limestone bedrock and consisted of several components (Lohse and Findlay 2000: 181).

The main components were two linear cavities in the limestone surface with depths of 20 cm that were connected by a 4-5 m long, 10-15 cm wide and 30-35 cm deep main canal. According to Lohse and Findlay (2000: 181), a depression situated uphill had apparently been artificially expanded and featured a dense filling of soil and sascab (see Figure 5.46d). The main canal's discharge of the uphill depression was facilitated by a supplementary canal, which drained downhill into a row of natural irregularities in the bedrock surface (see Figure 5.46d).

According to Lohse and Findlay (2002: 183), this system served to divert excess water away from the residential area after the gravel-enriched soils in the limestone cavities had been sufficiently water-soaked. Natural depressions, which would have otherwise pooled underground water, were connected through "passages" that drained excess moisture (Lohse and Findlay 2000: 181). Lohse and Findlay (2000: 183) claimed that the mixture of stones and soils might have reduced erosion in the documented system, increased the average soil temperature and compensated for temperature fluctuations (Lohse and Findlay 2000: 183). According to Lightfoot (1996: 206), this form of "lithic mulch"[92] would have increased the germination capacity of the cultivated plants. Thus, the modifications of the limestone bedrock and the application of lithic mulch would have protected the adjacent residential areas from floods and also increased the water storage capacity of the natural depressions (Lightfoot 1996: 183; Lohse and Findlay 2000). In addition to this drainage feature, Lohse (2007) and Trachman (2007: 231) documented a number of reservoirs that are presented in Chapter 5.6.4.3.8.5.

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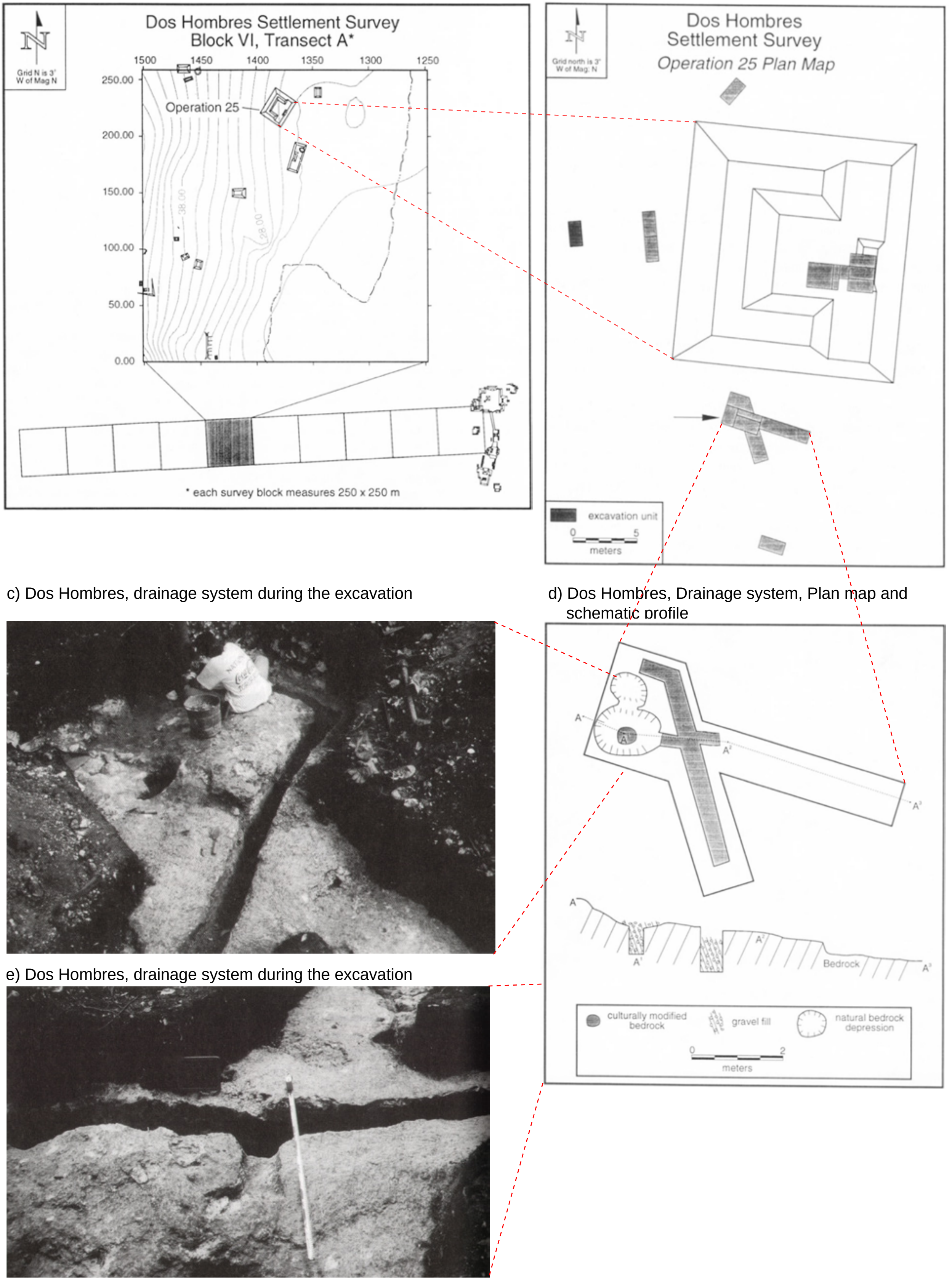
[91] Dos Hombres forms part of the Programme for Belize Archaeological Project (PfBAP) in northwest Belize, which is managed by the Río Bravo Conservation and Management Area (RBCMA) (Trachman 2007: 5). The different sets of hydraulic features documented in the RBCMA shall be presented in Chapter 5.6.4.3.8.

[92] According to Lohse and Findlay (2000: 183), the advantage of this "lithic mulch" would have been also used in the *chicluum* soils within the *rejolladas* of Yucatán (Kepecs and Boucher 1996) and southern Petén (Dunning *et al.* 1997: 259).



a) Dos Hombres, Site map showing location of Operation 25

b) Dos Hombres, Excavation units of Operation 25

c) Dos Hombres, drainage system during the excavation

d) Dos Hombres, Drainage system, Plan map and schematic profile

e) Dos Hombres, drainage system during the excavation

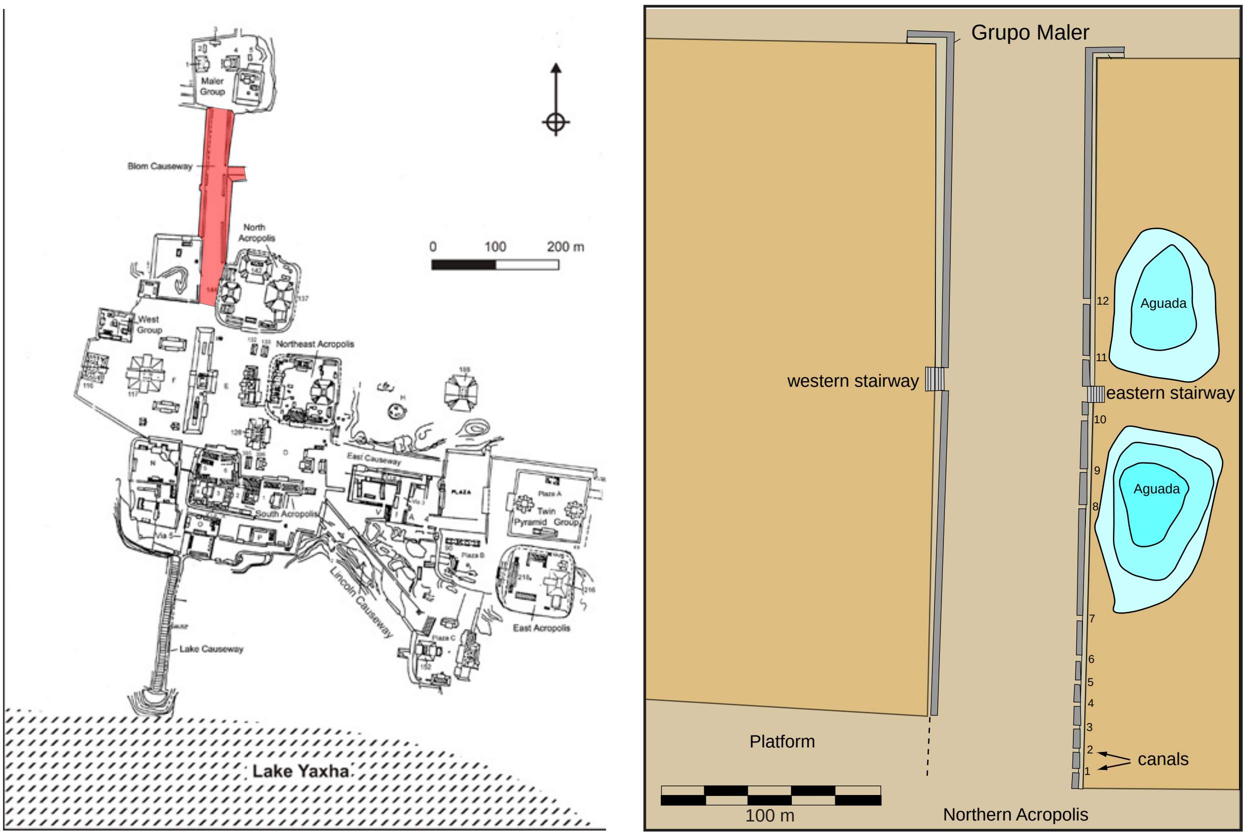
Figure 5.46: Dos Hombres, Location of drainage-features. (a) (source: Lohse and Findlay 2000: Figure 2); (b) (source: Lohse and Findlay 2000: Figure 3); (c) (source: Lohse and Findlay 2000: Figure 5); (d) (source: Lohse and Findlay 2000: Figure 4); (e) (source Lohse and Findlay 2000: Figure 6). Courtesy of the Programme for Belize Archaeological Project (PfBAP). Reproduced with kind permission of Jon Lohse and Fred Valdez.

5.5.2 Yaxha, Calzada Blom

In the site of Yaxha, located at the northern shore of the Lago Yaxhá, Hermes and Ramos (2004) documented a sophisticated drainage system connected to the Blom sacbe. This causeway is located in the site's northern section and connected Plazas F and G with the Maler Group (Hellmuth 1993; Hermes and Ramos 2004: 607; see Figures 5.47a, and 5.47b). To the east, the causeway is bordered by two aguadas (see Figure 5.47b). During the archaeological investigation of the feature, Hermes and Ramos (2004: 608) observed that the causeway and drainage system connected to it had developed through four different construction stages ranging from the Late Preclassic to the Terminal Classic.

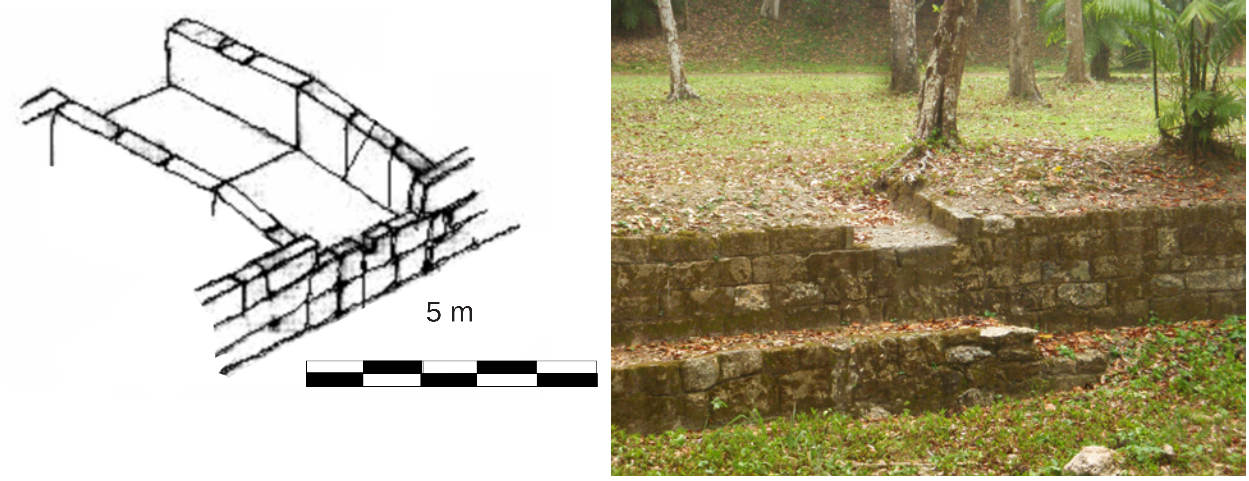
During the Late Preclassic, Yaxha's pre-Hispanic inhabitants built the foundation of the causeway. In the middle of the Late Classic, this foundation was complemented by two lateral walls (parapets) at the eastern and western edge of the causeway (Hermes and Ramos 2004: 609; see Figure 5.48d). During the last construction phase in the Terminal Classic, the surface of the causeway was artificially sloped to the east, so rainfall would drain off in this direction (Hermes and Ramos 2004: 610; see Figure 5.48d). Simultaneously, a series of 12 narrow canals at the eastern parapet of the causeway were installed (see Figures 5.47b, 5.48a, 5.48b and 5.48c). Each of these canals featured a width of 2.50 m and a height of 20 cm (see Figures 5.48a, 5.48b, 5.48c, and 5.48c). According to Hermes and Ramos (2004: 610), these canals performed two basic functions.

On the one hand, the small canals would have prevented the causeway surface from flooding and enabled the quick discharge of any rainfall. On the other hand, the canals would have enabled the collection of runoff water by directing it towards the two adjacent aguadas where it would have been stored for the dry season (Hermes and Ramos 2004: 610; see Figure 5.47b). Apart from the intricate design of this drainage feature, another peculiarity is the fact that it was constructed in a site with relatively good access to permanent water resources.


a) Map of Yaxha, indicating the location of Calzada Blom

b) Planum drawing of Calzada Blom

Figure 5.47: Yaxha, Calzada Blom, Location of drainage features. (a) modified from Hermes *et al.* 1998: Figure 2); (b) (redrawn after Hermes and Ramos 2004: Figure 9). Reproduced with kind permission of Bernard Hermes.


a) Isometric drawing of canal feature

b) Photo of canal at the western embankment of Calzada Blom

c) Photo of the western embankment of Calzada Blom

d) North-profile of Calzada Blom

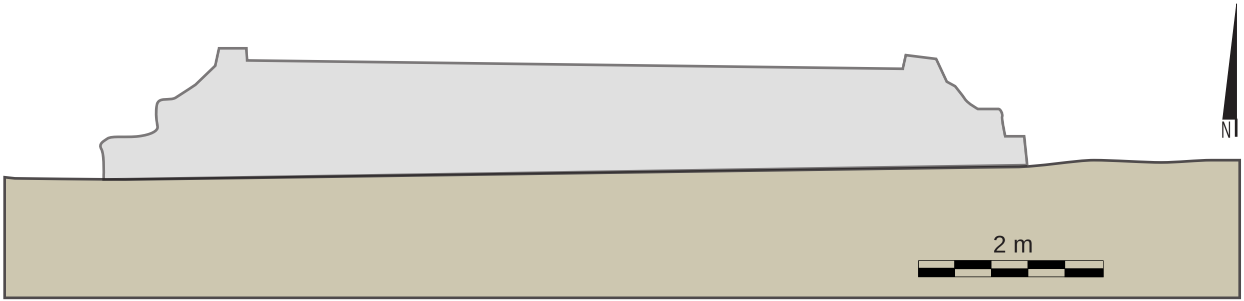


Figure 5.48: Yaxha, Calzada Blom, Details of drainage features. (a) (source: Hermes and Ramos 2004: Figure 12); (b-c) (Photo: N. Seefeld); (e) (redrawn after Hermes and Ramos 2004: Figure 5). Reproduced with kind permission of Bernard Hermes.

5.5.3 Nakum, Structure 14, Drainage feature

Nakum is a medium-sized center that consists of two separate architectonic sectors (the northern and southern sectors). The site is located near the Holmul River, a potential source of water in pre-Hispanic times. Another important water source is the aguada[93] located to the west of the site's acropolis (Źrałka and Koszkul 2014, see Figure 5.49a and 5.49i).

In Structure 14, located in the northern portion of the Acropolis, Źrałka and Koszkul (2014) documented a sophisticated drainage system (Noriega and Quintana 2003; Tobar and González 2007; Źrałka and Koszkul 2014; Źrałka *et al.* 2011). As excavations revealed, Structure 14 was erected in a series of construction phases between the Protoclassic and the Late Classic (1st century BC to AD 800; Źrałka and Koszkul 2014).

According to Źrałka and Koszkul (2014), all archaeological data indicate that the drain to the west and northwest of the Red Building (see Figure 5.49c) was constructed during the final part of the Early Classic Period. The drain began somewhere on the second terrace of Structure 15 and proceeded 6 m to the west (Źrałka and Koszkul 2014, see Figures 5.49c and 5.49d). In this section, the gutter is situated immediately above the wall and is formed out of U-shaped stone blocks (see Figure 5.49e). After flowing 6 meters to the west, the gutter turns 90 degrees and continues another 6 meters on the upper-interior part of the wall (height: 2.7 m) until it protrudes through a small opening in the exterior of the wall (Źrałka and Koszkul 2014; see Figure 5.49e).

Subsequently, the gutter descends down to the level of the platform through a trapezoidal masonry element attached to the wall (see Figures 5.49d and 5.49f). It then continues south on the platform on which the Red Building stands (see Figure 5.49d) before it disappears below Structure 13, which postdates the gutter and covers it completely. The excavations of Źrałka and Koszkul (2014) proved that the whole hydraulic feature proceeds until the western border of the Central Acropolis and drains water into the large aguada of Nakum (see Figures 5.49a, 5.49h and 5.49i). According to Źrałka and Koszkul (2014), the presence of a trapezoidal masonry feature in the drain system of Structure 14 is of special importance because it acted as a water conduit and, just like the wall, it was covered with stucco and painted red. Źrałka and Koszkul (2014) suggested this drainage feature could have been a man-made replica of a sacred mountain or "water mountain" and that it served both practical and ritual functions.

Calderón *et al.* (2006) documented another canal in the western part of the Acropolis that drained the large Patio 1 and its surroundings during the rainy season (Źrałka and Koszkul 2014). Its origin is located in the southwestern corner of Patio 1 from where it runs in a southwestern direction and passes below Patio 4. The canal ends between Structures M and L on the western wall of the Acropolis complex where it drains into the neighboring aguada (Źrałka and Koszkul 2014, see Figure 5.49a). Below the end of the canal and at the base of the Acropolis, Calderón *et al.* (2006) also discovered a small well which might have been used to extract water collected from the Acropolis (Źrałka and Koszkul 2014).

The canal was 55 cm wide at its base, 94 cm in height and covered with well-worked capstones set in mortar. Its good condition was illustrated by the fact that the stucco lining in its interior was still preserved. Based on the stratigraphy and the associated material, Calderón *et al.* (2006) dated it to the Late or Terminal Classic (Źrałka and Koszkul 2014). In conclusion, Źrałka and Koszkul (2015) claim that the documented drainage feature shares many similarities with the canals of Palenque (Crandall 2009: 14; French 2002; see Chapter 5.8.3). Although numerous similar features have doubtlessly been erected within the Central Lowlands, the presented examples are the only published features that can be defined as drainage features. After this overview on the few published examples of pre-Hispanic drainage features, the upcoming chapter will analyze reservoirs, an extensive hydraulic feature group.

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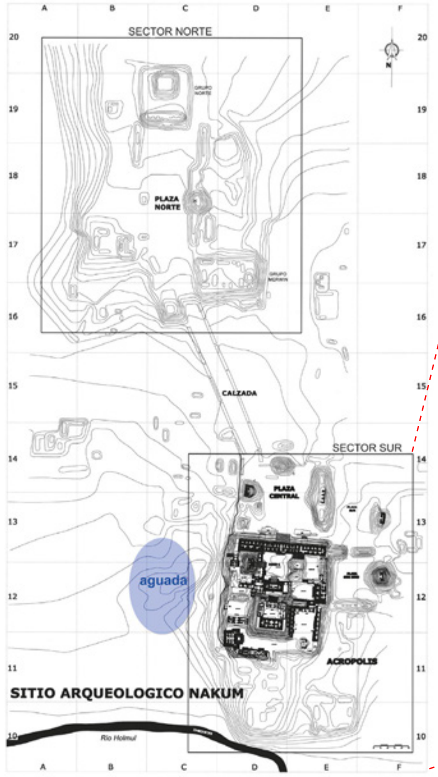
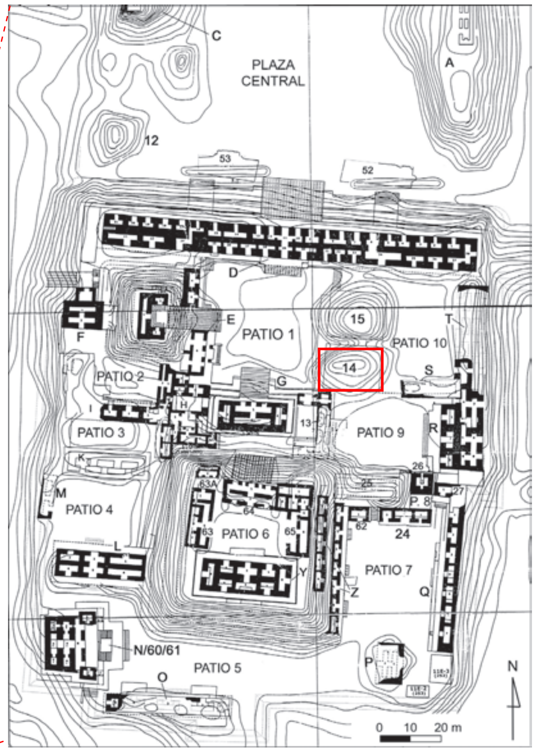
[93] The fact that a shrine was located at the eastern side of the aguada brought Źrałka and Koszkul (2014) to the conclusion that it might have been used during rituals of a water cult (Calderón 2008; Calderón *et al.* 2006; Koszkul and Źrałka 2013).

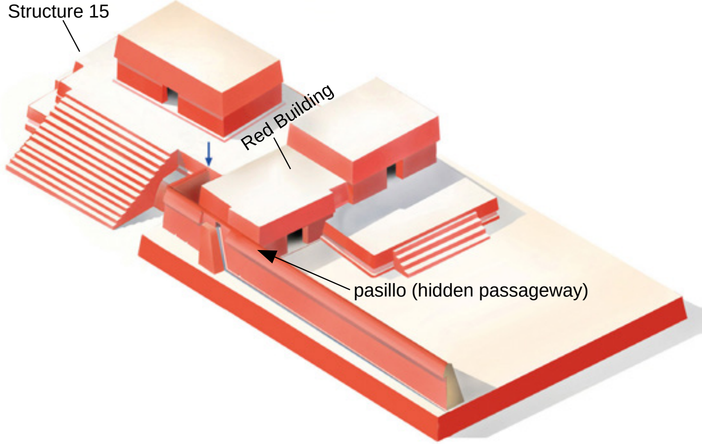
a) Nakum, Map showing location of Acropolis



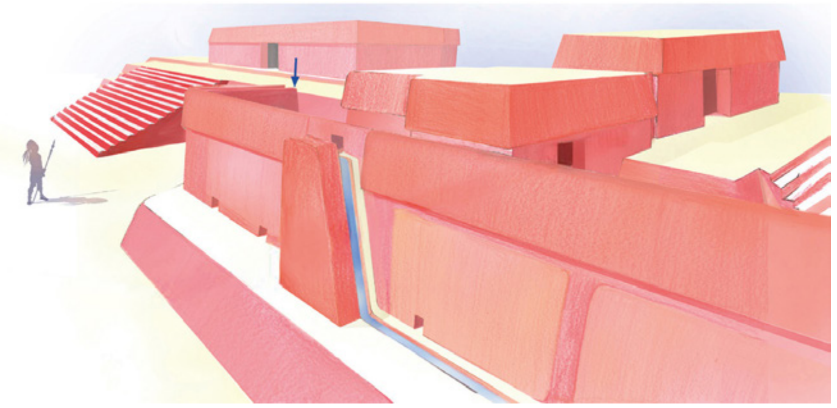
b) Nakum, Map showing location of Structure 14



c) Nakum, Structure 14, Reconstruction of the drain's functionality

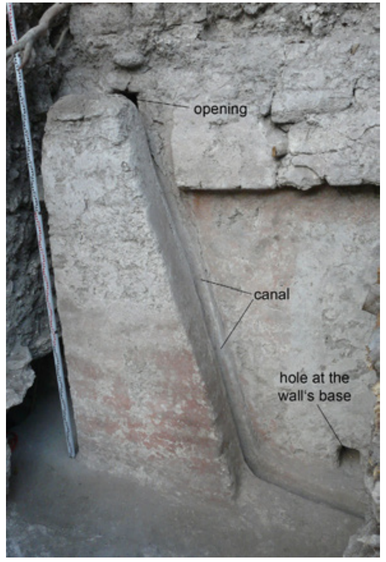


d) Nakum, Structure 14, Reconstruction of the drain's functionality

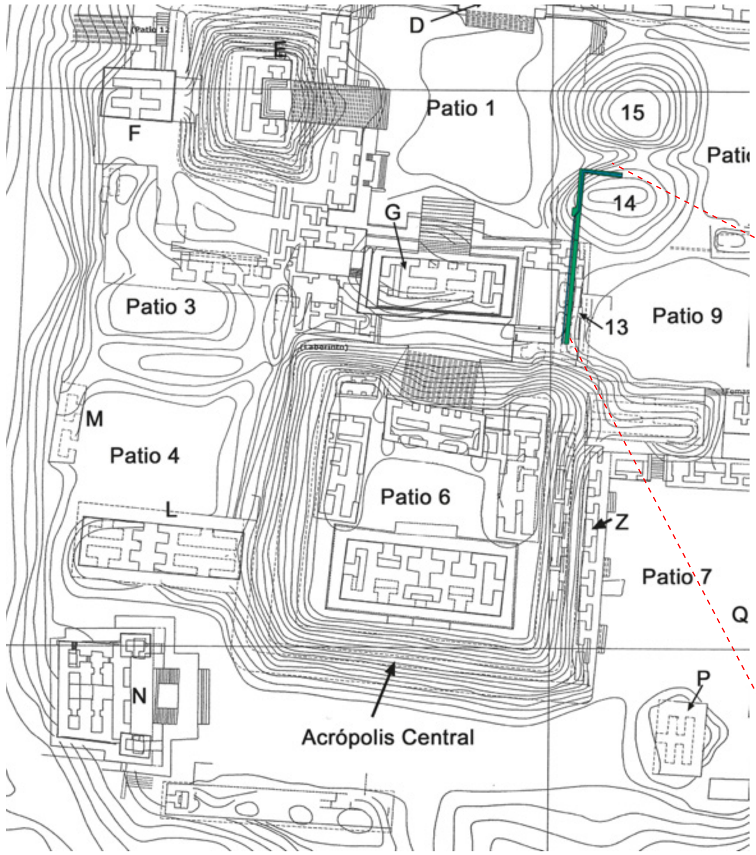


e) Nakum, Structure 14, Drainage feature, South view

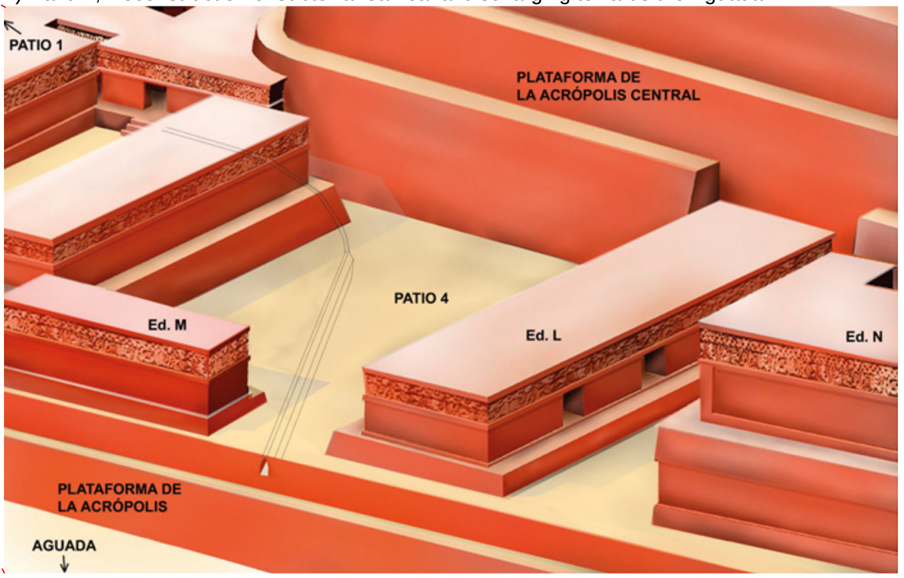
f) Nakum, Structure 14, Drainage feature, Trapezoidal element



g) Nakum, Map of Acropolis, Direction of drainage canal is indicated in green



h) Nakum, Reconstruction of subterranean canal discharging towards the Aguada



i) Nakum, Photo of modified Aguada

Figure 5.49: Nakum, Acropolis, Structure 14, Drainage-feature. (a) (source: Koszkul and Źrałka 2013: Figure 1; (b) (source: Koszkul and Źrałka 2013: Figure 4); (c) (modified from Koszkul and Źrałka 2013: Figure 6a); (d) (source: Koszkul and Źrałka 2013: Figure 6b); (e) (Koszkul and Źrałka 2013: Figure 11); (f) (source: Koszkul and Źrałka 2013: Figure 13a); (g) (source: Koszkul and Źrałka 2013: Figure 8); (h) (Koszkul and Źrałka 2013: Figure 17); (i) (source: Koszkul and Źrałka 2013: Figure 3). Reproduced with kind permission of Jaroslaw Źrałka.

5.6 Reservoirs

The last large group of hydraulic features covered here is reservoirs, a feature group prevalent throughout the entirety of the Maya Lowlands (Gunn *et al.* 2002: 298). Due to their relevance for water supply during the dry season, they have been investigated relatively intensively (see Chapter 3). They exist in an enormously broad spectrum of forms and sizes. However, since they all serve to retain or impound water, they have been clustered in a single large group. Based on formal criteria, the different reservoir subtypes have been split into several subgroups: small depressions (Chapter 5.6.1), chultunes (Chapter 5.6.2), wells (Chapter 5.6.3), and reservoirs and modified aguadas (Chapter 5.6.4). The description of these subtypes begins with the least imposing landscape features – the small depressions.

5.6.1 Small depressions

Small depressions are a category of landscape features defined rather recently by Estella Weiss-Krejci and Thomas Sabbas (2002). In contrast to Tikal, where all small depressions associated with households were assigned a seasonal water storage function (*pozas*) and all small depressions with no housemound association were interpreted as quarries (Carr and Hazard 1961: 14), Weiss-Krejci and Sabbas came to a different conclusion during their investigation of small depressions in the area around La Milpa. The investigation of 16 small depressions revealed that these features are either natural sinkholes (dolines) [94] or quarried cavities. A water storage function could be established for four of these depressions (see Figure 5.50). After Weiss-Krejci and Sabbas' (2002) publication, the term "small depression" was adapted by several other scholars such as Brewer (2007), Chmilar (2007) and Trachman (2007).

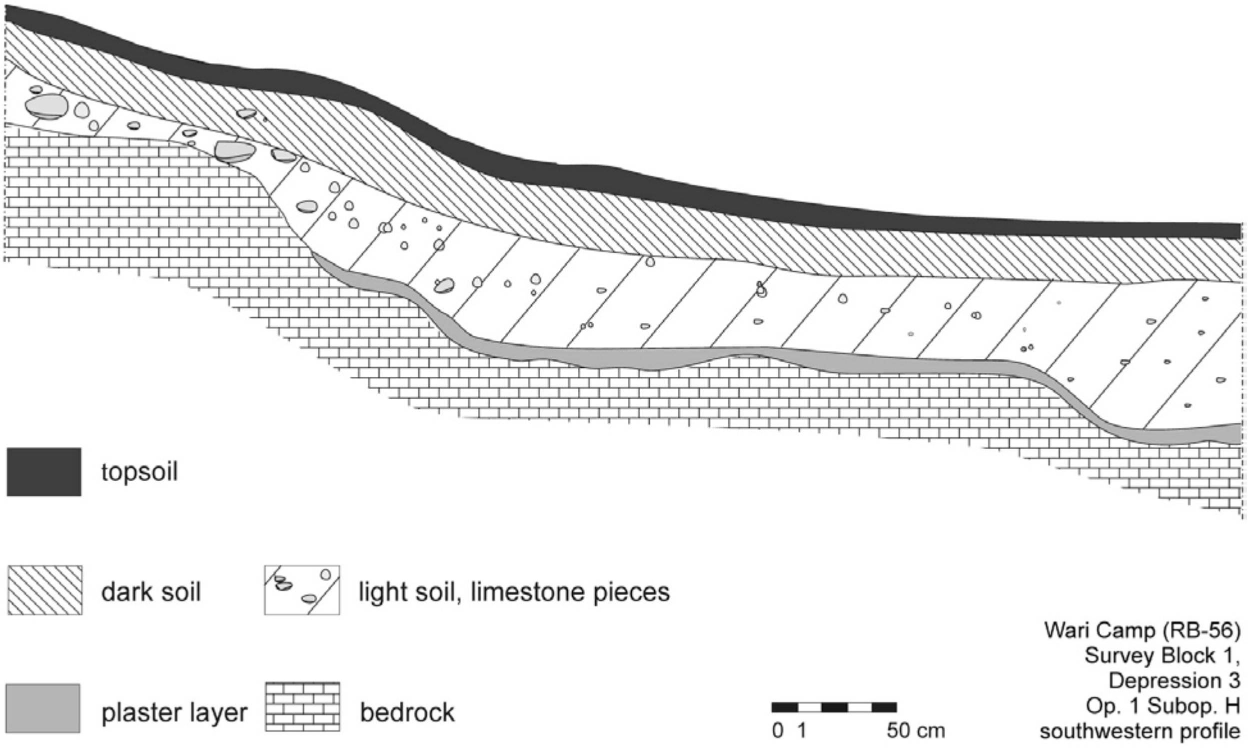


Figure 5.50: La Milpa, Wari Camp, Depression 3, Profile (source: Weiss-Krejci 2013: Figure 3). Reproduced with kind permission of Estella Weiss-Krejci.

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[95] Dolines are characterized as cavities or depressions in the soil and are a frequent phenomenon in Karst systems (Jennings 1985: 106; Lene 1997: 14). They frequently occur in clusters as well (Jennings 1985: 114). However, very small holes can also be the result of uprooted trees (Weiss-Krejci and Sabbas 2002: 346). In three depressions, quarrying for construction materials and mining for clay was evident and two depressions were the remains of collapsed chultunes. Depressions probably served as areas where household activities were carried out and played a role as gardens or were used as trash dumps (see also Weiss-Krejci 2004).

For one of the excavated depressions, Weiss-Krejci and Sabbas (2002: 354) made detailed water input/output calculations. This showed that small depressions were able to store water year-round. Therefore, Weiss-Krejci and Sabbas (2002: 343) claimed that these landscape features constituted a greater importance in pre-Hispanic Maya society than previously thought. Furthermore, the investigations in La Milpa showed that several of the features that had previously been considered anthropogenic, were actually natural depressions that the pre-Hispanic inhabitants had modified for their own interests (Weiss-Krejci and Sabbas 2002: 346).

Although the intensified research regarding hydraulic features in the last decade has shown that small depressions similar to those studied in La Milpa are distributed throughout the entire landscape of the Maya Lowlands, a focused investigation of these landscape features was only realized in the Río Bravo region. However, since these features form part of a larger hydraulic system, they are described in the context of the region's other hydraulic features (see Chapter 5.6.4.3.8).

In general, most archaeological projects tend to overlook "unspectacular" surface depressions. As Beach *et al.* (2015a: 259) emphasized, these decisions lead to serious misconceptions because almost any pronounced natural or artificial cavity represents a place to collect water. Consequently, even the most unimposing body of stored water may have represented a valuable element of pre-Hispanic residential areas. Furthermore, the personal experience of the author has shown that small surface depressions can signal more extensive "invisible features" (see Chapter 6.2.5). As erosion processes can be seen in most archaeological contexts, newly documented surface depressions or cavities will always appear smaller than they originally were in pre-Hispanic times. Therefore, the author would like to encourage a more serious appreciation of these landscape features.

5.6.2 Chultunes

Chultunes[95] are large, mostly bell-shaped cavities that have been artificially shaped from the limestone bedrock (Calderón and Hermes 2004: 2; Wilson 1980: 18; Zapata Castorena 1995: 23). In the past, a vast number of functions have been ascribed to this feature class. These include the usage as:

1) Latrines (Haviland 1963: 505),

2) Limestone mines (Calderón and Hermes 2004: 10; Smith 1950; Pinto and Acevedo 1992: 241),

3) Fermentation chambers (Dahlin and Litzinger 1986: 724),

4) Sweat baths (Maudslay 1889-1902: 25),

5) Weaving chambers (Ricketson 1925: 390),

6) Burial chambers (Calderón and Hermes 2004: 8; Hunter-Tate 1994: 68; Pinto and Acevedo 1992: 241; Seefeld 2013b),

7) Food storage chambers (Miksicek 1991: 77-80; Puleston 1971: 335; Reina and Hill 1980; Tozzer 1913: 191),

8) Water cisterns (e.g. Brainerd 1958; García Ayala 2006; Maler 1911: 5; Maudslay 1889-1902: 40; Pinto and Acevedo 1992: 240; Scarborough *et al.* 1995: 109; Weiss-Krejci and Sabbas 2002: 349), and

9) Trash pits (Pinto and Acevedo 1992: 241).

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[95] According to Puleston (1971: 322) the term of *chultun* is deflected form the Maya words *chul* ("wet" or "become wet") or possibly *tsul* ("to clean" or "to excavate") as well as *tun* ("rock" or "stone") and according to Dahlin and Litzinger (1986: 721) could be as translated as "wet rock" or "field place that becomes wet" (Tozzer 1913: 190).

González de la Mata (2002: 1017), on the other hand, separated chultunes into the two functional categories of *chultun-cisterna* "water reservoirs" (1) and *chultun silo* "food stores" (2).

The exact function of a chultun seems to depend quite specifically on its location. Since thousands of chultunes have been documented in the Northern and Southern Lowlands and because this class of features would require a separate, extensive examination, mapping these features would go beyond the scope of this study. Therefore, it will only be indicated that they had apparently been used as water tanks in some cases. González de la Mata (2002: 1009) provides a brief outline of the research history on chultunes. In this context, it is important to emphasize that chultunes were among the first hydraulic features of the Maya Lowlands to be described (Beach *et al.* 2015: 17).[96]

As Gonzalez de la Mata (2002: 1017) observed, the chultunes of the Central Lowlands primarily constitute silos,[97] whereas those of the Northern Lowlands were mostly used as reservoirs. According to McAnany (1990: 226), this geographic and functional differentiation is also supported by the fact that the chultunes of the Northern Lowlands (particularly in the Puuc region) are coated with stucco on their interiors, which would have lessened or entirely impeded the seepage of water. Due to this reason, many scholars, particularly during the early phases of Maya archaeology, interpreted the chultunes of the Northern Lowlands as reservoirs (Crandall 2009: 28; Puleston 1971: 324).[98] In order to support this hypothesis, some scholars also argued that their small openings would have reduced the evaporation of stored water (Scarborough 1991: 111).

Another peculiarity of chultunes in the Northern Lowlands[99] is their combination with modified catchment areas: The chultunes of Labná, Sayil and Ek' Balam were surrounded by funnel-shaped catchment areas that collected rain and directed it into the interior (see Figures 5.51a, 5.51b, 5.51c and 5.51d). Other features were connected to canals that also guided water into the interior (González De la Mata 2002: 1018; Seefeld 2013b). González de la Mata (2002: 1018) suggested that the water collected in this manner would have been considerably cleaner than that of cenotes or aguadas. At the current state of research, it also seems like the chultunes of the Northern Lowlands generally featured larger dimensions than those of the Central Lowlands (Matheny 1982; Thompson 1897).[100]

Generally, the characterization of chultunes in the Central Lowlands is far more difficult. Despite the fact that chultunes were documented in vast quantities and are distributed fairly homogenously across the Central Lowlands, their exact function is still widely unknown for many regions and sites (Beach *et al.* 2015: 17; Dahlin *et al.* 2005; Matheny 1971; Wyatt 2014). According to Dahlin and Litzinger (1986: 724), this issue is largely the effect of an overt concentration on a small number of ethnographic references and the lack of focused archaeological research in chultunes. Dahlin and Litzinger (1986: 724) also claimed that chultunes seem to be more frequent in areas with many edible nuts and fruits. Nevertheless, they claimed that the distribution of chultunes seemed to be largely culturally determined as opposed to being based on ecological factors (Dahlin and Litzinger 1986: 724). Therefore, chultunes would not be

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[96] In 1546, the "Relación de Ek' Balam" (de la Garza 1983) mentions the presence of chultunes on residential platforms of Ek' Balam (see Chapter 5.7.1), which served for the recollection of water (Castillo Borges and Vargas de la Peña 2008: 143). Stephens (1843: 227) described a series of chultunes inside an aguada. According to Stephens (1843: 227), these features had been used as seeps in the dry season (Beach *et al.* 2015: 17). Later on, Desirée Charnay (1886) described a chultun in Ek' Balam in a remarkable state of preservation that still had its stone lid.

[97] According to Garrison and Dunning (2009: 543), most of the chultunes in the Central Maya Lowlands were probably used "chiefly to store portions of the agricultural surplus, using technologies that may be lost today" (Puleston 1968).

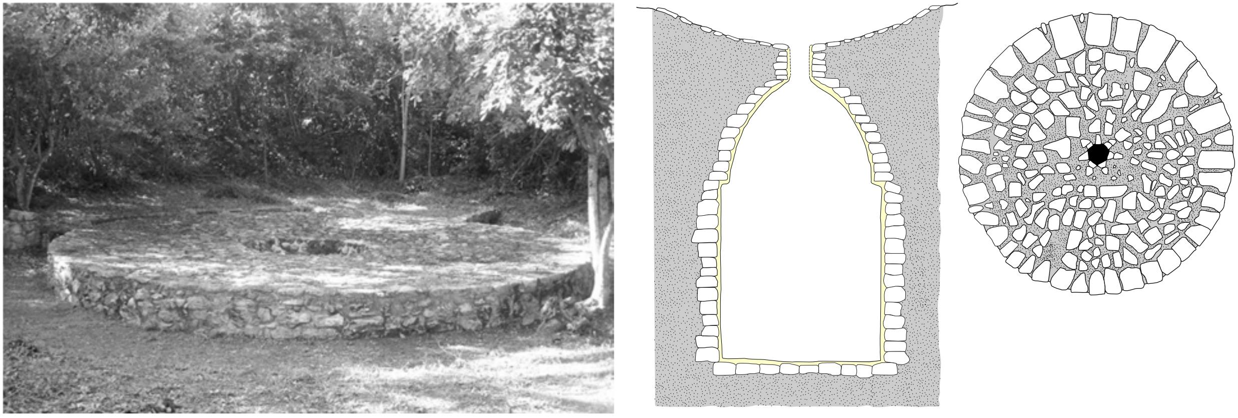
[98] According to Dahlin and Litzinger (1986: 729) the fact that chultunes are not homogenously distributed within sites, argues against a water storage function. Brainerd (1958: 30), on the other hand, pointed out that the chultunes of the Puuc region would be the "only known watersources during the dry season" (Wilson 1980: 18). In this relation, Wilson (1980: 18) claimed that almost all of the structures in Puuc sites would be oriented to artificially leveled plazas paved with applied stucco pavement. In order to illustrate the effectiveness of chultun constructions in the Puuc region, Wilson (1980: 18) also pointed out that workers in Sayil would continue to repair and clean the site's pre-Hispanic chultunes in order to use them as sources of wash water.

[99] In functional terms, the stucco floor surrounding the entrance to the artificial cave of Uxul (see Chapter 6.2.5) demonstrates a very similar technical approach (Seefeld 2013b). Nevertheless, the feature is located in the Central Lowlands.

[100] Thompson (1897) described the existence of 60 jug-shaped chultunes in Labná with a total capacity of 7,500 gallons. Based on this information, Wilson (1980: 18) calculated that these 60 chultunes would have been able to support 3,000 persons during the dry season.

equally distributed in the landscape, but would rather show a higher concentration near more extensive residential areas and sites (Dahlin and Litzinger 1986: 729). However, it should be highlighted that a relationship between chultunes and residential areas is not always discernible. In the author's opinion, the location of many chultunes in the Central Maya Lowlands cannot be entirely explained by the proximity of residential areas.

Once again however, the relationship between chultunes and residential areas appears to be more obvious in the Northern Lowlands. In the site of Ek' Balam (see Chapter 5.7.11) for instance, Castillo Borges and Vargas de la Peña (2009: 143) documented many chultunes both inside and outside of the "walled compound". In some cases, these chultunes were incorporated into residential complexes.


a) Ek' Balam, Photo of Chultun with modified catchment surface.

b) Labná, Profile and Planum of Chultun

c) Sayil, Schematic cross section of Chultun

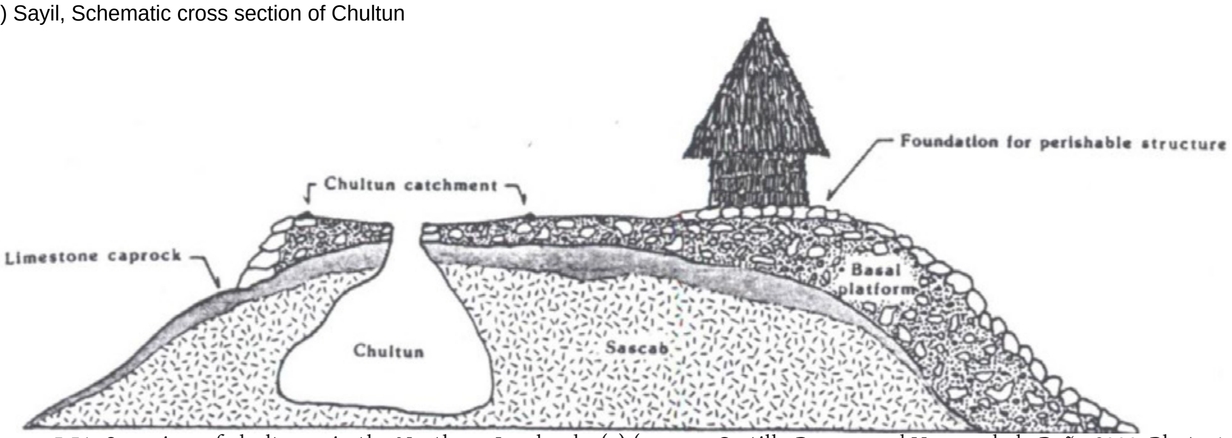


Figure 5.51: Overview of chultunes in the Northern Lowlands. (a) (source: Castillo Borges and Vargas de la Peña 2009: Photo 1. Reproduced with kind permission of Victor Castillo Borges); (b) (redrawn after Thompson 1897: Figures 1 and 2. Copyright 1897, by the Peabody Museum of Archaeology and Ethnology, Harvard University); (c) (source: McAnany 1990: Figure 4). Reproduced with kind permission of Patricia McAnany.

A sub-variety of chultunes are house cisterns which have been documented in association to residential units in sites without direct access to perennial water resources. Similar to the chultunes of the Puuc area, they were apparently fed by runoff from the surrounding patios (Arroyave et al 2008; Scherer and Golden 2009; Scherer *et al.* 2015). One of the few examples of such a house cistern was documented in the site of Tecolote/Petén (Scherer *et al.* 2015: 674). As Figure 5.52 illustrates, discarded grinding stones had been deposited around the cistern's entrance in order to serve as drains. Its form, size and location bear many similarities to the well feature included in Platform 1 near the artificial cave in Uxul (see Chapter 6.2.5). Furthermore, the same application of stair treads included in its shaft could also be documented in the circular reservoir D 17 in Structure 1 of Ek' Balam (see Chapter 5.7.10). In conclusion, it should be emphasized that chultunes have already been documented in great quantity and their respective function mostly varies from case to case. Because of this, the extent and scope of this book does not allow for the investigation of this group of features in further detail.

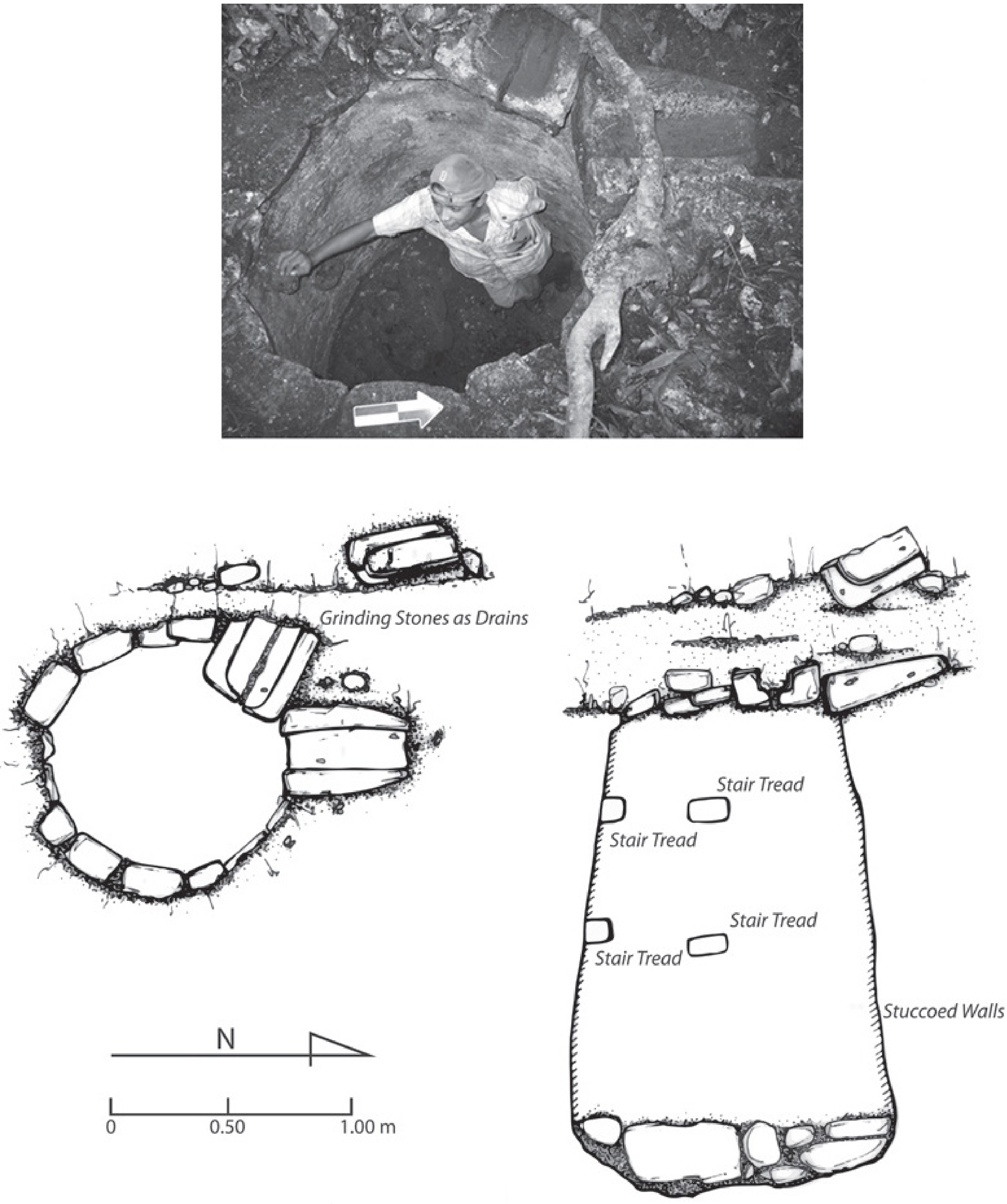


Figure 5.52: Tecolote, Household cistern (Photograph and drawing by Ana Lucia Arroyave courtesy of the Sierra del Lacandón Regional Project. Reproduced with kind permission of Andrew K. Scherer).

5.6.3 Well features

Well features are vertical shafts that extend down to the underground water table and exhibit signs of anthropogenic modification (Scarborough 1991: 108). Surprisingly, reports or publications on well features of the Maya Lowlands are relatively scarce (Johnston 2004a; see Figure 5.53). However, Robichaux (2002: 344) is convinced that numerous well features must have existed in the Maya Lowlands that have either been overlooked or misinterpreted as chultunes. In his view, water could have been extracted from such wells by means of ceramic vessels on lowered ropes, just like in the Old World (Robichaux 2002: 344). However, Scarborough (1993: 43) stated that wells would not have constituted a reliable means of water supply in the Maya Lowlands. Wilson (1980: 17) even pointed out that the technology of the pre-Hispanic Maya "was not advanced enough to drill deep wells into the bedrock". Contradicting these earlier stances, Johnston (2004a: 281) highlighted the fact that most known pre-Hispanic Maya wells were located in areas where the water table was very deep.[101] In fact, many published well features were located in the Central Lowlands, an area with a very low aquifer level.

In order to systematize the knowledge on pre-Hispanic Maya wells, Johnston (2004a) developed the first thorough typology of Maya wells, which is still in use today. Based on their construction, the geographic location and the geologic zone they occur in, Johnston (2004a) subdivided the well features of the Maya Lowlands into four general categories (Silverstein *et al.* 2009: 51):

(1) Groundwater-penetrating wells,

(2) Chenes-type wells,

(3) *Buk'te'ob,* and

(4) Fault spring wells.

Each of these well types conforms to the particular hydrographic conditions of the local landscape (Silverstein *et al.* 2009: 51). The specific properties of these different well types are presented in the following section.

5.6.3.1 Well type 1: Groundwater-penetrating wells

According to Johnston (2004a: 283), hundreds of groundwater-penetrating wells have been reported in the Maya area. They can usually be found in areas where the water table is situated closer to the surface and their construction would have provided a direct and consistent water supply for the inhabitants.[102] Due to the shallow depth of the aquifer, most groundwater-penetrating wells were documented in the Northern Lowlands (Tozzer 1957:3).

In Dzibilchaltún, the aquifer is located at a depth of 2-3 meters (Kurjack 1979: 6; Matheny 1982: 168). The shallow depth of the local aquifer in the crater of the Chixculub meteorite and the high density of natural wells and cenotes that were partially caused by the meteorite's impact (see Chapter 2.1.1.1) made the Dzibilchaltun area a desirable place for early human settlers (Maldonado *et al.* 2012: 51). Within several household contexts of the site, Stuart *et al.* (1979) and Maldonado *et al.* (2012: 51) located a total of 128 well features. As Maldonado *et al.* (2012: 51) suggested, this imposing number was the result of the shallow local aquifer, which would have motivated the pre-Hispanic inhabitants to construct wells due to the relative ease. Furthermore, the homogenous distribution of wells in the settlement landscape suggests that these water sources were not controlled by elites (Maldonado *et al.* 2012: 52).

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[101] In Tikal for instance, the water table is situated more than 200 m below ground surface (Johnston 2004a: 281; Puleston 1973: 283).

[102] According to Johnston (2004a: 281), this can be observed in Dzibilchaltún (Kurjack 1979: 6) and Quirigua.

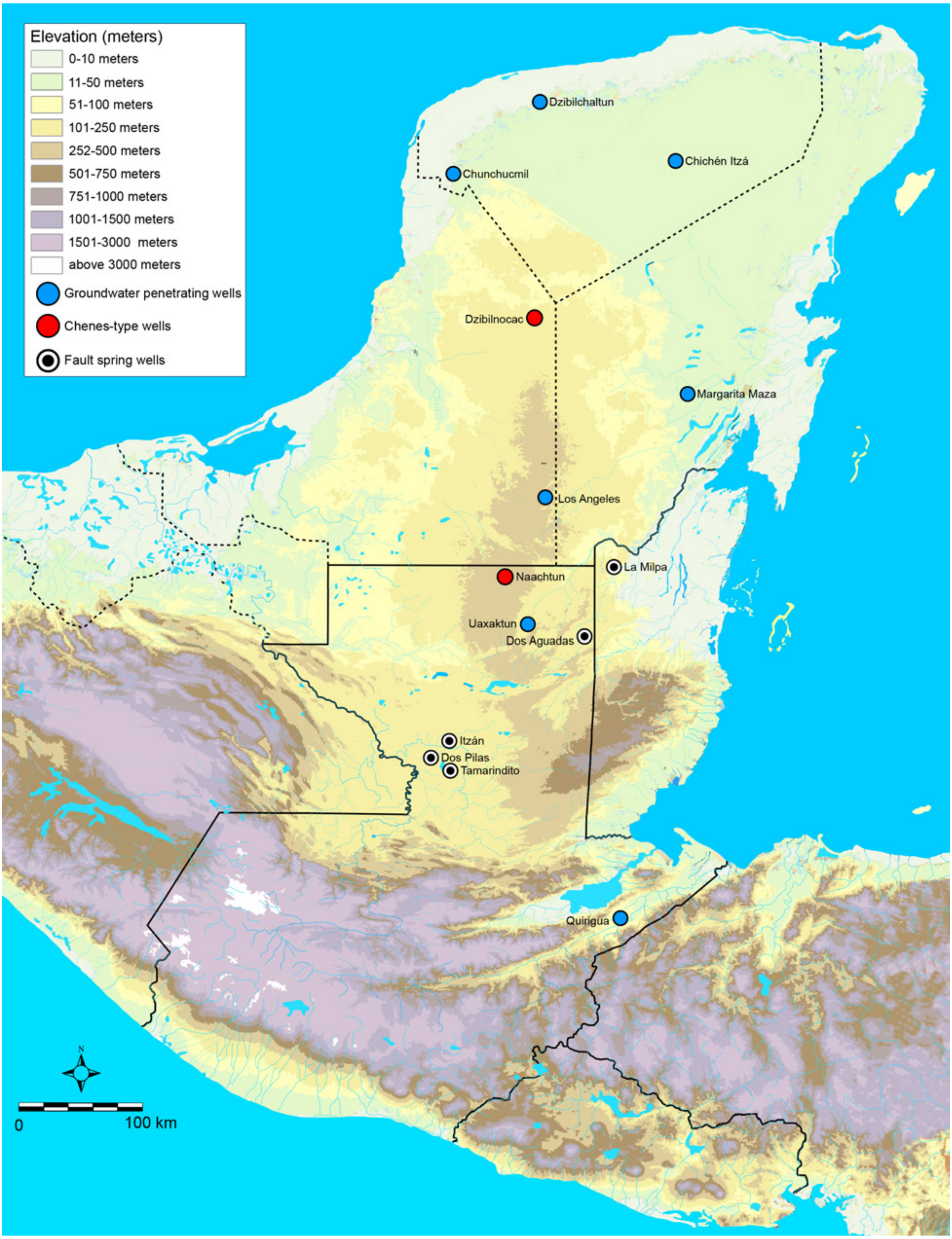
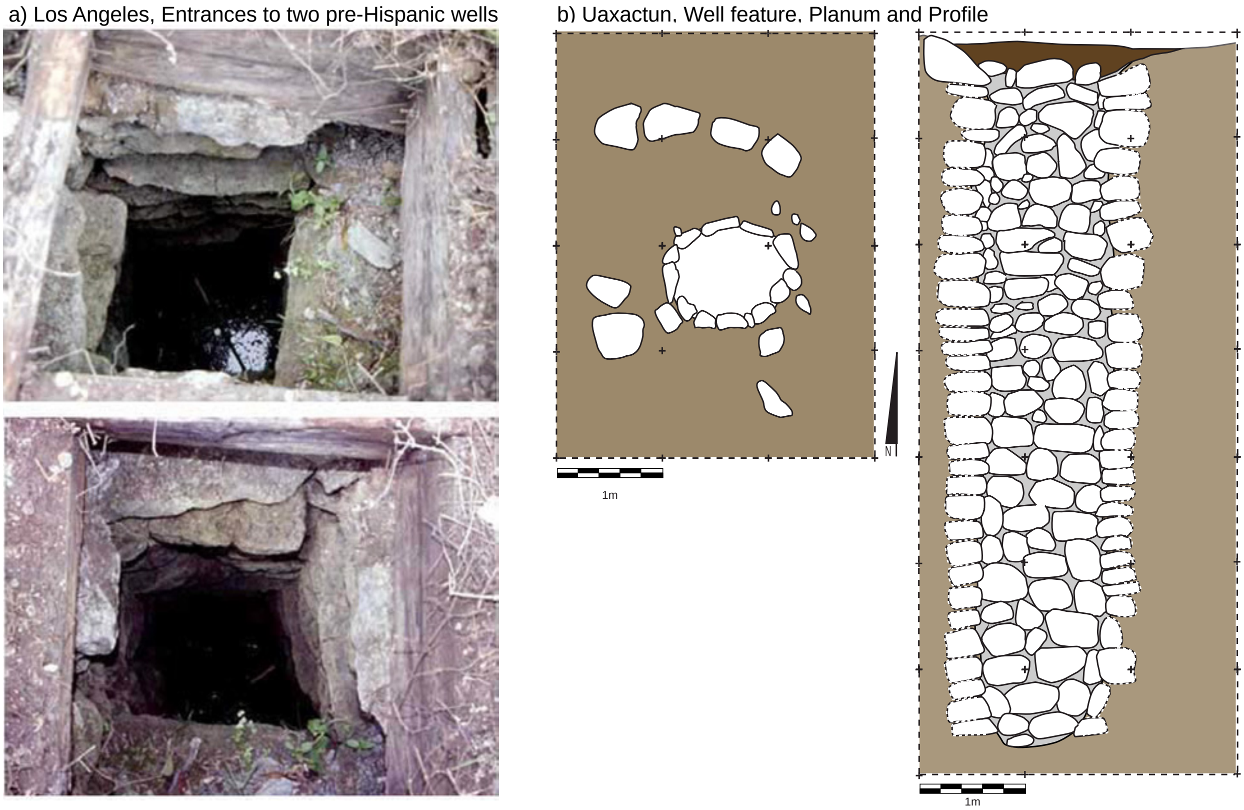


Figure 5.53: Map showing the location of published well features in the Maya Lowlands. (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

Inside the *rejollada* Pozo de la Abuelita in Chichén Itzá, González de la Mata (2006: 307) documented an artificial well with an oval layout. Its shaft was clad with a lining of dressed stones made up of 16 rows. The entrance to the well had an opening 1.50 x 2.20 m wide (González de la Mata 2005: Figure 2).

In Margarita Maza (southern Quintana Roo), Harrison (1993: 78-81) described the deepest groundwater-penetrating well. It is 0.93 m wide at its opening and has a depth of 22.65 m (Harrison 1993: Figures 4 and 5; Johnston 2004a: 283). Near the site of Los Angeles (southeastern Campeche), Šprajc (2001: 23) located two pre-Hispanic stone-lined wells with a rectangular shape. One had a depth of 3 m and filled with up to 2-3 m of water, while the other filled up to 4 m of water (Robichaux 2002: 343; see Figure 5.54a). In Uaxactun, Acevedo (2000) discovered a well near the site center composed of unworked stones that formed a cylindrical shaft (see Figure 5.54b). The other two were located at the settlement's margins. One of these was 7 m deep and filled with up to 4 m of water (Johnston 2004a: 281; Robichaux 2002: 343).


a) Los Angeles, Entrances to two pre-Hispanic wells

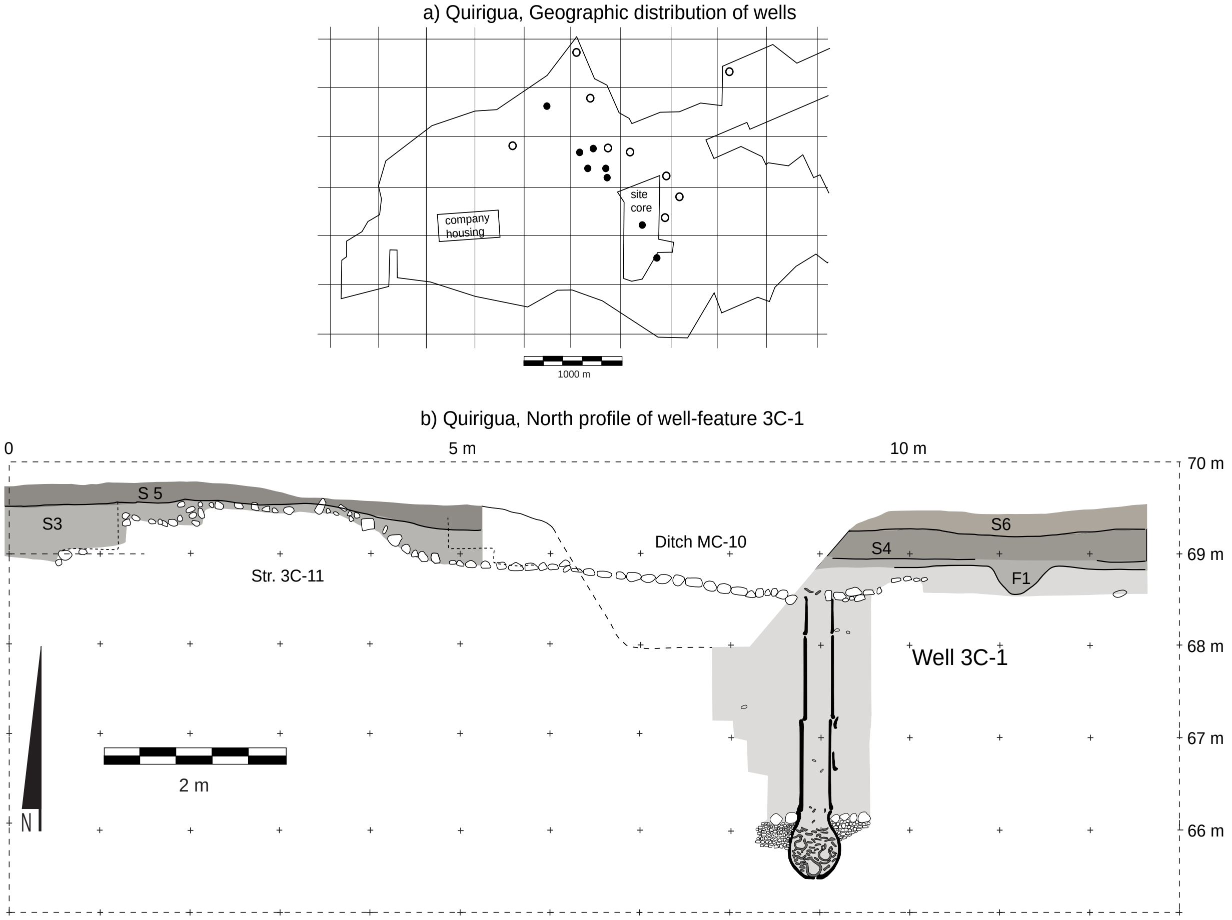
b) Uaxactun, Well feature, Planum and Profile

Figure 5.54: Overview of well features in the northern Maya Lowlands. (a) (source: Šprajc 2002: Figure 24; Reproduced with kind permission of Ivan Šprajc); (b) (redrawn after Acevedo 2000: Figure 1.Reproduced with kind permission of Renaldo Acevedo).

In Quirigua, Ashmore (1984: 151) documented eight entirely preserved wells dating to the 8th century AD (Ricketson 1935: 103, see Figure 5.55a). These consisted of three ceramic pipe elements stacked on top of each other and then set on the opening of a large jar-like vessel in the manner of a chimney (see Figure 5.55b). This composite construction was excavated into the soil and fed via the groundwater through the gaps between the ceramic elements (Ashmore 1984: 149). The peculiarity of this feature lies in its location, since it was found in an area with reliable and permanent water access.

In Chunchucmil, where the groundwater is usually accessible less than one meter below the surface, Luzzadder-Beach (2001: 498) documented 14 well features of pre-Hispanic and modern origin, which were approximately 4 m deep and featured diameters of 1 m (Johnston 2004: 283).

A sub-category of the groundwater-penetrating wells are the so-called walk-in wells of the Northern Lowlands (Matheny 1978). Due to the shallow depth of the aquifer and the presence of (collapsed) cenotes, some natural water-bearing cavities were modified in such a way that they could be accessed more easily by the pre-Hispanic population (Scarborough 1991: 109; Stephens 1943: 96).


a) Quirigua, Geographic distribution of wells

b) Quirigua, North profile of well-feature 3C-1

Figure 5.55: Well features of Quirigua (source: Ashmore 1984: Figures 1 and 2). Reproduced with kind permission of Wendy Ashmore and Cambridge University Press.

5.6.3.2 Well type 2: Chenes-type wells

Chenes-type wells are located in areas where the water table is either extremely deep or otherwise inaccessible (Silverstein *et al.* 2009: 51). Typical examples of areas with low-lying water tables are the Tikal[103] and the Chenes[104] regions (Johnston 2004a: 283; Silverstein *et al.* 2009: 51). The close relationship is apparent in the fact that "Chenes" is the Spanish pluralisation of the Maya word *chen* (well). As the name of the area suggests, it generally features a large number of wells (Johnston 2004a: 283). According to Johnston (2004a: 283), these wells do not actually come into contact with the water table. Instead, they collect water during the rainy season, which seeps through the surface limestone (Silverstein *et al.* 2009: 51). Overall, only few of these wells are needed to ensure a reliable supply of water for the entire dry season (Johnston 2004a: 283).

Within Dzibilnocac, De Bloois (1970: 104: 104-106) documented 19 well features (Brainerd 1953: 11; Chi and Folan 1991; Matheny 1982: 166-168; Nelson 1973: 33-34). The depth of these wells varies between 2.6 and 13.6 m. The wells' shafts are clad with mortarless masonry with some wells also featuring stone pavements (Matheny 1982: Figure 5; see Figure 5.56). Nelson (1973: 33-34) divided the wells of Dzibilnocac into two types:

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[103] During the 1950s, wells with depths of 180 m were drilled without coming into contact with the water table (Puleston 1973: 238; Silverstein *et al.* 2009: 51).

[104] Near Dzibilnocac, the water table is situated at a depth of more than 180 m (Nelson 1973: 33).

(a) Round wells with diameters between 0.85 and 1.10 m, and

(b) Rectangular wells with side lengths between 0.55 and 0.75 m.

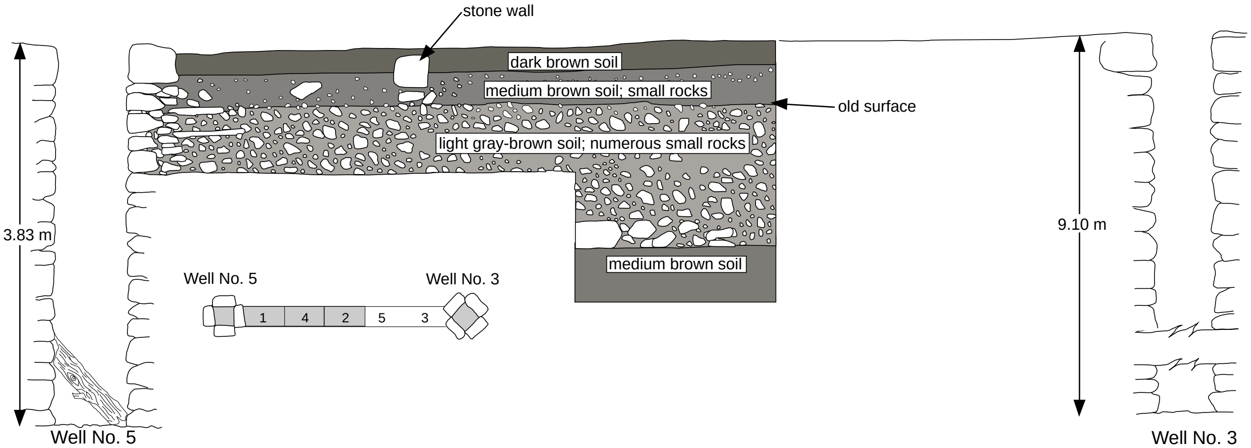

Figure 5.56: Dzibilnocac, Well system (Redrawn after Matheny 1982: Figure 5). Reproduced with kind permission of Ray Matheny and Elsevier).

In Naachtun, Chenes-type wells were reported at the margins of a bajo (Silverstein *et al.* 2009: 51). However, graphic documentation material of these features has not been published to date.

5.6.3.3 Well type 3: *Buk'te'ob*

Although *buk'te'ob* can be defined as well features they only occur in conjunction with modified aguadas. Since they represent a constructional sub-element of aguadas, they are presented in greater detail in Chapter 5.6.4.2.1.

5.6.3.4 Well type 4: Fault spring wells

Fault spring wells only appear in conjunction with local springs formed by geological discontinuities such as crevices or fractures and take advantage of them (see Chapter 2.1.4.1.1). According to Johnston (2004a: 278) and Silverstein *et al.* (2009: 51), the tendency of water to follow the contours of the surface has been exploited by numerous cultures in the form of *galerías filtrantes*[105] (Mexico), *qanats* (Persia), *salaiba* (South Asia), and *puquios*[106] (Peru) (Beekman 1999; Schreiber and Lancho Rojas 1995, 2003). According to Johnston (2004a: 278) and Silverstein *et al.* (2009: 51), the pre-Hispanic Maya also were also aware of these geologic discontinuities and took advantage of them wherever they were available.

As Johnston (2004a: 286) noted, the natural landscape of the Maya Lowlands exhibits numerous locations where the permanent, but buried water table lies near the surface. In these locations it would have been possible to excavate a well almost anywhere along the surface. Due to this observation, Johnston (2004a: 286) stipulated that fault spring wells should be incorporated into the list of "invisible structures" because they cannot be detected on the surface and may even be overlooked in excavations if they are

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[105] *Galerías filtrantes* are subterranean canals built in Puebla during the Colonial Period (Beekman 1999; Palerm Viqueira *et al.* 2002; Silverstein *et al.* 2009: 51). They are planned in such a way that they can absorb underground water, infiltrate downwards and direct it towards a reservoir or populated areas by means of underground aqueducts (Silverstein *et al.* 2009: 55).

[106] *Salaiba* (Hanan 2006; Kahlown and Hamilton 1996) and *puquios* (Schreiber and Rojas 1995, 2003) collected rainfalls to fill shallow reservoirs. The stored water was used for irrigation in arid acreages (Silverstein *et al.* 2009: 55).

not lined with stones.[107] However, some springs, such as those on the top of hill ridges, may show traces of their existence on the surface as the openings of karst springs vary considerably (Johnston 2004a). According to Johnston (2004a: 282), the pre-Hispanic Maya lined their wells with dry-laid masonry in order to avoid clogging them with sediment.[108] To improve the flow of fault springs on top of hill ridges, the pre-Hispanic Maya would have actually excavated the natural soil cover until they reached the surface of the limestone bedrock. This would have exposed crevices and provided them access to the water (Johnston 2004a: 282). Inevitably, these processes would have required an extensive knowledge of the local water sources (Johnston 2004a: 286). By lining the well shafts with stones, the Maya would have prevented crevices fed by underground springs from being choked with sediment (Johnston 2004a: 282).

Johnston (2004a: 281) even claimed that most of the previously documented wells would have in fact been fed by fault springs. In order to prove this hypothesis, he emphasized that the water level of most known Maya wells was situated at a depth between 2 and 5 m and would consequently be too high to represent the general phreatic surface. Due to these observations, Johnston (2004a: 281) concluded that these wells were actually fed by covered water tables, e.g. water tables which formed through the retention of water in spatially isolated, impermeable rock layers located above the phreatic zone. According to Johnston (2004a: 282), the fault wells of the Maya Lowlands can be divided into two categories:

(1) Low shafts constructed by rural peasants with a depth of approximately 1 m. The interiors were lined with clay and cobbles while their openings were surrounded with a stone pavement.

(2) Deeper wells with a depth between 4 and 7 m featuring stone-lined shafts mostly concentrated in the eastern section of the Central Lowlands.

In contrast to centrally located reservoirs that would have been at risk of contamination by local residents, the water extracted from fault spring wells was generally cleaner due to the filtering effect of the limestone (Johnston 2004a: 279). At the current state of research, six published features were identified as fault wells: A well feature north of Dos Lagunas (1), a well feature in El Cedro (2), the "Poza Maya" close to La Milpa (3), a well feature in the site of El Arroyo (4), two well features in the site of Tamarindito (5), and a well feature in the site of Itzán (6) (Johnston 2004a: 279; see Figure 5.57).

(1) The well feature of Dos Lagunas (or Dos Aguadas) lies one mile north of the site core at the base of a long slope and near the margin of a bajo (Bullard 1960: 363). Bullard (1960: 363) noted that this well was located near a residential area and represented the only source of water in a 2 km radius (Robichaux 2002: 343). According to Bullard (1960: 363), it featured a round shaft with a diameter of 85-100 cm, was at least 5 m deep (see Figure 5.57a) and "presumably fed by subterranean percolate water along the slope", which indicates that the well tapped a source along the foot of the slope (Johnston 2004a: 281). The well shaft was reinforced with dry-laid, unworked stones.

(2) In the Chiclero Camp of El Cedro, Graham (1967: 33) located a well feature at the foot of a long slope, which suggested that it was fed by a natural spring (Johnston 2004a: 281). As Figure 5.57c indicates, its shaft was reinforced with dressed stones (Robichaux 2002: 343). Graham's (1967: 33) observations showed that the well exhibited a diameter of 65 cm, becomes wider towards its base, reached a total depth of 3.45 m and had a water level of 1.25 m in 1961.

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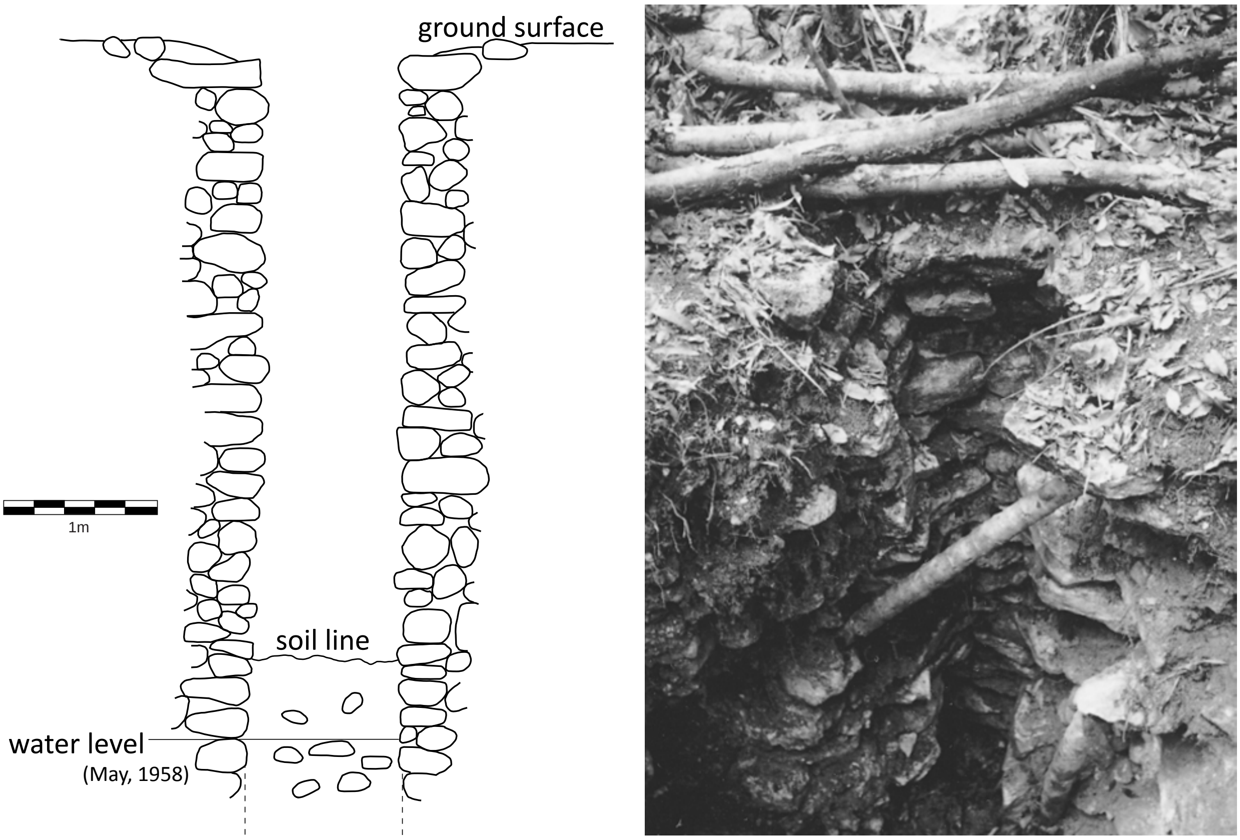
[107] Although a few fault spring wells were documented in La Milpa, Dos Aguadas, Uaxactun, El Cedro and Los Angeles (see below), Johnston (2004a: 279) is convinced that many more features could be discovered through systematic prospections.

[108] According to Palmer (1990: 189; Figure 4), the upstream ends of groundwater flow-routes in karst rocks increase in size to become funnel-shaped openings. If these openings did not develop a turbulent flow, they would tend to become choked near the surface causing the water to disperse close to, but underneath the surface without being used (Johnston 2004a: 277, 282).


a) Dos Aguadas, Section of well

b) La Milpa, El Arroyo, Photo of well entrance

c) El Cedro, Photo of well entrance

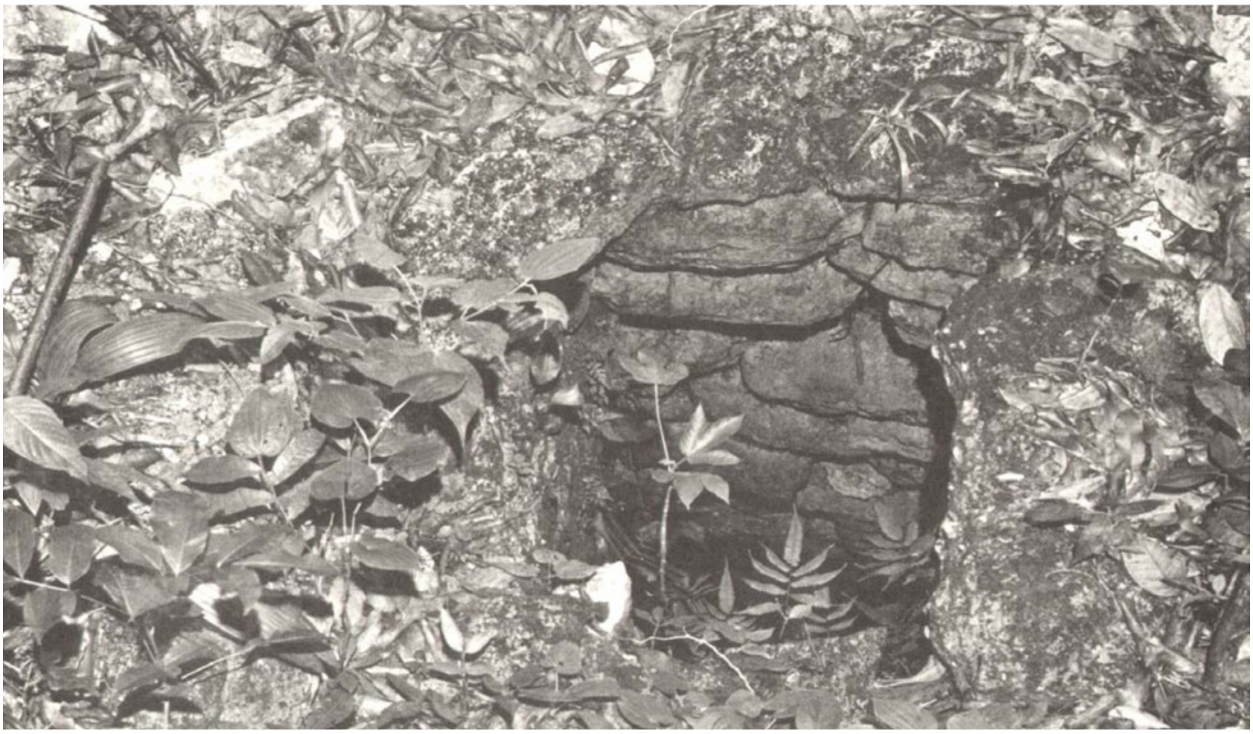


Figure 5.57: Fault springs of Dos Aguadas, El Arroyo and El Cedro. (a) (source: Bullard 1960: Figure 6. Reproduced with kind permission of Cambridge University Press); (b) (Photo courtesy of Nicholas Dunning. Reproduced with kind permission of Nicholas Dunning); (c) (source: Graham 1967: Figure 22). Reproduced with kind permission of the Middle American Research Institute (MARI).

(3) The Poza Maya lies in a residential group 3 km northeast of La Milpa's center (UTM coordinates: E 284.5 N 1971.5; Johnston 2004a: 279; Scarborough *et al.* 1995a: 101, 118). The well shaft is lined with carefully set stones and measures 2.5 m in width and 4.22 m in depth. Many scholars observed that the well is fed by a source on the hill ridge that features a "flow rate of 37 liters per minute during the dry season" (Guderjan *et al.* 1991: 76; Robichaux 2002: 343).

(4) In the site of El Arroyo, located near La Milpa, Valdez (1995) identified a fault spring well. The well showed many similarities to the Poza Maya and its shaft was lined with stones along its entire depth (Johnston 2004a: 279; Robichaux 2002: 343; see Figure 5.57b).

(5) In the site of Tamarindito, Beach and Dunning (1997: 278) documented two springs at the foot of slopes. In their view, these springs exhibited a strong flow and apparently recharged the Laguna Tamarindito. As Johnston (2004a: 278) emphasized, the geological history and morphology of the Río Pasión area would have favored the formation of fault springs and, consequently, would have motivated the construction of fault spring wells. In order to support this hypothesis, Johnston (2004a: 278) referred to a well documented in the site of Itzán, which represents the most thoroughly investigated fault spring well of the Maya Lowlands.

(6) The site of Itzán[109] is located 6 km north of the Río de la Pasión and 13 km east of Altar de Sacrificios (Johnston 2004a: 268). The settlement is concentrated on a hilltop and the lateral flanks of a long hill ridge. To the east, it is delimited by the Laguna Itzán (Akpinar 2011: 20; Johnston 2004a: 268). In the residential group of IT4, situated 4 km south of the site center, Johnston (2004a: 271) documented the opening of a fault spring well. It was located in a patio group (IT4A) covering the eastern slope of a low hill ridge that divides and runs perpendicular to the north-south axis of the Itzán-escarpment (Johnston 2004a: 272; see Figure 5.58a).

In the southern portion of this residential group, which is mainly composed of "invisible structures", Johnston (2004a: 272) located a structure consisting of a dense pavement of limestone cobbles surrounding a fault spring well (see Figure 5.58b). The well's opening had been modified to facilitate the extraction of water (Johnston 2004a: 272; see Figures 5.58c and 5.58d). In the section where the well penetrated the surface, it featured two chambers situated directly above one another (Johnston 2004a: 272, see Figure 5.58b). The upper chamber has a diameter of 70 cm, a depth of 60 cm and reaches 30-90 cm below the surface (see Figure 5.58d). It consists of a vertical, clay-lined shaft, which the pre-Hispanic inhabitants had covered with cobbles (Johnston 2004a: 272). According to Johnston (2004a: 275), this chamber would have been large enough to accommodate a small jug, cup or scoop.

The adjacent, deeper chamber extended between 80 and 190 cm beneath the surface and was only connected to the upper chamber through a narrow, bent shaft (Johnston 2004a: 275, see Figure 5.58c). This oblong chamber was bulb-shaped and, according to Johnston (2004: 275), featured a base area of "several square meters", and had apparently not been culturally modified. After the removal of sediment, cobbles and artifacts, the lower chamber filled with about 7.5 liters of water per hour (Johnston 2004a: 275).[110] Based on the recovered artifacts, Johnston (2004a: 276) determined that this well had been used over a period of 1200 years. The documentation of a water storage vessel[111] in the lower chamber convinced him that the pre-Hispanic inhabitants had used it in order to extract water from the spring (Johnston 2003: 276).

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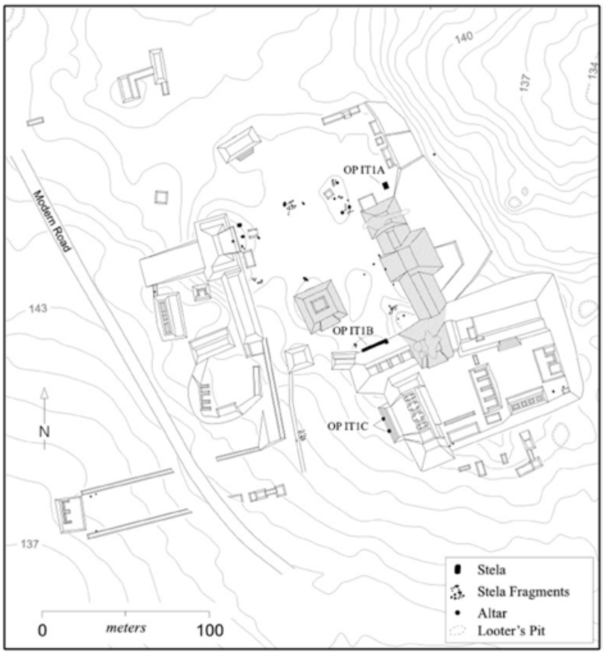
[109] The occupation of the settlement ranges from the early middle Preclassic to the Terminal Classic (900 BC to AD 900) (Johnston 1994; 2003, 2004a: 268, 2006).

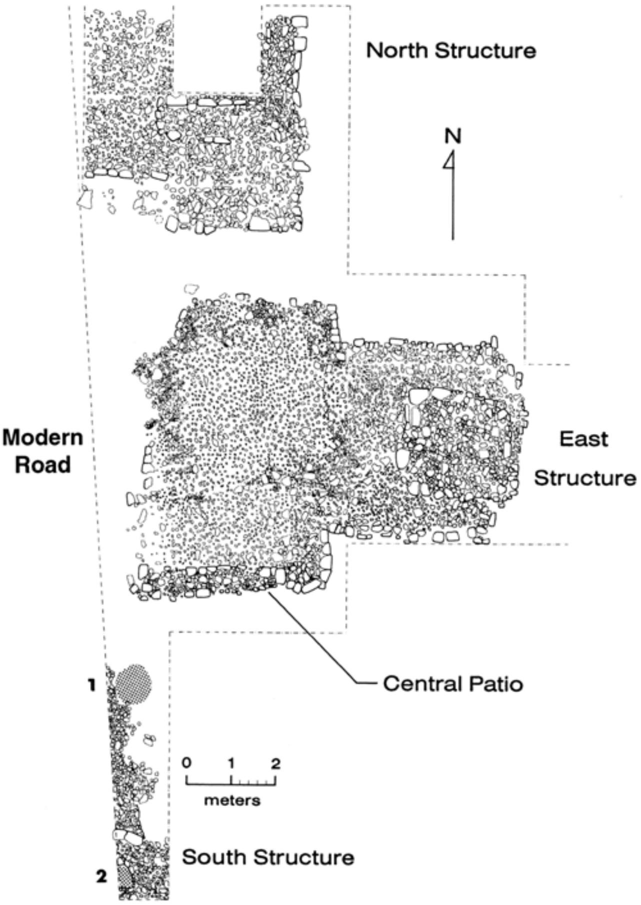
[110] In this connection, it is important to note that, according to Johnston (2004a: 275), the upper chamber had been excavated at the end of the dry season, during times of lower water levels.

[111] According to Johnston (2004a: 276), the fragments of the jug (Tinaja Red) show many similarities with modern storage vessels of the Maya (Deal 1985; Deal and Hagstrum; Johnston 1994a: 450; Reina and Hill 1978: Figure 24e, 49e).

a) Itzán, Map of ceremonial center



b) Itzán, Plan of IT4A Group



c) Itzán, Fault-spring, Photo of lower chamber

d) Itzán, East-profile of south-structure

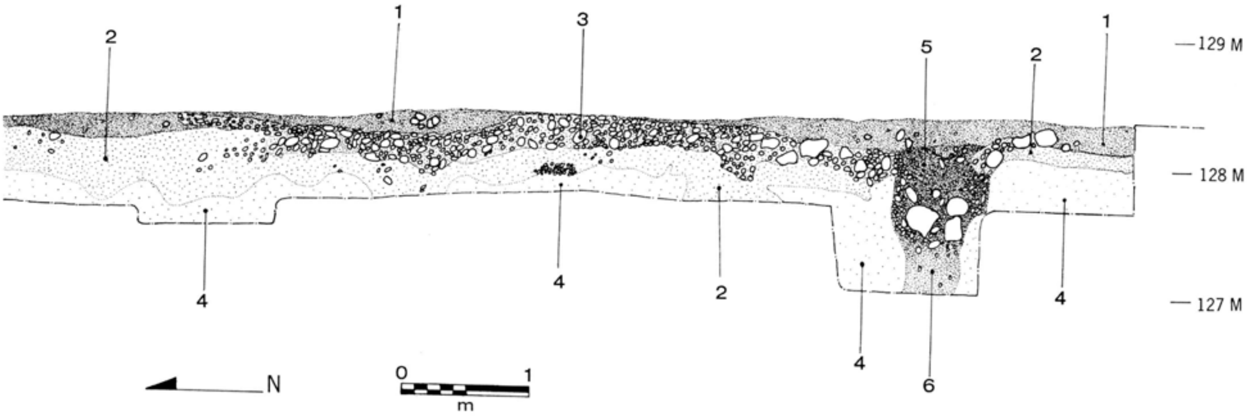


Figure 5.58: Itzán, Fault spring well in Group IT4A. (a) (source: Johnston 2006: Figure 3). Reproduced with kind permission of Kevin Johnston and Cambridge University Press; (b) (modified from Johnston *et al.* 1992: Figure 4); (c) (Photo courtesy of Kevin Johnston. Reproduced with kind permission of Kevin Johnston); (d) (source: Johnston 1994: Figure 5). Reproduced with kind permisison of Kevin Johnston.

5.6.4 Reservoirs and modified aguadas

Technically, reservoirs and modified aguadas are open collecting ponds constructed in regions without sufficient surface water. As these constructions formed an important aspect of the adaptation strategies of the pre-Hispanic Maya, a considerable number of these landscape features have been discovered and described in the Maya Lowlands. While reservoirs are entirely artificial constructions deliberately built for the sole purpose of water storage, modified aguadas either have a natural origin or served other functions in the past.

Whereas some authors believe that most modified aguadas originated as natural dissolution features,[112] other scholars[113] are convinced that they would have originally been quarries that were later on converted into reservoirs. Akpinar-Ferrand *et al.* (2012: 85) even promoted the idea that "most of the naturally occurring aguadas in the vicinity of ancient Maya settlements were later lined by the Maya with plaster, and/or stone facing to improve their ability to hold water" (Adams 1981; Ancona 1889; Nondédéo 2003: 28; Wahl *et al.* 2007). However, it is the author's opinion that the proximity to architectonic features does not indicate that the respective aguada had been modified. Due to several experiences with sophisticated modifications of natural landscape features (see Chapter 6), the author would also like to point out that it is almost impossible to discern if a specific aguada is of a natural or cultural origin without archaeological excavations. Since only a few have been studied archeologically, it is not even possible to estimate the ratio between natural and artificially modified aguadas.

In some cases however, thorough archaeological investigations were indeed able to ascertain that particular aguadas had originally been used as quarries and were subsequently converted into reservoirs (e.g. Akpinar-Ferrand *et al.* 2012: 85; Beach *et al.* 2008; Bullard 1960; Dunning *et al.* 2007; Hester and Shafer 1984; Weiss-Krejci *et al.* n.d.). Flores-Nava (1994) defined this special type of aguadas as "quarry aguadas". In the author's opinion however, a general problem exists in the way the construction process of "quarry aguadas" is understood. Specifically, most scholars imply that the primary motivation for the excavation of an artificial depression would have been the recovery of building material. In this respect however, it is important to emphasize that the primary motivation for the excavation of an artificial depression cannot generally be determined explicitly by means of archaeological excavations. The reason for this methodological issue lies in the limited interpretability of modified bedrock. While in most cultural and natural "layers", all cultural processes leave traces that can be verified by accurate stratigraphic documentation, the observation of the bedrock only enables an understanding on the most recent cultural modifications. Therefore, all of the earlier modification phases of the natural bedrock are no longer able to be documented during the excavation process. In this case, the only explicit evidence suggesting a reservoir was once used as a stone quarry is the documentation of stone tools in association with it (Weiss-Krejci and Sabbas 2002: 348).[114] In all other cases, the author would prefer to designate aguadas that have traces of cultural modifications with the less biased term of "modified aguadas" due to the above mentioned methodological issues. Furthermore, it is important to highlight that it is difficult to precisely determine the extent to which a particular aguada was modified or if it was an entirely artificial construction (Dunning *et al.* 2015b: 10).

In order to prevent water seepage and use existing depressions as reservoirs, the pre-Hispanic Maya had to carry out a number of modifications (Adams 1981; Beach *et al.* 2015b: 260). The following section reconstructs the procedures the pre-Hispanic Maya applied in the modification of natural bodies of water and the construction of artificial reservoirs.

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[112] e.g. Jennings 1985: 106; Lene 1997; Siemens 1978.

[113] e.g. Akpinar-Ferrand and Dunning 2011; Beach et al. 2008; Carr and Hazard 1961; Domínguez Carrasco and Folan 1996: 178; Hester and Shafer 1984; Matheny 1978: 204; Wahl et al. 2007: 216.

[114] In some cases, such as the Aguada Lagunita Elusiva of La Milpa (see Chapter 5.6.4.3.8.3) and the aguadas of Colha (see Chapter 5.6.4.3.9), chert was documented in the context of quarry aguadas.

5.6.4.1 Construction process of modified aguadas and artificial aguadas

Due to the general geologic composition of the Maya Lowlands and the relatively consistent shape of reservoirs, the construction process of most of the modified features included two central procedures:

(1) The extension of the natural surface depression or the excavation of a new artificial surface depression, and

(2) The application of a sealing layer at the bottom of the artificially modified depression

5.6.4.1.1 Extension of the natural surface depression or the excavation of a new artificial surface depression

Based on several documented stone tools at the bottom of modified aguadas, Weiss-Krejci and Sabbas (2002) were able to reconstruct that this process was carried out with stone tools in most cases (Brewer 2007: 87). Owing to the relatively simple process of limestone extraction, several scholars developed the idea that in some pre-Hispanic Maya communities, there would have been an approximately 1:1 relationship between the volume of extracted material during the excavation of artificial reservoirs and the volume of the construction fill for monumental architecture (Gill 2000; Scarborough 1983, 1991b).

5.6.4.1.2 Application of a sealing layer at the bottom of the artificial depression

The application of a sealing layer mainly aimed to reduce the extent of percolation and thus increase the amount of water stored in the respective reservoir. To this end, the pre-Hispanic Maya employed three basic methods.

a) The application of a water-impervious clay layer,

b) The lining with a stucco layer, and

c) The construction of a pavement composed of limestone slabs (Parry 2007: 17, 30; Scarborough 1998: 139; Smith 1950: 61, Figure 99b).

(a) Application of a sealing clay layer

Functionally, the application of impermeable clay layers at the bottom of a reservoir impeded the seepage of water into the fractured limestone surfaces (Akpinar-Ferrand and Dunning 2011: 110; Flores-Nava 1994). However, it should be noted that this sealing layer would not have necessarily been applied artificially, because the accumulation of clay and organic material sometimes occurred without human interference (Adams 1981; Ancona 1889; Mathewson 1988; Scarborough *et al.* 2011: 11; Siemens 1978). As Akpinar and Dunning (2011: 111) noted, the extent of anthropogenic influence during the deposition of these clay layers varied from one aguada to another. As pointed out in Chapter 2.1.4.3.1, recent findings seem to indicate that some of the water-impervious bentonite clay layers at the bottom of aguadas were not applied by the pre-Hispanic Maya, but rather originated from degraded volcanic ash that deposited after volcanic eruptions in Guatemala and Mexico (Dunning *et al.* 2015a: 100; Ford and Rose 1995: 159; Grim and Grüven 1978: 128; Tankersley *et al.* 2015: 190, 211; Weiss-Krejci *et al.* n.d.). Because the existence and functionality of bentonite clay layers on aguada bases has only been analyzed in very few Maya centers, future research will hopefully provide a more thorough picture of the distribution of natural bentonite depositions and their effect on the water storage capacity of natural aguadas.

(b) Application of a stucco layer

The application of stucco layers had a similar effect as the sealing of patio surfaces in that it impeded the seepage of water into the bedrock. In addition to this sealing effect, many scholars also claim that the lime contained in the stucco layers may have also killed pathogens in freshwater bodies (Ganguly *et al.* 1999). Thus, the dissolving process of the stucco layers would have released lime into the stored water and reduced the dissemination of water-borne diseases (Akpinar-Ferrand and Dunning 2011: 118).

(c) Construction of a stone pavement

Ultimately, the most elaborate form of sealing layer consisted of the construction of limestone pavements at the bottom of artificial reservoirs. Due to the required labor input, this has only been documented in a relatively small number of modified aguadas. In addition to the sealing layers, some reservoirs featured additional constructional elements at their bases that are described in the following section.

5.6.4.2 Constructional elements at the bottom of aguadas

Among the most common constructional elements at the bottom of aguadas are *buk'te'ob*.

5.6.4.2.1 Buk'te'ob

As already mentioned in Chapter 5.6.3, some scholars (e.g. Johnston 2004a: 283) define *buk'te'ob* as a "well type". However, since they only occur at the bottom of aguadas, the author chose to define them as a constructional element of aguadas. *Buk'te'* constructions are stone-lined filtration wells at the bottom of aguadas or rejolladas (Dunning 1992: 22; Dunning *et al.* 2003; Huchim Herrera 1991; Johnston 2004a; Tozzer 1957: 3; Weiss-Krejci and Brandl 2011; Weiss-Krejci *et al.* n.d.). Their walls are usually covered with crude masonry assembled without mortar (Johnston 2004a: 283). Technically, *buk'te'ob* collected water that filtered through the clay sediment in the rainy season (Akpinar 2011: 31, 118). During the dry season, a *buk'te'*[115] provided access to the sunken water table and temporarily increased the water-holding capacity of a reservoir (Dunning 1992: 20-23; Johnston 2004a: 283; Silverstein *et al.* 2009: 51; Weiss-Krejci *et al.* n.d.). At the current state of research, *buk'te'ob* seem to be more frequent in the Northern Lowlands than the Central Lowlands (Weiss-Krejci *et al.* n.d.).

A variety of *buk'te'ob* are the *casimbas* (Casares 1905: 218; Stephens 1843: 13-137), which were built without stone lining. *Casimbas* (buckets) were simple "holes" or "pits" into which water infiltrated during the dry season (Johnston 2004: 284). Due to their more simple construction method, casimbas are more frequent landscape features (Johnston 2004a: 284).[116]

Within the Chenes, Stephens (1843: 145) documented an aguada that featured 40 stone-lined *buk'te'ob* with depths between 6 and 8 m. Some of the *buk'te'ob* had deep and narrow shafts, while others were bell-shaped constructions with broad bases that reputedly provided water throughout the entire dry season (Johnston 2004a: 284, Stephens 1962; see Figure 5.59). The fact that the same process was later described

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[115] The *Diccionario de la lengua maya* of Pío Pérez (1866-1877: 33) from the 16th Century A.D defines *buk'te'ob'* as *„aljibes o depósitos hechos en el fondo de las aguadas para recibir el agua que se infiltra, y se usa cuando la fuerza del sol ha secado aquellas"* (see also Barrera Vásquez 1980: 69 and Barrera Rubio and Huchim Herrera 1989: 283).

[116] In an aguada near Iturbide (northeastern Campeche), Stephens (1843: 135) described the existence of four well constructions and 400 *casimbas*, which would have provided abundant water supply for the local population of the 19th century (Johnston 2004a: 284).

by Brasseur du Bourbourg (1865) and in Ancona's (1978) history of the Yucatán shows the widespread and prolonged usage of these humble reservoirs (Akpinar 2011: 31).

Within the Puuc-Region, where the groundwater table lies at a depth of 65 m, *buk'te'ob* are also common features of aguadas (Dunning 1992: 20-22; Dunning *et al.* 1998: 22). According to Johnston (2004a: 285), some pre-Hispanic *buk'te'ob* are still being used today (see Figure 5.66). Besides the *buk'te'ob* that Barrera Rubio and Huchim (1989) excavated in the Aguada Chen Akal near Uxmal (see Chapter 5.6.4.3.1), only a few of the many *buk'te'ob'* have been studied and published upon by archaeologists (Johnston 2004a: 285). Among them is a *buk'te'* documented at the bottom of the La Milpa Aguada in the site of La Milpa (see Chapter 5.7.8.1). Furthermore, the stone lined wells at the bottom of rejolladas (see González de la Mata 2006) near Chichén Itzá and other sites are comparable to the *buk'te'ob* (Johnston 2004a: 284; Roys 1939: 4; see Figure 5.60).[117]

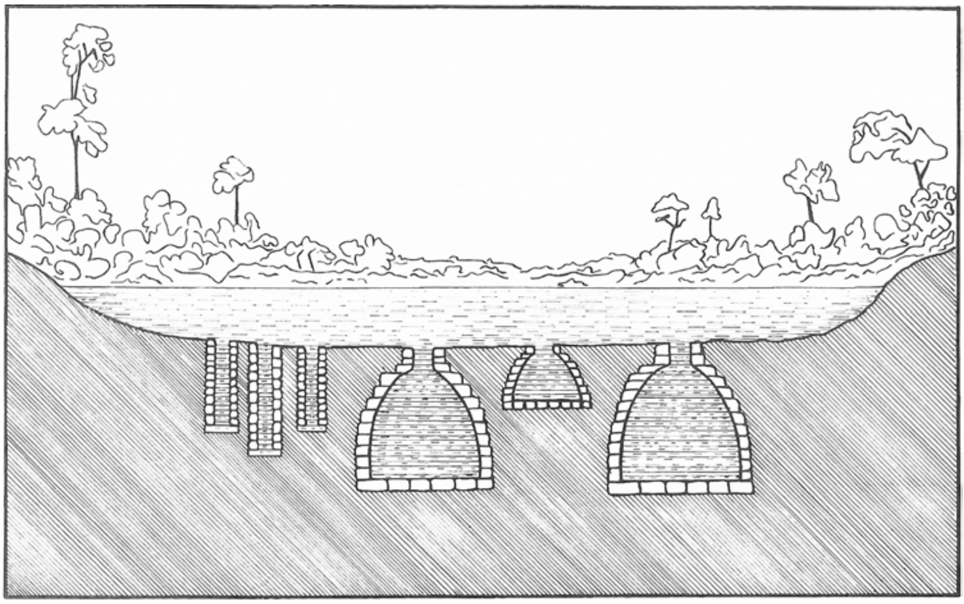

Figure 5.59: Rancho Jalal, Schematic cross-section of *buk'te'ob* (source: Stephens 1843 II: Plate 25).

Figure 5.60: Aguada Ichpich, Photo of *buk'te'* (Photo courtesy of Nicholas Dunning. Reproduced with kind permission of Nicholas Dunning).

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[117] In this connection, Johnston (2004a: 285) names the *rejolladas* near Ek' Balam (Kepecs and Boucher 1996: 79) and also the well near La Milpa (see below).

In order to provide a better understanding of the functionality of the aforementioned constructional elements, the upcoming section provides a detailed presentation of the published examples of modified aguadas.

5.6.4.3 Published modified aguadas and reservoirs

As mentioned in Chapters 2 and 3, thousands of modified aguadas and reservoirs have been documented in the Maya Lowlands (Beach *et al.* 2015a: 16). However, out of this huge group, only a relatively small number have been investigated in a focused scientific manner. From the relatively small group of studied aguadas, the features in Figure 5.61 show clear signs of anthropogenic modification. Interestingly, these reservoirs show a distinct concentration in the core of the Elevated Interior Region (EIR). Even though this concentration is to some extent a consequence of the density of archaeological investigations in this core area, it nevertheless clearly illustrates the direct relationship between the water scarcity due to geological conditions and the adaptation strategies of the pre-Hispanic Maya. While Figure 5.61 shows all published reservoirs and modified aguadas of the Maya Lowlands, the following catalog will first present water storage features that do not form part of a complex hydraulic system of interrelated features. The constructions integrated into larger hydraulic systems will be presented in Chapter 5.7. For the calculation of the storage capacity of reservoirs, most scholars used the following formula developed by Gallopin (1990: 103):

$$Volume = \left(\frac{Height\ of\ the\ cone}{3}\right) x\ \pi\ x\ \left(\frac{Length\ of\ surface}{2}\right) x\ \left(\frac{Width\ of\ surface}{2}\right)$$

Later on, Gallopin’s (1990) original formula was slightly modified by Brewer (2007), Crandall (2009: 23), and Akpinar-Ferrand *et al.* (2012: 87):

$$Volume = \left(\frac{Height\ of\ the\ cone}{2}\right) x\ \pi\ x\ \left(\frac{Length\ of\ surface}{2}\right) x\ \left(\frac{Width\ of\ surface}{2}\right)$$

In this modified formula, the height of the cone (depth of the reservoir) is divided by 2 instead of 3. Consequently, this modified formula leads to the calculation of higher storage capacities.

Figure 5.61: Map of reservoirs and modified aguadas (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

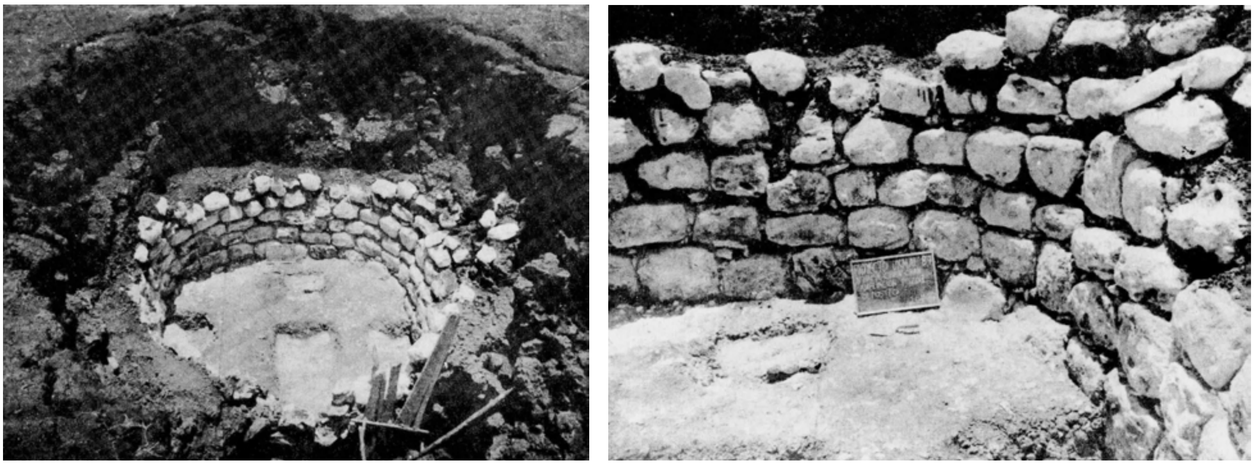
5.6.4.3.1 Uxmal, Aguada Chen Chan Akal

The Aguada Chen Chan Akal is the largest of Uxmal's aguadas and lies 550 m west of the cemetery group (Barrera Rubio and Huchim Herrera 1989: 279; Huchim Herrera 1991). John Lloyd Stephens (1843: 248-250) was one of the first visitors to describe this reservoir during his explorations and reported that, according to local informants, the "remains of stone embankments were still visible in several places" during the dry season, (Barrera Rubio and Huchim Herrera 1989: 279). During the second half of the 19th century, the aguada was also described by Brasseur du Bourbourg (1984: 20).

The Aguada Chen Chan Akal has an irregular form and features a northwest-southeast orientation. It has a maximum length of 300 meters with a width of 100 m at its widest point and 20-30 at its narrowest (Barrera Rubio and Huchim Herrera 1989: 279). In some portions, the height-difference between the interior base and the outer edge is 5 m (Barrera Rubio and Huchim Herrera 1989: 279).

In 1987, Barrera Rubio and Huchim Herrera (1989: 282) tried to verify Stephen's (1943) description of a stone embankment and defined two test pits. The first unit, a 2 x 2 m trench, was located at the northern border of the aguada, while the second, a 4 x 4 m trench, was located in the aguada's center. In the first unit, the excavations reached a depth of 3.70 m without finding any hints of a stone embankment (Barrera Rubio and Huchim Herrera 1989: 282).[118]

The second excavation unit located in the center reached a maximum depth of 4 m and led to the discovery of a circular buk'te' feature with a diameter of 4 m and a possible depth of 3 m (Barrera Rubio and Huchim Herrera 1989: 282; see Figure 5.62a). As Figure 5.62b indicates, the construction did not feature a stucco layer. Instead, it was formed out of roughly worked stone blocks that were assembled into circular rings. The remaining gaps were filled with smaller pebbles and the floor was formed out of compacted clay mixed with small stones (see Figure 5.63).


a) Uxmal, Aguada Chen Chan Akal, General view of *buk'te'*

b) Uxmal, Aguada Chen Chan Akal, Detail of *buk'te'* construction

Figure 5.62: Uxmal, Buk'te' feature at the base of the Aguada Chen Chan Akal. (a) (source: Barrera Rubio and Huchim Herrera 1989: Photo 21); (b) (source: Barrera Rubio and Huchim Herrera 1989: Photo 22). Reproduced with kind permissipn of Alfredo Barrera Rubio and José Huchim Herrera.

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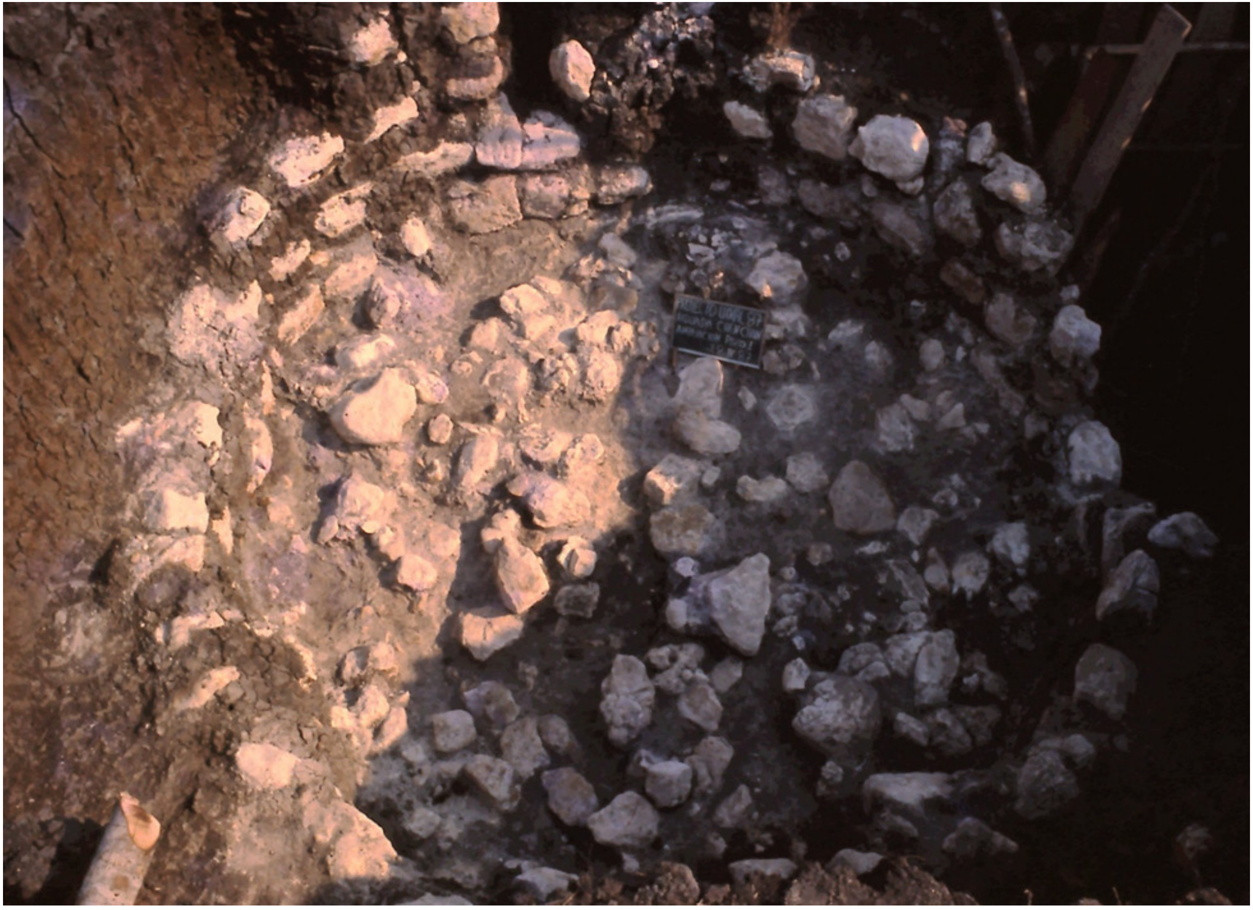
[118] The lack of a limestone pavement could be the result of a large-scale landscape modification in 1936 and 1937, when the Aguada Chen Chan Akal and the Western Aguada No. 2 were cleared, burned and blasted in order to dry out the reservoirs and thus prevent the further distribution of Malaria in the area.

a) Uxmal, Aguada Chen Chan Akal, Buk’te’ during the excavation process



b) Uxmal, Aguada Chen Chan Akal, Buk’te’ during the excavation process

Figure 5.63: Uxmal, Aguada Chen Chan Akal, Buk’te’ during the excavation process (Source: Huchim Herrera 1991). Photos were provided by and reproduced with kind permission of José Huchim Herrera.

5.6.4.3.2 Nakbe, Aguada Zacatal

Nakbe is located in the eastern Mirador Basin, 12 km southeast of El Mirador. It is one of the earliest urban sites in the Maya Lowlands and was already abandoned at some point during the Late Preclassic Period (Akpinar 2011: 28; Gunn *et al.* 2002). According to Akpinar (2011: 28) and Brewer (2007), the site featured numerous canals, dams, reservoirs and chultunes indicating the importance of water management for its pre-Hispanic inhabitants.[119]

Near the small site of Zacatal, 4 km west of Nakbe's site center, Wahl *et al.* (2007: 214) investigated the Aguada Zacatal (17°40'670"N, 89°52'109"W). The reservoir is situated on the eastern edge of the Narros Bajo and may have represented the site's primary source of water during the dry seasons (Forsyth *et al.* 1998: 90; Wahl *et al.* 2007: 215). The round reservoir features a diameter of 100 m and, similar to the reservoir of Kinal (see Chapter 5.7.8), its border is surrounded by a circular berm (see Figures 5.64 and 5.65). Wahl *et al.* (2007: 220) noted that this berm would have increased the storage capacity of the reservoir and prevented desiccation during the dry season (Hansen *et al.* 2002). The southern portion of this embankment features a small gap, which Wahl *et al.* (2007: 217) interpreted as a type of regulating point that would have likely enabled the filling and draining of the aguada.

During the extraction of sediment samples in the aguada's center, Wahl *et al.* (2007: 218) documented an artificial stucco floor at a depth of 110 cm, which presumably reduced water seepage considerably. Wahl *et al.* (2007: 219) presumed that the Aguada Zacatal once represented a natural landscape feature, which later underwent an anthropogenic modification.

Based on their investigations, Wahl *et al.* (2007: 219) were unable to clearly identify if the reservoir had been used for the irrigation of acreages during the dry season or if it would have only been used for domestic purposes. However, the relatively small size of the reservoir and the fact that it is located below the level of the surrounding bajos led Wahl *et al.* (2007: 220) to the conclusion that the water would not have been used for irrigation. They note that for the application of an actual irrigation system, inhabitants would have either been forced to extract the water from the reservoir or to deepen the surrounding acreages (Wahl *et al.* 2007: 220).[120]

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[119] Unfortunately, no other hydraulic feature, apart from the Aguada Zacatal has been published to date.

[120] In the author's opinion, the deliberate lowering of the surrounding acreages does not appear to be a realistic scenario. On the one hand, this process would have required considerable investments of labor, and on the other hand, the thin layer of agriculturally productive topsoils above the natural bedrock would have considerably diminished the desired effect.

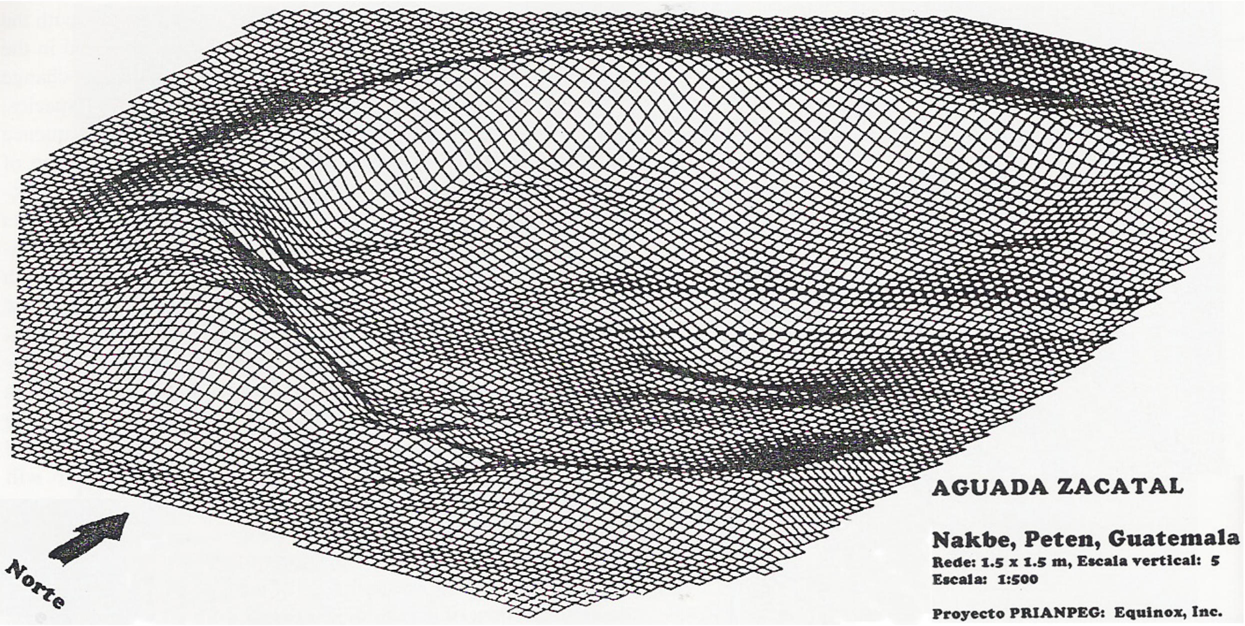

Figure 5.64: Nakbe, Topographic relief of Aguada Zacatal (source: Hansen *et al.* 2002: Figure 14). Reproduced with kind permission of Richard D. Hansen.

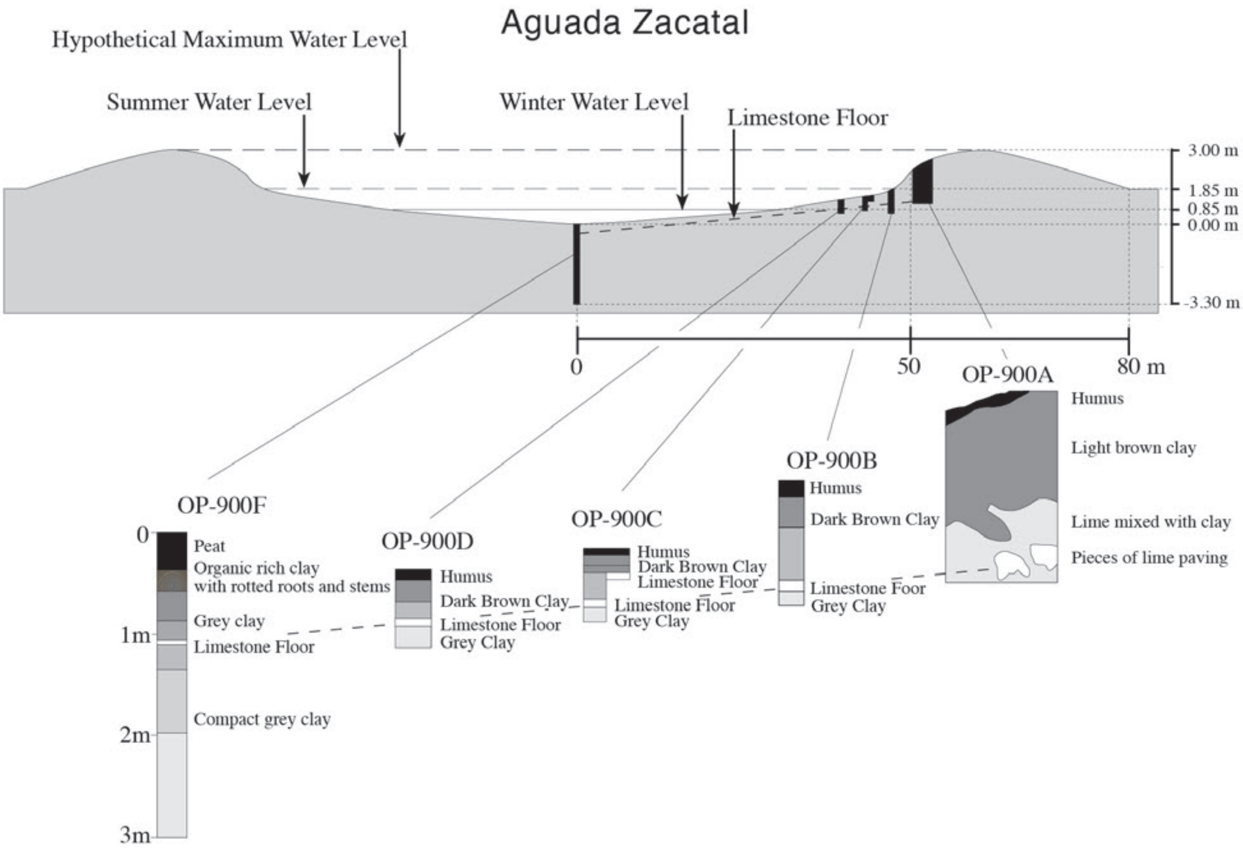

Figure 5.65: Nakbe, Schematic profile drawing of Aguada Zacatal (source: Wahl *et al.* 2007, 216: Figure 3). Reproduced with kind permission of David Wahl and Cambridge University Press.

5.6.4.3.3 Modified reservoir of Naachtun

Naachtun (N 7 48’18’; E 89 44’00’) is located on a physiographical rise in the Lowlands known as the Mirador basin, and lies within the Naachtun–Dos Lagunas National Biotope (Hansen *et al.* 2012: 273; Parry 2007: 2; Ruppert and Denison 1943: 45). The site survived the collapse of El Mirador at the end of the Late Preclassic and continued to grow through the Late Classic before it was finally abandoned during the Terminal Classic (Arredondo Levia 2005: 62; Dunning *et al.* 2002: 271; Nondédéo *et al.* 2013; Parry 2007: 4; Range and Reese-Taylor 2005: 1).

In the central compound of Naachtun, between the large eastern and western plazas of Group A, lies a rectangular reservoir with an extension of roughly 29 x 26 m featuring edges lined with large stone boulders (Parry 2007: 6; 165; see Figures 5.66b and 5.66c). According to Parry (2007: 165), this central location would have enabled access both to the inhabitants of the civic and ceremonial buildings of the city and to the people living in the two residential compounds located to the east and west (see Figure 5.66b). Furthermore, the location of the reservoir and its rectangular shape indicate that it formed part of the civic architecture (Parry 2007: 190). The fact that a wall had been built around the structure during the Late Classic suggests that access to the water would have been prohibited to the general public and those not living in direct relation to the feature (Parry 2007: 165, 192).

In order to determine the technical layout of this landscape feature,[121] Parry (2007: 6) investigated it by means of a single large archaeological trench, Operation 3. This trench exposed a complete stratigraphic profile of the reservoir’s western boundary near its northwestern corner (see Figures 5.65c and 5.65d-j). The whole trench was subdivided into five units (Sub-operations A-E), all of which were excavated down to the sterile bedrock (Parry 2007: 56). While Suboperations A, B, and D were joined to create a 12 x 1 m trench, Sub-operation C, a 1 x 4 m trench, was located further uphill and connected to Sub-operation E, a 2 x 2 m excavation unit (see Figure 5.66b).

During the excavation of Sub-operation A, located at the western slope of the reservoir, Parry (2007: 68) documented a cobble wall or filtering device (similar to a footslope terrace) that had been anchored by two large boulders (see Figure 5.66f). The overall shape of the wall was formed by a pile of unshaped cobbles in a matrix of silty loam (Parry 2007: 89). The excavations of Sub-operation B showed that the western edge of the reservoir had been fortified by a shallow boulder wall with a height of two courses, whose upper edge had already been exposed prior to the excavations (Parry 2007: 68, see Figure 5.66f). In Sub-operation C, Parry (2007: 181) documented a meter high wall that formed part of the western platform of Group A (see Figure 5.66d). In Sub-operation D, Parry (2007: 74) documented a low rock wall consisting of two courses featuring several dressed stones (see Figure 5.66e).[122] According to Parry (2007: 182), the meter high wall in Sub-operation C and the low rock alignment in Sub-operation D would have been part of a platform remodeling event that created large angled steps down to the base of the feature. These steps could have either been used to facilitate maintenance routines or in order to access water during low levels (Parry 2007: 182). In Sub-operation E, a 2 x 2 m trench opened diagonally to Sub-operation C, Parry (2007: 76) documented further remains of Group A’s western platform (see Figure 5.66a). During the excavation, Parry (2007: 166, 177, 220) only documented sequential layers of sandy sediments. These layers might have formed a “hardened carbonate cement together with the limestone parent material” and minimized the seepage of water from the base (Brenner *et al.* 2002: 145). As the position within the settlement indicates, the reservoir was fed by runoff diverted from the southeastern and northwestern Plazas of Group A (Parry 2007: 173; see Figures 5.66b and 5.66c). During the investigation, no inlet or outlet features could be documented. In Parry’s (2007: 172) opinion, the function of the reservoir would have been to maximize the amount of collected rainwater during the rainy season to last through the dry season.

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[121] It should be noted that even after completing these investigations, Parry (2007: 6) still defined the feature as a “potential reservoir” as she could not be entirely sure that it had been modified.

[122] As Parry (2007: 195) noted, this low-lying and angled rock wall is similar to a dam in La Milpa, which was only one course high and had been constructed with uncut stones (Scarborough *et al.* 1995: 103, see Chapter 5.7.9.1).

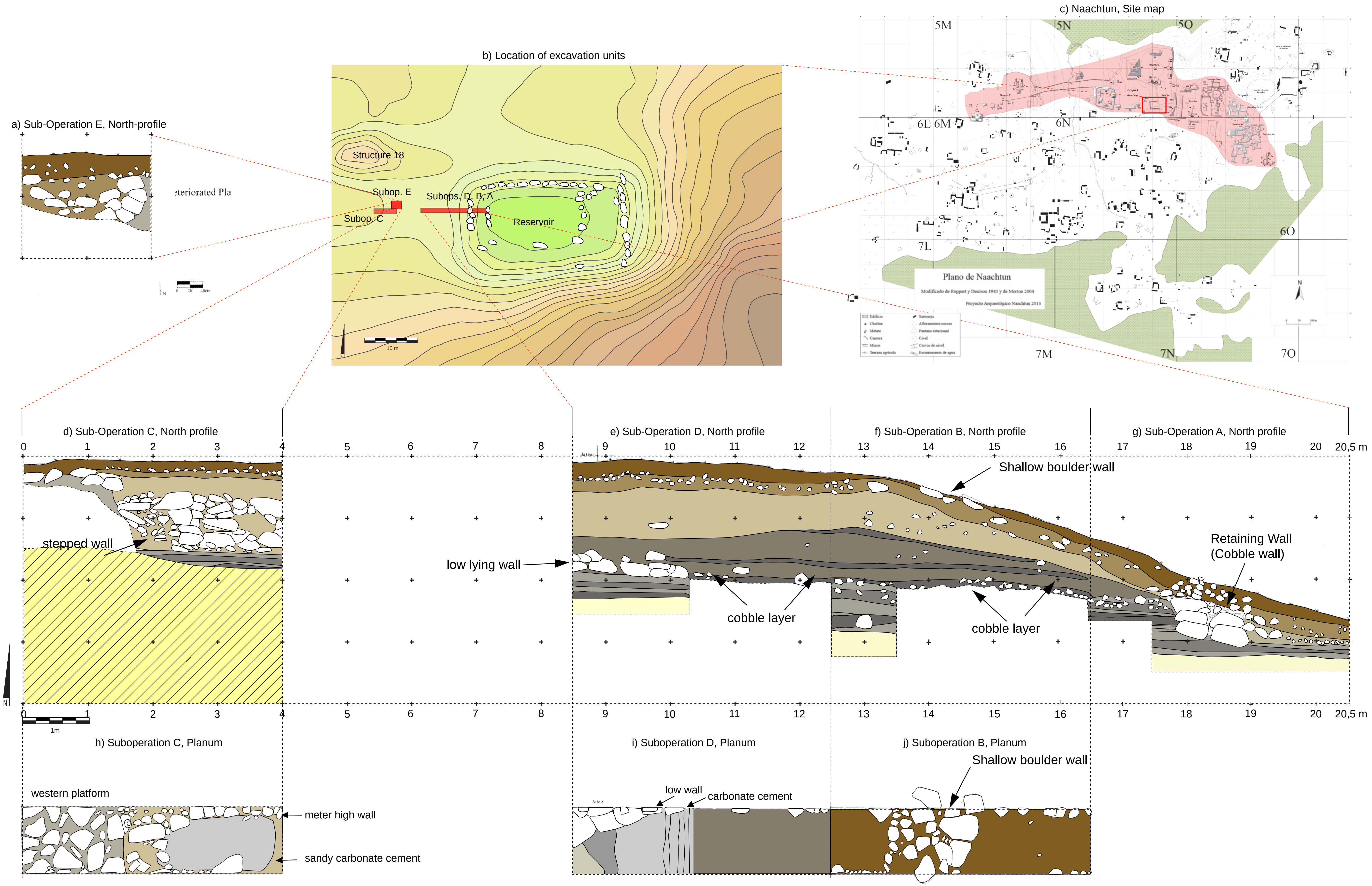


Figure 5.66: Naachtun, Modified reservoir, Plana and profiles of Sub-operations A, B, C, D, E. (a) (modified from Parry 2007: Figure 4.4); (b) (modified from Parry 2007: Figure 1.2); (c) (source: Nondédéo et al. 2013: Figure 2); (d-g) (modified from Parry 2007: Figure 5.2); (h) (modified from Parry 2007: Figure 4.5); (i) (modified from Parry 2007: Figure 4.7); (j) (modified from Parry 2007: Figure 4.3). Reproduced with kind permission of Philippe Nondédéo and Roberta G. Parry.

According to Parry (2007: 167), the cobble wall documented in Sub-operation A was built during the Naachtun V phase (AD 554-562) in order to prevent sediment from entering the reservoir and to confine the stored water to a restricted area. Thus, this wall would have extended on all four sides of the reservoir (Parry 2007: 179). In Parry's (2007: 167) opinion, the layer of grey fill documented behind the wall would have been deliberately applied in order to create a restricted area to collect water. After the construction, water below the height of the wall would have collected in the wall-enclosed basin, preventing it from spreading across the entire surface of the basin (Parry 2007: 17).

Furthermore, Parry (2007: 180) argued that the cobble layer observed behind the cobble wall also might have served to filter the inflowing water. Due to the retention wall, washed in sediments could have settled, so that the water east of the wall would have been much cleaner (Parry 2007: Figure 5.2). In Parry's (2007: 180) view, the low alignment of rocks in Sub-operation D (see Figure 5.66e) might have served canalized water when water levels were low.

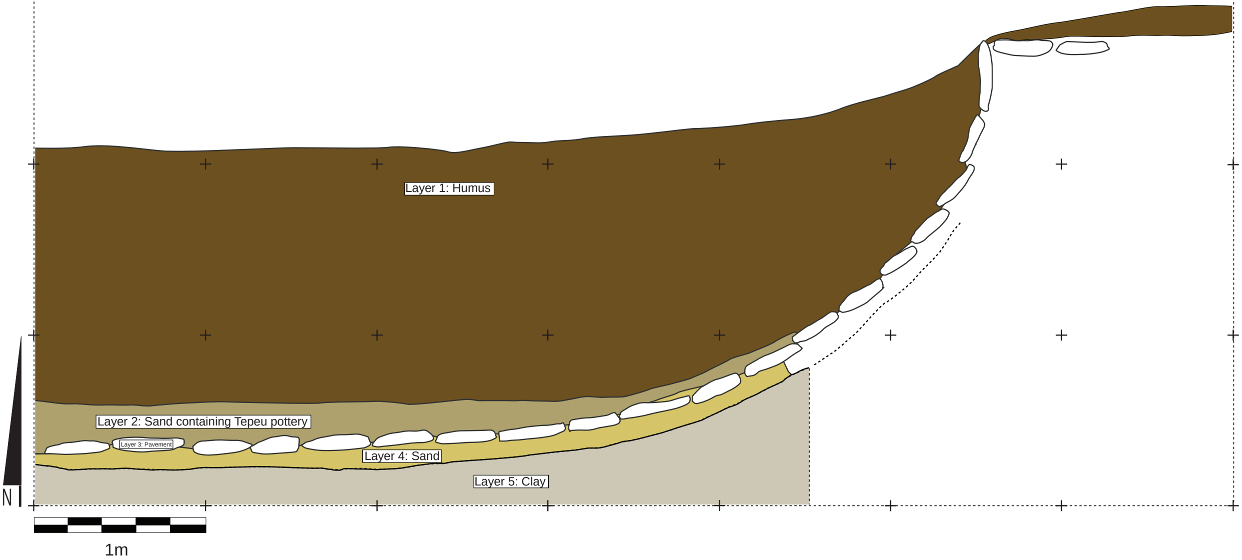
As the recovered ceramic material indicated, the reservoir was used for approximately 500 years, from Naachtun IV (AD 292-554) until Naachtun VI B (AD 652-790). However, according to Parry (2007: 187), the reservoir had already been built during the Preclassic or Early Classic, and later remodeling events destroyed the earlier evidence. Parry (2007: 187) also asserts that the reservoir was originally a natural depression used by the earliest settlers and that it would have been converted into a formal feature during the Late Classic Period. In this process, the pre-Hispanic inhabitants of Naachtun would have quarried the limestone bedrock in order to form a rectangular basin with sloping sides (Parry 2007: 176). Based on the exposed profile, Parry (2007: 194) calculated that the reservoir would have had a catchment capacity of 1,508 m^3 and, thus, would have been comparable with the reservoir of Tamarindito (see Chapter 5.6.4.3.10).

5.6.4.3.4 Artificial reservoirs of Uaxactun

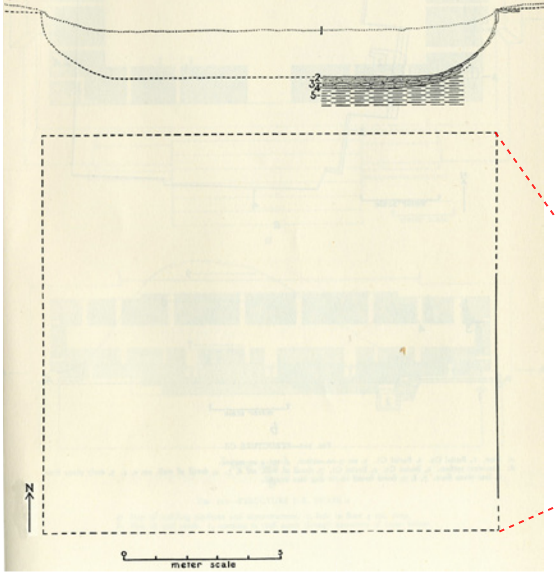
In 1937, Smith (1950: 61) carried out the first excavations of an aguada in Maya archeology. To the west of the causeway connecting groups A and B in Uaxactun, Smith (1950: 61) located two reservoirs (Reservoir A and Reservoir B). On its western side, the causeway featured a 15 m wide gap in the parapet that allowed water to drain from the Main Plaza of Group A into Reservoir A (Smith 1950: 61). Reservoir A, a rectangular construction with an extension of 14.5 x 12.5 m, lies 30 m west of this gap and is fed by runoff from the immediate vicinity and the causeway (Smith 1950: 61; see Figure 5.67). Through the excavation of an archaeological trench (of unspecified dimensions), Smith (1950: 61) was able to determine that Uaxactun's pre-Hispanic inhabitants had removed "the natural clay to a depth of about 2.5 m at the center and graded the surrounding ground level". During the excavations, Smith (1950: 61) also observed that the reservoir's basin was covered with an 8 cm thick layer of sand, upon which the builders had created a pavement of limestone slabs. Finally, the slabs "were covered by a 20 cm thick layer of sand" (see Figures 5.67a and 5.67b). Interestingly, the builders also applied this pavement to the sloped embankment of the reservoir. Based on the documentation of Tepeu 3 sherds in the upper sand layer (see Figure 5.67a), Smith (1950: 61) concluded that Reservoir A had been used until the Late Classic Period.

Reservoir B, an oval shaped depression with a diameter of 30 m and a maximum depth of 5.5 m, is located southwest of the Main Plaza of Group B (Smith 1950: 61; see Figure 5.67c). During the excavation of a trench on the reservoir's northwestern edge, Smith (1950: 61) observed large stones forming a sloping wall, which were interpreted as an artificial dam blocking the head of a shallow corriental. To the east of the reservoir, Smith (1950: 61) observed a spillway, which would have served to decelerate the influx of runoff from the Main Plaza. Due to the presence of Tzakol 2 ceramics at the bottom of Reservoir B, Smith (1950: 61) concluded that it was most likely constructed during the Early Classic Period.

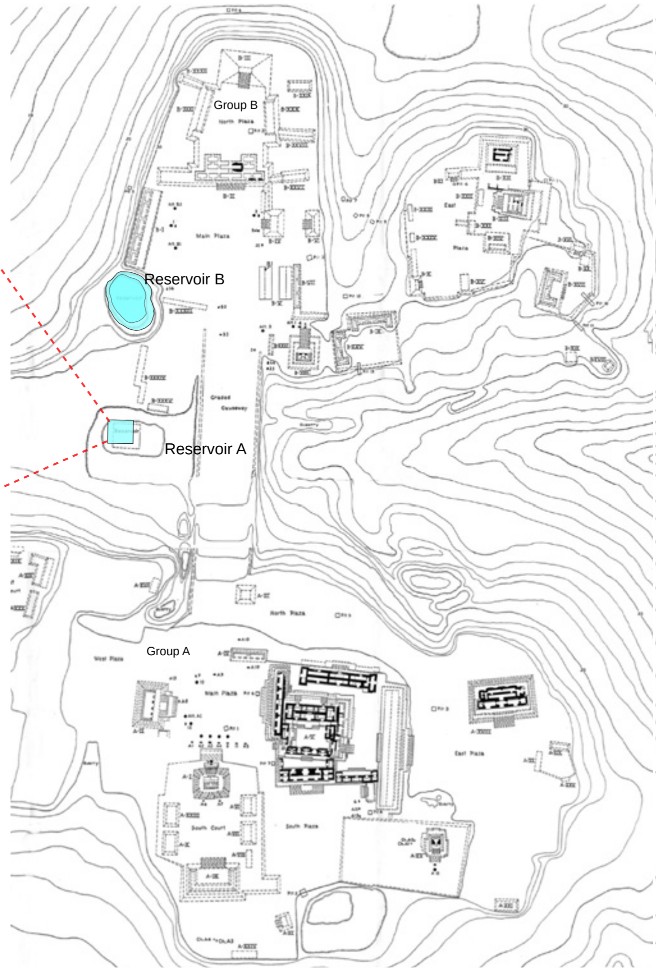
a) Uaxactun, Group B, Reservoir A, Cross section



b) Uaxactun, Group B, Reservoir A, Cross section and planum



c) Map of Uaxactun, Groups A and B



d) North view of Reservoir A

Figure 5.67: Uaxactun, Group B, Reservoirs A and B. (a-b) (modified from Smith 1950: Figure 99b); (c) (modified from Smith 1950: Figure 142); (d) (source: Smith 1950: Figure 49a). Reproduced with kind permission from the Carnegie Insitution of Washington.

5.6.4.3.5 El Zotz, modified Aguada

El Zotz lies in the middle of the Petén Karst Plateau, 20 km west of Tikal (Beach *et al.* 2015b: 259, 2015a: 17). The site of El Zotz sits at an elevation of almost 400 meters, a position that may have provided a defensive advantage. The surrounding landscape is marked by a deep valley running southwest to northwest. El Zotz was settled during the transition from the Late Preclassic to the Early Classic and remained occupied into the Postclassic Period (Beach *et al.* 2015b: 261; Doyle *et al.* 2012; Garrison and Garrison 2010). At the western margin of the site, located at an elevation of 234 m above sea level, lies the Aguada El Zotz (Beach *et al.* 2015b: 260). The aguada has a roughly circular shape with a northeast to southwest length of 280 m and a northwest to southeast length of 200 m (Beach *et al.* 2015b: 260; see Figure 5.68a). Along its western and eastern edges, the reservoir is bordered by two prominent berms (see Figure 5.68d). In order to determine potential indications for cultural modifications, Beach *et al.* (2010, 2015b: 261) excavated five archaeological trenches extending from the reservoir center to the eastern berm (see Figure 5.68b). An additional trench (EZ-13-A5) was excavated on the berm in the western portion, but showed no cultural stratification. Based on the excavations in the reservoir's center, Beach *et al.* (2015: 261) were able to determine four main layers (see Figure 5.68b):

1. A Late Classic layer consisting of compacted gravel and plaster located at a depth of 105-115 cm showing a sediment accumulation from the Postclassic.

2. A thick depositional zone that accumulated between the Early Classic and the Late Classic.

3. An Early Classic floor composed of worked limestone slabs, clay and ceramics located at a depth of 230 cm (see Figure 5.68e).

4. A paleosol layer located underneath the Early Classic floor.

According to Beach *et al.* (2015a: 17, 2015b: 266), the Early Classic pavement bears several similarities to the pavement documented in the Palace Reservoir of Tikal (Scarborough *et al.* 2012, see Chapter 5.7.7.2.2) and the Aguada Oriental of Uxul (Seefeld 2013a, 2013c, see Chapter 6.2.2). Unfortunately, Beach *et al.* (2015a, 2015b) did not publish any graphic material of the ceramic layer. The upper, Late Classic floor had a thickness of 10 cm and was composed of compacted limestone gravel (Beach *et al.* 2015b: 266). According to Beach *et al.* (2015a: 266), the construction and maintenance of this floor would have required a smaller investment of labor and highly resembled the floor at the bottom of the Aguada Los Tambos in Xultun (Akpinar-Ferrand *et al.* 2012; see Chapter 5.6.4.3.7). In addition to the Aguada El Zotz, Beach *et al.* (2015b: 268) studied the Aguada Los Bocutes (located 1.42 km northeast of the site center), the Aguada Bejucal Cival (located 0.5 km southwest of the ruins) and the Aguada El Diablo by means of test pits. These operations did not document traces of cultural modifications in any of the three aguadas (Beach *et al.* 2015b: 269).

Beach *et al.* (2015a: 17) calculated that the main reservoir of El Zotz would have been able to hold about 87,920 m^3 of water,[123] and consequently had a comparable storage capacity to the sizable Palace Reservoir of Tikal (Scarborough and Grazioso Sierra 2015; Scarborough *et al.* 2012; see Chapter 5.7.7.2.2). Based on these data, Beach *et al.* (2015b: 276) calculated that the aguada may have originally provided drinking water for 48,000 to 120,000[124] people. The oval-shaped El Diablo Aguada, with an extension of 30 x 23 meters, would have been able to store up to 1,083 m^3 of water and support 590 to 1,500 people. According to Beach *et al.* (2015a: 17, 2015b: 274), the construction of the floors at the bottom of the El Zotz Aguada would have required a high input of labor. These modifications would have enabled the aguada to maintain the quality of the stored water and decrease losses from percolation. Based on the monumental size of the El Zotz Aguada, Lentz *et al.* (2015b: 283) argued that its "oversized dimensions" might have been one of the reasons why the city of El Zotz remained populated into the Postclassic Period.

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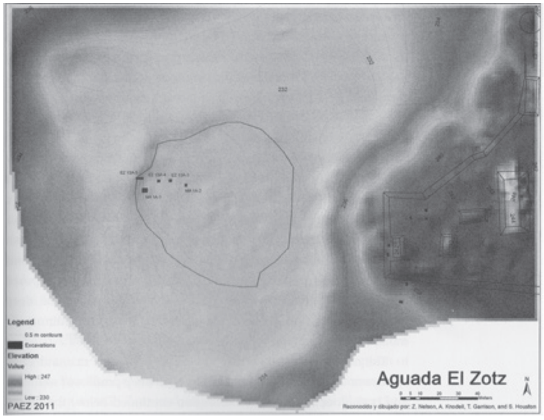
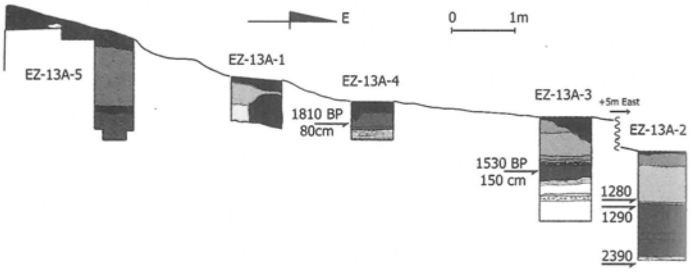
[123] For the calculation of the storage capacity, Beach *et al.* (2015: 276) used the elliptical cone-volume formula developed by Brewer (2007); see Chapter 5.6.4.3.

[124] For this calculation, Beach *et al.* (2015: 276) used a broad range of daily water per person consumption of 2-5 liters.

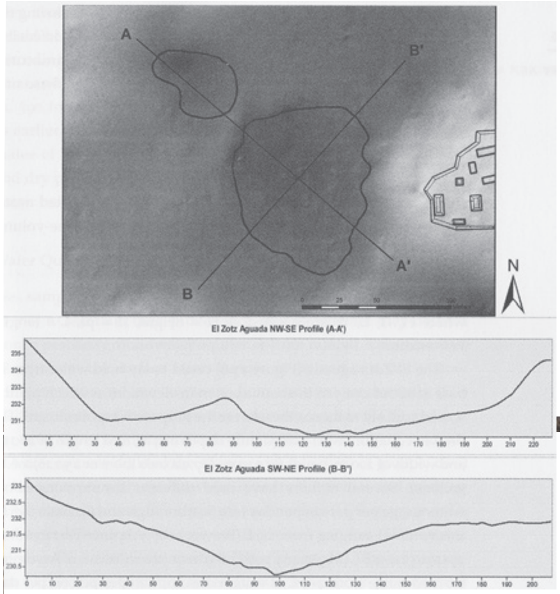
a) El Zotz, Aguada El Zotz, Location of excavation units



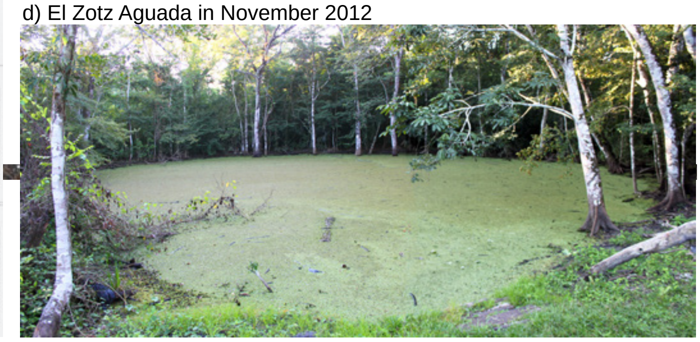
b) Aguada El Zotz, Operations EZ-13A-1,2,3,4 and 5, North Profile



c) El Zotz, El Zotz Aguada, Cross section



d) El Zotz Aguada in November 2012



e) El Zotz, El Zotz Aguada, Photo of Early Classic pavement

Figure 5.68: El Zotz, Aguada El Zotz. (a) (source: Beach *et al.* 2015b: Figure 12.2); (b) (source: Beach *et al.* 2015b: Figure 12.2); (c) (source: Beach *et al.* 2015b: Figure 12.6); (d) (Photo: N. Seefeld); (e) (source: Beach *et al.* 2015a: Figure 8). Reproduced with kind permission of Timothy Beach, Elsevier and Cambridge University Press.

5.6.4.3.6 Poza Maya, Aguada Maya

The Aguada Maya is located to the southwest of the site of Poza Maya, which lies within the Bajo La Justa, approximately 5 km north of Yaxhá, and 8 km south of Nakum (Fialko 2013; see Figure 5.69). The site was occupied from the Late Preclassic up -to the Terminal Classic. Previous investigations in the area suggest that Poza Maya was politically dominated by the neighboring Yaxha (Fialko 2013). Despite its small size (approx. 60 mapped structures), Poza Maya features an enormous aguada with an extension of 230 x 230 m, which was originally a natural depression, but was later converted to a rectangular reservoir. With a catchment volume of 13,200 m^3, this aguada is one of the largest known modified aguadas of the Maya Lowlands and one of the few hydraulic features clearly visible in Google Earth (Grazioso Sierra *et al.* 2000: 206; Weller 2006: 34; see Figure 5.69). The fact that this reservoir is apparently connected to influx- and drainage canals suggests that it was used for intensified irrigation agriculture (Fialko 1999).

Figure 5.69: Poza Maya, Google Earth Image of the “Aguada Maya” (Image: Google Earth).

The lack of residential structures and the documentation of several "potential drainage canals" led many scholars to the hypothesis that the reservoir had been used for agricultural purposes (Akpinar-Ferrand and Dunning 2011: 120; Culbert *et al.* 1996; Dunning *et al.* 2002, 2006: 92; Sever and Irwin 2003). The aerial photographs (see Figure 5.70) that Jarosław Źrałka took in 2001 from a helicopter impressively illustrate the monumental dimensions of this reservoir and the extent of cultural modification indicated by its rectangular shape.

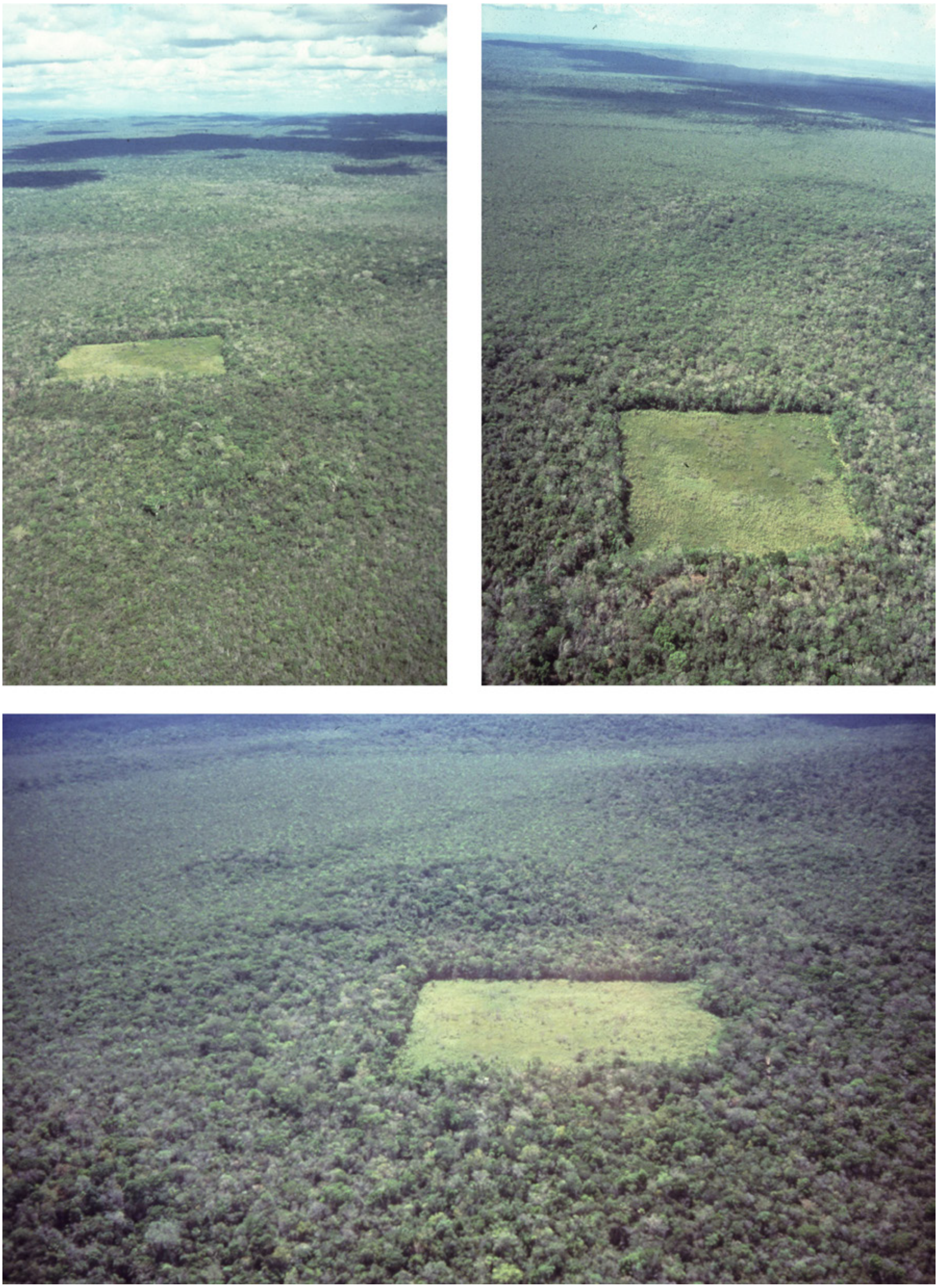


Figure 5.70: Poza Maya, Aerial pictures of the "Aguada Maya" (Photos: Courtesy of J. Źrałka. Reproduced with kind permission of Jaroslaw Źrałka).

5.6.4.3.7 Modified aguadas of San Bartolo and Xultun

The sites of San Bartolo (16 Q 245036 E, 1940939 N) and Xultun (16 Q 243368 E, 1934323 N) were both important Preclassic centers (Akpinar-Ferrand *et al.* 2012: 86). However, while San Bartolo was abandoned at the end of the Late Preclassic Period, before being briefly resettled during the Late Classic, Xultun evolved into one of the largest Classic Period Maya centers in the region (Akpinar-Ferrand *et al.* 2012: 86; Garrison 2007; Garrison and Dunning 2000, 2009). An important source of water between the two sites is the Ixcan Río that largely dries up during the dry season (Akpinar-Ferrand *et al.* 2012: 84). However, the area features several aguadas homogenously distributed throughout the landscape (see Figure 5.71b).

In San Bartolo, only one aguada (Aguada San Bartolo) lies in the city center, while the Aguada Los Loros (16 Q 248318 1942780) and the Aguada Chintiko (16 Q 247949 1941025) are located in the hinterland (Akpinar-Ferrand *et al.* 2012: 86). Aguada Los Loros is situated 3.6 km northeast of San Bartolo on the border of a small inner bajo, while the Aguada Chintiko lies in a zone of well-drained uplands, 3.2 km southeast of the site center (Akpinar-Ferrand *et al.* 2012: 86, see Figure 5.71b).

The **Aguada Los Loros** is an irregularly shaped reservoir of approximately 30 x 40 m surrounded by berms. This led Akpinar-Ferrand *et al.* (2012: 87) to the assumption that it had been "most likely dredged to increase its volume by increasing or maintaining tank depth and berm height". The reservoir had a water depth of 3 m during use and consequently could have stored up to 1,414 m^3 of water (Akpinar-Ferrand *et al.* 2012: 87). Based on a sediment core, Akpinar-Ferrand *et al.* (2012: 88) determined that the maintenance of the aguada would have ended after the Late or Terminal Classic Period. Two excavation units (23SBD 1 and 23SB-D 2) were defined in order to investigate this feature (see Figure 5.71c). In unit 23SB-D2, located in a depression next to a well-defined berm, Akpinar-Ferrand *et al.* (2012: 88) documented several boulders, which they interpreted as "an arrangement to control water movement in and out of the aguada to follow for filtering in a *silting tank*". Unfortunately, no graphic material that might prove this hypothesis was published.

The **Aguada Chintiko** has a roughly circular shape with a diameter of 40 m and a depth of 3.5 m (Akpinar-Ferrand *et al.* 2012: 92). Originally, the reservoir might have stored up to 3,436 m^3 of water (Akpinar-Ferrand *et al.* 2012: 93). The observation of several scattered stones on the surface led Akpinar-Ferrand *et al.* (2012: 93) to hypothesize that the interior slope of the berm surrounding the aguada was lined with stone.[125] Three excavation units were defined: A 1 x 1 m unit located on a berm next to the aguada (23SB E 2), a unit in a flat, lower area immediately outside of the aguada's berm (23SBE 2) and a unit on a flat surface 3 m from the edge of the aguada (Akpinar-Ferrand *et al.* 2012: 93; see Figure 5.71e).

Near Xultun, Akpinar-Ferrand *et al.* (2012: 86) documented six aguadas of which the Aguada Hormiguero, the Aguada Los Tambos (16 Q 244037 1932227) and the Aguada El Delirio (16 Q 243681 1936336) were studied intensively. Later investigations in the center of Xultun led to the discovery of a sophisticated hydraulic system (Ruane 2015).

The **Aguada El Delirio**[126] has an oval shape and a diameter of "about 20-30 meters" (Akpinar-Ferrand *et al.* 2012: 94). The hydraulic feature was investigated by means of three excavation units. Two of the units (units 23SBF1 and 23SBF2) were placed roughly 10 m from the aguada next to the berm on the eastern side of the aguada, while the third unit (23SFB3) was opened on the berm itself (Akpinar-Ferrand *et al.* 2012: 94, see Figure 5.71a).

The **Aguada Los Tambos** has an irregular shape, a diameter of roughly 80 m and holds water year-round (Akpinar-Ferrand *et al.* 2012: 94). Akpinar-Ferrand *et al.* (2012: 94) estimated that the reservoir would have had a total depth of 4 m, resulting in a maximum storage capacity of 10,053 m^3.

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[125] However, Akpinar-Ferrand *et al.* (2012: 94) stress that no dates were determined for this construction, as the interior slope could not be excavated due to the standing water.

[126] In contrast to the other investigated features, the Aguada Delirio could not be cored due to an abundance of chert on its floor (Akpinar-Ferrand *et al.* 2012: 94).

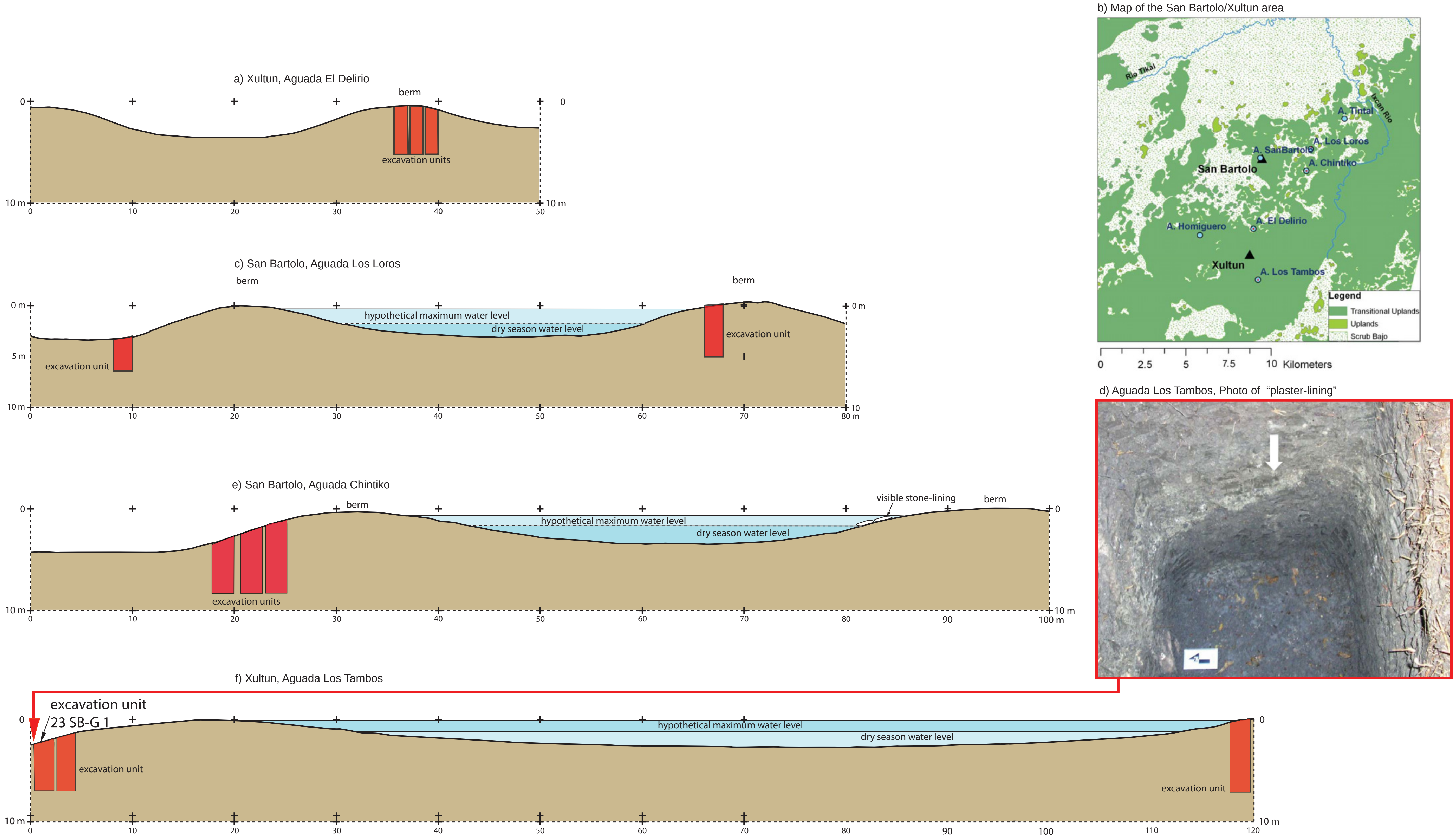

Figure 5.71: Modified aguadas of San Bartolo and Xultun. (a) (redrawn after Akpinar-Ferrand *et al.* 2012: Figure 3); (b) (source: Akpinar-Ferrand *et al.* 2012: Figure 2); (c) redrawn after Akpinar-Ferrand *et al.* 2012: Figure 3; (d) (redrawn after Akpinar-Ferrand *et al.* 2012: Figure 5); (e) (redrawn after Akpinar-Ferrand *et al.* 2012: Figure 3); (f) redrawn after Akpinar-Ferrand *et al.* 2012: Figure 3). Reproduced with kind permission of Cambridge University Press.

The Aguada Los Tambos was investigated by means of three excavation units: A unit placed in a depression 10 m to the east of the reservoir (unit 23SBG1), a unit located on a raised surface 15 m north of the aguada (unit 23SBG2) and a unit in the western part of the aguada (unit 23SBG3) (Akpinar-Ferrand *et al.* 2012: 94; see Figure 5.71f). In the first unit (23SBG1), located *outside* of the Aguada, Akpinar-Ferrand *et al.* (2012: 94) discovered a layer resembling stucco 40-70 cm beneath the surface that could also be observed in the east profile (see Figure 5.71d). The ceramic material recovered underneath this "plaster-lining" dated exclusively to the Preclassic (Akpinar-Ferrand *et al.* 2012: 94; Rivera Castillo 2007). Unfortunately, Akpinar-Ferrand *et al.* (2012: 94) do not provide a plan view of this plaster-lining in units 23SBG1 and 23SBG 3.[127]

5.6.4.3.8 Reservoirs and modified aguadas of the Río Bravo region, Northwestern Belize

Part of the Río Bravo region in northwestern Belize is owned and managed by the non-profit organization Programme for Belize (PfB) (Brokaw and Mallory 1993). Geologically, the region is heavily marked by limestone faults (Dunning *et al.* 1999, 2003; Garrison 2007; Kunen 2004). The largest sites of the region are La Milpa (e.g. Hammond and Tourtellot 2003, 2004, Houk and Zaro 2011; Zaro and Houk 2012), Dos Hombres (e.g. Lohse 2004, Trachman 2007), Maax Na (King and Shaw 2003) and Wari Camp (Levi 2011). Apart from Tikal, the hydraulic systems of the Río Bravo region are the most intensively studied systems in the Central Maya Lowlands. Furthermore, it is the only region where hydraulic features were studied not only at ceremonial centers, but also in the hinterland.

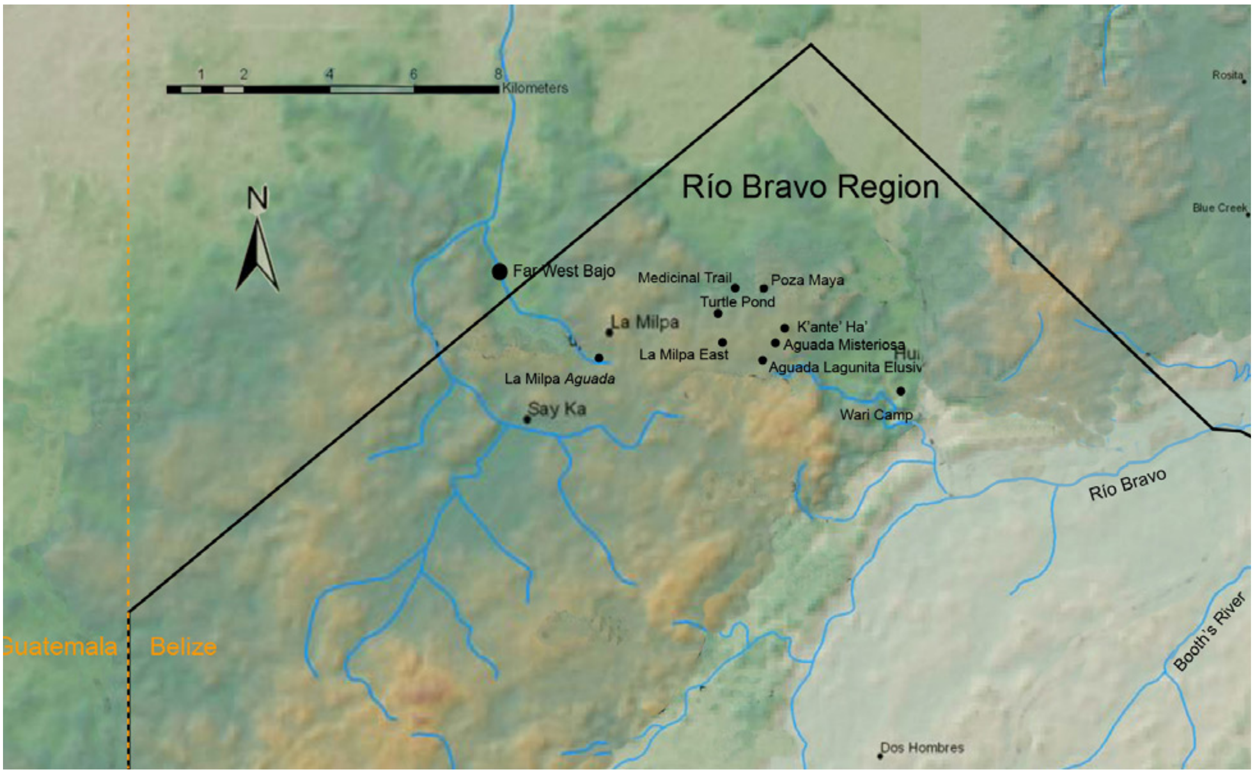

Figure 5.72: Map of the Río Bravo region and the PfB property line (modified from Garrison 2007: Figures 6.8, 6.9, 6.10 and Brewer 2007: Figure 2.1. Reproduced with kind permission of Jeffrey Brewer and Thomas Garrison).

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[127] In this respect, the author would also like to remark that the profile view of the "plaster-lining" shows a discontinuous white layer which may be the result of a number of different natural or cultural processes. Furthermore, the "plaster-lining" is actually located outside of the actual reservoir. Due to these observations, the author would like to point out that, despite Akpinar-Ferrand's *et al.* (2012) conviction, the Aguada Los Tambos shows no clear evidence of a "plaster-lining".

The investigations began in the 1990s, when Scarborough *et al.* (1995) studied the complex hydraulic system in the center of La Milpa (presented in Chapter 5.7.9). In the late 1990s, Weiss-Krejci (Weiss-Krejci 2004; Weiss-Krejci and Sabbas 2002) conducted a survey focused on small depressions in the larger region (including the ceremonial center of Wari Camp, La Milpa East and La Milpa West; see also Chapter 5.6.1). A single reservoir at Guijarral was investigated by Hughbanks (Hughbanks 2006: 233, 251). In the first decade of the 21st century more investigations followed: Aguada Lagunita Elusiva was cored by Dunning (Weiss-Krejci *et al.* n.d.); Chmilar studied Turtle Pond, a small reservoir in the periphery of the Medicinal Trail site, Me-Bar (2005) and Brewer (2007) investigated a small dry depression at the Medicinal Trail site, and Trachman (2007) and Lohse (2004) studied two reservoirs in Dos Hombres. In 2008, Weiss-Krejci began excavations at Aguada Lagunita Elusiva (Weiss-Krejci 2013). Thus, the hydraulic systems of northwestern Belize have been studied in eight main sections (see Figure 5.72).

5.6.4.3.8.1 Medicinal Trail Site

The Medicinal Trail site[128] is a small rural Late Classic community northeast of La Milpa's site center that was under the center's sphere of influence (Brewer 2007: 9; Chmilar 2005: 22; Dunning *et al.* 1999, 2003; Hammond *et al.* 1998; Tourtellot *et al.* 1993, 2003; Scarborough and Valdez 2003; see Figure 5.78). In the site, two small depressions, the Medicinal Trail depression (1) and the Aguada Turtle Pond (2) were archaeologically studied.

5.6.4.3.8.1.1 Medicinal Trail depression

The Medicinal Trail depression has a roughly ellipsoidal shape, a maximum depth of 1.5 m, a north-south extension of 15 meters and an east-west extension of 10 m (Brewer 2007: 2; see Figure 5.73). Even before excavations, the depression's close proximity to several terraces and house mounds coupled with the absence of any apparent permanent water sources in the immediate vicinity led Brewer (2007: 3) to the assumption that it had been used as a primary source of water. In order to determine the stratification and history of the depression, Brewer (2007: 44) excavated a series of 11 trenches (see Figures 5.73 and 5.74). In each unit, Brewer (2007: 102) documented a layer of sealing clay[129] above the bedrock, which he interpreted as a cultural modification[130] to reduce percolation (see Figures 5.73a, 5.73b; 5.74a, 5.74b). Furthermore, Brewer (2007: 91) observed indications that the bedrock surface had undergone artificial leveling. Unfortunately, he did not provide a photograph of this clay layer (Brewer 2007).

According to Brewer (2007: 101), the exposed features, the recovered cultural material and the proximity to several house mounds indicate that this depression had been used and modified by the pre-Hispanic Maya as a source of potable water during at least some part of the year. The presence of a "sealant clay layer" above the bedrock convinced Brewer (2007: 102) that the local population had also manipulated the natural depression in order to increase its water retention. Nevertheless, Brewer (2007: 102) also highlighted that even this clay layer would have been unable to prevent the reservoir from drying up during the dry season. Furthermore, he speculated that the (empty) depression might have been used as a lithic workshop during the dry seasons before it was finally converted into a waste pit. Based on the excavations, Brewer (2007: 101) determined that the reservoir originally could have stored up to 88 m^3 of water. According to this calculation, a full reservoir with no evaporation could have provided over 120 people with sufficient water for every day of the year (Brewer 2007: 102).[131]

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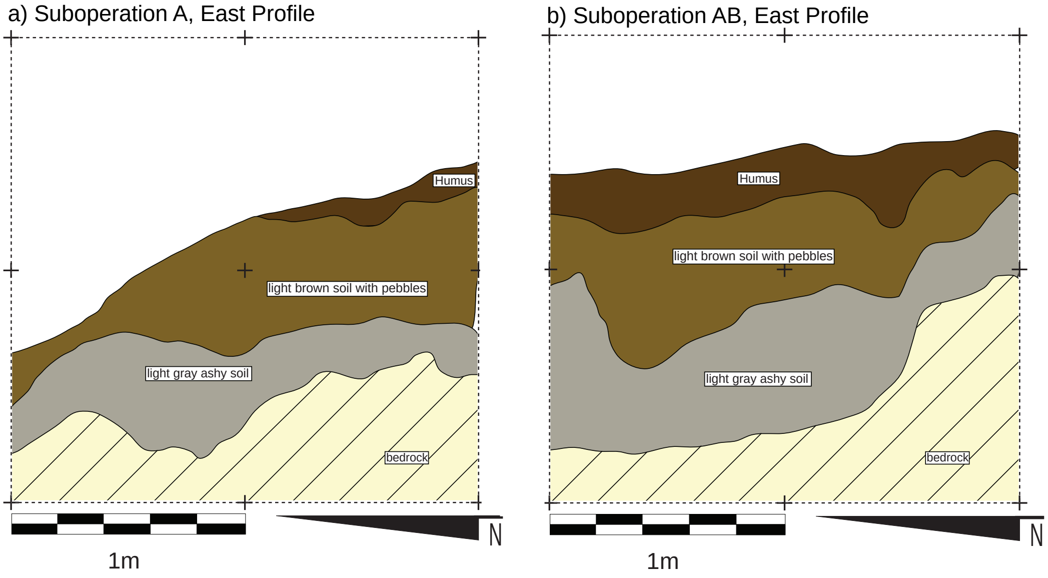
[128] The site was named for the abundance of medicinal plants found around the site during its discovery (Brewer 2007: 9).

[129] Each unit of the depression was excavated in order to verify the presence of the clay layer (Brewer 2007: 4).

[130] In the author's opinion, the uneven surface and thickness of this clay layer does not indicate that it is the result of a cultural modification.

[131] For the calculation, Brewer (2007: 101) used a daily ration of 1.9 liters of water per person. The reservoir capacity was estimated with the formula presented in Chapter 5.6.4.3: $Volume = \left(\frac{Height\ of\ the\ cone}{2}\right) x\ \pi\ x\ \left(\frac{Length\ of\ surface}{2}\right) x\ \left(\frac{Width\ of\ surface}{2}\right)$

Due to these calculations, Brewer (1007: 101) remarked that the reservoir's storage capacity would have been comparable to that of other small depressions in the vicinity, such as Wari Camp and La Milpa East (Weiss-Krejci 2013: 90; Weiss-Krejci and Sabbas 2002).



a) Suboperation A, East Profile

b) Suboperation AB, East Profile

c) Location of excavation units

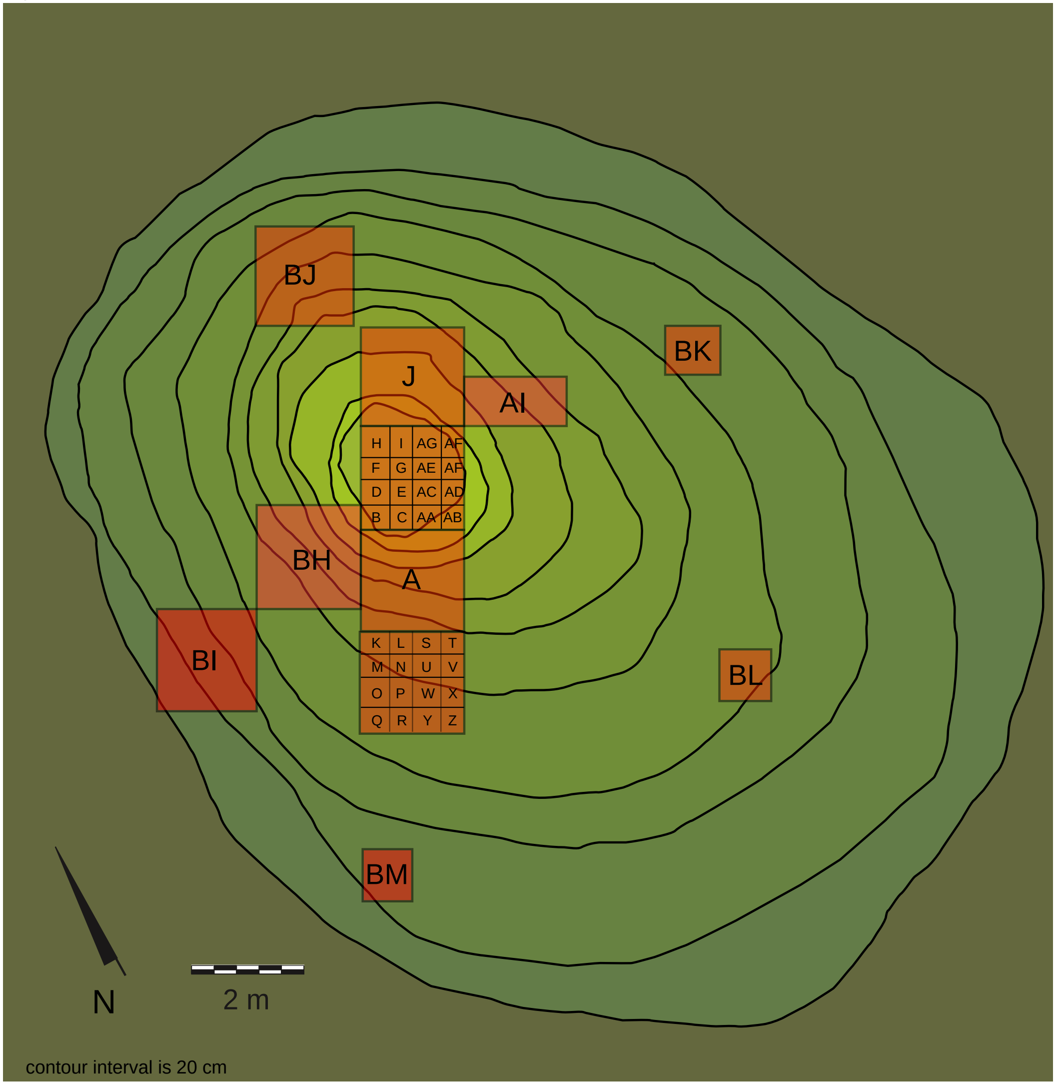


Figure 5.73: Medicinal Trail site depression. (a) (redrawn after Brewer 2007: Figure 5.1); (b) (redrawn after Brewer 2007: Figure 5.4); (c) (redrawn after Brewer 2007: 49; Figure 4.1); Reproduced with kind permission of Jeffrey Brewer.

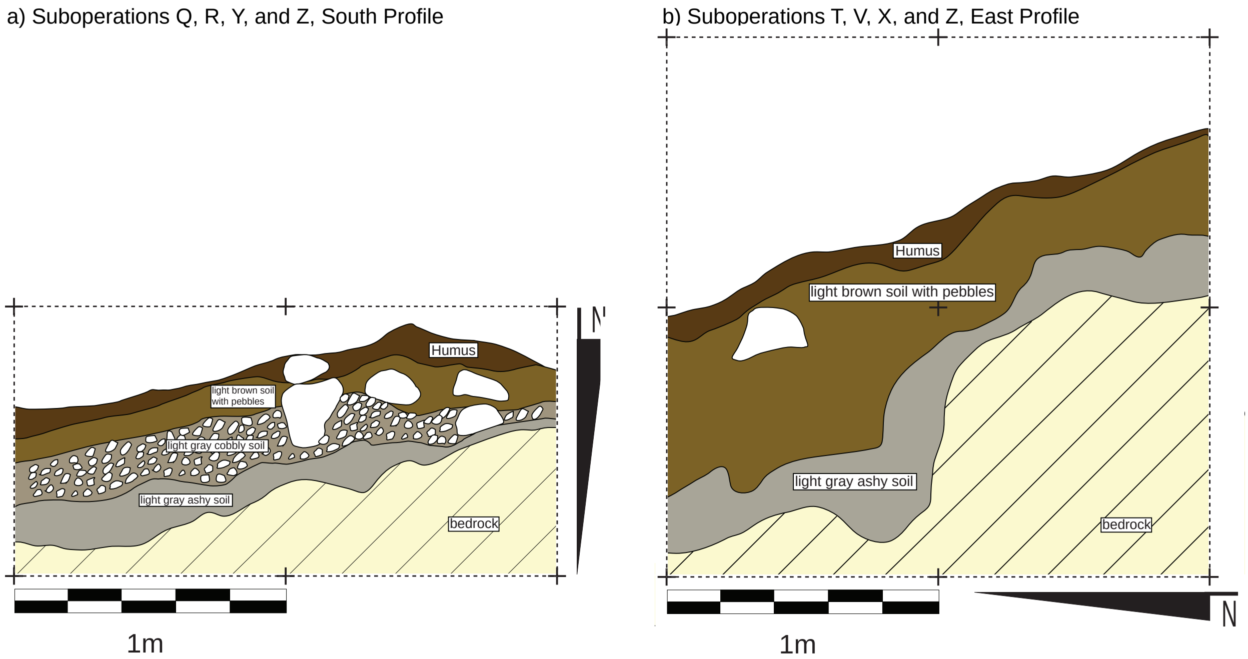


Figure 5.74: Medicinal Trail site depression. Suboperation Q, R,Y, Z, T, V, X and Z. (a) (redrawn after Brewer 2007: Figure 5.2); (b) (redrawn after Brewer 2007: Figure 5.3). Reproduced with kind permission of Jeffrey Brewer.

5.6.4.3.8.1.2 Aguada Turtle Pond

The Aguada Turtle Pond lies 100 m west of a system of agricultural terraces and is surrounded by flat terrain that may have been suitable for agriculture or residential structures (Chmilar 2005: 23). The aguada has a north-south extension of 25 m and an east-west extension of approximately 40 m (Chmilar 2005: 1, with Figure 3.1).

Between the 1950s and 1970s the aguada experienced considerable disturbances when local Mennonites extracted the clay layer at the bottom of the reservoir. In order to identify the functionality and the origin of the aguada, Chmilar (2005: 14) investigated the feature by means of five excavation units and a pollen analysis. However, the excavations could not verify if the pre-Hispanic Maya had used and/or modified the aguada's interior (Chmilar 2005: 80). Nevertheless, the extracted pollen sequence indicated that maize[132] had been cultivated in the immediate area in pre-Hispanic times (Chmilar 2005: 80). Based on these observations, Chmilar (2005: 14) speculated that the Aguada Turtle Pond was originally a natural depression that the local inhabitants later modified with a clay lining to provide standing water of 1 m for at least "a part of the year". Despite the lack of evidence, Chmilar (2005: 79) concluded that the pre-Hispanic inhabitants had exploited this natural depression and modified it in order to increase its storage capacity and to secure a constant supply of water for the population living nearby.

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[132] In Mahogany Ridge, an aguada located close to La Milpa featured high C4 signatures and also indicated the presence of maize during the Classic Period (Beach *et al.* 2008).

5.6.5.4.8.2 La Milpa East, Depression A

The small ceremonial center La Milpa East was mapped during the La Milpa East Transect (LaMAP ET) and is located 3.5 km east of La Milpa's site center (Tourtellot *et al.* 2003b; Weiss-Krejci and Brandl 2011: 143; see Figure 5.75). Even though all visible architecture dates to the Late Classic, excavations indicated that the site was already occupied in the Early Classic (Everson 2003; Hammond *et al.* 2000; Sagebiel 2005: 621; Weiss-Krejci n.d., 2004, 2008, 2009; Weiss-Krejci and Sabbas 2002). In the center, four dry depressions were identified, of which only Depression A had served to store water in pre-Hispanic times (see Figure 5.76). Nevertheless, this depression has a complex and dynamic history of use that included several different functions.

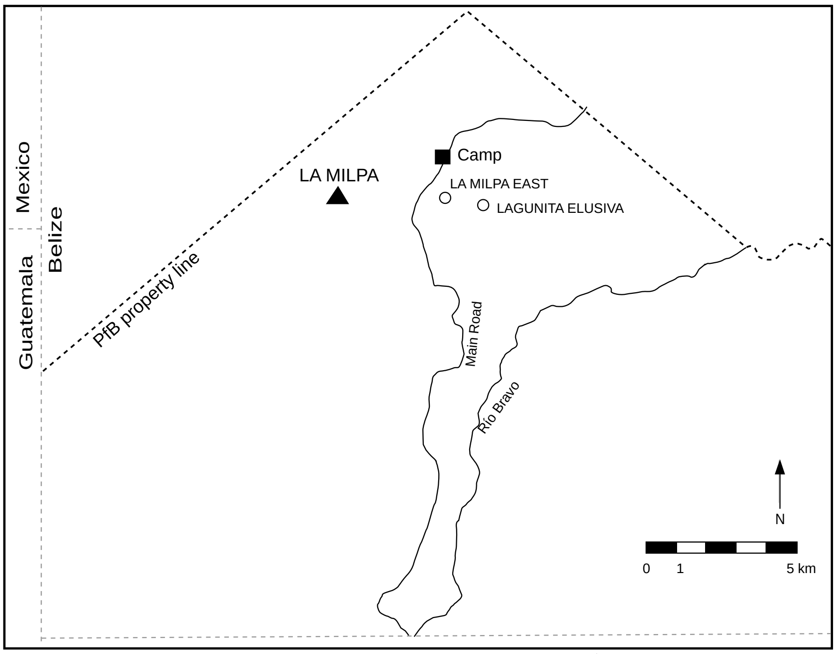


Figure 5.75: Location of La Milpa East and Lagunita Elusiva (source: Weiss-Krejci and Brandl 2011: Figure 1). Reproduced with kind permission of Estella Weiss-Krejci.

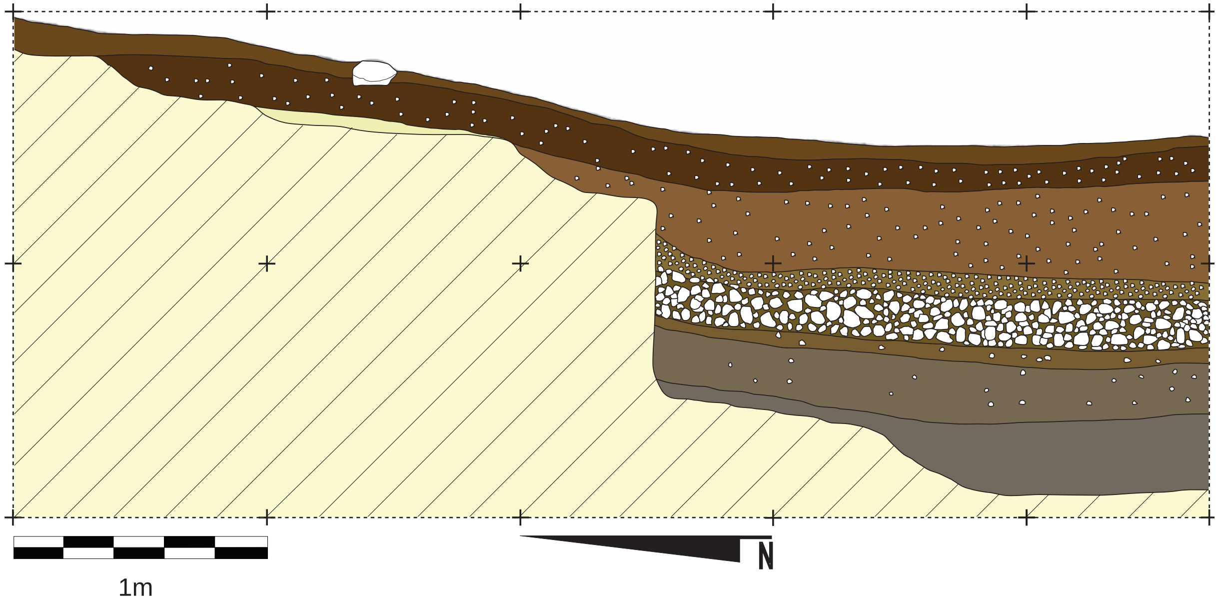
Depression A is a deep-cut depression located 15 meters southeast of Structure 2040, the La Milpa East southeastern temple, and currently lacks any standing water (Weiss-Krejci and Brandl 2011; Weiss-Krejci and Sabbas 2002: 350; see Figures 5.76a and 5.76b). West of the depression, Weiss-Krejci and Sabbas (2002: 350) documented a 25 cm deep and 1.7 m wide ditch in the bedrock that might have served as an influx canal (Operation K14).

At the bottom of the depression, Weiss-Krejci and Sabbas (2002: 350) documented a 10-30 cm thick gray clay layer (e.g. K 0110/K0109; K161) that may be a residue of an artificial plaster layer (Weiss-Krejci 2013: 89; see Figure 5.76a). Based on the recovered ceramics, this layer was dated to the Early Classic (AD 250-600) (Sagebiel 2005: 621; Weiss-Krejci n.d.). During this time, the population density was low and Depression A was used as a reservoir (capacity: 151 m^3) (Weiss-Krejci n.d., 2013: 89). Furthermore, at thin layer above the ceramic deposition (K0108; K 1609) dates to the Late Classic (AD 600-700) (Sagebiel 2005: 639; see Figure 5.76a).

During the 7th century AD, the depression's use as a reservoir ceased and it was filled with gravel, lithic debitage and thousands of ceramic sherds (Weiss-Krejci 2004: 1046; 2013: 89; Weiss-Krejci and Sabbas 2002: 351-352; K0106/0107; K 1606/1607; Weiss-Krejci n.d.: Figure 5). Curiously enough, this modification took place at exactly the same time or shortly after when the region saw a tremendous population increase (Weiss-Krejci 2013: 89). Weiss-Krejci (2004: 1046, 2013: 89) calculated that approximately 200,000 sherds weighing between 1,000 and 3,000 kg were thrown into Depression A. The lower layers (K 0106/0107; K 1606/1607) contained large and nicely preserved sherds with sharp edges, while the sherds of the upper layer (K0105/1605) showed clear signs of erosion. Based on these observations, Weiss-Krejci (2013: 89) believes that this filling event must have happened rather rapidly.

During the same construction period, the pre-Hispanic inhabitants had built an apsidal structure in the northeastern part of Depression A (Weiss-Krejci n.d.; 2013: 89; see Figure 5.76b). These structures are believed to be temples dedicated to the god of wind and rain and resemble Terminal Classic Yucatec style shrines (Weiss-Krejci 2013: 89).[133]

a) La Milpa East, Depression A, East profile



b) Depression A, Feature 2, View of apsidal structure

Figure 5.76: La Milpa East, Depression A. (a) (Courtesy of Estella Weiss-Krejci); (b) (source: Weiss-Krejci 2013: Figure 4. Reproduced with kind permission of Estella Weiss-Krejci).

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[133] Similar buildings have been discovered in the Agua Lluvia Group of Dos Hombres (Trachman 2007: 225; see Chapter 5.6.4.3.8.5), and the Rosita Group of Blue Creek (Guderjan *et al.* 2010), in the coastal zones of Belize (Harrison-Buck and McAnany 2006; Harrison Buck 2012; McAnany 2007) and other sites in Guatemala and Mexico.

5.6.4.3.8.3 Aguada Lagunita Elusiva

Aguada Lagunita Elusiva lies 5 km southeast of La Milpa’s site center (17°49’40.40.42’’N, 89°00’17.54’’W), is located 130 meters above sea level on a low slope and is surrounded by a system of seasonal streams that drain into a nearby bajo (Weiss-Krejci *et al.* n.d.: Figures 2 and 4). It has a roughly circular shape with a diameter of 30 meters and a surface area of 615 m^2 (see Figure 5.77). Based on these observations, Weiss-Krejci (2013: 92) calculated a storage capacity of 450 m^3 and claimed that the aguada usually dries up during the dry season, but rapidly fills again at the onset of the rainy season in June or July.[134]

Earlier research in the eastern section of La Milpa has shown that the area north of the Aguada Lagunita Elusiva experienced a very early occupation (Everson 2003: 304-326; Weiss-Krejci *et al.* 2011: 74). In the immediate vicinity of the aguada, Weiss-Krejci *et al.* (2011: 75) did not observe any residential structures. Instead, they located a number of box terraces[135] which might have been used as seedbeds or intensive gardens (Dunning and Beach 1994: 58; Dunning *et al.* 2005; Lohse 2004: 129; Weiss-Krejci n.d.: Figure 2).

To determine the stratification and chronology of the reservoir, as well as its potential relation to nearby settlements, Weiss-Krejci *et al.* (2011: 79) defined 11 excavation units (Weiss-Krejci n.d.: Figure 2). In Sub-operation E and Sub-operation H, Weiss-Krejci (2015: 146) documented buk’te’ features in the form of large holes, which probably provided access to the lower water table for modern chicleros during the dry season (Weiss-Krejci 2015: 146; Weiss-Krejci n.d.: Figure 12).[136] The pollen core from the aguada showed that the reservoir had already been heavily used in the late part of the Early Classic (Dunning and Beach 2010: 381-382; Weiss-Krejci 2013: 92).[137] The natural bottom of the Aguada consisted of bentonite, an impermeable geologic stratum (Weiss-Krejci 2013: 92; see Chapters 2.1.4.3.1 and 5.6.4.1).

Based on the exposed features, Weiss-Krejci *et al.* (n.d.) assume that the Aguada Lagunita Elusiva most likely originated as a shallow natural depression. Later on, the inhabitants would have constructed the platform and the *buk’te’ob* in order to provide better access to the water, to regulate water-inflow and to preserve the water quality (Weiss-Krejci *et al.* n.d.). The terraces and field walls near the aguada were presumably constructed during the Late Classic Period (Hughbanks 1998; Tourtellot *et al.* 2003). Due to the vast amount of lithic waste, Weiss-Krejci *et al.* (n.d.) concluded that the aguada also served as a chert resource and production site throughout its occupation history. In conclusion, they characterized Lagunita Elusiva as a multi-resource economy in which water, agricultural products, chert and clay might have enabled an economic independence from the center of La Milpa (Weiss-Krejci 2015: 145; Weiss-Krejci *et al.* n.d.).

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[134] According to Weiss-Krejci *et al.* (n.d.), precipitations of a little over 235 mm seem sufficient to fill the reservoir in its current dry state. The formula for calculating Aguada fill-up is a follows: Aguada surface plus catchment area (three times the aguada surface) multiplied with precipitation minus 30 percent for catchment seepage. Aguada fill up = [Aguada surface m^2 + (3 x aguada surface m^2) x precipitation – [3x aguada surface m^2/100) x 30 x precipitation]: [615 + (3 x 615) x 235] = 448,027.5 liters.
According to Weiss-Krejci (n.d.), this calculation is supported by observations in the field. On May 29, 2008, tropical storm Arthur hit Belize bringing 217 mm of precipitation. When Weiss-Krejci and her team visited the aguada again on June 3, it was almost full: [615 + (3 x 615)] x 217 – [(3x 615 / 100) x 30 x 217] = 413,710.5 liters (Weiss-Krejci n.d.).

[135] In this context, Weiss-Krejci *et al.* (n.d.) remarked that box terraces would usually be associated with residential structures and not aguadas. However, box terraces were also documented in the vicinity of a small urban reservoir in Tamarindito (Beach and Dunning 1997; see Chapter 5.4.2).

[136] Due to the finding of a small green bottle in the *buk’te’* of Sub-operation H, (Weiss-Krejci *et al.* n.d.) reasoned that it had been dug in modern times by chicleros or loggers. In order to support this hypothesis, Weiss-Krejci *et al.* (n.d.) referred to a description by Eric Thompson where he writes in his diary of 1938 that digging pits for water in dry aguadas would have been common among loggers.

[137] Like Cyperaceae and Asteraeceae, *Cecropia peltata* is a weedy species and can be found in cleared areas or secondary growth (Lentz and Dickau 2005). A particularly interesting economic aspect of this species is reported by Standley and Steyermark (1946): “its split trunk is sometimes employed as troughs or conduits for conducting water”. Weiss-Krejci *et al.* (n.d.) remark that while it is possible that the Maya were cultivating this plant near the Aguada, they consider it more likely that is was opportunistically harvested. According to Weiss-Krejci *et al.* (n.d.), the dramatic decrease in cultigens in correlation with a sudden decrease in fern spore is consistent with the archaeological record, which suggests that the region was rapidly deserted around AD 830 (Hammond *et al.* 1998; Hammond and Tourtellot 2004). Weiss-Krejci *et al.* (n.d.) assume that by AD 900, the area around the aguada was largely, if not completely, abandoned and recolonized by upland forest.

Figure 5.77: La Milpa, Aguada Lagunita Elusiva, Photo of cobble-feature (source: Weiss-Krejci 2013: Figure 5); Reproduced with kind permission of Estella Weiss-Krejci.6

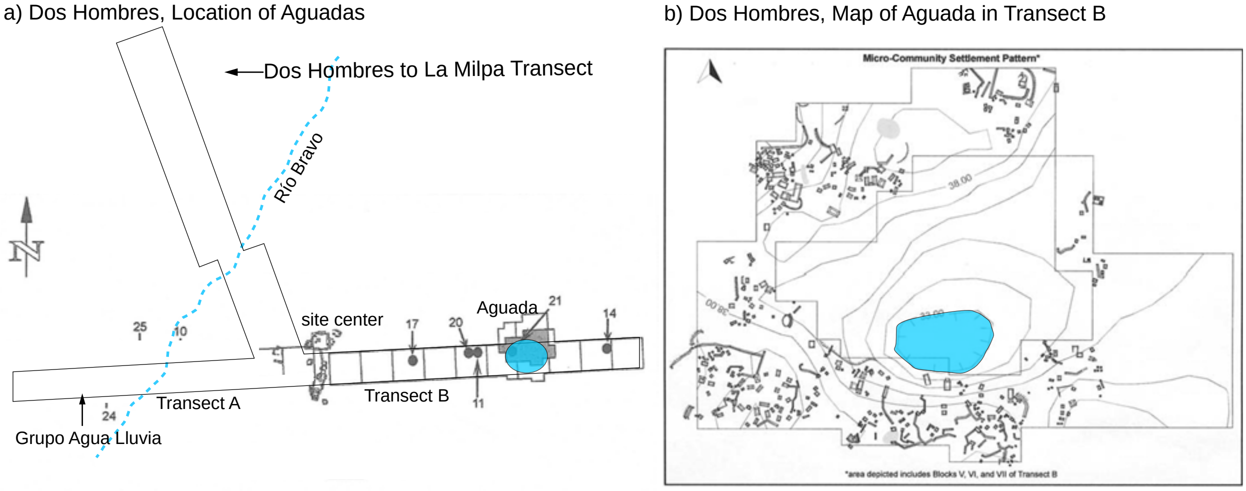
5.6.4.3.8.4 Aguada Misteriosa and cival K'ante' Ha'

Approximately 6 km to the east of the La Milpa center, Weiss-Krejci and her team (2013: 93) discovered the Aguada Misteriosa and the cival K'ante' Ha (see Figure 5.78). The Aguada Misteriosa lies roughly 700 m northeast of Aguada Elusiva, while the cival K'ante Ha ("K'an tree water") lies around 500 m further to the northeast. The cival covers an area of approximately 47,000 m^2 with two aguadas in its boundaries and is characterized by highly diverse ecozones (Weiss-Krejci 2013: 93). One of these aguadas is surrounded by a horseshoe-shaped cobble berm with a diameter of 100 m and can be easily identified in Google Earth (Weiss-Krejci 2013; see Figure 5.78). Due to its form, the berm shares many similarities with the berms documented in conjunction with the Aguada Zacatal (see Chapter 5.6.4.3.2) and the modified aguadas of San Bartolo and Xultun (see Chapter 5.6.4.3.7). Owing to the large dimensions of cival K'ante Ha', Weiss-Krejci (2013: 93) suggested that during the rainy season, the inner aguada could have only been accessed by canoe.

Figure 5.78: La Milpa, Cival K'ante' Ha', Google Earth picture showing the extension of the berm around Aguada 1 (source: Weiss-Krejci 2013: Figure 7). Reproduced with kind permission of Estella Weiss-Krejci.

5.6.4.3.8.5 Modified aguadas of Dos Hombres

Dos Hombres is a site dating chiefly to the Late Classic (AD 600-850) and is situated in the Río Bravo region in northwestern Belize (Lohse 2004: 117; see Figure 5.79a). In Transect B, located 1.4 km east of the site center, Lohse (2004: 129) documented an extensive seasonal aguada characterized as a natural, irregularly shaped depression with an extension of 200 x 300 m (see Figures 5.79a and 5.79b). The reservoir is located in an upland area where Lohse (1998, 2004: 129) reported some of the highest settlement densities in northwestern Belize (see Figure 5.79b). Furthermore, the immediate margins of the reservoir were marked by numerous dry slope terraces (Lohse 2004: 131 and Chapter 5.3.4.5).


a) Dos Hombres, Location of Aguadas

b) Dos Hombres, Map of Aguada in Transect B

* each survey block measures 250 x 250 m

Figure 5.79: Dos Hombres, Location of aguadas in Transects A and B. (a) (modified from Trachman (2007: Figure 1.5) and Lohse 2004: Figure 6.1); (b) (source: Lohse 2004: Figure 6.10). Reproduced with kind permission of Jon Lohse, Clarissa Trachman and the University of Texas Press.

In Transect A, Trachman (2007: 214) investigated the small Reservoir 1 located in the northeastern portion of the Agua Lluvia group located 1.7 km west of the site center (see Figures 5.79a and 5.80a). The feature measures 7.5 m in diameter and featured a maximum depth of 2.4 m (see Figure 5.80e). Excavations revealed that most of the rim was cut bedrock, whereas the eastern side joined the terrace wall of the group (Trachman 2007: 231; see Figure 5.80b). According to Trachman (2007: 233), the portion that joins to the terrace wall can be interpreted as an artificial rim. The bottom of the reservoir, dating to the Tepeu 2-3 ceramic phase, was covered by a plaster lining that increased the impermeability (Trachman 2007: 233; see Figures 5.79c and 5.80d).

Furthermore, the excavations revealed that the reservoir had been cut into the natural bedrock. In the plaster lining at the bottom of the reservoir, Trachman (2007: 233) also documented three potential post holes. Although they were heavily eroded, Trachman (2007: 233) speculated that a thatch roof structure might have once covered the reservoir. This covering might have helped to reduce evaporation or acted to condense it for reclamation (Trachman 2007: 233; Weiss-Krejci and Sabbas 2002). On the reservoir's western side, Trachman (2007: 233) also documented a ramp feature consisting of large stones and cobbles mixed with plaster that intentionally elevated the area. Trachman (2007: 233) proposed that this ramp might have been used to facilitate access during periods of low water levels. It had a very shallow grade extending eastwards for just under 2 meters (Trachman 2007: 233 with Figure 5.13). All other portions of the rim and sidewalls of the reservoir featured an abrupt, steep drop to the reservoir's floor (Trachman 2007: 234). Based on the exposed feature, Trachman (2007: 236) calculated that the maximum capacity of this reservoir would have originally been approximately 71.569 m^3. Consequently, Trachman (2007: 236) calculated that this reservoir could have stored a maximum of 38,000 person/day servings[138] and that a full reservoir not considering evaporation might have provided water for over 100 people each day of the

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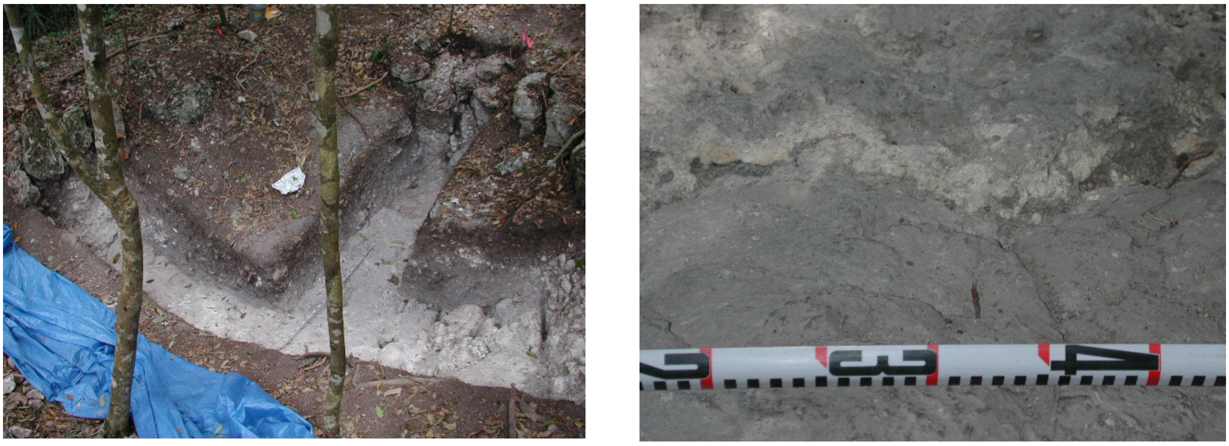
[138] The calculation is based on today's standard of 1.9 liters per day (Trachman 2007: 236).

year. According to Trachman (2007: 238), the feature fits into the category of a "small reservoir" as defined by Weiss-Krejci and Sabbas (2002), with the additional attribute of the plaster lining (Weiss-Krejci 2013: 90).


a) Dos Hombres, Map of Grupo Agua Lluvia

b) Dos Hombres, reservoir, rim section adjoined to terrace wall


c) Dos Hombres, Reservoir, Overview of plaster lining

d) Close-up of plaster-lining on the bedrock surface

e) Dos Hombres, Agua Lluvia Group, Reservoir 1. Suboperation X, North Profile

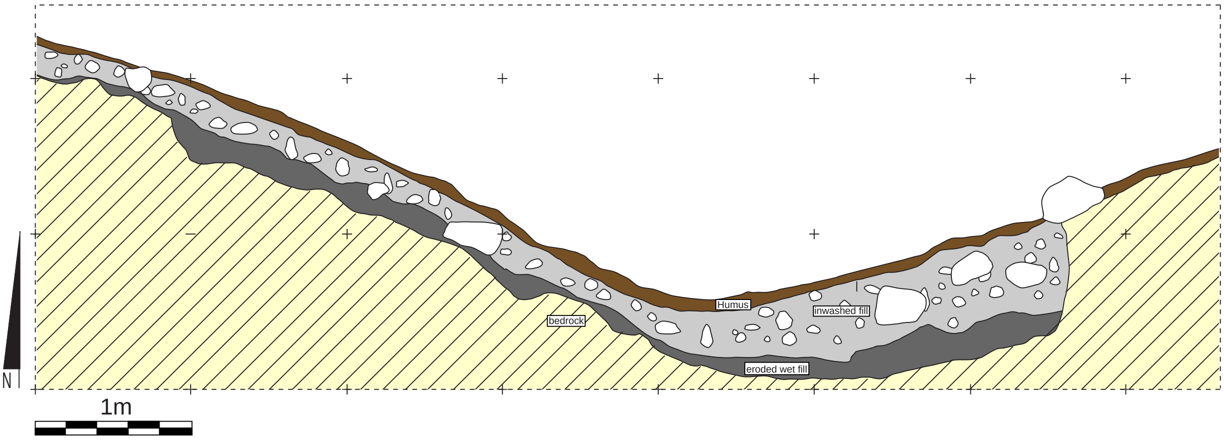


Figure 5.80: Dos Hombres, Grupo Agua Lluvia, Artificial reservoir. (a) (modified from Trachman 2007: Figure 5.6); (b) (source: Trachman 2007: Figure 5.10); (c) (source: Trachman 2007: Figure 5.11); (d) (source: Trachman 2007: Figure 5.12); (e) (modified from Trachman *et al.* 2007: Figure 5.9). Reproduced with kind permission of Clarissa Trachman.

5.6.4.3.9 Modified aguadas of Colha

In Colha, Kunen (2004) identified at least five natural aguadas throughout the site. Based on the archaeological evidence, Hester and Shafer (1984) argued that after initially being used as aguadas, the depressions would have later been used as workshops for chert processing.

5.6.4.3.10 Modified aguadas in the Petexbatun region

During the analysis of residential structures in the Petexbatun region, Dunning and Beach (1994) observed that the pre-Hispanic Maya had frequently modified rejolladas and aguadas (Akpinar 2011: 30). Some of the aguadas were also surrounded by agricultural terraces (see Chapter 5.3.4.4). From the many reported water sources, only the Aguada Catolina received a focused archaeological investigation (see Figure 5.81). According to Dunning and Beach (1994), this reservoir was formed around 100 BC by a considerable clay buildup plugging the karst drainage hole inside the feature (Akpinar 2011: 30; Dunning and Beach 1994).

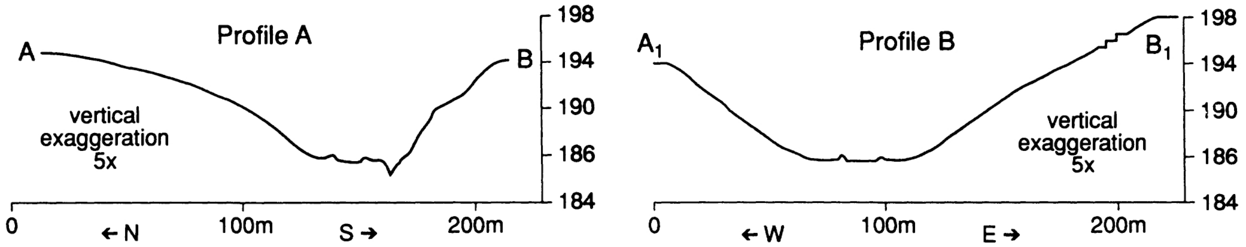


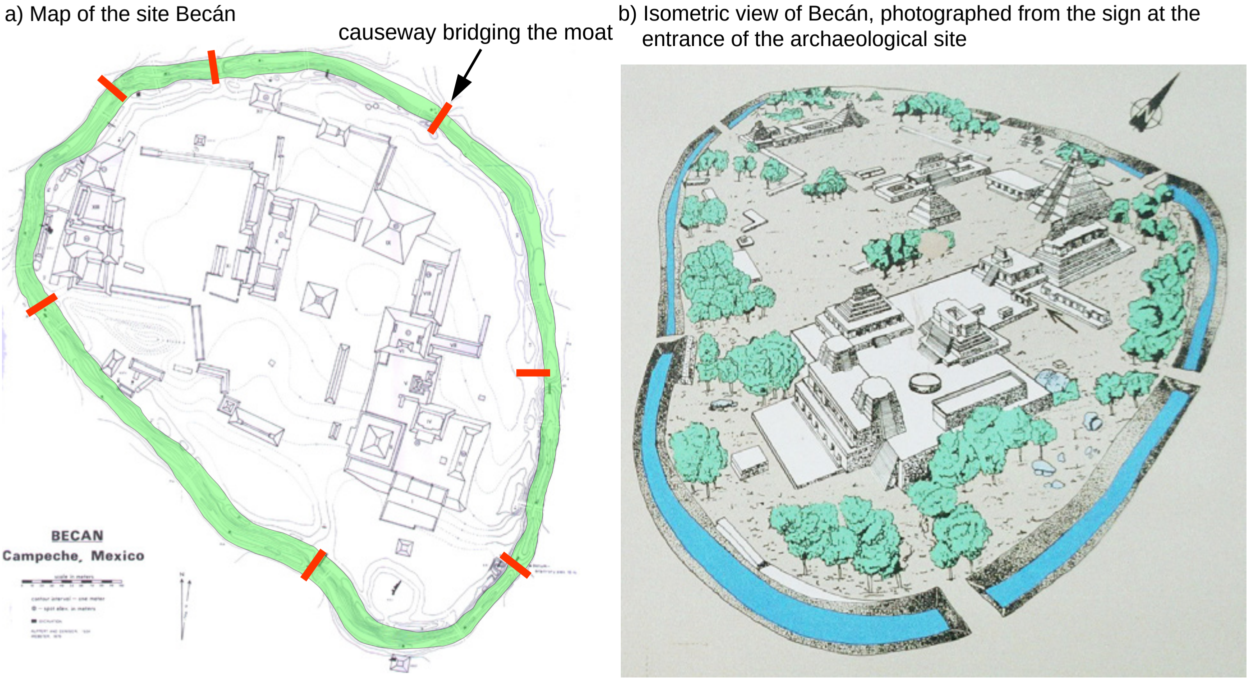
Figure 5.81: Cross-sectional profiles of Aguada Catolina (modified from Dunning and Beach 1994: Figure 5). Reproduced with kind permission of Nicholas P. Dunning and Cambridge University Press.

5.6.4.3.11 Artificial moats/reservoirs in Becán and Tintal

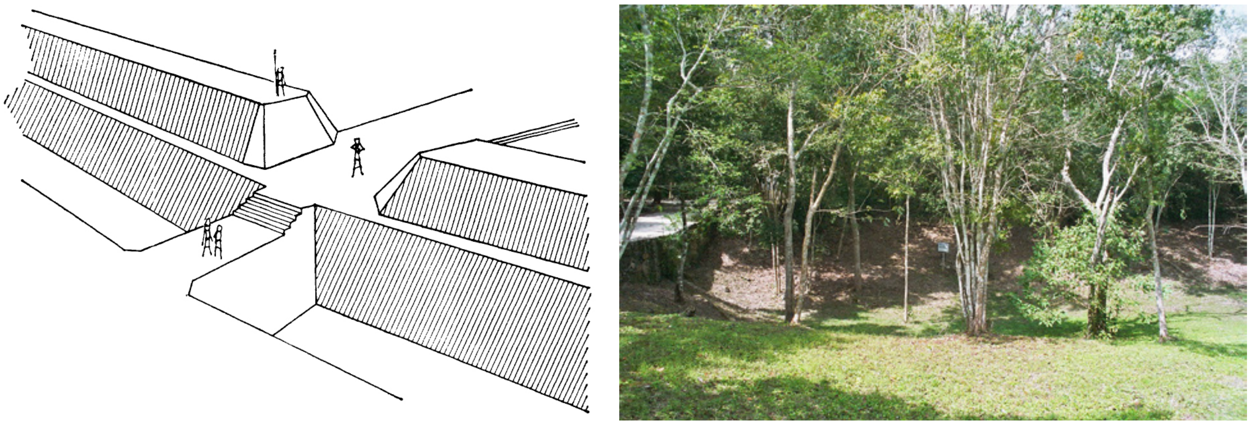
A special subtype of reservoirs is the artificial moat found surrounding the sites of Becán and Tintal. Even though they have been interpreted as canal systems, a comparison to the published canal features (see Chapter 5.2.4) suggests that they were mainly used as water storage features. In contrast to the previously described reservoirs, they did not have a circular or rectangular shape, but rather featured an annular form. Due to the very few documented examples, it is still debated as to whether or not these moats mainly fulfilled a defensive function or if they were primarily used as reservoirs.

Becán is a small center in the Río Bec region, first reported by Ruppert and Denison (1943: 54) during the Third Campeche Expedition of the Carnegie Institution. Due to the discovery of a long moat and embankment surrounding the site, Ruppert and Denison (1943: 54) gave the site its name Becán, a Maya word meaning “ravine or a canyon formed by water”. The main component of the fortifications is “a kidney-shaped ditch 1.9 km in circumference with an average width of 16 m and depth of 5.3 m” enclosing an area of 0.19 km^2 (Webster 1976b: 362). The embankment located on the inside of the circular moat originally had a height of 5 m (Webster 1976b: 362). During the systematic survey of this landscape feature, Webster (1976: 362) discovered seven causeways forming natural bridges of limestone “left in position when the various ditch segments were excavated” which would have provided access to the site (see Figures 5.82a, 5.82b, 5.82c, and 5.82d). The construction of the moat, which most probably took place during the Late Preclassic, would have required the excavation of about 117,000 m^3 of fill (Webster 1976b: 362). After its construction, it remained in use into the Late Classic. Currently, it is still unclear if the moat had been used for water storage or if it solely served a defensive function.

While Ruppert and Denison (1943: 54) interpreted the moat as a water-filled barrier, David Webster (1976: 363) ruled out this interpretation as he did not document any water-deposited sediment in the ditch. Due to the fact that the moat and the adjacent embankment formed an obstacle with a height of 11 m, the landscape feature clearly could have had a defensive function (Webster 1976b: 363). However, as Ruppert and Denison (1943: 54) pointed out, the moat could have been fed with water percolating from the bedrock. A similar explanation was later suggested by David Webster (2007) for the earthworks of Tikal as well (see Chapter 5.7.7.1), which featured a similar technical layout.


a) Map of the site Becán

b) Isometric view of Becán, photographed from the sign at the entrance of the archaeological site


c) Isometric drawing of the moat and the causeway bridging it

d) North view of the moat

Figure 5.82: Becán, Moat construction. (a) modified from Webster 1976a: Figure 111); (b) (Photo: N. Seefeld); (c) (source: Webster 1976a: Figure 2); (d) Photo: N. Seefeld). Reproduced with kind permission of David Webster and the Middle American Research Institute (MARI).

A quite similar construction was documented rather recently in the site of Tintal (N 17° 34’ 15.9’’/E 89° 59’ 54.8‘’), a Preclassic site in the Mirador Basin located 23 km southeast of El Mirador and 17 km northeast of Carmelita (Acuña 2014: 1; Hansen *et al.* 2006: 739). The site is located on seven hilltops separated by extensive bajos (Acuña 2014: 1). In pre-Hispanic times, the site was connected to El Mirador by means of a 23 km long causeway (Hernández and Schreiner 2006: 318). Donald Forsyth (1980) determined that the site had experienced a strong occupation during the Late Preclassic (between 300 BC and AD 150) and a later occupation during the Late Classic (Hansen *et al.* 2006: 741).

Even though Tintal was known to the scientific community since the 1950s, the first thorough topographic surveys were carried out in 2004 and resulted in the documentation of numerous reservoirs and more than 850 architectonic structures with heights of up to 50 m (Hansen *et al.* 2006: 740; Mejía *et al.* 2005; see Figure 5.83). Some of the architectonic groups were connected by well-defined causeways. During the survey, Hansen *et al.* (2006: 741) also discovered that the Complejo Mano de León, representing the site core of Tintal, was surrounded by a 2.2 km long artificial moat with an average width of 15 m and a depth of up to 8 m (see Figure 5.83). Even though the function of this Preclassic[139] moat could not be properly determined yet, Hansen *et al.* (2006: 742) argued that it might have served as a defensive structure or as a hydraulic feature. Even though it still unclear if some portions of the moat might be natural landscape features, the ongoing investigations of the El Tintal Arqueological Project will enable a more substantiated evaluation of the moat's origins and functions (Mary Jane Acuña, personal communication 2017).

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[139] The moat was only dated on the basis of several Preclassic residential structures in its vicinity (Hansen *et al.* 2006: 742).

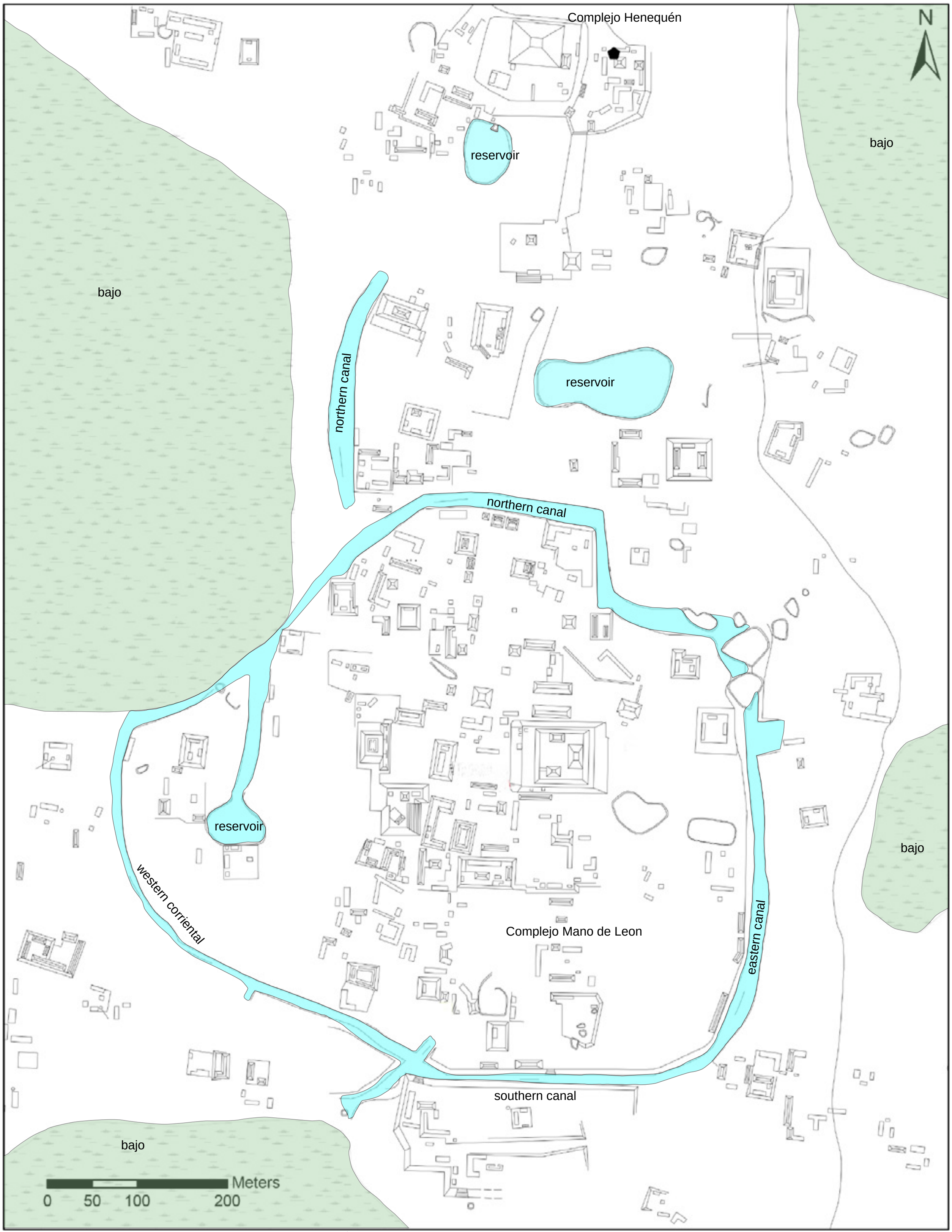


Figure 5.83: Tintal, Map of hydraulic features (modified from Acuña 2014: Figure 4.3; Map taken from Tsesmeli 2014: Figure 4.3. Based on original map by Mejía *et al.* 2005: Figure 1). Reproduced with kind permission of Mary Jane Acuña.

5.7 Complex hydraulic systems aimed at managing water scarcity

While the previous sections of this chapter have primarily focused on individual hydraulic features, this section will focus on the more extensive "hydraulic systems". From a conceptual point of view, the term "complex hydraulic system" was developed by the author in order to more adequately differentiate the functionality of the different types of hydraulic features.

Technically, complex hydraulic systems aim to collect and/or divert water. The central characteristic of complex hydraulic systems is the existence and coaction of several hydraulic features that form an interrelated and relatively complex compound (Gunn *et al.* 2002: 298). In this context, it is important to emphasize that a simple agglomeration of numerous hydraulic features, such as the wells in the site of Dzibilchaltun (see Chapter 5.6.3), should not be considered a complex hydraulic system. In the author's view, hydraulic systems should exhibit two central traits in order to be defined as a "complex hydraulic system".

1) The immediate interaction of different types of hydraulic features that form a larger entity, and

2) A recognizable intention in the interaction of the different elements.

Since complex hydraulic systems are made up of interrelated elements, the upcoming overview illustrates the specific functionality of the published complex hydraulic systems. Based on their general mode of action, the published hydraulic systems can be subdivided into complex systems aimed at managing water scarcity (1), and complex hydraulic systems aimed at managing water excess (2).

As Figure 5.84 illustrates, the geographic distribution of complex hydraulic systems aimed at managing water scarcity are mostly confined to the core area of the Elevated Interior Region (EIR), which also coincides with the distribution of inner bajos (see Chapter 2.4.3.3). The complex hydraulic systems aimed at managing water excess are logically confined to areas with high levels of annual precipitation and/or are connected to permanent rivers. The functionality of the different systems aimed at managing excess water is presented in Chapter 5.8. Beforehand, the overview will focus on systems aimed at managing water scarcity.

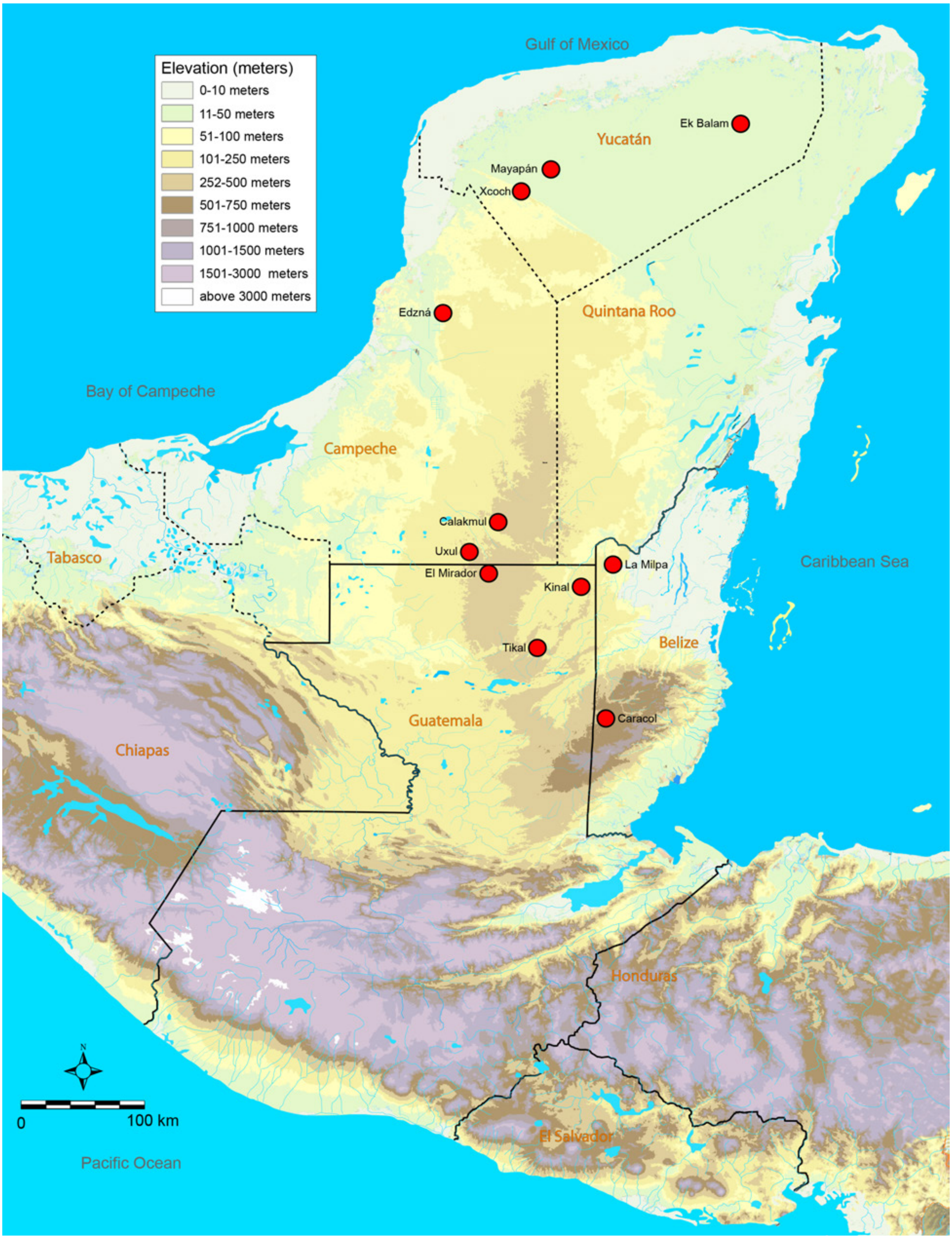


Figure 5.84: Map showing the location of published complex hydraulic systems aimed at managing water scarcity (Map: N. Seefeld; modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

5.7.1 Hydraulic system of Ek' Balam

Ek' Balam is located in the northeast of the Yucatán Peninsula in a geological fault called Chemax-Catoche, which some authors have identified as the "ring of cenotes" (see Chapter 2.1.1.1) (Beddows *et al.* 2007; Castillo Borges and Vargas de la Peña 2009: 141). Due to this location, the groundwater level lies at an accessible depth of 20-25 m below the surface. Nevertheless, in the immediate vicinity of the site, there are no natural sources of surface water (Castillo Borges and Vargas de la Peña 2008: 142). The closest natural sources of water are two cenotes. One is located 1.5 km east of the site, and the other 2 km to the west (Castillo Borges and Vargas de la Peña 2009: 142). According to Castillo Borges and Vargas de la Peña (2009: 142), the relative ease of water access was one of the reasons the location was chosen for the foundation of a settlement. In general, Castillo Borges and Vargas de la Peña (2009: 142) made a distinction between (1) the hydraulic features in Ek' Balam's center, and (2) the hydraulic features of the Acropolis (Structure 1).

In the northern Plaza of Ek' Balam, Castillo Borges and Vargas de la Peña (2009: 142) documented two artificial rectangular depressions located close to Structure 3. These were obviously fed by the culturally modified watershed nearby. On the backside of the Acropolis, Castillo Borges and Vargas de la Peña (2009: 143) documented a large, artificially modified rejollada.

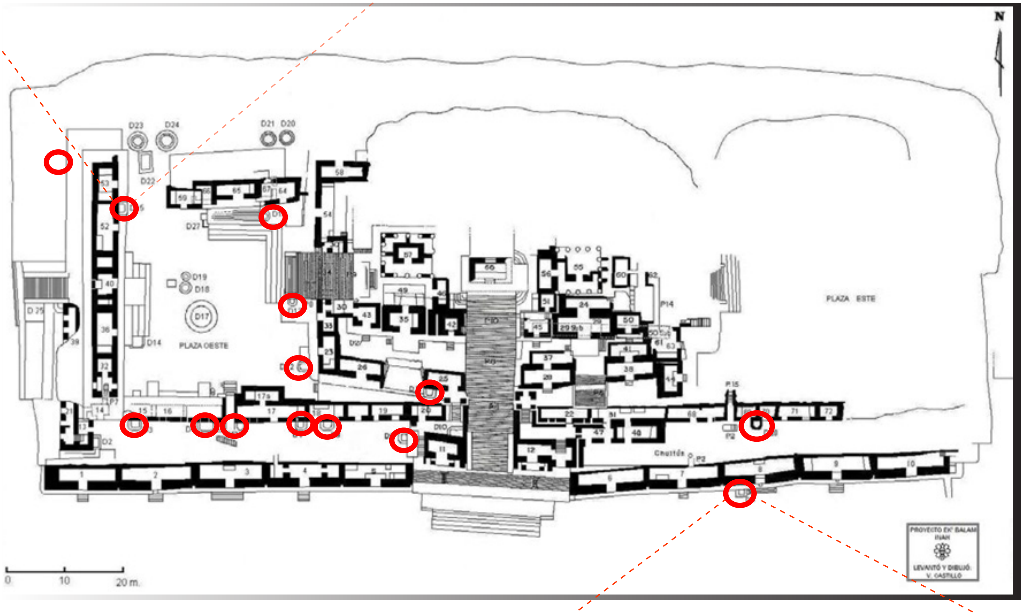
However, the highest density of hydraulic features was documented in conjunction with the Acropolis (Structure 1) of Ek' Balam, the palace of the ruler, Ukit Kan Lek Tok' (Castillo Borges and Vargas de la Peña 2009: 143). The Acropolis is a peculiar architectonical structure with six levels. Its central portion has a pyramidal shape with two wing-like extensions to the sides that feature elevated patios (see Figure 5.85b). On most of these levels, Ek' Balam's pre-Hispanic inhabitants installed drainage and water storage features. Furthermore, the location of these features and their integration into Structure 1 indicates that many architectural areas and elements were particularly designed to direct rainfall towards defined locations and collect it (Castillo Borges and Vargas de la Peña 2009: 143). According to Castillo Borges and Vargas de la Peña (2009: 143), the layout of these features and the way they interact indicates that the builders had a well-developed knowledge of constructing hydraulic features. Furthermore, the variety of the documented features suggests that the pre-Hispanic inhabitants constructed specialized features for specific needs. Due to the vast variety of hydraulic feature forms in Structure 1, Castillo Borges and Vargas de la Peña (2009: 144) distinguished between chultunes (1), rectangular reservoirs (2), C-shaped reservoirs (3), and circular reservoirs (4).

The chultunes of the Acropolis were positioned in the constructive fill of the different levels of the building (Castillo Borges and Vargas de la Peña 2009: 144). Similar to the chultunes of the Puuc region (see Chapter 5.6.2), the areas around their openings were always slightly sloped in order to serve as funnels. In total, three chultunes were documented on Structure 1. Two chultunes were fed by water running from the front terrace of rooms 36 and 44 both of which featured a slight inclination (Castillo Borges and Vargas de la Peña 2009: 144). The third chultun was located on the second level of Structure 1, close to rooms 47 and 48 and was integrated into the constructive fill of the roofs of the first level rooms. The roofs of the first level formed the terrace of the second level. The chultun was fed by runoff water from the bench located in front of rooms 47, 48 and 68-72. According to Castillo Borges and Vargas de la Peña (2009: 144), the location of these chultunes and their integration into the Acropolis suggest that the pre-Hispanic inhabitants of Ek' Balam had tried to install water reservoirs in the most convenient locations possible.

The rectangular and C-shaped reservoirs of Structure 1 were enclosed by low and narrow stone walls, which were connected to the walls of various rows of staircases (see Figure 5.85; Castillo Borges and Vargas de la Peña 2009: 144; Delgado Kú *et al.* 2012: 70). The first of these reservoirs, D-1,[8] was located near the southern façade of the first level of Structure 1 and was connected to a bench in front of Room 8 (Castillo Borges and Vargas de la Peña 2009: 145; see Figure 5.85c). It has a roughly rectangular shape and a height of approximately 40-50 cm. During the excavations, Castillo Borges and Vargas de la Peña

a) Ek' Balam, West-view of C-shaped reservoir D 15

b) Ek' Balam, Structure 1, Residues of stucco on C-shaped reservoir



c) Ek' Balam, Structure 1, Distribution of C-shaped reservoirs

d) Ek' Balam, Close-up of C-shaped reservoir)

e) Ek' Balam, Stucco-floor on the bottom of reservoir D-8

Figure 5.85: Ek' Balam, Structure 1, Distribution of rectangular and C-shaped reservoirs. (a) (Photo: N. Seefeld); (b) (source: Castillo Borges and Vargas de la Peña 2009: Foto 4); (c) (modified from Castillo Borges and Vargas de la Peña 2009: Figure 2); (d) (source: Castillo Borges and Vargas de la Peña 2009: Photo 2); (e) (source: Castillo Borges and Vargas de la Peña 2009: Photo 3). Reproduced with kind permission of Victor Castillo Borges and Leticia Vargas de la Peña.

(2009: 145) recovered numerous ceramic fragments covering the entire base of the reservoir (see Figure 5.85e). According to Castillo Borges and Vargas de la Peña (2009: 145), these ceramic fragments had been deliberately deposited at the base of the reservoir in the form of a mosaic, and served as a levelling element for a stucco layer that was applied upon it. The container was fed by runoff water from the sloped bench. Similar constructions were documented in Level 2 and 3 of Structure 1 (Castillo Borges and Vargas de la Peña 2009: 145; see Figure 5.85b).
Most of the C-shaped reservoirs were located on the second level of Structure 1. Both wings of Level 2 were dominated by rooms with residential functions connected to the staircases and C-shaped reservoirs (Castillo Borges and Vargas de la Peña 2009: 145). The western wing of Level 2 features eight C-shaped reservoirs[140] that showed almost identical dimensions and forms and are generally located close to the entrances (Castillo Borges and Vargas de la Peña 2009: 145; see Figure 5.85b). In front of Room 16, Castillo Borges and Vargas de la Peña (2009: 145) documented a double reservoir featuring a mosaic of ceramic fragments on its floor similar to Reservoir D-8. In this case, the ceramic layer also served as a solid subsurface for a stucco floor that was later applied to it. At the bottom of Reservoirs D-13 and D-16, Castillo Borges and Vargas de la Peña (2009: 145) were still able to document traces of a stucco floor (see Figure 5.85c).

The majority of the circular reservoirs could be documented on the third level of Structure 1. The largest example, Reservoir D-17, is located in the western patio of Level 3, has a conical cross-section and a depth of 3 m. It has a diameter of 5 m at its opening and 3 m at its base (Castillo Borges and Vargas de la Peña 2009: 145; see Figures 5.86b and 5.86d). The reservoir was fed by the runoff from the entire western patio, which had a slight inclination towards it. Its sidewalls were fortified by worked stones and its base was covered by a mosaic of ceramic sherds, similar to the aforementioned C-shaped reservoirs. According to Castillo Borges and Vargas de la Peña (2009: 146), these ceramic sherds were originally covered with a stucco layer that served to seal the reservoir. Another interesting detail of this reservoir are the stone pins extruding from the stone walls. These apparently served as stepping stones and would have facilitated access for cleaning and maintaining the reservoir or for the extraction of water when levels were low (Castillo Borges and Vargas de la Peña 2009: 146). Most of the remaining circular reservoirs of Structure 1 (D-18, D-19, D-22, D-23, and D-24) are concentrated on the western portion of Level 3 and feature more modest dimensions (Castillo Borges and Vargas de la Peña 2009: 146; see Figure 5.86b).

Among these smaller circular reservoirs, Castillo Borges and Vargas de la Pena (2009: 146) also documented two circular reservoirs (D-10 and D-12) in the northwestern corner of Level 3 that featured bench-like steps in their interiors (see Figure 5.86a). As Castillo Borges and Vargas de la Peña (2009: 146) suggested, these stepped elements would have been deliberately installed as benches. Their reasoning is that the dimensions of these benches were precisely adequate for a person to sit down within the reservoir and still be covered with water. Due to these observations, Castillo Borges and Vargas de la Peña (2009: 146) argued that these two circular reservoirs may have been used as bathtubs.

According to Castillo Borges and Vargas de la Peña (2009: 146), the great need for a consistent supply of water is reflected in the work invested in the construction of the hydraulic features in Structure 1. In their view, the many inhabitants of the Acropolis would have required considerable labor investments to secure this constant water supply and had therefore invested additional construction material and labor for the luxuries of hygiene and enjoyment (Castillo Borges and Vargas de la Peña 2009: 146).

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[140] Reservoirs D-2, D-3, D-4, D-5, D-7, D-8, D-9, and D-10.


a) Ek' Balam, Structure 1, Close up of Reservoir D 12

c) Ek' Balam, Structure 1, Level 3, West-Plaza, East-view.

b) Ek' Balam, Structure 1, Location of rectangular and circular reservoirs

d) Ek' Balam, Close-up of Reservoir D 17.

e) Ek' Balam, Structure 1, Level 3, west-plaza, North-west-view

Figure 5.86: Ek' Balam, Structure 1, Distribution of circular reservoirs. (a) (source: Castillo Borges and Vargas de la Peña 2009: Photo 7); (b) (modified from Castillo Borges and Vargas de la Peña 2009: Figure 2); (c) (source: Castillo Borges and de la Peña 2009: Photo 6); (d) (Photo: N. Seefeld); (e) (Photo: N. Seefeld). Reproduced with kind permission of Victor Castillo Borges and Leticia Vargas de la Peña.

In addition to the rectangular, C-shaped and circular reservoirs, Castillo Borges and Vargas de la Peña (2009: 146) also documented some channelized stones on Structure 1, which could be interpreted as gutters. Along the facades on the fourth level of the Acropolis, these gutters were able to be documented in their most intact state. In order to serve their intended function, they had to be coordinated with the different sets of hydraulic features on all levels of Structure 1. When it rained, these gutters collected the runoff and directed it towards stone pipes, or so-called *chulub,* that led it towards an intermediate conduit, which then drained into another catchment area connected to Room 25 on Level 3 of the Acropolis (Castillo Borges and Vargas de la Peña 2009: 146; Delgado Kú *et al.* 2012: 70). Room 25 featured a small canal that directed the water towards Reservoir D 10 on Level 3. According to Castillo Borges and Vargas de la Peña (2009: 147), the roofs of Level 2 collected water in a similar fashion to those on Level 3, as they also directed the water towards the reservoirs attached to these rooms. The sophisticated layout of this hydraulic system and the interaction of its components indicated that its construction had been carefully planned. Due to the interaction of these different hydraulic features, the inhabitants of Structure 1 were able to collect and store considerable amounts of rain (Castillo Borges and Vargas de la Peña 2009: 147).

Interestingly, the way in which these rain gutters function was even depicted on a small wall painting in Room 63 of the Acropolis (see Figure 5.87). This wall painting shows the profile of a house featuring a roof with a gutter and is represented with black lines. Curiously, the artist even painted the water falling from the gutter with black dots. As far as the author is aware, this mural is the only representation of a hydraulic feature in Maya art that has been published to date.

Figure 5.87: Ek' Balam, Structure 1, Room 63, Mural depicting a rain gutter (source: Castillo Borges and Vargas de la Peña 2009: Figure 9). Reproduced with kind permission of Victor Castillo Borges and Leticia Vargas de la Peña.

5.7.2 Hydraulic system of Mayapán

Mayapán is located 42 km to the south of Mérida (Delgado Kú *et al.* 2012: 69). In contrast to the Puuc region where water is practically "inaccessible", Mayapán is located on a large plain of the karstic limestone bedrock where the structure of the terrain enables rain to filter into the interior of the subsoil (Delgado Kú et al 2012: 71). In general, Mayapán is characterized by a dense concentration of structures. Inside the walled compound of Mayapán, several generations of scholars documented 32 cenotes, while only two cenotes were documented outside of it (Delgado Kú *et al.* 2012: 33; Shook 1952; Uc 2000: 287). The principal architectonic groups were placed around these cenotes in order to satisfy water requirements during the dry season (Delgado Kú *et al.* 2012: 71). Furthermore, the surfaces of architectonic structures, terraces and plazas were modified in order to create an artificial watershed that would direct all rainfall towards the cenotes. The larger plazas were also constructed with a gradient, which prevented inundations during the rainy season (Delgado Kú *et al.* 2012: 71).

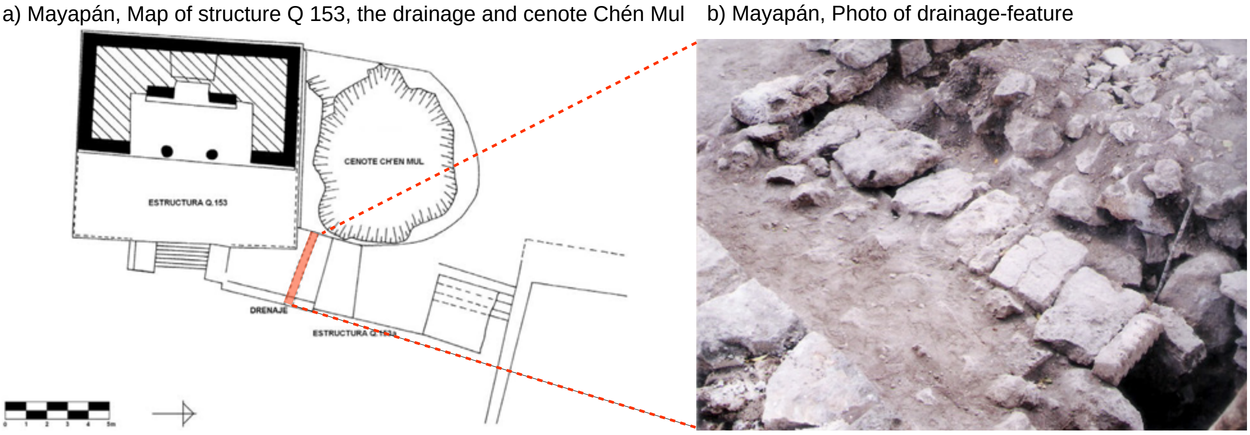
In the earliest construction phases of the Central Plaza, the natural gradient of the terrain directed the runoff towards the Cenote Ch'en Mul (Delgado Kú *et al.* 2012: 72; see Figure 5.88a). In a later construction phase, the flow of water was directed towards the southeastern corner of the Castillo de Kukulkán (Delgado Kú *et al.* 2012: 72, see Figure 5.88b). During the second construction phase of the Castillo de Kukulkán, the inhabitants decided to level a small plaza to the east of the structure and consolidate the rim of the Cenote Ch'en Mul (Delgado Kú *et al.* 2012: 72). At the same time, the builders left an open space between the modified cenote rim and the northeastern corner of Structure Q.153 in order to drain the central precinct plazas (Delgado Kú *et al.* 2012: 72).

a) Mayapán, Original flow of surface-discharge

b) Mayapán, Modified flow of surface-discharge

Figure 5.88: Mayapán, Main group, Direction of natural and modified surface flow. (a) (source: Delgado Kú *et al.* 2012: Figure 4); (b) (source: Delgado Kú *et al.* 2012: Figure 11). Reproduced with kind permission of Pedro Delgado Kú.

In the next step, Mayapán's inhabitants built Platform Q.153, which featured a 40 cm wide drainage system that canalized the runoff from the plaza floors into the cenote's interior (Delgado Kú *et al.* 2012: 72; see Figure 5.89a). This drainage was located 3.10 m from the northern balustrade of Structure Q.153's staircase (Smith 1955: 113) and was bordered and covered with unworked stone slabs (Delgado Kú *et al.* 2012: 72; see Figure 5.89b). After restoring the drainage feature and Structure Q.153, Delgado Kú *et al.* (2012: 73) observed that rainwater collected in the northeastern and eastern plazas passed through the newly restored canal and flowed into the Cenote Ch'en Mul (see Figure 5.88b).


a) Mayapán, Map of structure Q 153, the drainage and cenote Chén Mul

b) Mayapán, Photo of drainage-feature

Figure 5.89: Mayapán, Structure Q. 153, Drainage canal. (a) (source: Delgado Kú *et al.* 2012: Figure 8); (b) (source: Delgado Kú *et al.* 2012: Figure 7). Reproduced with kind permission of Pedro Delgado Kú.

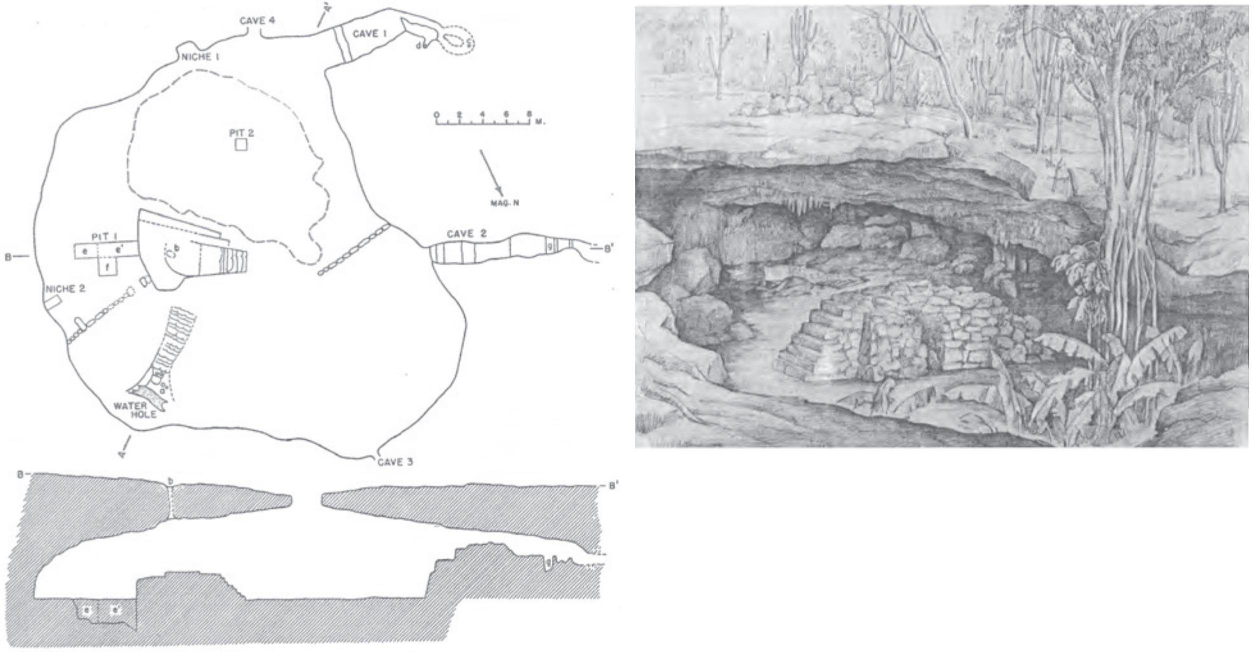
In the Xcotón Group, located in the northeastern portion of Mayapán's walled compound, Smith (1953) documented an artificially constructed platform inside the Cenote Xcotón (Delgado Kú *et al.* 2012: 73). This platform was wedge-shaped and featured both a stairway in the east, and a stairway leading down towards a crater-shaped depression extending down to the water table (see Figure 5.90a). This stairway was composed of 18 steps, two of which were cut into the bedrock (see Figure 5.90c).

Just above the water table, the builders left a prominence in the bedrock. This prominence featured two semi-circular depressions that may have served to hold storage vessels (Delgado Ku *et al.* 2012: 73). The last step of the stone featured a third depression, possibly with the same use (Delgado Kú *et al.* 2012: 73). Delgado Kú *et al.* (2012: 73) claimed that this platform might have had a ceremonial function (Smith 1953) due to the central position in the cenote, the remnants of a stucco floor in the east portion of the structure and the stairway leading into the water.

In the Itzmal Ch'en group, located approximately 2 km northeast of the ceremonial center, Delgado Kú *et al.* (2012: 73) documented another modified watershed. Here, the main plazas and the domestic units were built on top of natural elevations, which created an artificial watershed that directed runoff into the Cenote Itzmal Ch'en (Delgado Kú *et al.* 2012: 73).

a) Mayapán, Cenote Xcotón, Planum and Profiles

b) Cenote Xcotón, Reconstruction drawing of Platform



c) Stairway leading towards the water-surface

d) Stairway leading towards the water-surface

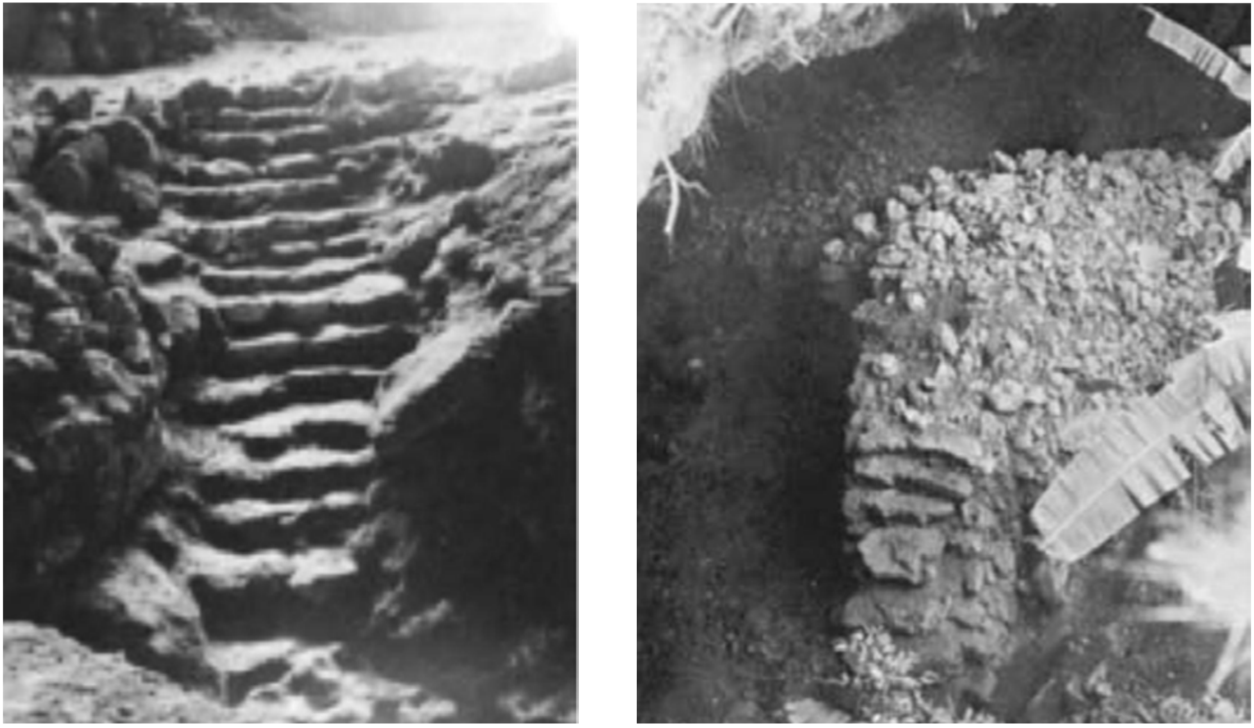


Figure 5.90: Mayapán, Cenote Xcotón. (a) (source: Smith 1953: Figure 5.1); (b) (source: Smith 1953: Figure 5.3); (c) (source: Smith 1953: Figure 5.3); (d) (source: Smith 1953: Figure 5.3). Reproduced with kind permission from the Carnegie Institution of Washington.

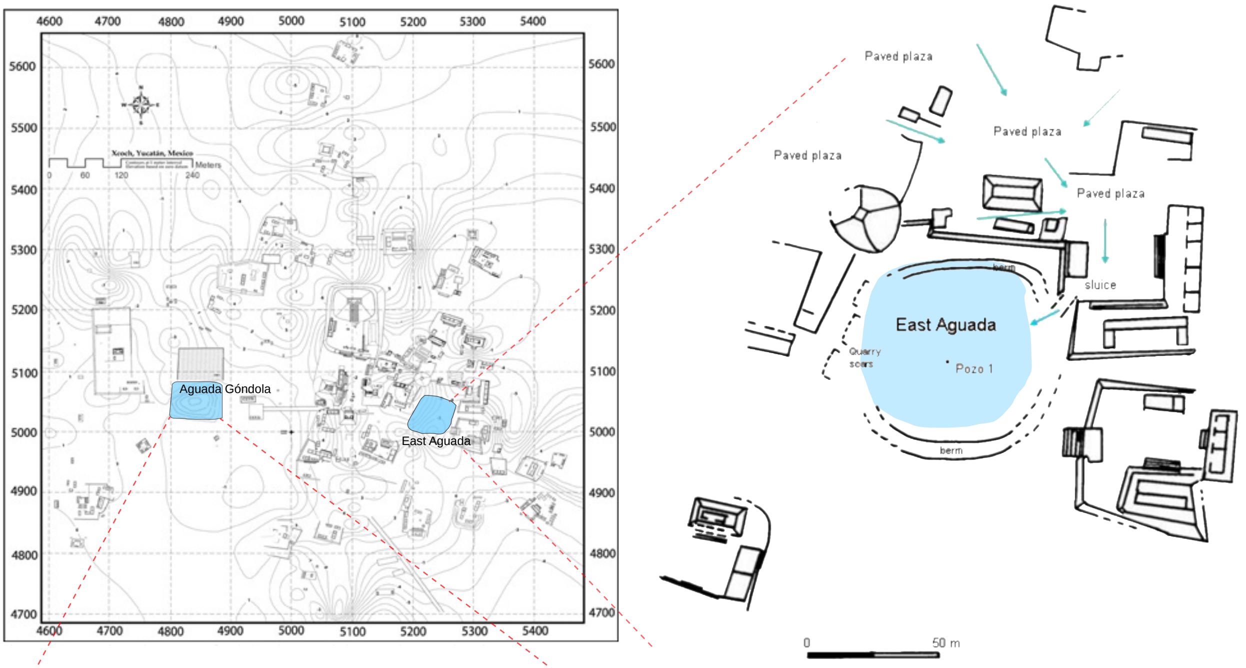
5.7.3 Hydraulic system of Xcoch

In the site of Xcoch, located in the Puuc region, Dunning *et al.* (2014: 70) documented three larger modified reservoirs: the East Aguada (1), the Aguada La Gondola (2) and the Aguada South 1 (3) (Akpinar-Ferrand and Dunning 2011: 11). While the East Aguada and the Aguada La Gondola were located in the site's residential zone and were thus defined as "urban reservoirs" (Dunning *et al.* 2014: 70), the Aguada South 1 was located 1.2 km south of the site center (see Figure 5.91a).

The East Aguada is a circular depression with a diameter of 65 m and is bordered by artificial berms on its northern and southern edges (Dunning *et al.* 2014: 70). As Figure 5.91b indicates, the reservoir is fed by the runoff from the more elevated paved plazas in its vicinity. Based on these observations, Dunning *et al.* (2014: 70) calculated a catchment capacity of 8,300 m^3.

The Aguada Gondola features an extension of 11 x 80 m and a maximum depth of 6 m. At its northeastern and northwestern corners, the aguada was connected to two sluiceways linking it to the Great Pyramid and the Xcoch central plaza by means of two canals (see Figure 5.91c). In addition, the reservoir is surrounded by low berms on almost all sides. During an archaeological excavation of the reservoir, Dunning *et al.* (2014: 71) documented a sequence of three different floors composed of a mixture of clay and sascab (see Figure 5.97d). The excavations also revealed that the berms surrounding the reservoir had been constructed by means of stone retaining walls and that the average depth of the aguada was approximately 9 m (see Figure 5.91d; Dunning *et al.* 2014: 71). Along the interior slopes of the aguada, Dunning *et al.* (2014: 72) also documented a series of terraces or benches composed of dressed stone, rubble and plaster that might have been used to facilitate access to water in the reservoir. Based on these observations, Dunning *et al.* (2014: 71) calculated a capacity of 79,200 m^3.

The Xcoch Aguada South 1 has a circular shape with a diameter of 60 m and lies in an extensive low-elevation area dominated by agriculturally productive *kankab* soils (Dunning *et al.* 2014: 72; see Figures 5.91e and 5.91f). It was encircled by prominent clay berms and connected to an inlet canal and an outlet canal. Archaeological excavations revealed the existence of a floor consisting of compact clay and sascab (Dunning *et al.* 2014: 72). Due to its proximity to agriculturally productive soils and the connection to canals, Dunning *et al.* (2014: 72) argued that the reservoir, featuring a storage capacity of approximately 9,000 m^3 had been used for the intensified irrigation of the surrounding farmland.

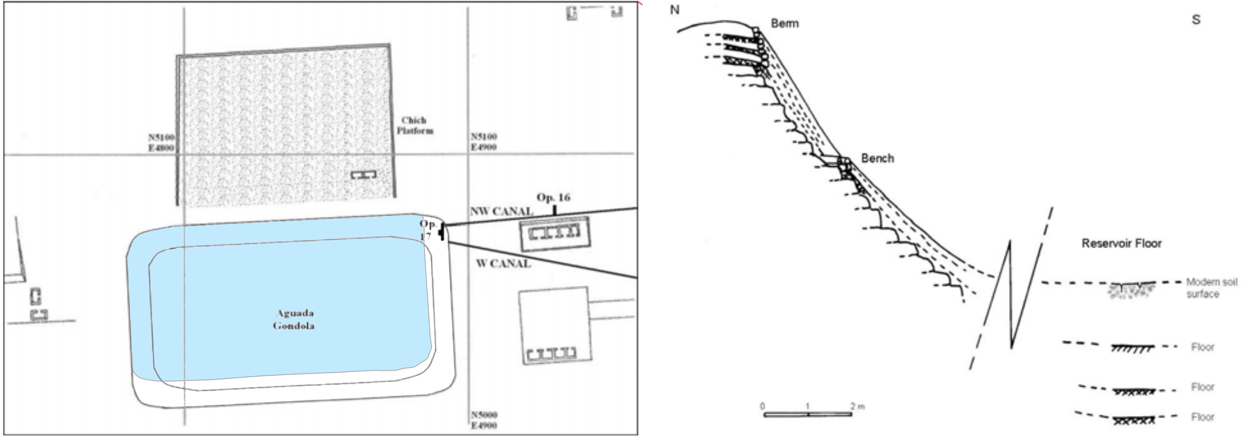


a) Xcoch, Site Map with location of modified reservoirs

b) Xcoch, East Aguada, Direction of surface flow

c) Xcoch, Aguada Gondola, Map

d) Xcoch, Aguada Gondola, Cross section



e) Xcoch, Aguada South 1, Map

f) Xcoch, Aguada South 1, Cross section

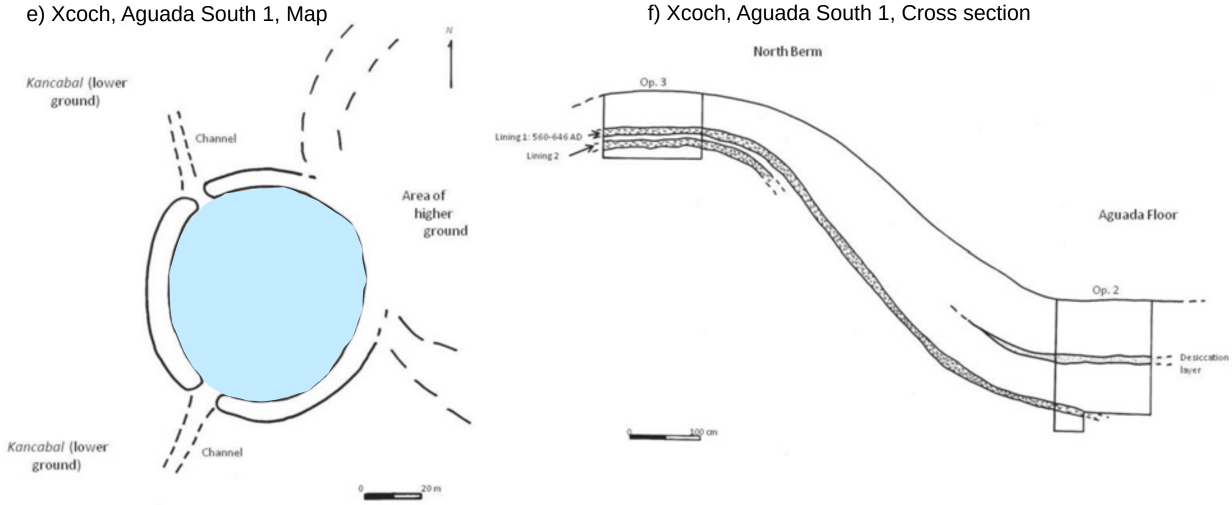


Figure 5.91: Xcoch, Modified Reservoirs. (a) (modified from Smyth and Ortegón-Zapata 2010: Figure 2. Reproduced with kind permission of Michael P. Smyth); (b) (modified from Dunning *et al.* 2014: Figure 4.5); (c) (modified from Dunning *et al.* 2013: Figure 3); (d) (source: Dunning *et al.* 2014: Figure 4.6). Reproduced with kind permission of Nicholas P. Dunning; (e-f) (Drawings courtesy of Nicholas Dunning. Reproduced with kind permission of Nicholas P. Dunning).

5.7.4 Hydraulic System of Edzná

The hydraulic system of Edzná, presumably one of the largest public building projects of Mesoamerica, is located in the 53 km long and 20 km wide valley of Edzná (Matheny *et al.* 1983: 67). This valley is a solution depression (*polje*) that receives only 1,000 mm of annual rainfall (Matheny and Matheny 2012: 26). The city was established near the head end of the valley (Gunn *et al.* 2002). In the natural landscape, no cenotes, caverns, streams, springs or other sources of water could be documented. The only sources of surface water are the natural, flat dissolution aguadas (Matheny 1978; Matheny *et al.* 1983: 67; Scarborough 1993).

During the Middle Preclassic (100-400 BC), the earliest settlers in Edzná likely took advantage of the water retaining qualities of the clay-lined valley floor (Akpinar 2011: 23). During the Late Preclassic (400 BC – AD 250), the inhabitants constructed canals and additional reservoirs in order to increase the water holding capacity of the city. Surprisingly, the hydraulic features of Edzná were already identified in aerial photos[141] taken in the 1940s. In the 1970s, the site was once again studied by means of aerial photos before the hydraulic features were systematically mapped and excavated (Matheny and Matheny 2012: 26; Matheny *et al.* 1983: 68). In this process, Matheny *et al.* (1983) identified a large main canal, several small canals, numerous reservoirs and small water tanks (see Figures 5.92, 5.93, 5.94 and Table 10 in Chapter 8.7).

The main canal was a monumental, 14 km long construction that constituted the main drainage for a catchment area of 180 km^2 (Matheny *et al.* 1983: 68; see Figures 5.92 and 5.94c). According to Matheny *et al.* (1983), the canal had a storage capacity of 900,000 m^3. While the depth cannot be determined, its average width appears to be 50 m (Matheny and Matheny 2012: 30). The canal originated at the "fortress structure", proceeded 3 km to the south, deviated towards the southwest and ended in or near a seasonal swampy savannah (Matheny *et al.* 1983: 68; see Figure 5.92). To the south of Edzná's main canal, Matheny *et al.* (1983: 78) documented an area surrounded by several canals with an average depth of 3 m and an average width of 20 m (Matheny *et al.* 1983: 78, Map 9). Due to the defensive character of this arrangement, the enclosed area has also been designated as the "Fortress" (see Figures 5.92 and 5.93c). The Fortress was connected to the Great Acropolis by means of an elevated causeway. Apparently, the main canal also fed the smaller ditches of the fortress connected to it – an effect that would have further increased the defenses of the "fortress" (Matheny et a. 1983: 73).

Apart from this main canal, Matheny *et al.* (1983: 73) documented numerous other canals that formed a network that extended for 22 km and had a storage capacity of 1,489 m^3 (see Table 10 in Chapter 8.7). All of these radiated out from the site's central plaza, collected the precipitation of the valley and secured the water supply for the residential areas of the elites (Matheny *et al.* 1983: 81). According to Akpinar-Ferrand (2011: 23), the canals captured around 88% of the rainfall in the valley. Technically, they were not only used as drainage canals, but also as reservoirs (Gunn *et al.* 2002: 298). As Matheny (1978: 203) observed water lilies and hyacinths during the investigation of these canals, he speculated that these plants also would have been deliberately used in Preclassic times in order to reduce the evaporation rates of the canals. Furthermore, Matheny *et al.* (1983: 81) argued that the canals provided water for construction purposes and that they could have also been used as water transport routes for canoes and the import and export of goods. Following this theory, Gunn *et al.* (2002: 298) argued that a waterway transport of agricultural goods may have been beneficial in comparison to land transport by human carriers, especially when the site center featured a redistribution center (Matheny *et al.* 1983: 82).

Apart from this complex canal system, Matheny *et al.* (1983: 74) documented 29 larger reservoirs and 58 smaller reservoirs in residential areas, which might have served for the collection and short-term storage of rainwater (see Table 10 in Chapter 8.7). In their view, these constituted cavities had evolved as "byproducts" during the extraction of building material (Matheny *et al.* 1983: 76).[142] The fact that some of

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[141] Most aerial photos were taken during the rainy season with an infrared film, causing a better contrast between the vegetation and the inundated canals (Matheny and Matheny 2012: 31).

[142] Matheny *et al.* (1983: 76) are convinced that the materials for the construction of house-platforms had been extracted from adjacent cavities.

the resulting depressions are located downhill might have facilitated the drainage of the housemounds (Matheny *et al.* 1983: 76).[143] Scarborough (2003: 50) later calculated that the entire system would have been capable of storing up to 2,000,000 m^3 of water and that the reservoirs would have deliberately been positioned higher than the connected canals. Matheny *et al.* (1983: 76) suggested that Edzná's pre-Hispanic inhabitants would have tried to modify the surface of the entire valley in such a way to maximize the amount of water diverted into the center and thus stored in its reservoirs (Gunn *et al.* 2002: 298).

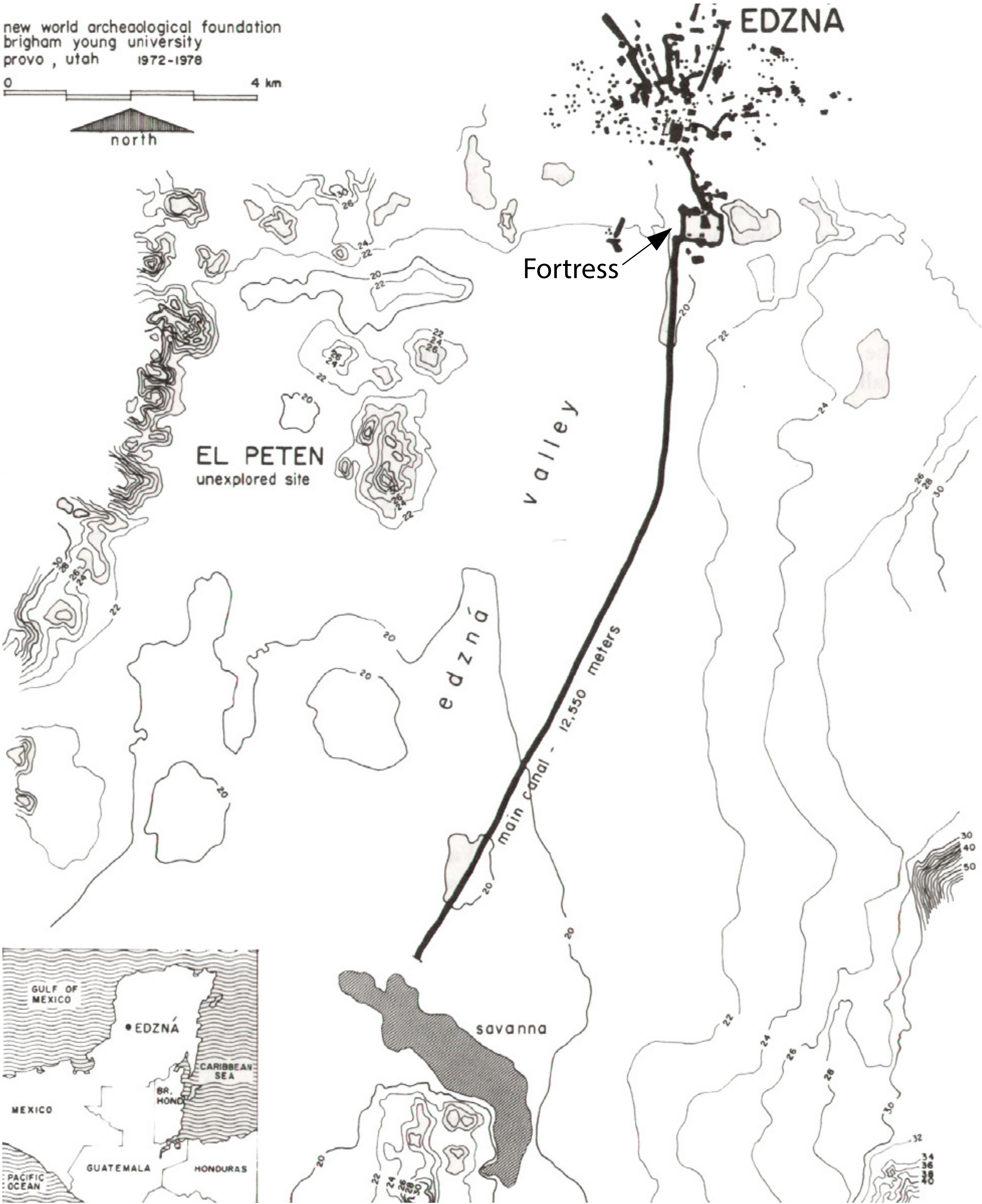

Figure 5.92: Map of the valley of Edzná. (source: Matheny *et al.* 1983: 2, Figure 2). Reproduced with kind permission of Ray T. Matheny and courtesy of the New Word Archaeology Foundation and the Brigham Young University.

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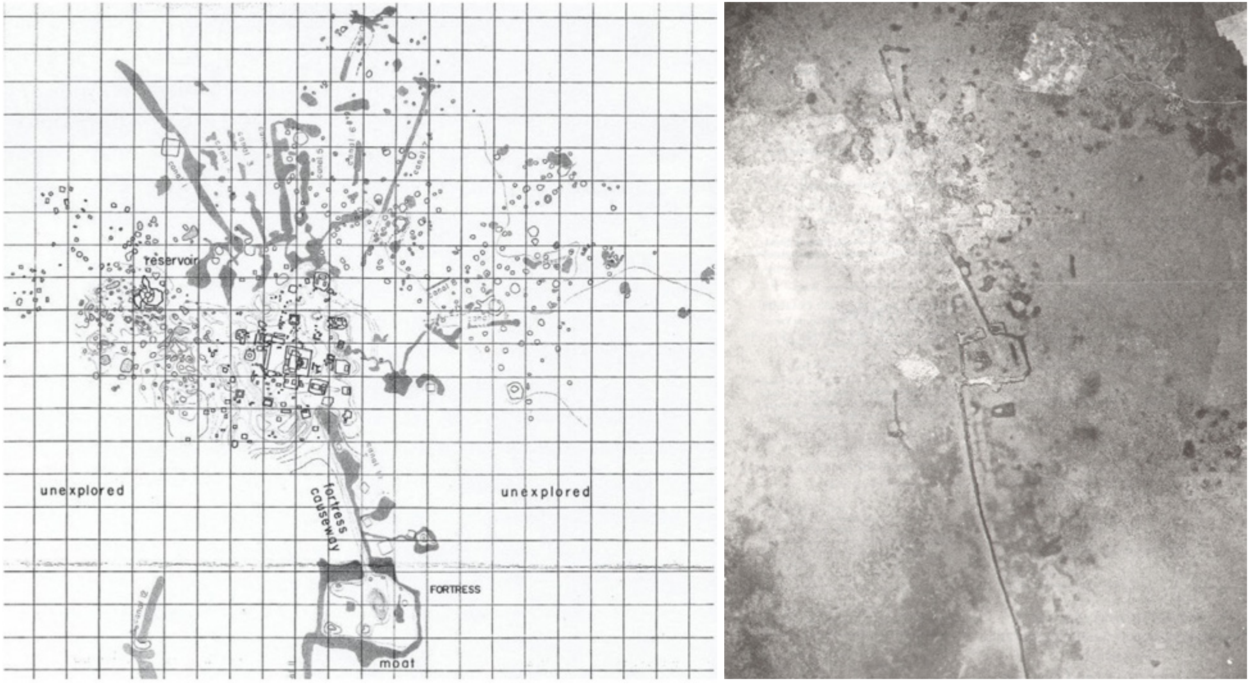
[143] Please note the quite similar interpretation of the drainage system at Dos Hombres (see Chapter 5.5.1).

After the publication of Matheny's (1982) monograph on Edzná's hydraulic system, Doolittle (1990) argued that large portions of the canal system in the northern portion of Edzná (Matheny 1976: 642) represent natural geologic depressions in the form of "structural chasms created by solution processes in karstic landscapes" (Akpinar 2011: 23; Matheny and Matheny 2012: 37). However, Matheny and Matheny (2012: 39) rejected Doolittle's (1990) theory.

In Yohaltún, near Edzná, Morales and Sandoval (1982: 13-27) discovered similar hydraulic features including canals and aguadas (Delgado Kú *et al.* 2012: 71; Zetina 2007: 33). As Matheny and Matheny (2012: 38) noted, the aguada bases of Yohaltún were covered with cut stones while the remaining gaps were filled with mortar. Furthermore, Morales and Sandoval (1982) documented evidence of a canal network that extended for several kilometers from north to south (Matheny and Matheny 2012: 39). In the village of Pich, Faust (1998) investigated a paved aguada, an influx canal and two drainage canals (Matheny and Matheny 2012: 39).


a) Edzná, Map indicating the location of hydraulic features

b) Edzná, Aerial picture of hydraulic system

c) Edzná, Isometric reconstruction of the northern canal, the ceremonial complex and the "fortress"

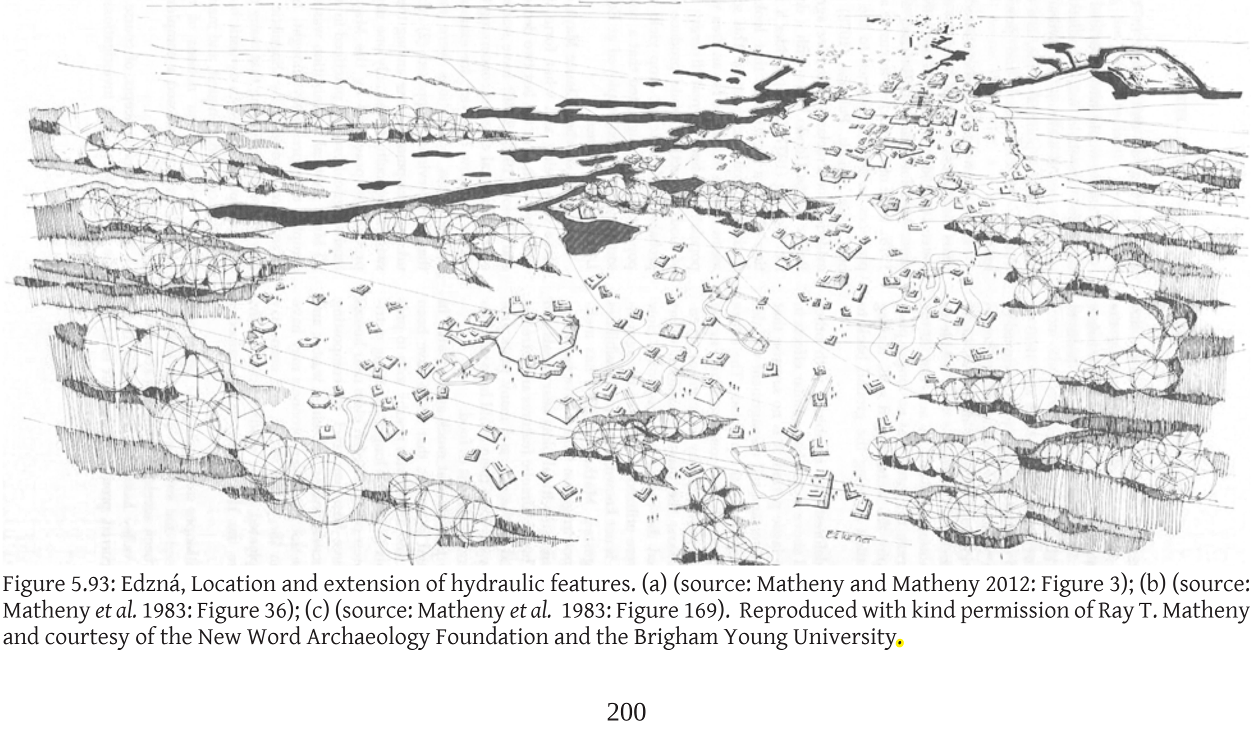


Figure 5.93: Edzná, Location and extension of hydraulic features. (a) (source: Matheny and Matheny 2012: Figure 3); (b) (source: Matheny *et al.* 1983: Figure 36); (c) (source: Matheny *et al.* 1983: Figure 169). Reproduced with kind permission of Ray T. Matheny and courtesy of the New Word Archaeology Foundation and the Brigham Young University.

a) Edzná, Aerial picture of Canals 4 and 5

b) Edzná, Aerial picture of the”fortress” and the main canal

c) Edzná, Aerial picture of the main canal and the “fortress” in the background

Figure 5.94: Edzná, Aerial photos of hydraulic features. (a) (source: Matheny and Matheny 2012: Figure 7); (b) (source: Matheny and Matheny 2012: Figure 5); (c) (source: Matheny and Matheny 2012: Figure 4). Reproduced with kind permission of Ray T. Matheny and courtesy of the New Word Archaeology Foundation and the Brigham Young University.

5.7.5 Hydraulic system of Calakmul

The site of Calakmul is situated approximately 250 m above sea level and is delimited on its western side by the 34 x 8 km Bajo El Laberinto. Several additional bajos surround it on all other sides (Folan *et al.* 1995b: 311; Gunn *et al.* 2002: 298; see Figure 5.95). The settlement is located on a 25 m high limestone summit that forms part of a natural promontory (Folan *et al.* 1995b: 312). Calakmul is apparently connected to adjacent regions by eight sacbe'ob[144] and is linked with many interconnected natural and cultural features such as bajos, aguadas, streams and canals (Domínguez Carrasco 1985, 1993: 42; Domínguez Carrasco and Folan 1996: 172). The site is surrounded by a large creek, the Arroyo El Tomatillo, which encloses the majority of the 22 km² residential area known as "inner Calakmul" (Folan *et al.* 1995b: 311; see Figure 5.95).[145]

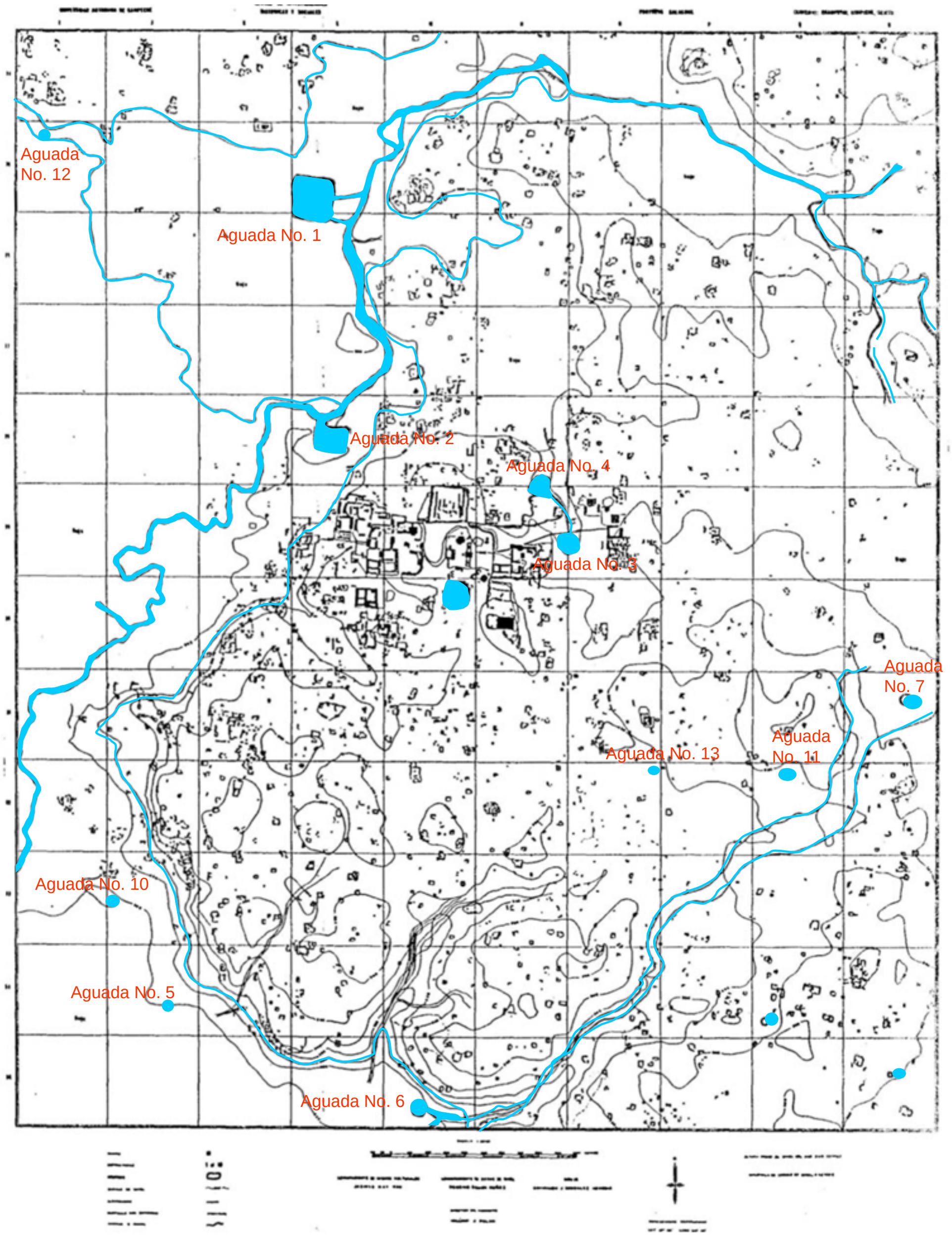


Figure 5.95: Calakmul, Map of hydraulic features (redrawn after Domínguez-Carrasco and Folan 1996: Figures 2 and 4). Reproduced with kind permission of María del Rosario Domínguez Carrasco.

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[144] Sacbe'ob ("causeways") is the plural form of the Maya word sacbe ("white way" or "white path"). Sacbe Nr. 6 leads to El Mirador, which is situated 38 km to the southwest and was studied by Hansen (1991). Other elevated roads lead even further to Nakbe, El Güiro and Tintal (Graham 1967; Hansen 1991). Other causeways led to the southwest towards a satellite site of Calakmul called Laberinto (Folan *et al.* 1995b: 278).

[145] Due to this „border", Folan *et al.* (1995b: 311) see parallels to the Maya centers of Becán and Cerros.

Apparently, the Arroyo Tomatillo was also modified by the pre-Hispanic Maya (Folan *et al.* 1995b: 312). Presumably, the first settlement of Calakmul evolved during the Preclassic at the margin of the Bajo El Laberinto (Folan *et al.* 1995b: 312). In the 9th century AD, this system declined due to lacking precipitation (Gunn *et al.* 2002: 302). Overall, Domínguez Carrasco and Folan (1996: 74) documented 13 aguadas within Calakmul. They are concentrated primarily along the margins of bajos with only a few being located in the more elevated portions of the settlement (Domínguez Carrasco and Folan 1996: 74; Gunn *et al.* 2002: 302; see Figure 5.95 and Table 10). According to Winemiller (2012: 117), the largest aguadas were located adjacent to or north of the site center. By assuming an average depth of 2 m, Domínguez Carrasco and Folan (1996: 174) calculated that all 13 aguadas had a total capacity of 228,150 m^3 (see Table 10 in Chapter 8.7).

The two largest aguadas, Aguada No. 1 (105,000 m^3) and Aguada No. 2 (33,000 m^3) were documented at the eastern margin of the Bajo El Laberinto (Folan *et al.* 1995b: 312). They were fed by canals, precipitation and the Arroyo El Tomatillo, which had been "modified" specifically for this purpose (Domínguez Carrasco and Folan 1996: 174; Gunn *et al.* 2002: 299). As soon as the larger Aguada No. 1 had been filled, the excess water was led into the smaller Aguada No. 2 (Domínguez Carrasco and Folan 1996: 175; Folan *et al.* 1995b: 312).

Within the northern core area of Calakmul, Domínguez Carrasco and Folan (1996: 175) documented three moderately smaller aguadas (No. 3, 4, and 5). Aguada No. 4 and No. 5 are interconnected by a 250 m long and 80 cm deep canal with a height difference of 4 m over its total length (Domínguez Carrasco and Folan 1996: 175; Folan *et al.* 1995b: 312). Excavations within Aguada No. 4 revealed worked stone slabs measuring 30 x 50 cm and 5-10 cm thick that were interpreted as a pavement of the aguada floor (Domínguez Carrasco and Folan 1996: 176; see Figure 5.96a). Some authors (e.g. Ancona 1978; Stephens 1843) suggested that this pavement might have helped to impede the seepage of water stored in the aguada (Domínguez Carrasco and Folan 1996: 176).

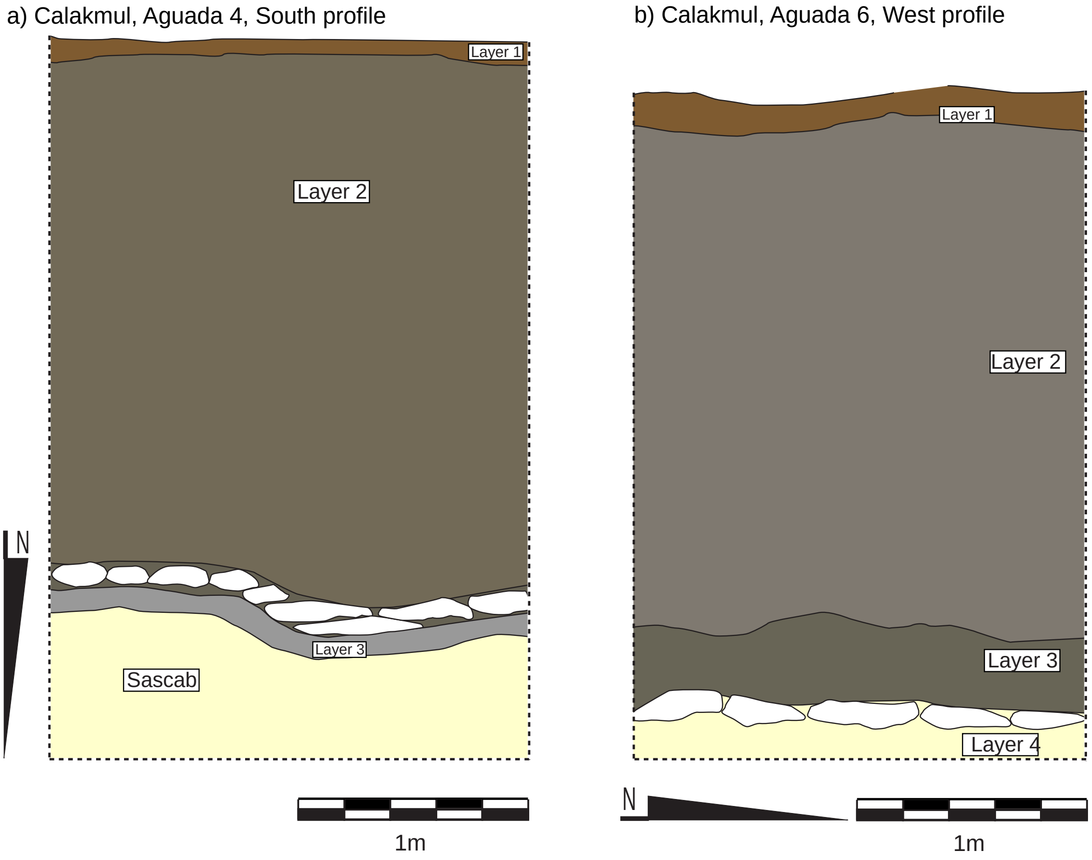

Figure 5.96: Calakmul, Stratigraphic profile of Aguada No. 4 and No. 6. (a) (redrawn after Domínguez Carrasco and Folan 1996: Figure 15); (b) (redrawn after Domínguez Carrasco and Folan 1996: Figure 14). Reproduced with kind permission of María del Rosario Domínguez Carrasco.

At the margin of the Bajo El Laberinto, Domínguez Carrasco and Folan (1996: 175) documented six smaller aguadas (No. 6-11) with capacities varying between 2,050 and 9,800 m^3 (see Table 10 in Chapter 8.7). The bottom of Aguada No. 6 was modified with a pavement of limestone slabs similar to the pavement documented in Aguada No. 4 (see Figure 5.96b).

At the margin of the settlement's center, Domínguez Carrasco and Folan (1996: 175) documented two small reservoirs, Aguada No. 12 (capacity: 1,250 m^3) and Aguada No. 13 (capacity: 5,000 m^3), that appeared to be related to adjacent residential areas and were thus interpreted as containers for drinking water for domestic use (*aguadas vecindales*). In addition, Winemiller (2012: 117) located 27 chultunes, which were mostly concentrated south of the site center.

Based on the hypothesis that the core area of Calakmul was inhabited by at least 25,000 people, Domínguez Carrasco and Folan (1996: 176) concluded that the water stored in the documented aguadas would have had a relatively high chance of being contaminated. Therefore, Domínguez Carrasco and Folan (1996: 176) reasoned that the pre-Hispanic inhabitants would have been forced to use chultunes (Zapata Castorena 1995: 27), large storage vessels (Domínguez Carrasco 1995), or smaller neighborhood aguadas (*aguadas vecindales*) to bolster the demand for potable water. In doing so, the inhabitants would have been supplied with less contaminated water. In conclusion, Domínguez Carrasco and Folan (1996: 174) argued that the aguadas of Calakmul would have been primarily used for agricultural purposes, such as intensified horticulture of maize, beans, calabash, chili, tomatoes and fruit trees within or between the residential areas.

5.7.6 Hydraulic system of El Mirador

El Mirador is generally considered to be the largest Preclassic urban center of the Maya Lowlands (Brewer 2007: 33; Hansen *et al.* 2002). The site is located on the margins of a large bajo and is traversed by four long causeways radiating out from the site center (Brewer 2007: 33; Dahlin 1984; Scarborough 1983, 1991a, 1991b, 1993a, 1994). According to Matheny (1980), the existence of a large natural aguada at the base of an escarpment was an important factor for the foundation of the settlement (Akpinar 2011: 27). In the Late Preclassic, El Mirador's inhabitants started to construct several artificial reservoirs with considerable storage capacities that served to complement the natural aguadas located below the limestone ridges (Akpinar 2011: 27). Apart from the extremely dry years, at least four of these aguadas likely stored water during the dry seasons (Akpinar 2011: 279; Matheny 1980; Nielsen 1980). Dahlin (1984) also speculated that the material recovered during the excavation of the artificial reservoirs was used for constructing the four large causeways, which would have subsequently served as dikes or dams in later periods (Brewer 2007: 33).

In a later map, Hansen *et al.* (2006) identified numerous canals, dikes, streams and 18 aguadas (Akpinar 2011: 28). Among the smaller reservoirs, Matheny (1982) located six chultunes (Brewer 2007: 33). According to Matheny (1982), the hydraulic features of El Mirador had been carefully planned, asserting that stone quarries for the procurement of building material would have been modified into artificial reservoirs. Hansen *et al.* (2002) also speculated that some portions of El Mirador's bajos had been used for agricultural purposes (Brewer 2007: 33; Dahlin *et al.* 1980; Dunning *et al.* 2006: 92). In this respect however, the author would like to remark that no graphic documentation material of these hydraulic features has ever been published. Therefore, it is difficult to understand their functionality or verify their actual existence.

5.7.7 Hydraulic system of Tikal

Of all known hydraulic systems in the Maya Lowlands, the hydraulic system of Tikal has been studied most intensively. The city of Tikal is situated near the southern end of the Elevated Interior Region (EIR) of the Maya Lowlands (Dunning *et al.* 2012, 2015b: 5). Similar to Calakmul, the city of Tikal sits on a promontory (Gunn *et al.* 2002). As Figure 5.97 indicates, the site is surrounded by bajos in all directions: the Bajo de Santa Fe and the Bajo La Justa to the East, the Bajo Ixtinto and the Bajo Socotzal to the south, the Bajo Bejucal to the West, and the Bajo de la Juventud to the north (Dunning *et al.* 2015b: 7). The ubiquity of bajo landscapes led Dunning *et al.* (2015: 8) to the assumption that they had played a significant role in the history of the region's settlement.

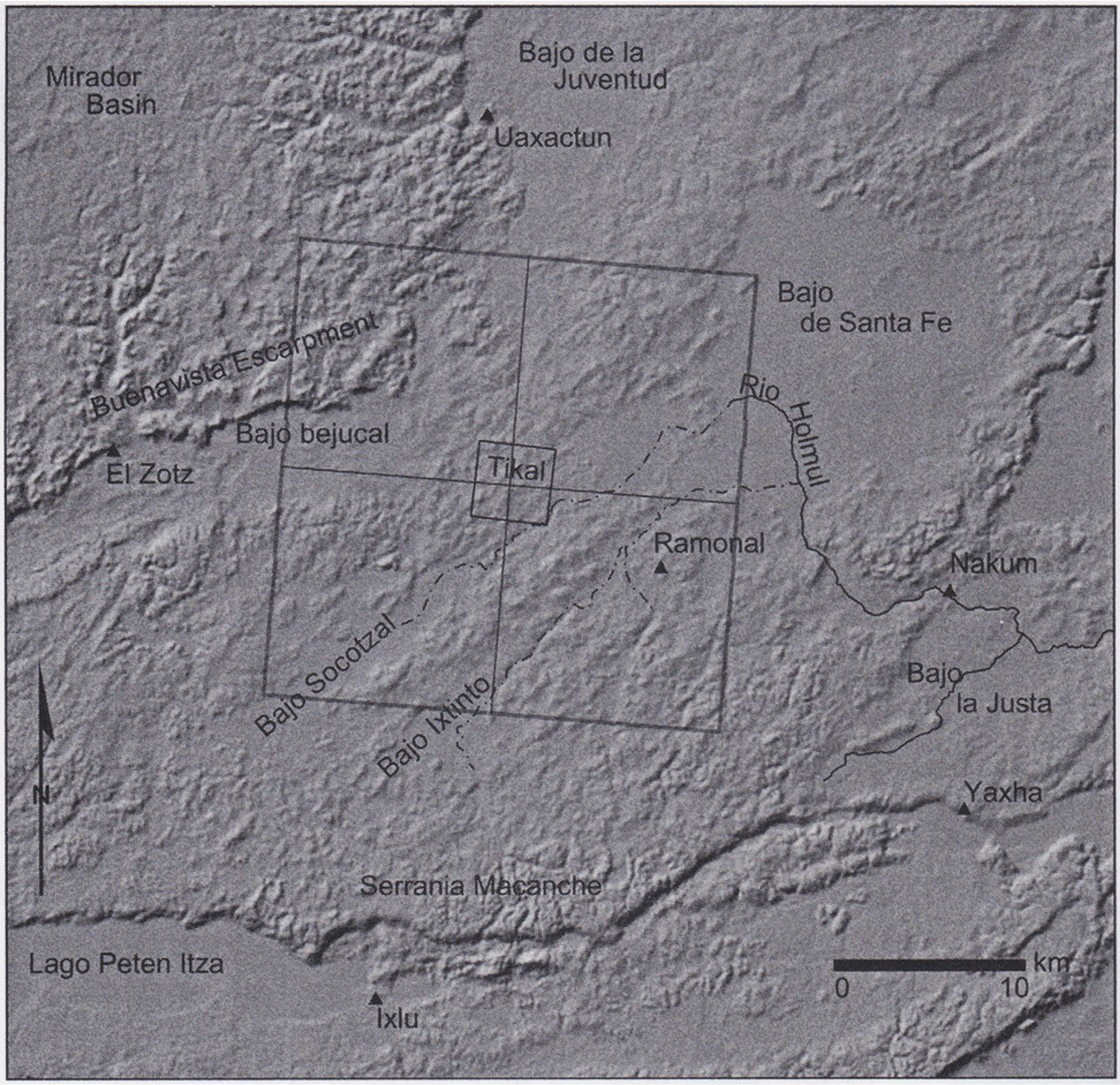

Figure 5.97: Regional Map of Tikal (source: Dunning *et al.* 2015b: Figure 1.3). Reproduced with kind permission of Nicholas P. Dunning and Cambridge University Press.

At the current state of research, most scholars believe that small populations began to reside in Tikal sometime prior to 700 BC (Dunning *et al.* 2015b: 12). By 600 BC, the inhabitants built the first monumental architectural complexes in the Northern Acropolis and the Mundo Perdido (Dunning *et al.* 2015b: 12; Laporte 2003). Silverstein *et al.* (2009: 49) noted that the natural landscape of Tikal offers very few sources of water and argued that this situation had been a true challenge for the sociopolitical development of the city.[146] This is a critical issue as Tikal presumably had a very impressive population. The estimates for the 120 km^2 area of Tikal range between 60,000 and 80,000 inhabitants (Scarborough and Lucero 2010). Based on the current hydraulic conditions, Silverstein *et al.* (2009: 45, 51) concluded that the absence of perennial rivers would have forced the pre-Hispanic inhabitants of Tikal to collect rain before it infiltrated into the soil. In this process, they would have created a modified watershed based on reservoirs along the edges of bajos and neighborhood reservoirs (Akpinar 2011: 28; Gunn *et al.* 2002). The following overview provides a concise description of the different sets of hydraulic features studied in the city of Tikal.

After the publication of Carr and Hazard's (1961) maps of Tikal's core region, the different hydraulic features were studied by at least five different research groups:

(1) Members of the Tikal Penn project excavating Tikal's aguadas and reservoirs (1960) (unpublished),

(2) Topographic surveys by Puleston and Callender (1967) that focused on the earthworks of Tikal,

(3) A group directed by Fialko (1999) that focused on the hydraulic features in the Mundo Perdido complex,

(4) A research group directed by David Webster (Webster *et al.* 2007a, 2007b) and Jay Silverstein (Silverstein 2009) that focused on the earthworks of Tikal, and

(5) The project of the University of Cincinnati (2009-2010) which concentrated on the hydraulic features of Tikal's central precinct (Lentz *et al.* 2015a; Scarborough *et al.* 2012).

Generally, the studied hydraulic features of Tikal can be divided into two groups, the northern and southern earthworks (see Chapter 5.7.7.1) and the hydraulic features of the center (see Chapter 5.7.7.2). As they mark the general exterior boundaries of the city of Tikal, the description of these landscape features will begin with the so-called "Earthworks of Tikal".

5.7.7.1 Earthworks of Tikal

Initially, the set of landscape features that would later become known as the "Earthworks of Tikal" were discovered during Puleston's and Callender's extensive topographic surveys in the 1960s (Puleston 1973, 1983; Puleston and Callender 1967). The features were located 4.5 km north of the Central Acropolis in an area with poor access to perennial sources of water (Silverstein *et al.* 2009: 45, 49). Initially, Puleston and Callender (1967) only mapped a 9.6 km long portion of this east-west running wall. Later, they mapped another 1 km long earthen wall running northeast to southwest, located 8.25 km south of the central acropolis (Silverstein *et al.* 2009: 45; see Figure 5.98). Based on three excavation trenches (see Figure 5.98), Puleston and Callender (1967) determined that the northern earthworks would consist of a 3.5 m wide and 3.1 m deep ditch. This ditch would have been accompanied by a 2 m high and 4 m wide dam on its southern bank (Silverstein *et al.* 2009: 49; see Figure 5.99).

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[146] "The lack of available water becomes clear each time one drives through the village of Zocotzal located at the entrance to the National Park of Tikal. There, every household has several large containers placed along the street that need to be refilled by a water-truck from the Guatemalan government" (Silverstein *et al.* 2009: 49). The exact risk of the canícula (see Chapter 2.2.2) for the region of Tikal is not known (Silverstein *et al.* 2009: 55).

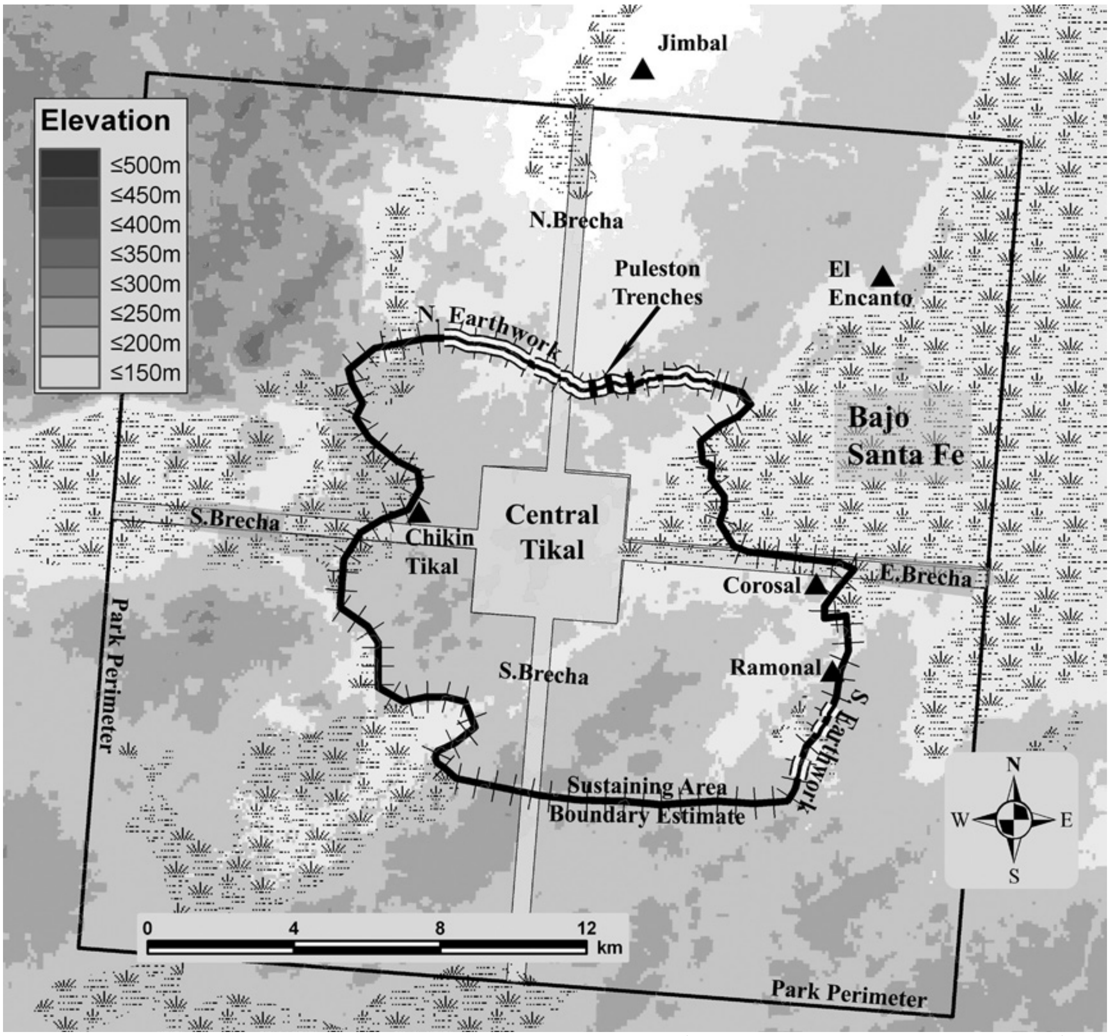

Figure 5.98: Tikal, Regional Map showing the location of earthworks (source: Silverstein *et al.* 2009: Figure 1). Reproduced with kind permission of Jay Silverstein and Cambridge University Press.

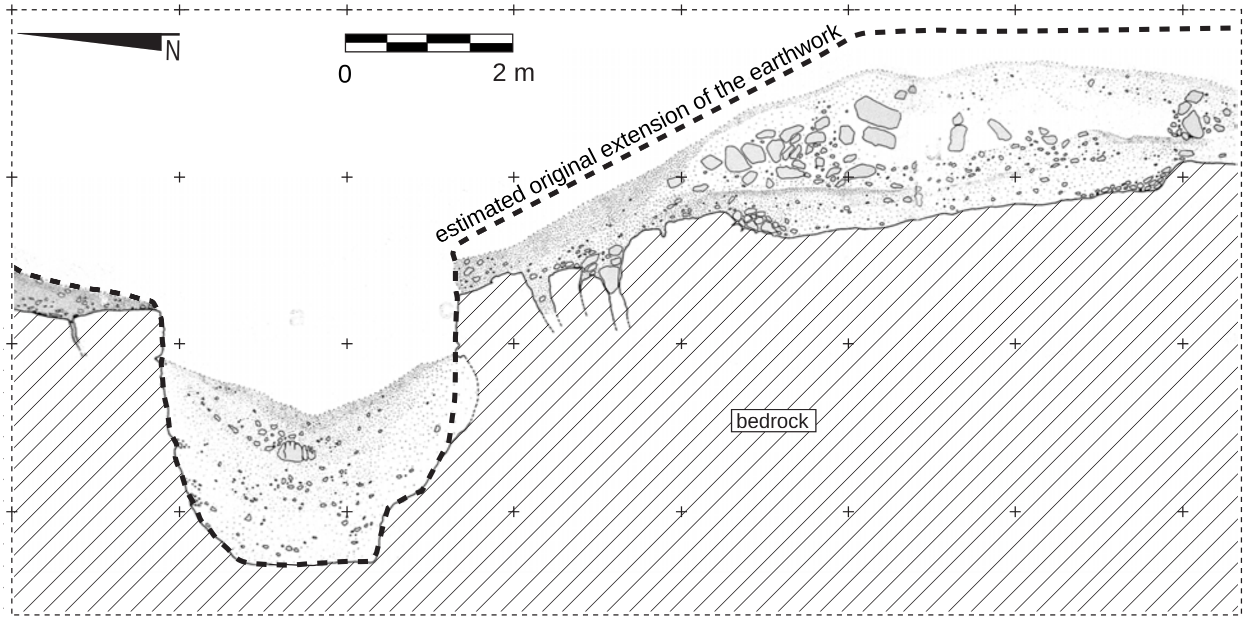

Figure 5.99: Tikal, Earth wall, East profile (modified from Silverstein et al. 2009: Figure 2. Originally published by Puleston and Callender 1967: Figure 2. Reproduced with kind permission of Olga Stavrakis Puleston, Jay Silverstein and Cambridge University Press).

The recovered ceramic material indicated that the earthworks had been created during the Early Classic (Fry 1969; 85; Puleston and Callender 1967; Silverstein *et al.* 2009: 46; Webster *et al.* 2004: 22-28). During the 1960s, Puleston and Callender (1967) did not carry out any excavations of the southern earthworks. Nevertheless, they claimed that it would have consisted of a pair of parallel walls demarcating the southern barrier of Tikal's hinterland (Silverstein *et al.* 2009: 46).[147] Based on the excavated trenches and the extensive survey, Puleston (1983) argued that the southern and northern earthworks had delimited an area of roughly 120 km^2, an area defined as "residential Tikal". In the following years, several scholars (e.g. Culbert *et al.* 1990; Haviland 2003) adapted Puleston's assertion without further verifications in the field (Silverstein *et al.* 2009: 46).

Between 2003 and 2006, a team of researchers led by David Webster carried out extensive topographic surveys and archaeological excavations in order to determine the exact extension and functionality of the earthworks (see Silverstein *et al.* 2009; Webster *et al.* 2004, 2007a, 2007b). In total, Silverstein *et al.* (2009: 47) mapped 24.6 km of the ditch (see Figure 5.100). This process led to the discovery of an additional western extension of the original ditch inside a bajo (Silverstein *et al.* 2009: 47). During the revision of the earthwork, Silverstein *et al.* (2009: 47) were unable to locate the southern earthwork described by Puleston (1983).

Due to the interrupted course and heterogeneous composition of the earthworks (see Figure 5.100), Silverstein *et al.* (2009: 44) rejected Puleston's (1983) original interpretation as a defensive feature. Instead, they interpreted the earthworks as a limestone filtration ditch that would have functioned by means of the same basic principles as filtration wells (see Chapter 5.6.3.4; Scarborough 2003b: 80). Due to the geological characteristics of Tikal's landscape, Silverstein (2009: 51) argued that filtration wells would have been an effective means of water collection in Tikal.[148] Thus, the earthwork was designed to detain underground water along its course downslope in the direction of the aquifer (Silverstein *et al.* 2009. 51). Due to the capillary fringe effect in porous rocks, water would have been sucked from the underlying water table even if the ditch did not reach the phreatic zone (Silverstein *et al.* 2009: 51; see Figure 5.101). This layout would have enabled the population to store rainwater at specific collection points and use it during the dry seasons.

In conclusion, Silverstein *et al.* (2009: 55) emphasized that even the interpretation of this feature as a limestone filtration ditch should be considered preliminary, but that it would be the most plausible explanation for *many* characteristics of the ditch. Consequently, Silverstein *et al.* (2009: 55) interpreted the wall and ditch rather broadly as a "multi-function construction" that would have served several purposes including water collection, communication, territorial demarcation, the quarrying of stone and defense. Due to the inherent difficulties in dating hydraulic features (see Chapter 7.3), Silverstein *et al.* (2009: 54) assumed that the earthworks was constructed over a long period between the Early Classic and Late Classic and that its construction had originally been triggered by a period of extreme drought (Webster *et al.* 2007).

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[147] Furthermore, Puleston and Callender (1967) assumed that the dam would have been additionally fortified by a row of palisades. However, it should be noted that they did not document any hints of postholes or other evidence indicating the existence of such a row of palisades.

[148] However, it should be highlighted that Chenes-like filtration wells have never been documented in the Tikal area.

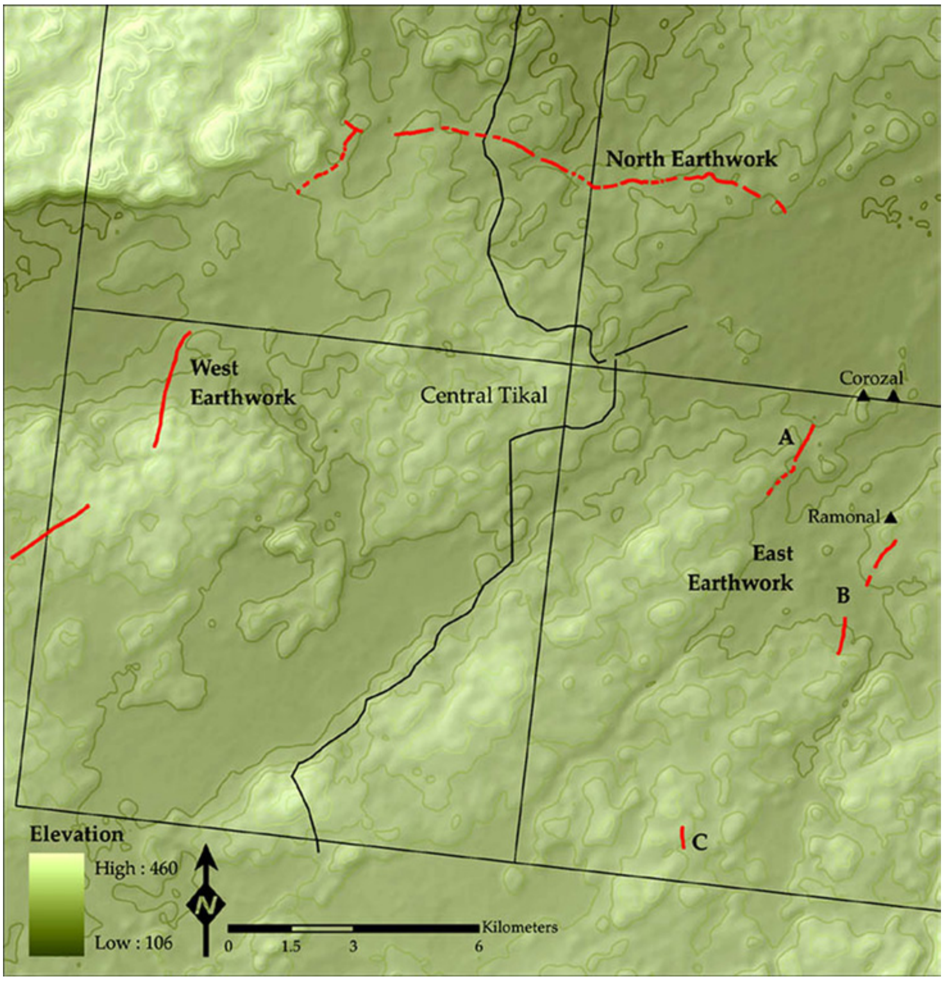

Figure 5.100: Tikal, Updated map of earthworks (source: Webster et al. 2007: Figure 3. Map produced by Timothy Murtha. Reproduced with kind permission of David Lee Webster).

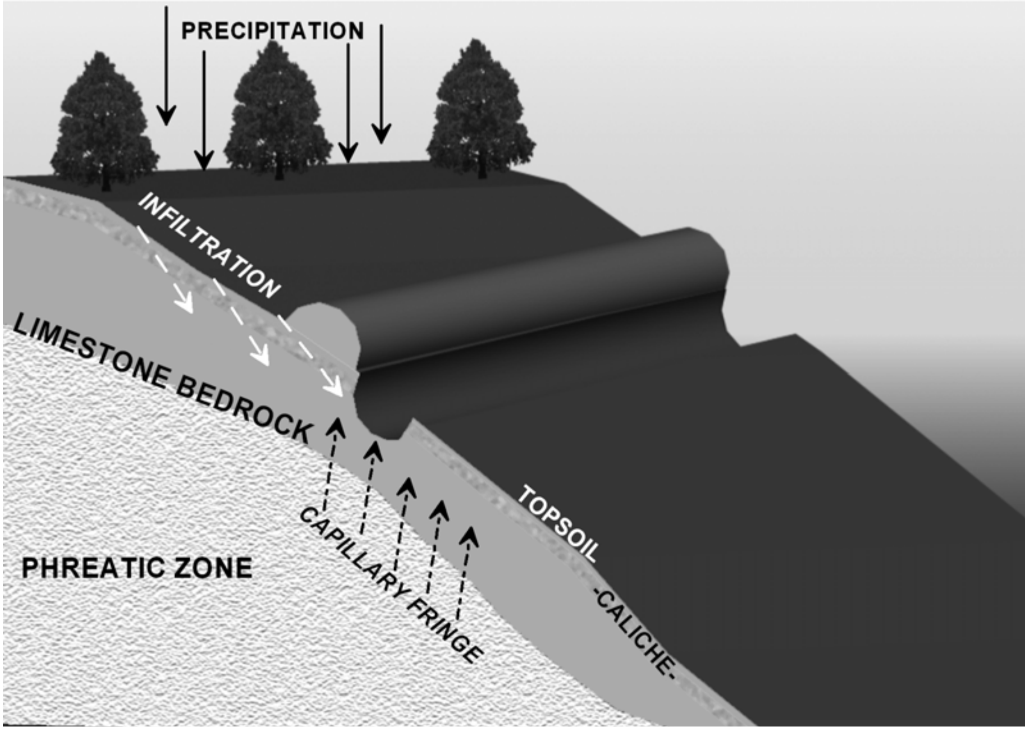

Figure 5.101: Tikal, Schematic of the functionality of the filtration ditch (source: Silverstein et al. 2009: Figure 6). Reproduced with kind permission of Jay Silverstein and Cambridge University Press.

5.7.7.2 Hydraulic system in the core of Tikal

Even though Carr and Hazard (1961) had highlighted Tikal's various sets of paved plazas (i.e. causeways and plazas in the center) and excavations of hydraulic features had taken place in the site core of Tikal as early as the 1960s, publications do not appear until the onset of the 1990s. Based on Carr and Hazard's (1961) maps, Scarborough and Gallopin (1991: 658) observed that the reservoirs of the site core were located at different elevations. This observation led Scarborough (1994: 192) to the hypothesis that the paved plazas were deliberately constructed with slight slopes in order to catch and drain rainfall and direct it towards these "tiered reservoirs".

In order to illustrate the functionality of this layout, Scarborough (1994: Figure 5) produced an isometric reconstruction of Tikal's pre-Hispanic settlement landscape highlighting the way in which the interconnected hydraulic features operate, which was subsequently cited and reproduced in many more publications. According to Silverstein *et al.* (2009: 49) and Fialko (1999: 686), the larger reservoirs would have featured spillways on their less elevated sides that would have been used to distribute water or to protect against overfilling. Thus, reservoirs located at various elevations were a key element of Tikal's hydraulic system as they would have enabled the controlled release of stored water during the dry season (Scarborough 1994: 182). In the central portion of the site, the causeways would have acted similar to dams by detaining water and thus ensuring constant and dry transport routes between the different parts of the settlement – even during the rainy season (Scarborough 1994: 192).

Once Scarborough and Gallopin's (1991) model of a tiered reservoir system was accepted, other scholars argued that even the smaller residential structures in Tikal's periphery had been connected to smaller water tanks (Fialko 1999; Scarborough 1994: 193). These smaller water tanks would have been fed by "numerous drainage canals" that would have been connected to the larger reservoirs located at higher elevations (Fialko 1999: 687; Scarborough 1994: 193; Scarborough and Gallopin 1991: 662). Furthermore, Scarborough and Gallopin (1991) argued that all surplus water not required by the local residents would have been directed towards additional reservoirs along the bajo margins. The water stored in these bajo margin reservoirs would have been used in order to irrigate elevated fields[149] – a form of intensified agriculture that would have enabled "continuous harvests" (Akpinar 2011: 28; Scarborough 1994: 193).

Whereas Scarborough and Gallopin's (1991) models were still mostly confined to an analysis of previously published maps, Fialko carried out a series of focused archaeological investigations of the hydraulic features in the core of Tikal (Fialko 1998, 1999: 685). For the most part, these investigations concentrated on the hydraulic features in the Mundo Perdido complex (Fialko 1999). However, as the graphic documentation material produced during these investigations was never published, the results of these investigations are not presented here in greater detail.

Between the field seasons of 2009 and 2011, a team of scholars from the University of Cincinnati and other academic institutions were able to carry out large-scale investigations of eight reservoirs in the central area of Tikal: the Aguada Madeira (1), the Temple Reservoir (2), the Palace Reservoir (3), the Perdido Reservoir (4), the Hidden Reservoir (5), the Inscriptions Reservoir (6), the Corriental Reservoir (7), and the Tikal Reservoir (8) (Scarborough *et al.* 2012: 12408; see Figure 5.102a). In order to illustrate the functionality of the "tiered reservoir chain" Scarborough *et al.* (2012: 12408) produced a schematic representation of the relative elevation of these different reservoirs and their connection to other hydraulic features (see Figure 5.102b). According to Scarborough *et al.* (2012: 12408), the central precinct of Tikal is defined by a north-south oriented ridge cut by three prominent corrientales from west to east (see Figure 5.102a). Although each of these three corrientales had been culturally modified, the southernmost corriental had apparently been modified to the largest extent (Scarborough *et al.* 2012: 12408). As Figures 5.102b and 5.102c indicate, the Temple Reservoir, the Palace Reservoir and the Hidden

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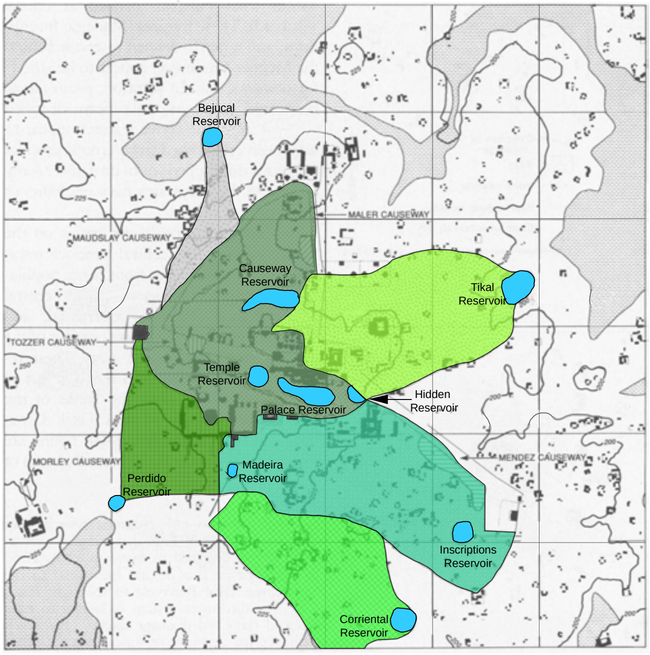
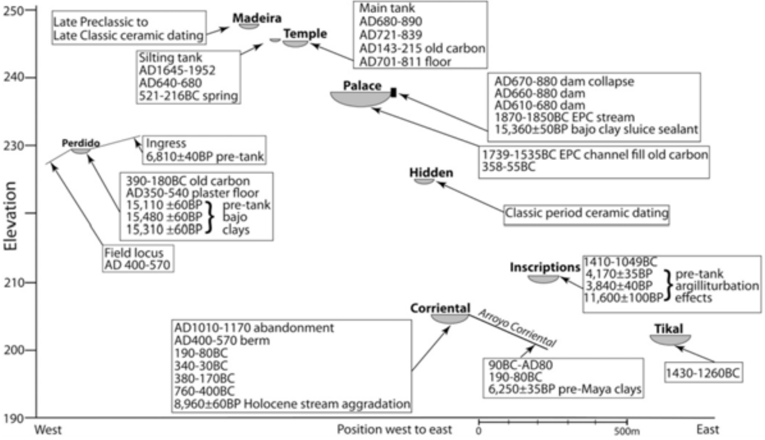
[149] In this respect, it should be emphasized that the existence of elevated fields along the bajo margins of Tikal was neither verified during the publication of this hypothesis (1994), nor the publication of this study (2018). For further information, refer to the discussion on the potential existence of canal systems in inner bajos (see Chapter 5.2.3).

a) Tikal, Location of reservoirs and their respective watersheds



b) Tikal, Schematic cross-section of southern hilltop including the elevation and datings of reservoirs



c) Chain of Temple Reservoir, Palace Reservoir and Hidden Reservoir

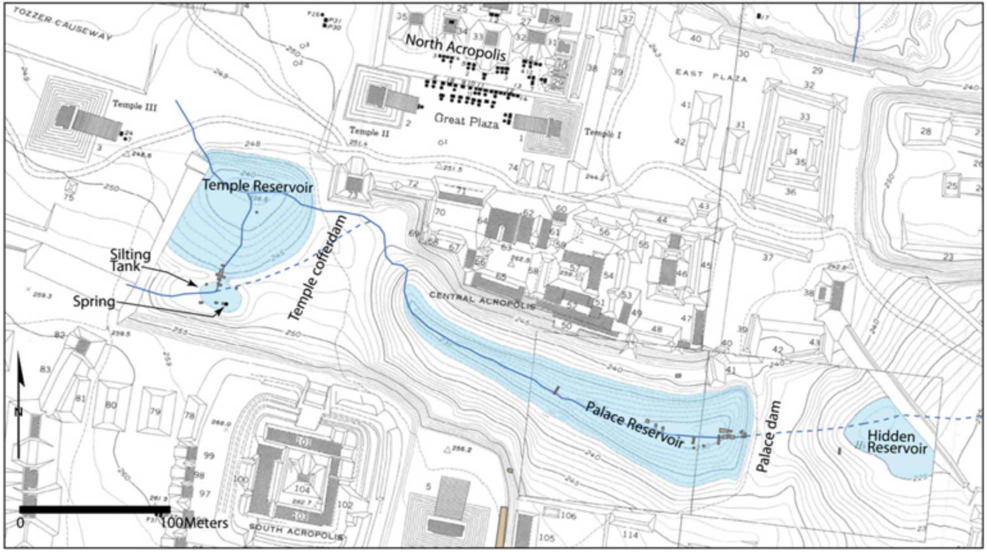


Figure 5.102: Tikal, Site-core, Overview of hydraulic features. (a) (redrawn after Scarborough *et al.*: 2012: Figure 1. Reproduced with kind permission of Vernon Scarborough and PNAS. Base map was originally published by Carr and Hazard 1961; Courtesy of the Penn Museum. ; (b) (source: Scarborough *et al.* 2012: Figure 3); (c) (source: Scarborough *et al.* 2012: Figure 2. Reproduced with kind permission of Vernon Scarborough and PNAS. Base map was originally published by Carr and Hazard 1961, Courtesy of the Penn Museum).

Reservoir formed a descending chain of artificially dammed tanks (Scarborough *et al.* 2012: 12408). The map of Tikal's central reservoirs and their respective catchment areas (see Figure 5.102c) also shows that the Corriental Reservoir and the Perdido Reservoir[150] were located closer to the bajo margins and separated by two adjacent, but independent catchment areas (Scarborough *et al.* 12409). The Inscriptions Reservoir and the Tikal Reservoir also formed part of the southern catchment system (Scarborough *et al.* 2012: 12409). The following overview will present the most intensively studied reservoirs in greater detail. These are the Temple Reservoir, the Palace Reservoir and the Corriental Reservoir.

5.7.7.2.1 Temple Reservoir

The Temple Reservoir was the smallest, but most elevated public water source and featured a storage capacity of 27,140 m^3 (Scarborough *et al.* 2012: 12409; see Figure 5.103a). To the south, the reservoir is bordered by a "silting tank" and to the east by a "cofferdam" that separates it from the Palace Reservoir (Scarborough *et al.* 2012: 12409). The silting tank and reservoir were connected by a narrow spillway that cut through the middle of the berm that separated them.

During the excavation of the silting tank, Scarborough *et al.* (2012: 12409) documented that the western berm was modified bedrock, while the eastern berm was composed of earthen fill (see Figure 5.103a). According to Scarborough *et al.* (2012: 12409), the western berm represents remains of the northern bank of a winding arroyo head and a hollowed silting tank feature. The documentation of water-worn cobbles in OP 7J (see Figure 5.103a) convinced Scarborough *et al.* (2012: 12409) that the depression south of the main reservoir had been used as a silting tank. Excavations in the middle of the reservoir (OP 7C, see Figures 5.103a and 5.103c) showed that the reservoir featured a poorly preserved clay lining (Scarborough *et al.* 2012).

Based on these observations, Scarborough *et al.* (2012: 12409) concluded that the location of the spillway would have been marked by a fault spring (see Chapter 2.1.4.1.1), a landscape feature that would have attracted Preclassic settlers. For some time, this water source would have provided clean water for a founding community "near a high point in the regional topography" (Lentz *et al.* 2015b: 282). When demographic stress exceeded the flow-rate of this alleged fault spring, Tikal's inhabitants would have expanded the head end of a natural streambed by constructing an elevated silting tank (Scarborough *et al.* 2012: 12409). In the next step, they would have quarried the deeper main reservoir to the north and east of the original streambed.

Based on the present-day contour lines and subsurface testing, Scarborough *et al.* (2012: 12409) deduced that the Temple Causeway, which separated the Temple Reservoir from the larger Palace Reservoir, would have been constructed from the exposed bedrock with added construction fill in order to prevent water flowing from the stream. As Scarborough *et al.* (2012: 12409) noted, the berm between the silting tank and the reservoir would have featured a constricted 2 m wide plastered spillway with an overall vertical drop of 3 m before cascading into the lower-lying basin 8 m below the base of the silting tank (see Figure 5.103a).

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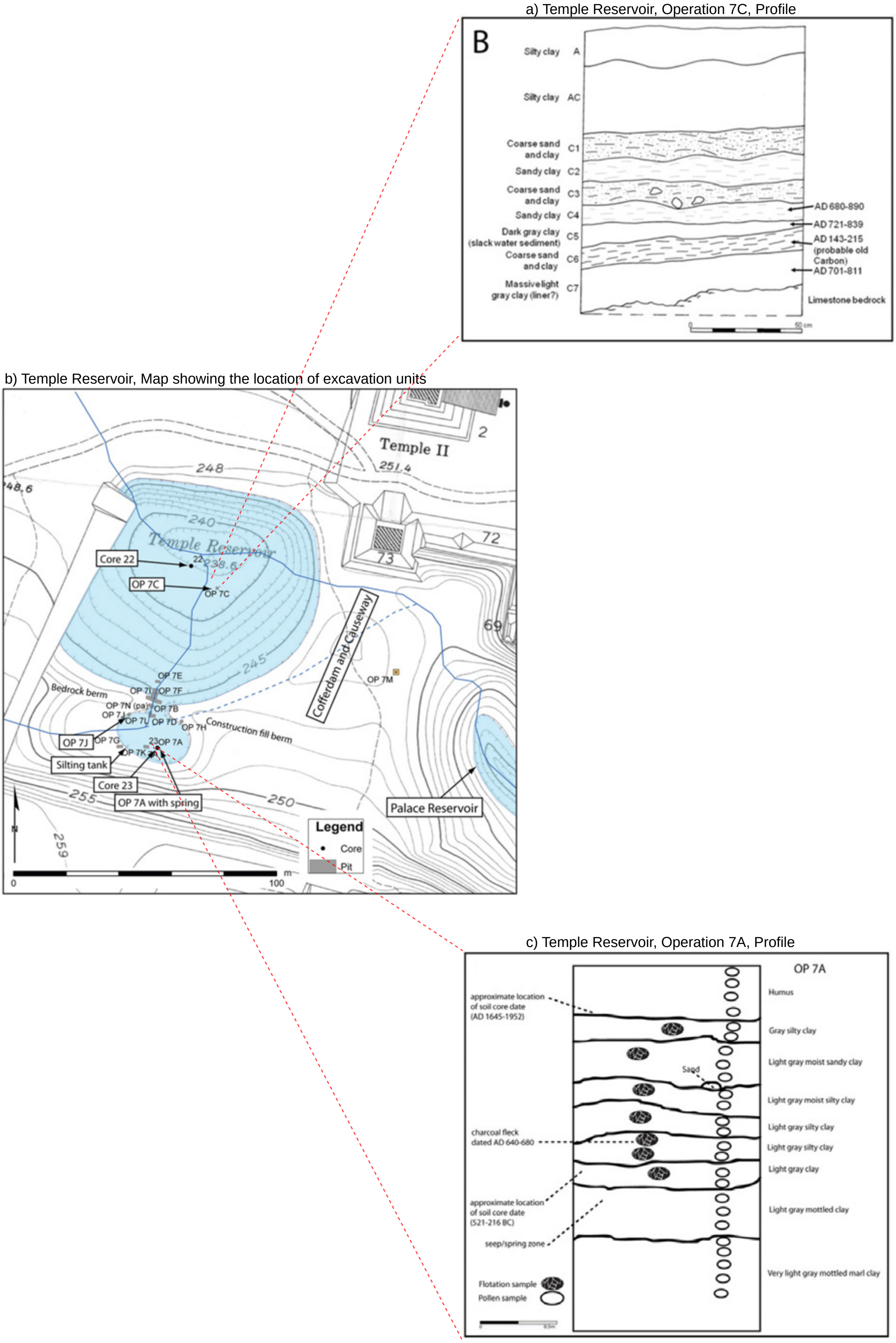
[150] The results of the investigation of the Perdido Reservoir were not published.



a) Temple Reservoir, Operation 7C, Profile

b) Temple Reservoir, Map showing the location of excavation units

c) Temple Reservoir, Operation 7A, Profile

Figure 5.103: Tikal, Temple Reservoir, Location and profiles of excavations units (modified from Scarborough *et al.* 2012: Figure S3. Reproduced with kind permission of Vernon Scarborough and PNAS. Base map was originally published by Carr and Hazard 1961, Courtesy of the Penn Museum).

5.7.7.2.2 Palace Reservoir and Palace Dam

The Palace Reservoir was the largest reservoir on Tikal's hilltop (storage capacity: 74,631 m^3) and extended from the lower margins of the Temple Reservoir to the Palace causeway (Gallopin 1990; Scarborough *et al.* 2012: 12410; see Figure 5.104a).

During the excavations, Scarborough *et al.* (2012: 12410) documented a small basal channel that could be identified as the remains of the same streambed that had already been documented further upstream (see above) (see Figures 5.104a and 5.104b). The bedrock channel, which was stratigraphically dated to the Middle or Late Preclassic (358-555 B.C), was constructed by altering a limestone bench on the immediate northern bank (see Figure 5.104a; Scarborough *et al.* 2012: 12411). Along the southern slope of the reservoir, Scarborough *et al.* (2015: 12411) documented a pavement of limestone slabs[151] (see Figure 5.104d), "which served to impede seepage". Based on these results, Scarborough *et al.* (2012: 12412) speculated that the location of the Palace Reservoir had originally been marked by a narrow stream, which was quarried and subsequently dammed.

Excavations in the Palace Dam suggested that an earlier dam construction had been cut directly into the bedrock and was later followed by the construction of a massive wall of earth, which was then sealed with veneer stones (Scarborough *et al.* 2012: 12411). Gaps between these "veneer stones" formed vertically stacked openings with widths of 30 cm and were interpreted as sluice gates (see Figure 5.104c).

By the end of the Late Classic Period, the dam fell into disrepair and ultimately collapsed (Scarborough *et al.* 2012: 12411). According to Scarborough *et al.* (2012: 12411), the Palace Dam was constructed during the Classic Period in order to enable the storage of the large quantities of water directed from the numerous sealed plaster surfaces of the central precinct. Due to its sloping basal dimensions of 80 x 60 x 10 m, and a conservative volume of approximately 14,000 m^3, Scarborough *et al.* (2012: 12411) defined this gravity dam as the largest hydraulic architectural feature in the Maya area.[152] Because the carved-out streambed featured a narrow course, Scarborough *et al.* (2012: 12411) surmised that some portions of the original escarpment had been left in place in order to form part of the dam (see Figure 5.104a).

As Scarborough *et al.* (2012: 12411) noted, the isolation of the elevated Temple Reservoir from the larger Palace Reservoir suggests that the dam dividing these two features served as a coffer dam when the reservoir would have been dredged or when the lower reservoir was in need of repair. Furthermore, Scarborough *et al.* (2012: 12411) assumed that after the completion of routine maintenance procedures, the stored water from the Temple and Palace reservoirs would have been released into the low-lying Hidden Reservoir in a controlled fashion before it would have dropped a total of 45 m into the Tikal Reservoir located at the bajo margins (Scarborough and Gallopin 1991, see Figure 5.103). Due to the apparent integration of the Palace Reservoir with the more elevated reservoirs, Scarborough *et al.* (2012: 12411) are convinced that it would have been constructed together with the overall system during the Late Classic Period.

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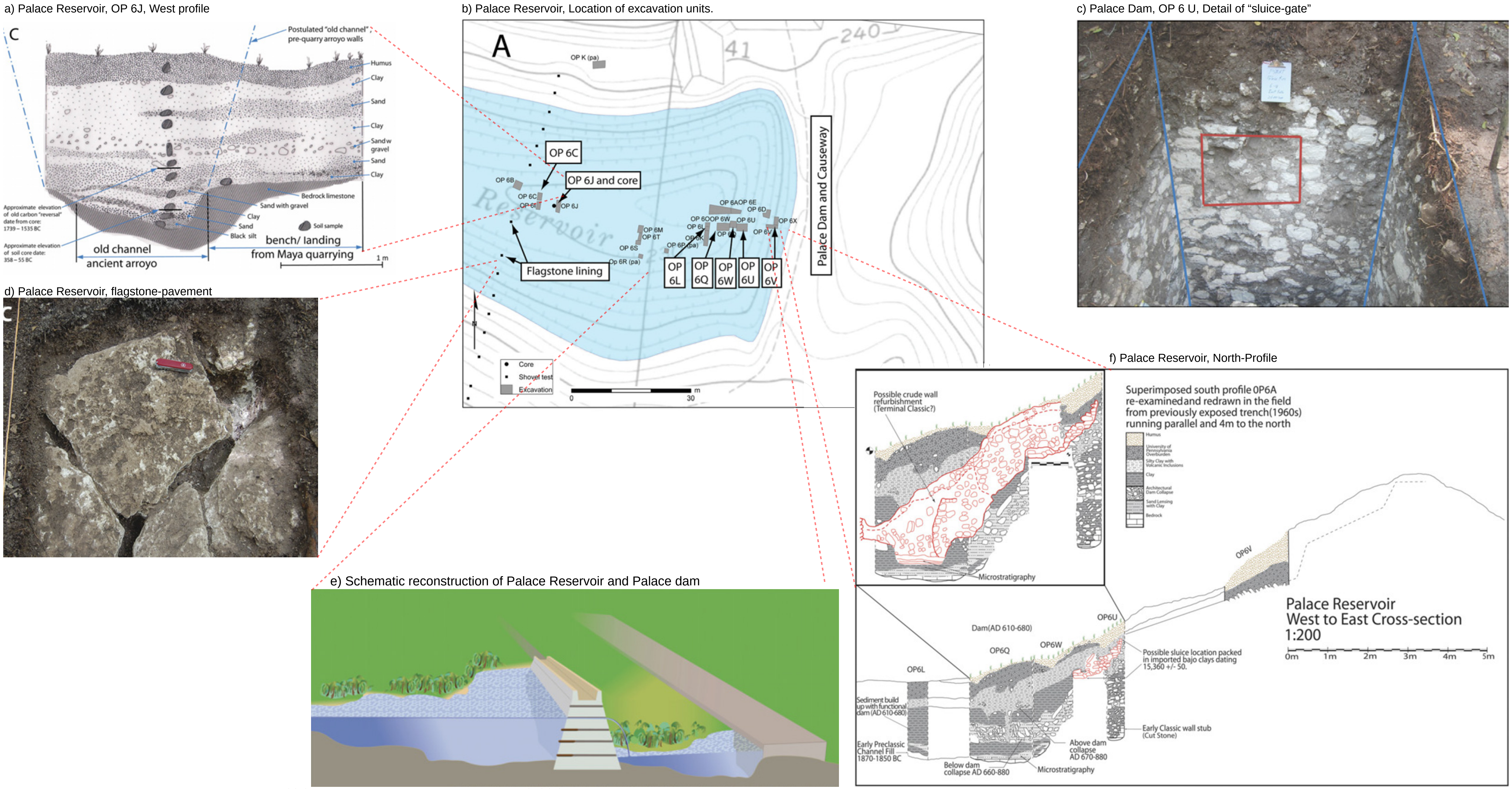
[151] According to Scarborough *et al.* (2012: 12411), this modification can be associated with a Late Classic expansion of the Reservoir.

[152] According to Scarborough *et al.* (2012: 12411), the only larger hydraulic feature in Mesoamerica is the Early Classic/Late Classic Purrón Dam in the Tehuacán Valley of Mexico (Aivulasit *et al.* 2010).


a) Palace Reservoir, OP 6J, West profile

b) Palace Reservoir, Location of excavation units.

c) Palace Dam, OP 6 U, Detail of "sluice-gate"

d) Palace Reservoir, flagstone-pavement

e) Schematic reconstruction of Palace Reservoir and Palace dam

f) Palace Reservoir, North-Profile

Figure 5.104: Tikal, Palace Reservoir and Palace Dam. (a) (source: Scarborough *et al.* 2012: Figure S4c); (b) (source: Scarborough *et al.* 2012: Figure S4a. Reproduced with kind permission of Vernon Scarborough and PNAS. Base map was originally published by Carr and Hazard 1961, Courtesy of the Penn Museum); (c) (source: Scarborough *et al.* 2012: Figure S6a); (d) (source: Scarborough *et al.* 2012: Figure 4c); (e) (source: Scarborough *et al.* 2012: Figure 4a); (f) (source: Scarborough *et al.* 2012: Figure S5). Reproduced with kind permission of Vernon Scarborough and PNAS.

5.7.7.2.3 Corriental Reservoir

The Corriental Reservoir was located south of the reservoir chain (Temple Reservoir, Palace Reservoir, Hidden Reservoir and Tikal Reservoir) and is located along the margin of a bajo (Gallopin 1991; Scarborough *et al.* 12411; see Figure 5.105a). It features a storage capacity of approximately 57,559 m^3 and was fed by the runoff from five different drainages: the northwest drainage (1), western drainage (2), southwest drainage (3), arroyo drainage (4), and northeastern drainage (5) (see Figure 5.105a). In the east, the reservoir was bordered by a berm with a height of 4-7 m, which featured two inlet gates and one complex outlet gate (Scarborough *et al.* 2012: 12411; see Figure 5.105d). Excavations revealed that the northwestern gate was built between AD 400 and 700 [153] and served to direct, divert and contain water (Scarborough *et al.* 2012: 12411; Tankersley *et al.* 2011; see Figure 5.105a).

On the eastern side of the berm, Scarborough *et al.* (2012: 12411) documented a feature that they interpreted as a “switching station”,[154] which would have been built in the Late Preclassic. According to their hypothesis, this feature would have enabled the diversion of water either into the northeastern drainage, the incipient reservoir, or directly into the arroyo corriental (Scarborough *et al.* 2012: 12411). Furthermore, they postulate the existence of a Late Classic dam (see Figure 5.105a). Unfortunately, Scarborough *et al.* (2012: 12411) did not provide further graphic documentation or an explanation on the way in which these “switching stations” operate. According to Scarborough *et al.* (2012: 12412), the eastern inlet gate and the eastern outlet gate[155] acted as a seasonally adjustable switching station or control point for one of the inflowing catchment flows that filled the Corriental Reservoir (see Figure 5.105d). Above the inlet gate, Scarborough *et al.* (2012: 12412) documented a 2 m deep canal dating to the Late Preclassic. This canal was cut into the hard bedrock and directed the inflowing water into a shallow and early version of the tank (Scarborough *et al.* 2012: 12412, see Figure 5.104c).

Based on these observations, Scarborough *et al.* (2012: 12412) assumed that the eastern gate would have been used to release water during the dry season by dismantling the earthen dam causing water to flow out of the tank instead of in. After the Late Preclassic, precipitation increased (Dunning *et al.* 2012) and spurred the inhabitants to carefully infill the deep, V-shaped canal (Op. 1 G) and seal it with a dense composite of crushed limestone cement similar to the plaza floor, thus preventing the redirection of water into the tank (Scarborough *et al.* 2012: 12412). Scarborough *et al.* (2012: 12412) suggested that a plug or dam (see Figure 5.105d) may have been added to close the encircling berm at the former east gate switching station. However, this plug or dam has since eroded.[156]

Theories on the historical development of Tikal’s hydraulic system

According to Lentz *et al.* (2015b: 281), the settling of Tikal began during the Middle Preclassic. Fialko (1999: 685) reasoned that the hydraulic system evolved simultaneously with the drained fields in the surrounding bajo communities. Scarborough *et al.* (2012: 12408) speculated that the early colonization of Tikal’s hilltop was triggered by the existence of springs at the head end of a natural ravine that the settlers would have widened and dammed (Fialko 1999: 685). However, the construction of paved plazas would have prevented the normal recharging of the springs that had originally attracted colonists. According to Scarborough *et al.* (2012: 12408), this development would have required the construction of modified reservoirs. Fialko (1999: 685) argued that these reservoirs were originally no more than byproduct of stone quarries.

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[153] See Scarborough *et al.* (2012: core 17, Table S 1).

[154] According to Scarborough *et al.* (2012: 12411) the maps of Carr and Hazard (1961:41) also suggest the existence of another switching station (South Gate) that would have served to direct water around the reservoir.

[155] According to Scarborough *et al.* (2012: 12412), excavations at the East Gate revealed an elevated drop from the bottom of the V-shaped canal into the upper edge of the Late Preclassic tank of 30 cm. The drop from this East Gate lip or elevated margin to the basal Late Preclassic reservoir depths was a least 1 m.

[156] In this context, Scarborough *et al.* (2012: 12412) stressed out the work of Carr and Hazard (1961) who noted the incidence of construction found below the East Gate drainage and suggested that the plug had collapsed after the abandonment of the site.

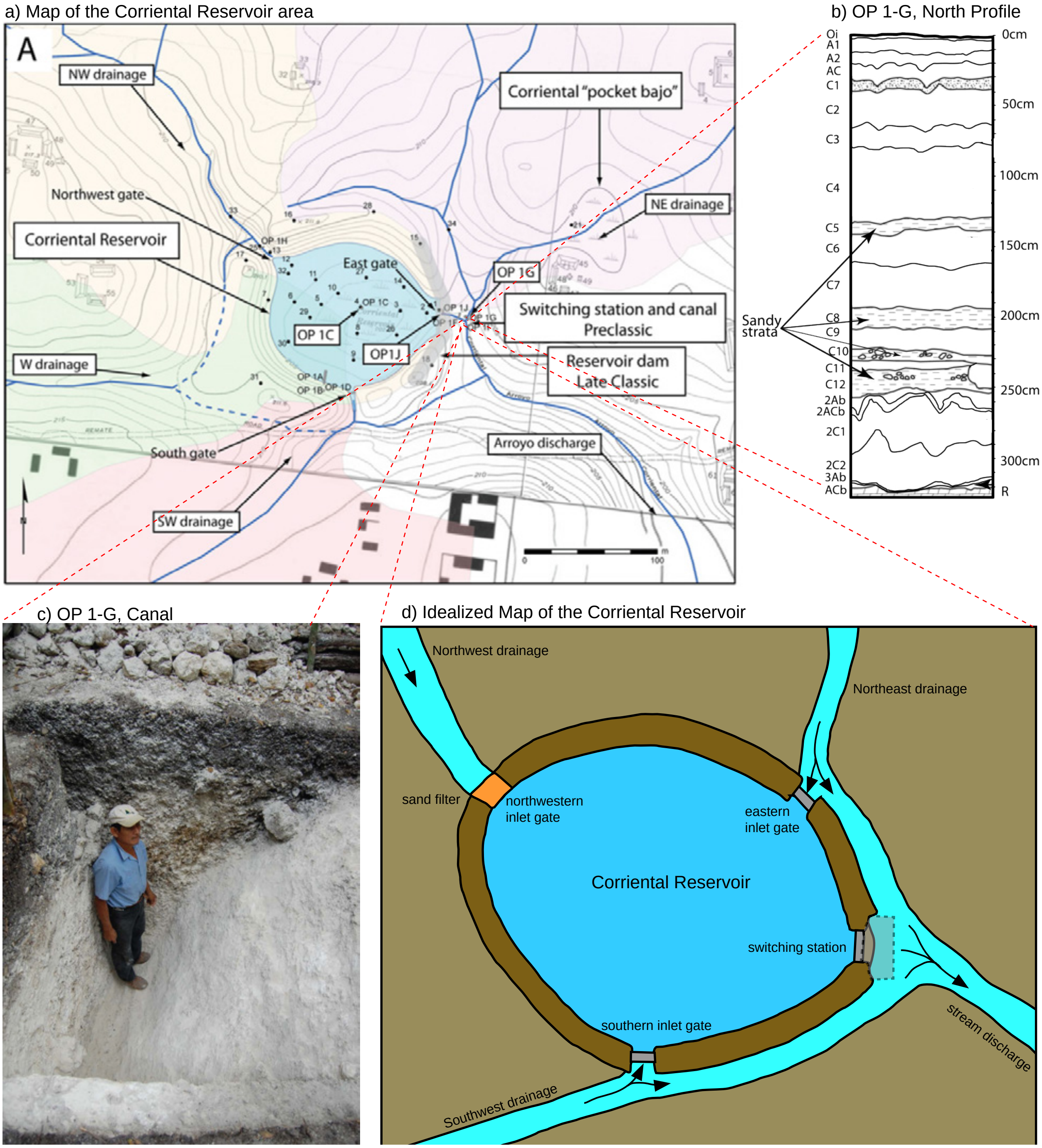

Figure 5.105: Tikal, Map of the Corriental Reservoir and associated hydraulic features. (a) (source: Scarborough *et al.* 2012: Figure S 7. Reproduced with kind permission of Vernon Scarborough and PNAS. Base map was originally published by Carr and Hazard 1961, Courtesy of the Penn Museum); (b) (source: Grazioso Sierra and Scarborough 2013: Figure 4. Reproduced with kind permission of Liwy Grazioso Sierra); (c) (source: Scarborough *et al.* 2012: Figure 5b. Reproduced with kind permission of Vernon Scarborough and PNAS); (d) (modified from Dunning *et al.* 2013: Figure 2). Reproduced with kind permission of Nicholas P. Dunning.

Finally, this strategy would have concluded in the creation of a modified watershed arranged in concentric rings.[157] According to Scarborough *et al.* (2012: 12412), the first large-scale and focused labor investments into Tikal's hydraulic system occurred during the Late Preclassic Period. The more intensified extension of the hydraulic system would have been triggered by the demographic pressure and the intense drought periods of the Late Preclassic (see Chapter 4.3; Scarborough *et al.* 2012: 12412).

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[157] It should be noted that Fialko neither published a map of these concentric rings, nor did she explain this theory in greater detail.

During the Classic Period, the continuing population growth would have required the construction of even larger water storage tanks in the site's central precinct that would have been filled by directed seasonal runoff (Scarborough *et al.* 2012: 12408). Scarborough *et al.* (2012: 12412) reasoned that the Late Classic constructions were not only focused on the maximization of stored water, but also on the improvement of the quality of stored water. Due to these innovations, the hydraulic system was cleverly adapted to the biophysical conditions and adaptively engineered to the evolving needs of a growing population for more than 1000 years (Scarborough *et al.* 2012: 12408). In fact, it would have been resilient and adaptable to natural and cultural forces until about 900 AD (Scarborough *et al.* 2012: 12412). Akpinar (2011: 28) reasoned that the key to Tikal's success would have been "a good interplay between intensive centralization and dissemination of settlements in its hinterlands".[158] Scarborough and Gallopin (1991: 23) estimated that the Central Acropolis of Tikal, with a surface of 62 hectares would have been able to catch 900,000 m^3 of rainwater annually, and that the reservoirs of the central compound would have had a total storage capacity of 100,000-250,000 m^3 (Carr and Hazard 1961: 12-15; Scarborough 2003a: 51). Lentz *et al.* (2015b: 282) suggested that the expansion of the urban infrastructure would have made Tikal's inhabitants even more dependent on the amount of rainfall and their artificially modified watersheds.

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[158] In this respect, Silverstein *et al.* (2009) criticized that the current models on the functionality of Tikal's hydraulic system still excluded the hinterland despite the fact that Puleston (1983) had repeatedly documented direct connections to different residential areas in the hinterland. According to Puleston (1973: 92), these hinterland aguadas were located in small residential groups, forming miniature models of the central acropolis and positioned in such a way that they would automatically be fed by runoff water from plazas and natural drainages.

5.7.8 Hydraulic System of Kinal

The site of Kinal is located in the northeastern Petén on top of an elongated limestone hillcrest between the Bajo de Azúcar in the southwest and an unnamed bajo in the northwest (Scarborough *et al.* 1994: 198; see Figure 5.106). According to Scarborough *et al.* (1994: 198), this geographic location provided the settlement with a good defensive position. The hillcrest's natural drainage runs from the southeast towards the north. As Figure 5.106 indicates, the natural landscape does not exhibit springs or other permanent water sources. The closest source of water is the Río Azul located 7.5 km southwest of the site (Scarborough *et al.* 1994: 98; see Figure 5.106). In Scarborough *et al.*'s (1994: 196) view, the hydraulic features can be described as a smaller version of Tikal's hydraulic system as the paved surfaces of the central precinct served as waterproof catchment areas. Over the course of their investigations, Scarborough *et al.* (1994: 196) documented four well-defined drainage systems, of which one (Kinal West drainage) was mapped and studied by means of several test pits (see Figures 5.107). The Kinal West drainage begins at the Plaza de Monos, which represents the lowermost point of the central precinct and consequently collected the majority of runoff from the site's hilltop (Scarborough *et al.* 1994 101; see Figure 5.107). By means of a shallow 25-35 cm deep canal cut directly into the limestone bedrock, water was directed towards the northeastern corner of the Plaza de Monos (Scarborough *et al.* 1994: 101). In this corner, the pre-Hispanic inhabitants had installed a drain that ended in a well-defined drainage canal with a length of 300 meters (Scarborough *et al.* 1994: 197; see Figures 5.107 and 5.108a). This drainage canal ran along the side of a steep slope of the limestone bedrock and decreased more than 25 m in elevation before flowing into a large reservoir (Scarborough *et al.* 1994: 101; see Figures 5.108a and 5.108c).

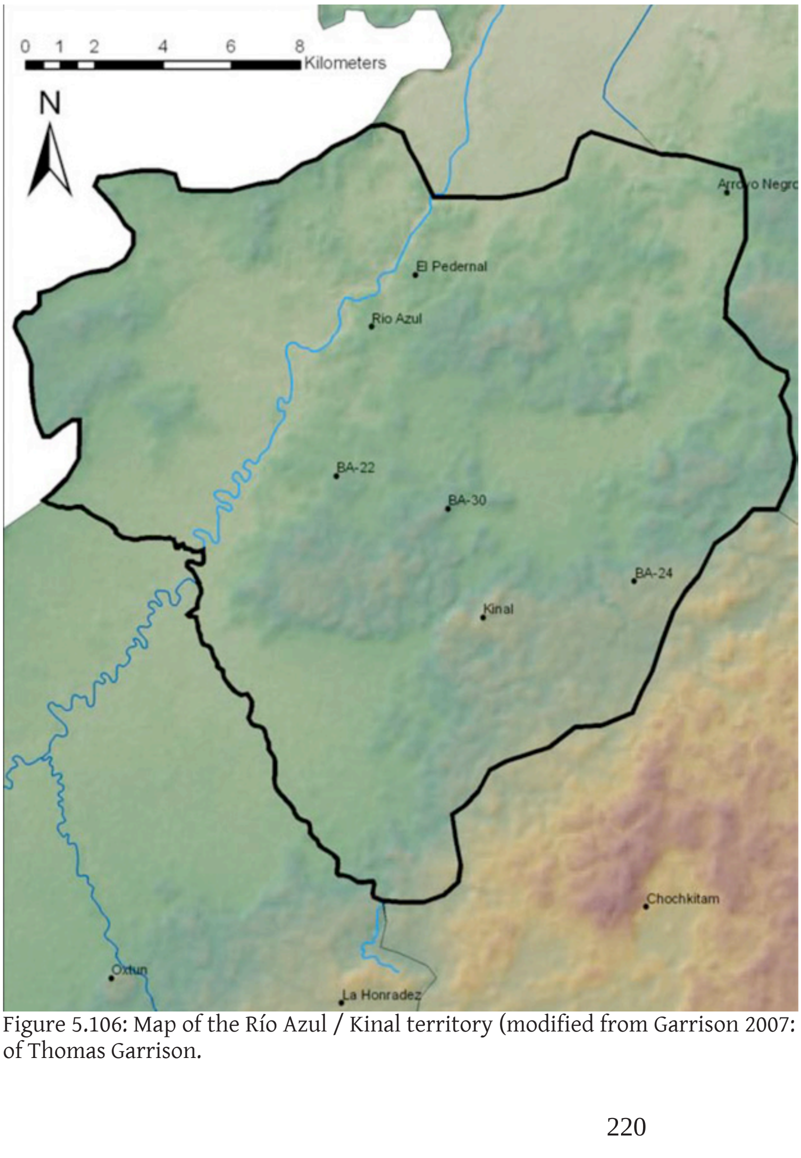

Figure 5.106: Map of the Río Azul / Kinal territory (modified from Garrison 2007: Figure 6.6). Reproduced with kind permission of Thomas Garrison.

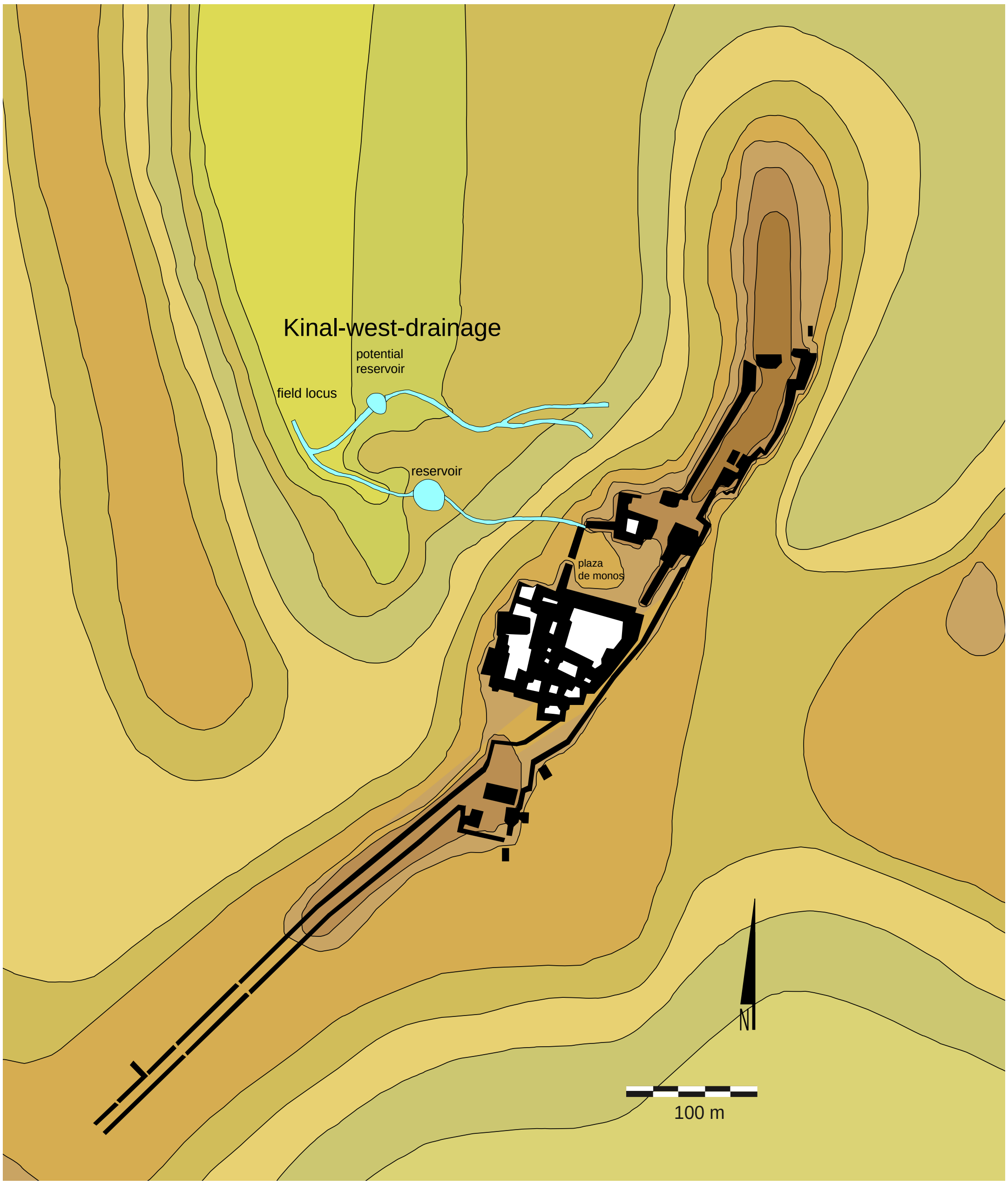

Figure 5.107: Kinal, Map of the site and its hydraulic system (redrawn after Scarborough *et al.* 1994: Figure 2). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.

Due to the intense inclination of this canal, the pre-Hispanic inhabitants installed several check-dam-terraces[159] throughout the slope, which reduced the risk of increased slope erosion (Scarborough *et al.* 1994: 197; see Figures 5.108a and 5.108c). In an excavation unit placed immediately above the reservoir, Scarborough *et al.* (1994: 196) documented a "diversion weir" (Sub-operations H, I, J, K, and L) that consisted of an 8 m long and 1 m wide wall composed of flat limestone blocks. This diversion weir (see Figure 5.108b) directed the water into a poorly preserved silting tank, which served as a filter[160] for refuse particles that were washed in from the central precinct due to the steep gradient of the drainage canal. According to Scarborough *et al.*'s (1994: 197) interpretation, this feature kept refuse particles out of the actual reservoir, so that washed-in silt would have to be removed less frequently (Matheny 1978: 204).

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[159] At the drainage canal's end, one of these check-dams was actually studied with an excavation trench (Sub-operation Q). The documentation showed that it consisted of five blocks, which had been set into the middle of the canal (Scarborough *et al.* 1994: 101).

[160] Scarborough *et al.* (1994: 102) considered the documentation of extensive gravel masses as evidence of a filter function.

After the water from drainage canal had passed through this filtering device, it poured into a well-defined reservoir with a diameter of 60 meters and a depth of 2 meters, which originally may have been able to store 1,000 m^3 of water (Scarborough *et al.* 1994: 102). The reservoir's border was surrounded by a circular wall that was presumably built in order to increase the reservoir's storage capacity (Scarborough *et al.* 1994: 102). The eastern rim of the reservoir wall (opposite the silting tank) featured a V-shaped drain or spillway, which reached down to the bottom of the reservoir and consequently would have enabled the reservoir to be completely emptied (Scarborough *et al.* 1994: 102). Because an agricultural field was documented 150 m to the northwest of the reservoir, Scarborough *et al.* (1994: 102) concluded that the reservoir was not used for storing potable water. Instead, the documented opening (spillway) would have facilitated the release of water during the dry season in order to irrigate the fields located downslope (Scarborough *et al.* 1994: 196). Unfortunately, no graphic documentation material of the described spillway has been published.[161]

5.7.9 Hydraulic system in the core of La Milpa

La Milpa is situated 25 km to the east of Kinal. The earliest settlers built the city on a natural hill, 180 m above sea level (Scarborough *et al.* 1995: 100). Around 700 AD, La Milpa accommodated approximately 50,000 inhabitants (Chmilar 2005: 21).[162] Between AD 700 and 800, the city was enlarged through monumental building programs (Dunning and Beach 2002: 196). According to Tourtellot *et al.* (1995: 9), this population increase might have resulted both from a migration out of the neighboring Petén and from a local population increase (Dunning and Beach 2002: 196). Between AD 800 and 830, elite-activity at La Milpa and other sites ceased (Hammond *et al.* 1998) and rapid depopulation of the entire area followed (Hammond and Tourtellot 2004; Weiss-Krejci *et al.* n.d.). According to Hammond and Bobo (1994), La Milpa was sporadically visited during the Postclassic and the colonial period (Weiss-Krejci *et al.* n.d.). The site does not exhibit any permanent water sources and its hinterland was used for cultivation with horticulture and terraces. The population occupied not only the site core, but the surrounding area in a radius of 3-5 km (Tourtellot *et al.* 1996, 2003a).[163] Nevertheless, the hinterland was less densely populated and was presumably used for cultivation, which enabled the sufficient supply of food for the site center (Tourtellot *et al.* 2003a: 40).

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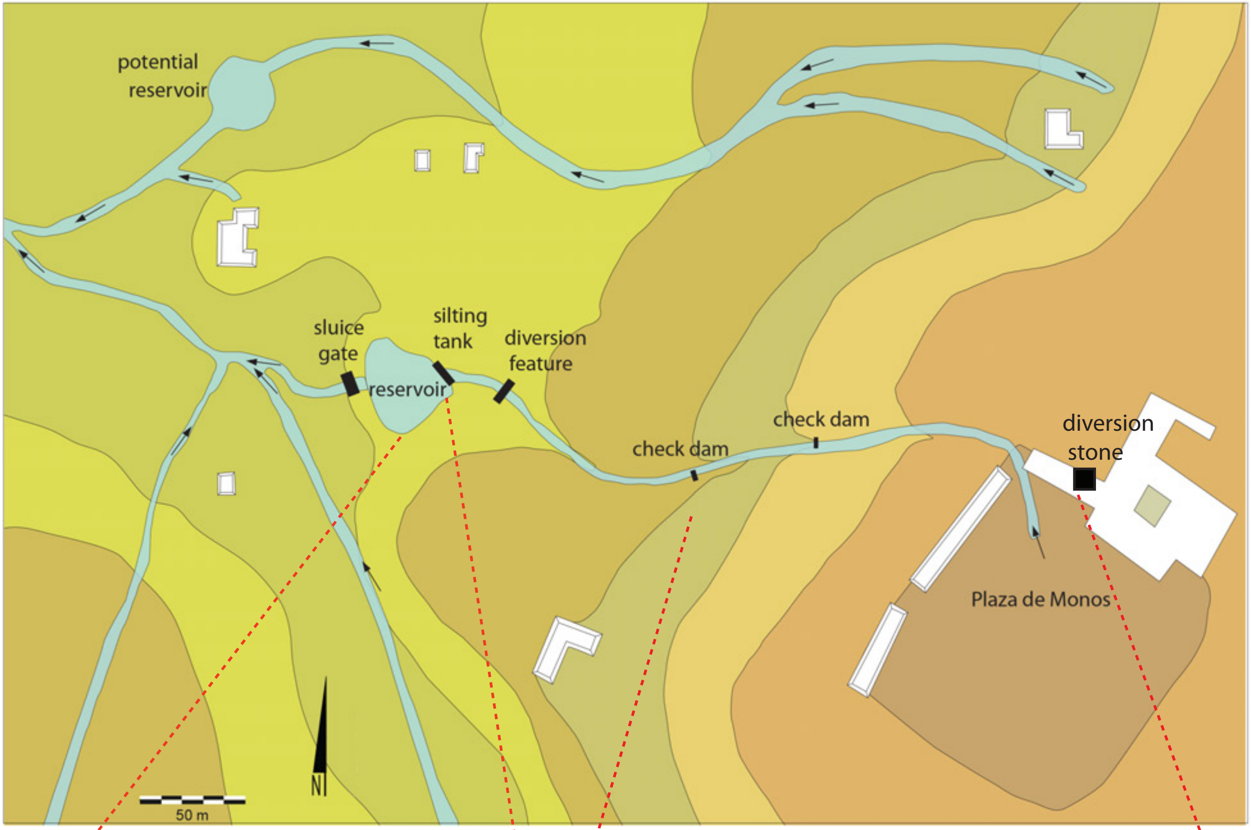
[161] In addition to the Kinal West reservoir, Scarborough et al. (1994) identified a similar artificial drainage at a distance of 150 m, which was not studied in greater detail. Culbert *et al.* (1991: 122) also documented and described an aguada near Kinal, which was fed with water through various canals. Although the description of this system shares some similarities with the system described by Scarborough et al. (1994), it does not seem to represent the same feature (see Culbert *et al.* 1991: 122). This also becomes clear in the fact that Scarborough (1994) did not refer to the feature described by Culbert *et al.* (1991). Culbert *et al.* (1991: 122) did not provide more precise indications on the exact geographic location of this feature nor was it described by other authors.

[162] According to Dunning and Beach (2000: 196), settlement surveys and excavations in La Milpa resulted in the detection of extremely high settlement densities (Tourtellot *et al.* 1994).

[163] According to Chmilar (2005: 21), the residential areas of La Milpa extend for more than 1 km towards the east of Turtle Pond (3 km to the east of La Milpa's site center before the settlement density markedly drops.

a) Map of Kinal west drainage



b) Map of Kinal Reservoir

c) Gradient profile of Kinal west channel

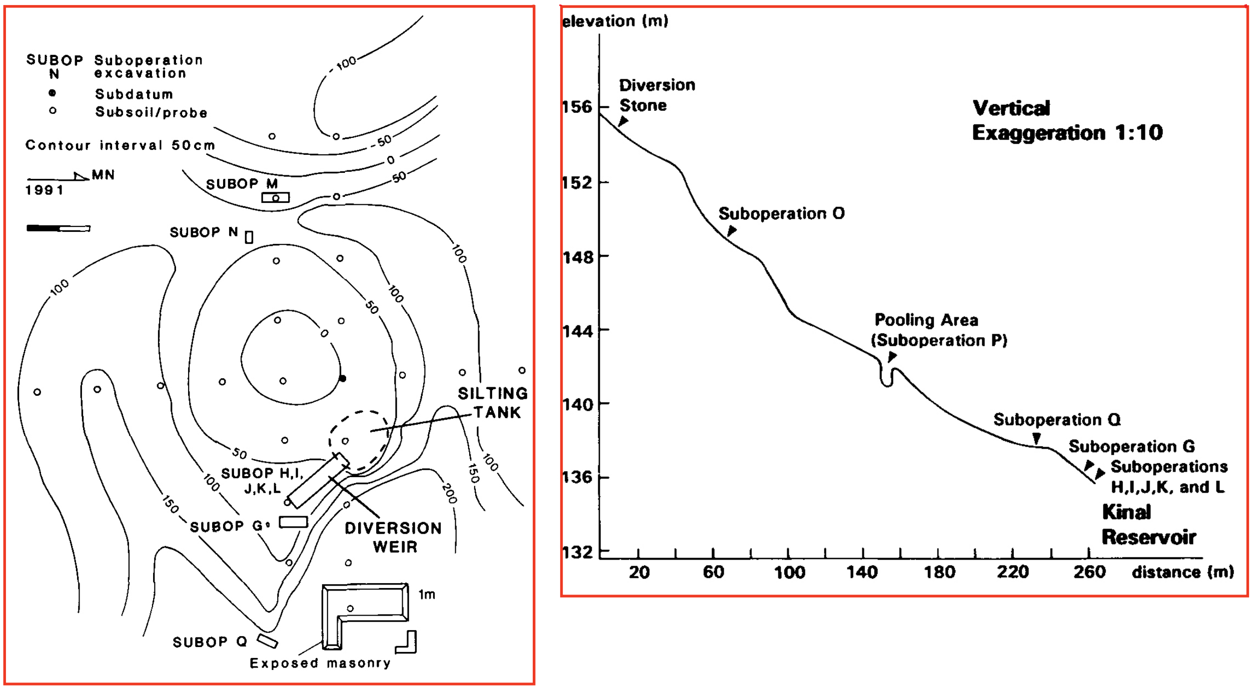


Figure 5.108: Kinal, Hydraulic features of the west drainage. (a) (redrawn after Scarborough *et al.* 1994: Figure 3); (b) (source: Scarborough *et al.* 1994: Figure 6); (c) (source: Scarborough *et al.* 1994: Figure 5). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.

5.7.9.1 Modified drainages in the site core

During their archaeological investigations in the site center, Scarborough *et al.* (1995: 115) documented hydraulic features that shared many similarities with the hydraulic systems in Kinal (see Chapter 5.7.8) and Tikal (see Chapter 5.7.7). In their view, this system evolved in two different construction periods. The first constructions and modifications of the watersheds were carried out during the Late Preclassic (Scarborough and Valdez 2003: 10). However, the majority of the hydraulic structures were built in the Late Classic (Scarborough *et al.* 1995: 115). Altogether, four main drainages were mapped, all of which originated in the site's central precinct:

Drainage 1 ran from the main plaza to the northeast and apparently drained into a bajo with an area of approximately 30 km^2 (Scarborough *et al.* 1995: 102; see Figure 5.109c). Along the course of the drainage canal, Scarborough *et al.* (1994: 195) identified and mapped 18 possible check-dam terraces that served to reduce the erosion of the slope sediments.

Drainage 2 led from the main plaza to the east (Scarborough *et al.* 1995:103). As it probably carried the majority of the main plaza's runoff, it was identified as the primary drainage. It was apparently connected to several other hydraulic features. From the northern end of Structure 9, a parapet wall extended out and operated as a diversion weir for the plaza's runoff (Scarborough *et al.* 1995: 103). Approximately 100 m to the west of this wall, a 17.5 m long, presumably Late Classic stone dam was located (Scarborough *et al.* 1995: 193; see Figures 5.109a and 5.109b). A profile trench indicated that builders had set stone blocks with diameters of 1.5 m vertically into a supporting matrix of marl and gravel fill in order to erect this dam (Scarborough 1994: 193; see Figure 5.109a). According to Scarborough *et al.* (1995: 103), this stone dam converted the area above it into a reservoir (Reservoir C). No spillways or sluice gates were identified along its perimeter (Scarborough *et al.* 1995: 105). Tourtellot *et al.* (1998) negate the existence of this Reservoir C, since, according to them, the documented "dam feature" is too short. Therefore, the depression would not stand out articulately enough in the topographic relief (Seefeld 2008: 80).

Drainage 3 is fed by the water stored in Reservoir A and flows to the south (Scarborough *et al.* 1995: 106; see Figure 5.109c). This 2 m deep and 4,230 m^2 reservoir features a drainage outlet in the form of a weakly pronounced earthen berm and a shallow, U-shaped canal with a width of 2.5 m and a depth of 70 cm, which had been directly cut into the limestone bedrock (Scarborough *et al.* 1995: 107; see Figure 5.109d). Twenty meters to the south of this feature, a well-preserved segment of the original drainage canal of Drainage 3 could be documented with a width of 1.6 m and a depth of 90 cm (Scarborough *et al.* 1995: 107). Seventy meters to the south of Reservoir A, Drainage 3 apparently splits into the Drainage 3a running towards the southwest and Drainage 3b running towards the south (see Figure 5.108b):

Drainage 3a drains into an area located in the southwest, which probably served as a field system, and then runs in the direction of the Far West drainage (see Figure 5.109c). Along the course of this drainage, two check-dam terraces were documented, each with a length of 5 m (Scarborough *et al.* 1995: 108). After Drainage 3b separates from Drainage 3a, it can be followed for another 270 m before it drains into the same cultivation area as Drainage 3a (see Figure 5.109c).[164] According to Scarborough *et al.* (1995: 109), this cultivated area had obviously been modified with drainage canals. Thus, the water stored within Reservoir A would have enabled controlled irrigation of the fields and could have resulted in additional harvests (Scarborough *et al.* 1995: 111).

Drainage 4 was studied in the lowest level of detail and begins at a reservoir with a depth of 5.2 m and an extension of 2,165 m^2 (Scarborough *et al.* 1995: 11; see Figure 5.109c). Although Scarborough *et al.* (1995: 11) admitted that they did not specifically know how the water from the reservoir might have been led into Drainage 4, they nevertheless reconstructed this process in a similar manner as in Drainage 3. Apparently, Drainage 4 also splits into two separate drainages: Drainage 4a flows towards the west and Drainage 4b flows towards the east (see Figure 5.109c; Scarborough *et al.* 1995: 111).

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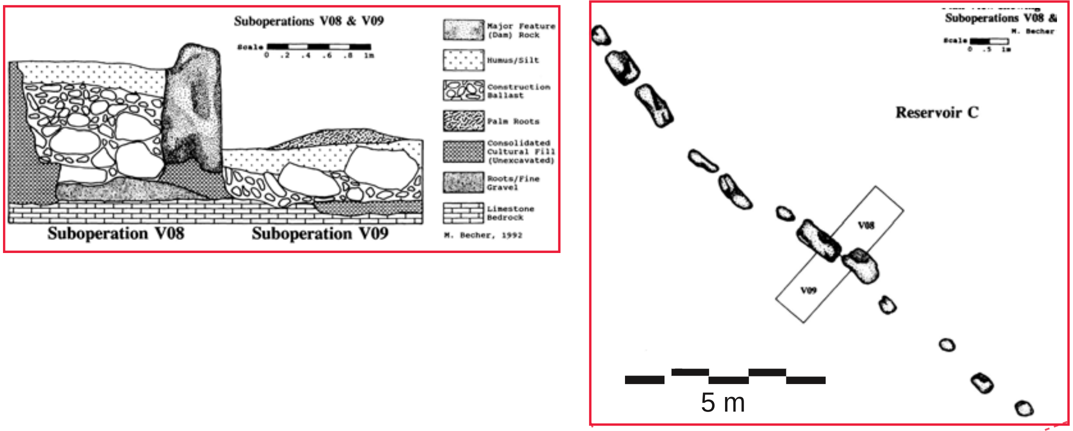
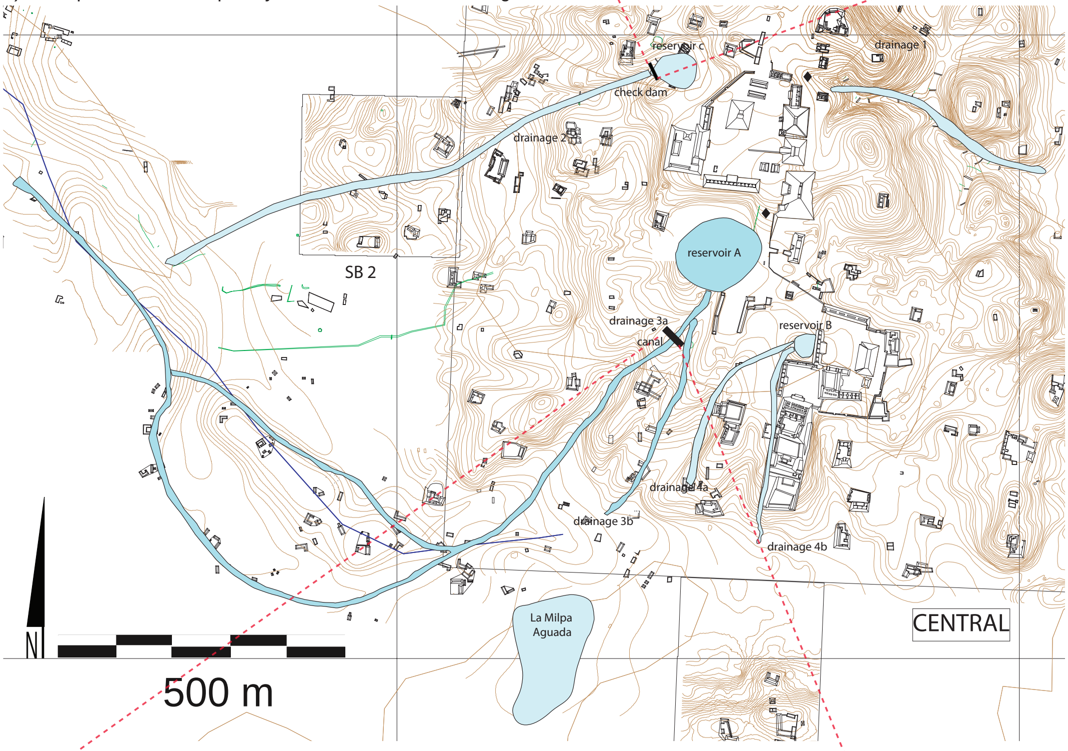
[164] According to Dunning (1992), the documented Phosphate-values measured in this area indicate an agricultural usage in pre-Hispanic times.



a) Profile of check-dam

b) Check-dam southwest of reservoir C, Planum

c) La Milpa, site core, Map of hydraulic features and drainages



d) North profile of drainage 3a canal

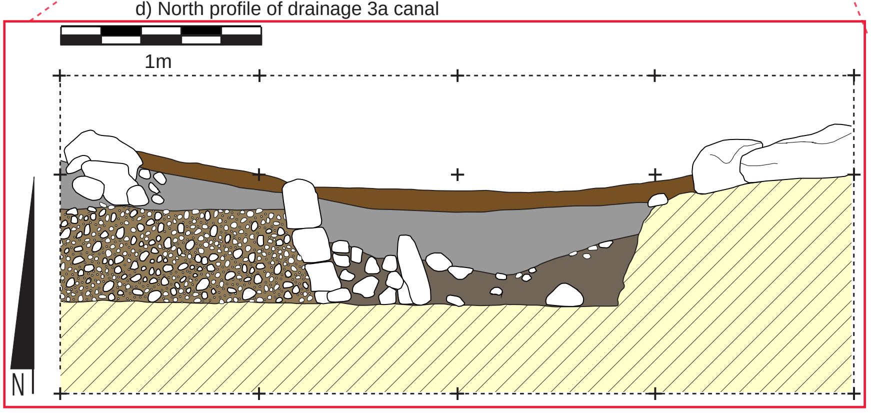


Figure 5.109: La Milpa, Hydraulic features in the site core. (a) (source: Scarborough *et al.* 1995: Figure 6); (b) (source: Scarborough *et al.* 1995: Figure 5. Reproduced with kind permission of Vernon Scarborough and Cambridge University Press); (c) (modified from Scarborough *et al.* 1995: Figure 2. Base Map was produced by Gair Tourtellot and digitized by Francisco Estrada Belli and Gair Tourtellot. Copyright Boston University La Milpa Archaeological Project, directed by Norman Hammond and Gair Tourtellot. http://www.bu.edu/lamilpa/ (d) (redrawn after Scarborough *et al.* 1995: Figure 10). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.

Tourtellot *et al.* (1998) criticized Scarborough *et al.*'s (1995) interpretation of the drainage's functionality since they could not observe a connection between Reservoir B and Drainage 4. Despite this expressed critique, Scarborough *et al.* (1995: 119) defended their interpretation by noting that subterranean drainage conduits would have been documented in other sites.[165] Without carrying out excavations to test this hypothesis, they postulated the potential existence of such a "subterranean drainage connection" between Reservoir B and Drainage 4 (Seefeld 2008: 81). Apart from these four main drainages, Scarborough *et al.* (1994: 112) also mapped the so-called "La Milpa Aguada" and the "Far West drainage" during the survey.

5.7.8.1 La Milpa Aguada

The La Milpa Aguada is located immediately to the south and southeast of La Milpa's central precinct and was apparently fed by Drainages 3 and 4 (see Figure 5.109c; Scarborough *et al.* 1995: 122). It may have attracted a pioneering population settling at La Milpa, which would have been a nucleated and modestly sized community in the Late Preclassic (400 BC-AD 250) (Hammond and Tourtellot 2003: 42; Martinez 2009; Scarborough *et al.* 1995: 112). In 1997, excavations showed that this reservoir was originally used as a quarry. Excavations also revealed a *buk'te'* (a stone-lined filtration well, see Chapter 5.6.4.2) with a stone-lined opening in its floor (Dunning and Scarborough 1997; Johnston 2004a: 280). The upper section of the well shaft consisted of compacted clay, while the lower portion was lined with stone (Johnston 2004: 279).[166] The excavation indicates that this well featured three different occupation phases (Johnston 2004: 280).

The lowermost, stone-lined well was used during the Early and Late Classic (AD 250-700) (Johnston 2004a: 280). In a later period, the well fell into disuse before it was opened again during the Terminal Classic (AD 700-900) and consolidated by lining it with two courses of stone (Dunning *et al.* 1999; Johnston 2004a: 280).

To the southwest of the La Milpa Aguada, Scarborough *et al.* (1995: 114) documented the Far West Drainage that drains into the nearby Far West Bajo. According to Scarborough *et al.* (1995: 114), the Far West Drainage provided a connection between the controlled reservoirs of the more elevated site core and the less elevated bajos.

In summary, Scarborough *et al.* (1995: 115) describe the hydraulic system of La Milpa's site center as an "artificial watershed" in which different hydraulic features such as reservoirs, canals, and diversion weirs were combined for the irrigation of fields, the storage of water and the control of erosion during the rainy season (Seefeld 2008: 82). In later surveys of La Milpa's settlement landscape, Dunning and Beach (2000: 196) also documented a number of cross-channel terraces, footslope terraces and box terraces that, according to them, were among the best examples they had yet seen in the Maya Lowlands. Dunning and Beach (2000: 197) suggested that the pre-Hispanic inhabitants tried to protect the remaining soils during the Terminal Classic and to save the slopes that had already eroded.

Tourtellot *et al.* (2003a: 48), on the other hand, argued that the reservoirs documented in La Milpa would have been too small for agricultural irrigation or to supply the substantial population inhabiting the site (Rose 2000). In their view, cultivation would not have been practiced in the center of La Milpa. Instead, the entire society would have been specialized on highland resources (Tourtellot *et al.* 2003a: 50). They assert that members of the elite and the inhabitants of the central precinct might have depended on the production of peasants living in La Milpa's hinterland, which would have supplied the center with food and other forest products (Tourtellot *et al.* 2003a: 48).

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[165] Regrettably they provide no hints, which sites they referred to. However, it seems probable that they referred to the aqueducts documented in the hydraulic system of Palenque (see Chapter 5.8.3).

[166] As Johnston (2004b: 280) noted, the stone lining consisted of 6 stone courses.

Following Tourtellot *et al.*'s (2003a) argument, Brewer (2007: 10) and Chmilar (2005: 21) are convinced that the reservoirs of La Milpa's city center were too small to support smaller hinterland communities near its borders. As a result, the hinterland inhabitants would have modified aguadas such as the Turtle Pond Aguada (Chmilar 2005; see Chapter 5.6.4.3.8.1.2), or small depressions such as the Medicinal Trail depression (5.6.4.3.8.1.1) in order to support the population in the immediate vicinity.

5.7.10 Hydraulic System of Caracol

Caracol is located on a high ridge of the Vaca Plateau of Belize, a karst region at an elevation between 450 and 650 m above sea level with an annual precipitation rate between 1,500 and 2,500 mm (Chase and Chase 1998: 61). The majority of Caracol's landscape is very diverse and features harsh contrasts between narrow canyons and steep slopes (Crandall 2009: 3). The settlement has an extension of approximately 200 km^2 and, within the 17 km^2 that were mapped in the 1990s, 4,400 single structures were mapped (Chase and Chase 1998: 61). Based on the excavation and survey data of the 1990s, Chase and Chase (1998: 61) determined that the occupation of Caracol began in 600 BC and ended around 1100 AD. Around 650 AD the city reached its demographic climax with a population of approximately 100,000 inhabitants (Chase and Chase 1998: 61). In 2009, a joint team carried out a LiDAR survey covering an area of 200 km^2, which enabled a groundbreaking and extensive representation of the entire settlement landscape of Caracol (Chase 2012: 27; Chase *et al.* 2011: 391; see Figure 5.110). This new data showed that the entire Vaca Plateau was "organized into a single urban system" (Chase *et al.* 2011: 391). Based on the new survey data, Chase *et al.* (2011: 395) calculated a maximum population of 115,000 in AD 650.

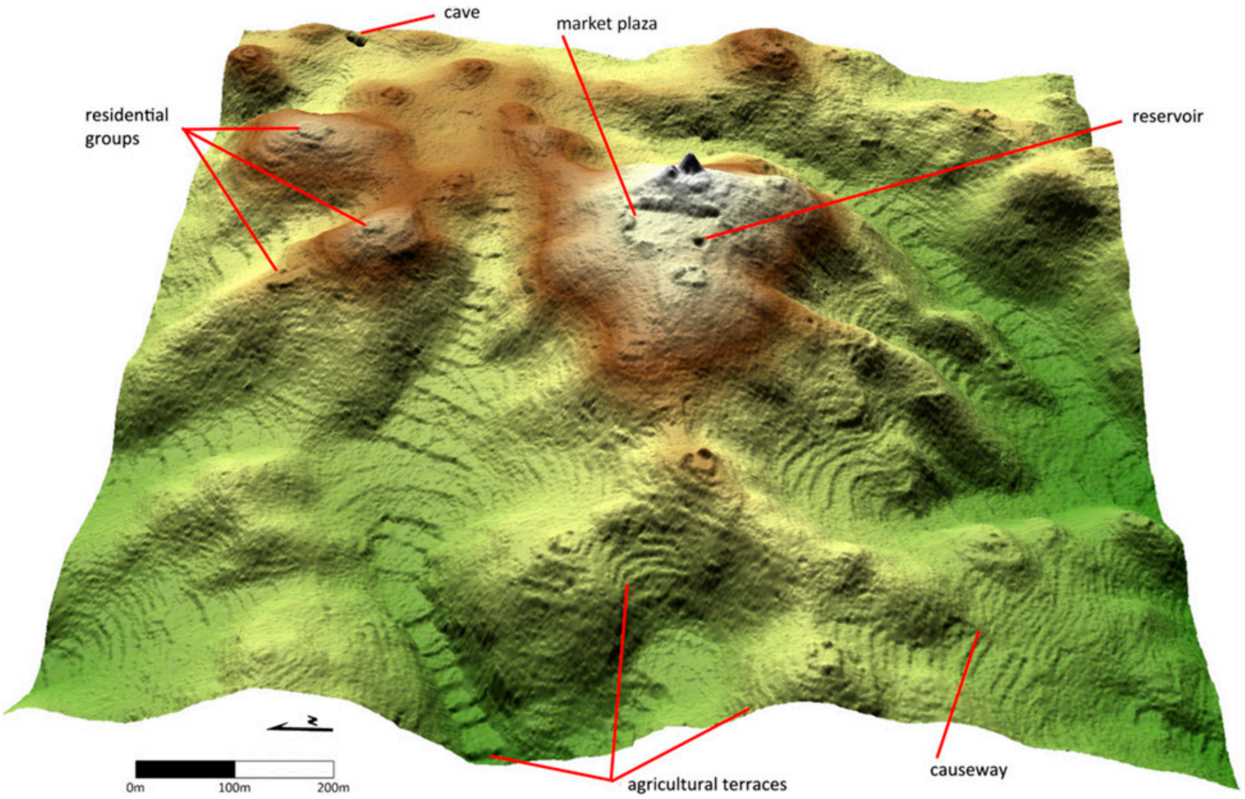

Figure 5.110: Caracol, Isometric landscape model based on LiDAR-data (Image: Courtesy of Arlen Chase, Caracol Archaeological Project).

As the natural landscape did not exhibit direct access to permanent sources of water[167], Caracol's pre-Hispanic inhabitants transformed the natural landscape into a complex network of residential areas intertwined with terraced acreages used for intensified production (see Chapter 5.3.4), market places and a system of artificial reservoirs (Chase and Chase 1998: 61; Crandall 2009: 3; see Figure 5.110). Furthermore, Caracol developed an extensive road system with a total length of over 90 km, which connected the different urban areas of Caracol (Chase and Chase 1998: 61).

Types of hydraulic features in Caracol

According to Crandall (2009: 34), the known and studied reservoirs of Caracol can be subdivided into two separate categories (Chase and Chase 1986, 1987; Jaeger 1991): Small reservoirs in residential areas outside of the center (1) and large reservoir within the center (2).

(1) Generally, the smaller reservoirs located in residential areas were connected to terrace systems (see Chapter 5.3.4). In Crandall's (2009: 40) view, their location and relative size indicate that they were constructed and maintained on a household level. Furthermore, the similar dimensions and forms led Crandall (2009: 34) to the conclusion that they had been used by the general public.

(2) The larger reservoirs of the center were constructed with the same techniques as the smaller reservoirs, but on a larger scale (Crandall 2009: 34).

Both the traditional surveys of the 1990s and the results of the LiDAR survey showed that the landscape of Caracol featured a very homogenous distribution of five reservoirs per square kilometer (Chase 1998: 70, 2012; Chase and Chase 1996a 1996b, 2007; Chase *et al.* 2011; Crandall 2009: 19). Based on the traditional surveys of the 1990s, Chase and Chase (1998: 79) observed that the reservoirs were mostly located in terrain above the fields, near the hilltop groups, a pattern interpreted as a means of reducing contamination by night soil and other dung (Chase and Chase 1998: 70). In a more recent study, Adrian Chase (2012: 6) analyzed the LiDAR data and visually identified reservoirs using different lighting schemes (Deveraus *et al.* 2008). During this process, Chase (2012: 23) confirmed Crandall's (2009: 40) observation that the largest reservoirs of the site were located in the center and near the terminal groups. However, Chase (2012: 23) also identified hundreds of smaller reservoirs located near plaza groups, households, and among terraced hillsides. Similar to Crandall (2009: 40), Chase (2012: 23) claimed that these smaller reservoirs would have belonged to local or extended families. In an initial visual inspection of the LiDAR data, Chase (2012: 47) identified 270 reservoirs. Through the development of special algorithms, Adrian Chase (2016: 892) later detected far more hydraulic features and calculated that the 200 km^2 area of Caracol's landscape would have originally been covered with 1,590 reservoirs (see Figure 5.111).

Despite this vast number of hydraulic features in Caracol's settlement landscape, our understanding of them is mostly confined to survey data because only some of the documented reservoirs were sampled (Chase 2012; Crandall 2009: 93; Jaeger 1991). However, Crandall (2009) carried out an intensive ground-thruthing of six reservoirs in the center of Caracol that included a natural aguada, Reservoir A, Reservoir B, Reservoir C,[168] Reservoir A 18 and Reservoir A 79 (see Figure 5.112).[169]

The natural aguada in the center lies to the east of Structure L 21, has an extension of 18.8 x 14.8 x 1.8 m[170] and carries water throughout the entire year (see Figure 5.112a). According to Crandall (2009: 34), its maximum storage capacity is 131 m^3.

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[167] The closest permanent water source is the Macal River, 20 km from Caracol's city center (Chase 2012: 20; Chase and Chase 1987; Crandall 2009: 3).

[168] Reservoirs A, B and C had already been described by Satterthwaite (1954) who ascribed them a connection to the central architecture of Caracol (Crandall 2009: 20).

[169] Except from the A 18 reservoir, all of these reservoirs had been published in earlier maps (Chase 1987:63; 2001). Furthermore, all of these reservoirs had already been ground-proofed prior to Crandall's investigations.

[170] As Crandall (2009: 23) did not have the possibility to determine the extension of these reservoirs in excavations, he highlight-

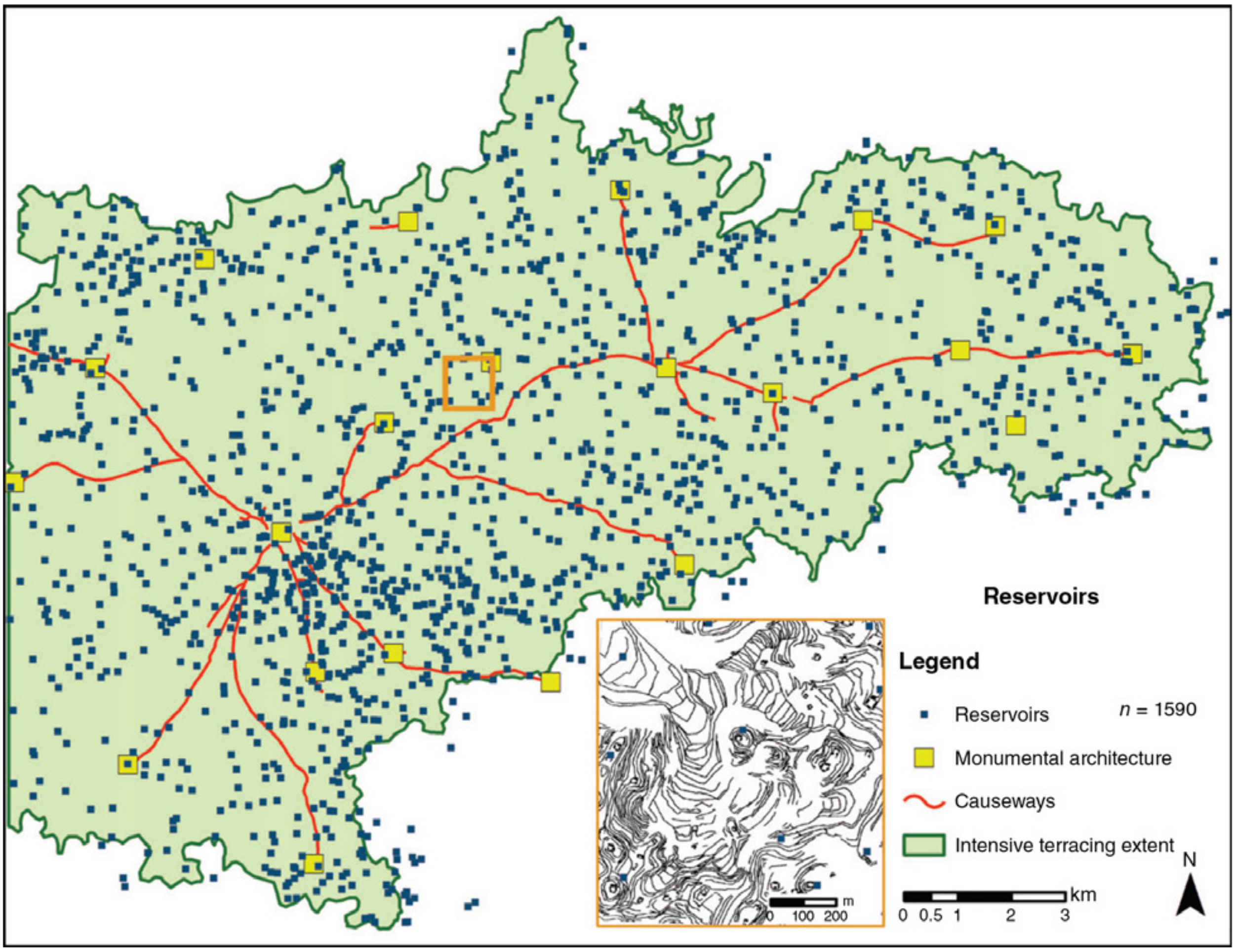

Figure 5.111: Caracol, Map of the 200 km² LiDAR survey area and the distribution of hydraulic features (source: Chase 2016: Figure 12. Reproduced with kind permission of Adrian S. Z. Chase).

The residential Reservoir A 79 is located in a small residential group, measures 6.9 x 5.5 m and is lined with cut stones (Crandall 2009: 27; see Figures 5.112a, 5.112b and 5.112c). Based on the ground-thruthing, Crandall (2009: 27) calculated a storage capacity of 10.9 m³ .[171] The residential Reservoir A 18 lies close to Structure A 18 at the base of a steep slope and is bordered by terraces and acreages, indicating that it might have been used for agricultural purposes (Crandall 2009: 28; see Figures 5.112a, 5.112f and 5.112h).[172] On the surface of the reservoir, which features an area of 6.8 x 3.4 m and a storage capacity of 15.7 m³, Crandall (2009: 28) observed a lining of cut and carefully assembled limestone blocks (see Figure 5.112h). In previous investigations, Jaeger (1991) had documented a number of similar reservoirs connected to terraces in Caracol (Crandall 2009: 29).

Reservoir A is a large and formally constructed reservoir that features a stone lining of carefully cut limestone blocks (Crandall 2009: 29; see Figures 5.112a, 5.112e, and 5.112g). Furthermore, traces of the limestone bedrock can be observed in today's landscape (see Figure 5.112i). This observation led Crandall (2009: 30) to the conclusion that this reservoir was constructed immediately on the already-exposed bedrock, or by extracting the existing bedrock to its current level. Crandall (2009: 30) also speculated that the pre-Hispanic Maya had modified the reservoir in order to reduce water seepage. Its storage capacity was 496.5 m³ and was fed by the runoff from Plaza B and the surrounding landscape (Crandall 2009: 30).[173]

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ed that his measurements should be considered "accurate but not precise".

[171] To the north of the epicenter, Chase and Chase (2005: Figure 8 and 9) documented another reservoir, which highly resembles reservoir A 79 (Crandall 2009: 28).

[172] As the modern population had still recently used this reservoir in order to irrigate their milpas, Crandall (2009: 28) assumed that the Classic Maya also would have used it for collecting water.

[173] Due to the exposure of the limestone-bedrock, reservoir B is the only of the central compound's reservoirs whose storage

Reservoir B is the largest artificial reservoir of Caracol and may have stored up to 6,402.4 m^3 (Crandall 2009: 31). Similar to Reservoir A, it is an oblong rectangular construction with sides lined with worked stones (see Figures 5.112j, 5.112k and 5.112l). On its southwestern corner, the reservoir was connected to a canal that directed the runoff from the area surrounding Structure A 13 into the interior. Due to its central location, the reservoir was most likely used for domestic purposes, and not for agricultural purposes (Crandall 2009: 32). The ^{14}C dates extracted from Healy *et al.* (1984: 401) indicated that Reservoir B was used from the Early Classic to the Terminal Classic (Crandall 2009: 31).

Reservoir C features a vertical cave entrance at its eastern shore, which may have been used as a drainage feature for overflowing water (Crandall 2009: 33). Due to the presence of worked stones at the cave opening's edge, Crandall (2009: 33) speculated that the pre-Hispanic Maya might have lined the cave entrance in order to consolidate it (see Figures 5.112a and 5.112d).

In order to determine the relevance of the studied reservoirs for Caracol's pre-Hispanic population, Crandall (2009: 36) employed Weiss-Krejci and Sabbas' (2002) evaporation model. Based on current precipitation rates, Crandall (2009: 36) calculated that in pre-Hispanic times, the amount of rainfall in Caracol would have been comparable to the La Milpa region (see Weiss-Krejci and Sabbas 2002). By assuming that evaporation rates and consumption rates were roughly the same as they are today, and by employing a daily water consumption of 4.8 liters, Crandall (2009: 36) calculated that even smaller reservoirs such as A 79 were able to support 11 persons throughout the entire year.

Thus, the hydraulic system of Caracol was mostly based on an interconnected system of terraces and reservoirs and, consequently, it was more comparable to the hydraulic system of Kinal than to that of Tikal (Crandall 2009: 37). However, while Kinal's hydraulic system was characterized by weir dams and check dams, Caracol's inhabitants controlled the flow of water by using the terraces to lead the water into natural drainages (Crandall 2009: 37). In this system, the inhabitants of small residential groups on the hilltops would have distributed the water, while the smaller reservoirs located below the terrace systems could have intercepted this water in order to use it for pot irrigation (Chase and Chase 1998: 71; Crandall 2009: 37; Denevan 1982: 187). Furthermore, Crandall (2009: 27) claimed that the location of small reservoirs on top of elevated platforms indicates that these platforms had been built as artificial watersheds – in a similar fashion to the wide, funnel-like plastered surfaces around the chultunes in the Puuc region (see Chapter 5.6.2). In general, the composition and functionality of Caracol's hydraulic system differed quite distinctly from the hydraulic systems in most other sites, which mainly distributed water by means of canals (Crandall 2009: 34; Gallopin 1990).

According to Crandall (2009: 29), the individual elements of Caracol's hydraulic system exhibit a relatively lesser extent of interconnection than those of other sites. This is because the reservoirs and terraces formed distinct sets of landscape features which were not necessarily dependent on each other. Despite the fact that no artifacts were recovered during the investigation of Caracol's features, Chase (2012: 109) and Crandall (2009: 18) assumed that the "majority of Caracol's reservoirs" were installed and used during the Late Classic Period, when the site reached its population apogee and the landscape was entirely urbanized.

In conclusion, the author would like to note that even the limited extent of published material on Caracol's hydraulic features indicates that the reservoirs were built with the utmost care resulting in an truly astonishing state of preservation. Particularly, the well-preserved lateral walls of some reservoirs (e.g. Reservoir B) would make it extremely worthwhile to carry out a systematic excavation of these features because, as of yet, formalized slope-fortifications in Maya reservoirs have never been published or thoroughly studied.

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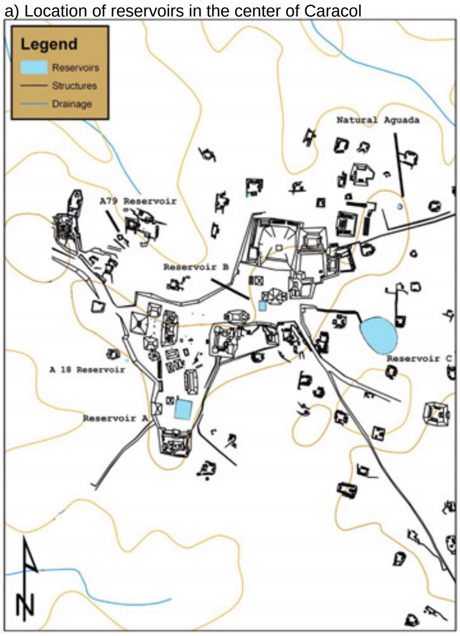
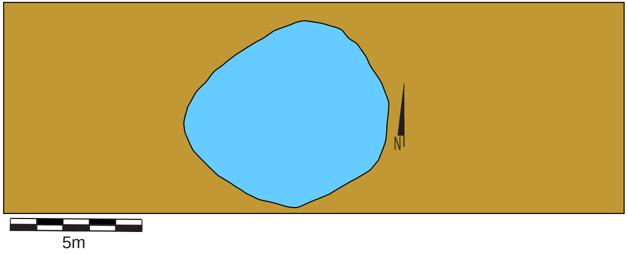
capacity could be determined precisely.

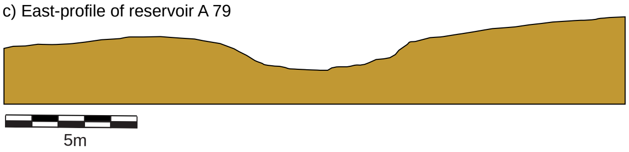
a) Location of reservoirs in the center of Caracol



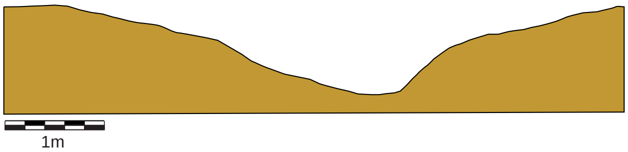
b) Plan of reservoir A 79



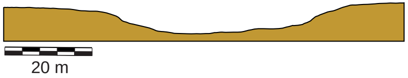
c) East-profile of reservoir A 79



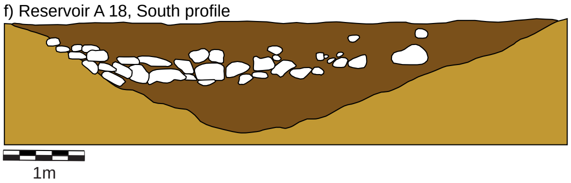
d) Reservoir C, Drainage, East profile



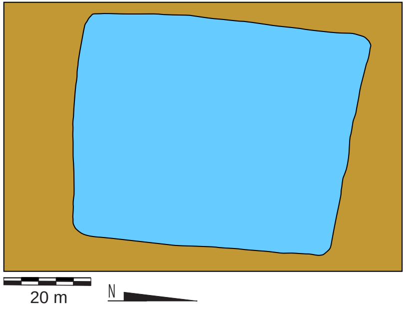
e) Reservoir A, West profile



f) Reservoir A 18, South profile



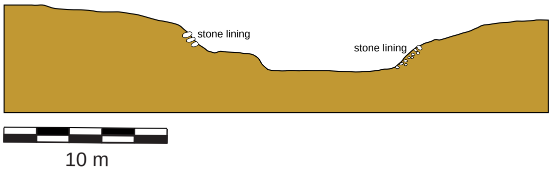
g) Reservoir A, Plan



h) Reservoir A 18, wall-lining

i) Reservoir A, southeast-view

j) Reservoir B, West Profile



k) Reservoir B, north-view

l) Reservoir B, detail of stone-lining

Figure 5.112: Caracol, Reservoirs in the city-center. (a) (source: Crandall 2009: Figure 4); (b) (source: Crandall 2009: Figure 6); (c) (source: Crandall 2009: Figure 7); (d) (source: Crandall 2009: Figure 23); (e) (source: Crandall 2009: Figure 20); (f) (source: Crandall 2009: Figure 10); (g) (source: Crandall 2009: Figure 21); (h) (Crandall 2009: Figure 11); (i) (source: Crandall 2009: Figure 16); (j) (source: Crandall 2009: Figure 15); (k) (Crandall 2009: Figure 13); (l) (source: Crandall 2009: Figure 14). Reproduced with kind permission of James M. Crandall.

5.7.11 Hydraulic System of Chau Hiix

The small site of Chau Hiix is situated between Lamanai and Altun Ha on the western shore of the seasonal Western Lagoon (Orange Walk District / Belize) and was occupied from the Early Preclassic until the Postclassic (after AD 1500) (Pyburn 2003: 123, with Figure 3). In the immediate vicinity of the site lies a 12 km^2 surface of well-drained and very fertile agricultural land. For Pyburn (2003: 123), the location of Chau Hiix along a very important inland water-route indicates that goods had been exported from this area via this waterway.

Surveys showed that the entire lagoon system had once been modified with extensive systems of canals, dams, levees and wells (Pyburn 2003: 124 with Figure 4). Although the frontiers of this system are still currently unknown, Pyburn (2003: 124) speculated that it had been connected to several nearby lagoons and wetlands by means of (so far unmapped) dams and canals. During the dry season, Pyburn (2003: 124) documented several parallel canals that crossed the Western Lagoon from east to west. These canals were 5 m wide and 2-3 m deep and connected the site with a section of elevated terrain roughly 1 km from the western shore of the Western Lagoon (Pyburn 2003: 124). According to an observation by Pyburn (2003: 125), most of these canals were connected to at least one well, each of which were excavated to the level of the phreatic zone. Pyburn (2003: 125) assumed that these modifications were aimed at improving control over the flow of water due to the fact that the beginning, duration and extent of rainy season precipitation in northern Belize has always been hard to predict.

At the inlet of the Spanish Creek, two dams were built in the lagoons around Chau Hiix, which may have regulated the influx of water during the rainy season. Perpendicular to the flow of water and parallel to the largest canals of the Western Lagoon, the pre-Hispanic inhabitants of Chau Hiix constructed two long levees with lengths between 500 and 600 m (Pyburn 2003: 125 with Figure 4). Presumably, these levees were able to influence the drainage of the lagoon and the adjacent fields. The wells connected to the canals may have been used for potwater irrigation during the dry season. Because the canals would refill even after moderate rainfall, the canals themselves might have been used for pot irrigation (Pyburn 2003: 124). Pyburn (2003: 125) suggested that the dams and levees prevented the inundation of the lagoon fields and acted as control mechanisms to enable late harvests on less elevated fields (Pyburn 2003: 125). During the rainy season floods, cultivation on the more elevated section of the seasonally varying edges of the lagoon and dams might have also been practiced. In addition to these hydraulic features, Pyburn (2003: 127) documented numerous terraces and reservoirs in the eastern portion of Chau Hiix that may have increased the agricultural production of the site. Through the interaction of its elements, this hydraulic system would have increased the fertility and productivity of the 12 km^2 acreages and may have enabled several harvests per year (Pyburn 2003: 128). The fact that such modifications had apparently not developed in Lamanai or Altun Ha led Pyburn (2003: 128) to the assumption that Chau Hiix might have supplied these two larger neighbouring sites with agricultural products. During the Terminal Classic, the settlement was largely abandoned.

However, some terraces and ditches indicate that the site apparently remained marginally populated until the Postclassic (Pyburn 2003: 127). Although Pyburn (2003) provided a very precise description of the composition and the (potential) interaction of the mentioned features, the publication of the hydraulic system did not contain documentation material such as maps or drawings. Therefore, it is difficult to understand their functionality or verify their actual existence. In contrast to the features intended to retain water in regions of harsh water scarcity as broadly reviewed above, some hydraulic systems located in the more humid regions of the Maya Lowlands were mostly aimed at protecting the respective settlements from excess water. These hydraulic systems will be presented in the next section.

5.8 Hydraulic systems built to manage excess water

As Figure 5.113 indicates, all hydraulic systems that aimed to control excess water are located in regions already defined as having excess water (see Chapter 2.1.4). Thus, they are mostly confined to the southern and southwestern portions of the Maya Lowlands (see Figure 5.113).

Figure 5.113: Geographic distribution of hydraulic systems for the management of excess water (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

The excess water in these regions forced the inhabitants to construct hydraulic systems like aqueducts, drainages, canals, dams and bridges (Davis-Salazar 2006: 124). Within Copán for example, these features primarily served to protect the erosion of buildings. Hence, the pre-Hispanic inhabitants decided to construct drainages and aqueducts that served to transport water both aboveground and underground. In some cases, canals were also installed below plazas. Dams, on the other hand, reduced the flow rate of water and thereby diminished the risk of erosion (Davis-Salazar 2001, 2002, 2003, 2006: 125). The following overview explains the functionality and technical design of hydraulic systems in regions with abundant water and highlights the primary technological differences to hydraulic systems in regions with water scarcity.

5.8.1 Hydraulic system of Comalcalco (Joy' Chan)

Contrary to other parts of the Lowlands to the east, the inhabitants of Tabasco's alluvial plains were forced to build dams and earthen mounds in order to be protected from periodic floods (Armijo and Gallegos 2012: 180). The sites located in these plains, such as Joy' Chan, used the Río Mazapa and the marine routes along the coast of the Gulf of Mexico as a means of communication and transport (Armijo and Gallegos 2012: 180 with Figure 3). The site of Joy' Chan sits on the eastern margin of the Río Mazapa. This is the final section of the Río Grande de Chiapas, a river that originates in the Altos Chuchumatanes and drains into the Gulf of Mexico at Barra de Dos Bocas (Armijo and Gallegos 2012: 178).

The central plaza of Joy' Chan was intersected by several drainage canals that directed rainwater towards the bajos located further to the north (Armijo and Gallegos 2012: 183). Additionally, Joy' Chan's pre-Hispanic inhabitants built a series of water pipes that prevented the inundation of food stocks, temple structures and funerary compounds (Armijo and Gallegos 2012: 183; see Figure 5.114).

In addition to these sophisticated drainage features, the inhabitants also constructed a series of reservoirs near the residential areas. Presumably, this spared them the more strenuous descent to the river for the procurement of water (Armijo and Gallegos 2012: 183). Due to the layout and interaction of these hydraulic features and the general composition of the settlement, Armijo and Gallegos (2012: 183) also speculated that the designers of these devices were aware of the destructive effects of consistent rainfall, cold fronts (*nortes*; see Chapter 2.2.2) and perhaps even hurricanes. In their view, this awareness is reflected in the roofs of some architectonic structures that featured adequate gradients for water to runoff and bore many resemblances to the *gotero* features of Palenque (see Chapter 5.8.3) and Ek' Balam (see Chapter 5.7.1). There, gotero features, or rain gutters, are small prominences situated between the exterior wall's facade and the edge of the roof that prevent water from dripping on and damaging the facade plaster and decorations (Armijo and Gallegos 2012: 183; see Figure 5.114 left). On the opposite side of the drainage tube, Armijo and Gallegos (2012: 184) documented a small reservoir located underneath a thatch roof that was fed by a small groove connected to the rain gutter.

As Figure 5.114 illustrates, the water pipes were composed of ceramic elements and had been installed underneath the patio of the large Acropolis in order to drain the residential and ritual areas within the compound (Armijo and Gallegos 2012: 184). Due to these observations, Armijo and Gallegos (2012: 177) concluded that the inhabitants of Comalcalco procured the water they needed from various sources such as rivers, bajos, lagoons and the ocean. These would have also supplied them with abundant food resources such as turtles, fish, shellfish and mollusks. The intricate network of canals, pipes and reservoirs was installed later on in order to protect the settlement from inundations and to divert and store rainwater.

Figure 5.114: Joy' Chan, Gran Plaza, Drainage tubes (modified from Armijo Torres *et al.* 2012: Figure 6). Reproduced with kind permission of Ricardo Armijo Torres.

5.8.2 Hydraulic system of El Tigre

According to Vargas (2012: 196), the site of El Tigre features a well-planned hydraulic system that enabled the planned drainage of excess rainwater, while simultaneously storing enough water to support its population of more than 15,000 inhabitants. Several large aguadas were located immediately behind Structure 1 (Vargas 2012: 196 with Figure 4). They apparently functioned in such a way that once one of the aguadas was entirely filled, the excess water was directed towards a less elevated aguada (Vargas 2012: 196 with Figure 4). Unfortunately however, Vargas (2012) did not provide a more detailed description of the extent and technical layout of these features. Moreover, Vargas (2012) did not publish a map of these hydraulic features or additional graphic documentation material on El Tigre's hydraulic system. Therefore, it is difficult to get a clear understanding of their functionality or verify their actual existence.

5.8.3 Hydraulic system of Palenque

The hydraulic system of Palenque can be considered the most extensive and elaborate hydraulic system for the management of excess water in the Maya Lowlands (French 2002, 2007, 2009; French *et al.* 2006; Golden and Scherer 2012: 68). In contrast to most other sites, the natural environment of Palenque provided an ample supply of water throughout the entire year. The settlement landscape featured nine separate waterways generated from 56 recorded springs (French 2009: 63). Of these nine streams, the Otolum was the longest and most extensive waterway. Owing to these circumstances, the largest threat for the settlement of Palenque was the rainy season. During this time of the year, these mountain streams expanded considerably and rushed towards the city center thereby endangering its public and private infrastructure (French 2009: 62).

Thus, for the city planners, the largest obstacle was not the lack of water, but the lack of habitable terrain (French 2009: 63). Despite these challenges, the city planners of Palenque were able to develop the second most densely populated city in the Maya region featuring a highly sophisticated hydraulic system (French 2009: 63). Due to the special conditions of the natural landscape, the hydraulic system of Palenque served three basic purposes: flood control (1), erosion control (2) and the creation of space (3).

Flood control was pursued by the construction of drains and aqueducts. As in most other Maya sites, drains were installed in order to prevent the flooding of plaza floors during the rainy season (French 2009: 62). However, contrary to most other Maya sites, Palenque's hydraulic system featured aqueducts, a type of hydraulic feature seldom documented. Currently, the only other example of an aqueduct was documented in conjunction with aguada 11J-19 in the center of Xultun (Ruane 2015: 192). These aqueducts did not only impede the erosion and flooding of the landscape, but also bridged residential areas that had originally been separated by one of the nine streams (French 2009: 67).

The following overview provides the reader with a general idea of the functionality of the system and the technical layout of its most prominent features. In order to control floods and erosion and to create additional space, the city planners of Palenque primarily used three elements:

(a) Terraces and regulation of natural streams,

(b) Drains, and

(c) Aqueducts.

In the settlement landscape of Palenque, French (2009: 72) documented 16 non-continuous km of residential terraces (see Figure 5.115) and artificial canalizations of all natural streams. These landscape modifications generally aimed to maximize habitable land and to facilitate communication.

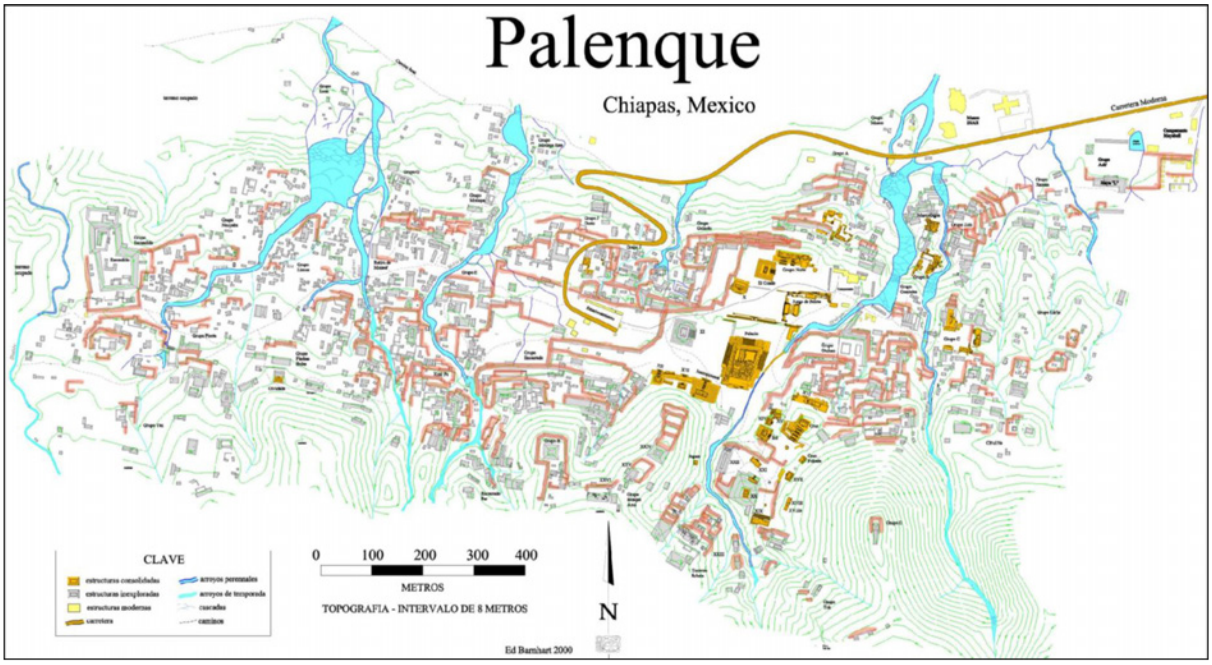


Figure 5.115: Palenque, Map of site showing the distribution of water streams. Terraces are highlighted in rose (adapted from French 2009: Figure 4.6). Reproduced with kind permission of Kirk D. French.

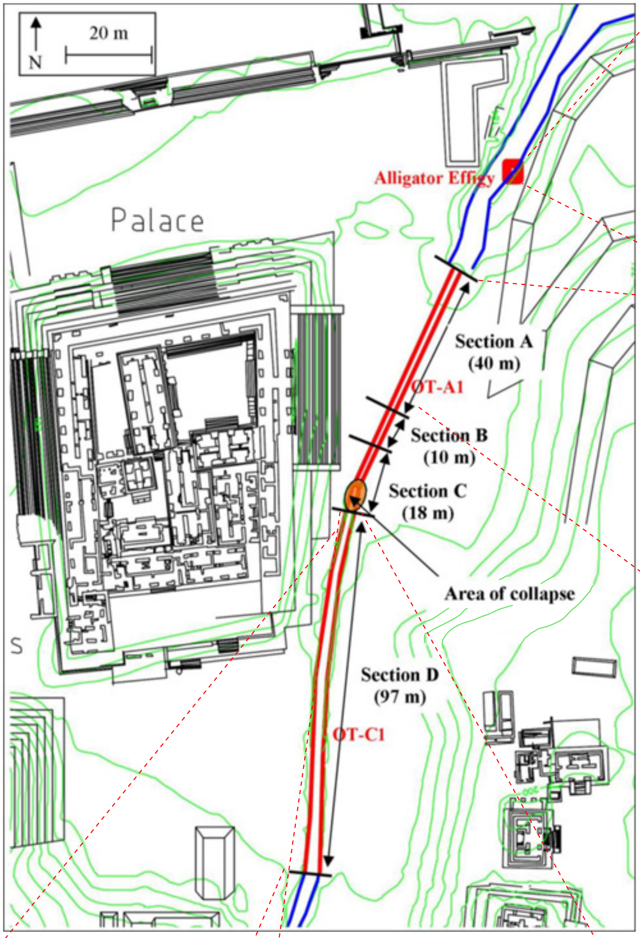
Like terraces and superficial canals, aqueducts were built to canalize natural streams and increase the extent of habitable land. To this end, Palenque's pre-Hispanic inhabitants covered some portions of the preexisting streams with plaza floors while allowing the water to flow beneath (French 2009: 67). According to French (2009: 160), there are "over a dozen examples in Palenque" where subterranean channels were created by excavating the bed of pre-existing streams and constructing limestone conduits, which were ultimately covered and sealed with fill. In order to reduce seepage, the interior walls of these aqueducts were also covered with stucco (French 2009: 170). One of the most prominent and best-preserved examples is the Palace Aqueduct.

Aqueduct OT-A1, also termed the "Palace aqueduct", was built to canalize the Otolum River, which previously flowed through the center of the site and thus represented a flood risk (French 2009: 63). To solve this issue, the city planners of Palenque forced the stream below the surface of the plazas (French

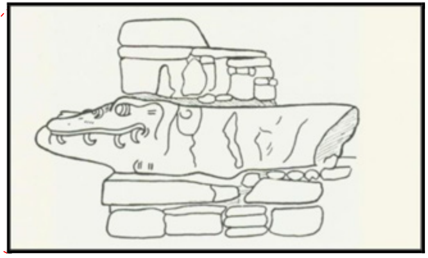
2009: 63, 131). As Figure 5.116a indicates, the aqueduct can be subdivided into two basic parts, OT-C1 and OT–A1. In this case, Aqueduct OT-C1 (or Section D) extends over a distance of 97 m before entering OT–A1. OT–C1 is a walled channel that flowed openly in some locations and was covered by a corbelled arch in others (French 2009: 135; see Figure 5.116).The intact section of OT-A1 is well preserved and served to canalize the Otolum stream over a distance of 58.5 m underneath the floor of the plaza at an elevation of 187.50 m (French 2009: 135). As Figure 5.116a indicates, OT-A1 consists of three different sections: Section A, Section B and Section C.

Section A is the earliest and best preserved section of the aqueduct and extends approximately 40 m southwards of the exit (French 2009: 135, see Figures 5.116a, 5.116c, and 5.116d). It consists of large cut-stone support beams found in the corbelled arch (French 2008: 15; see Figure 5.116d). After the stream exits OT-A1, a wall on the east side continues for 27 m (French 2009: 145). The water then passes an enormous alligator figure positioned 1 m above the flow of water (French 2009: 145, see Figure 5.116b).

a) Map of the Otolum stream, the Palace aqueduct and additional hydraulic features

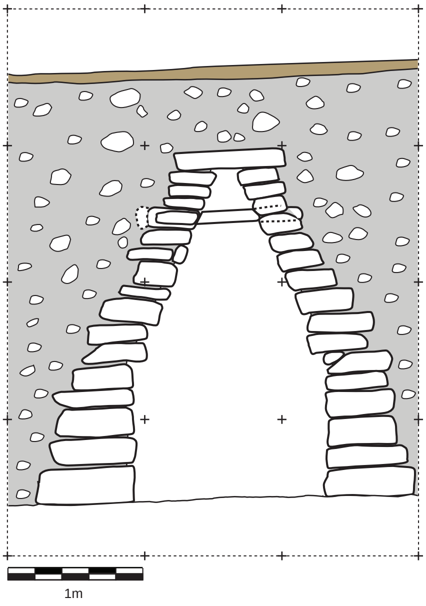


b) Alligator figure at the northern exit of OT-A1, Section A



c) Aqueduct OT-A 1, Section A, Interior view

d) Aqueduct OT-A 1, Section A, Cross-Section



e) Aqueduct OT-C 1, North view

f) Aqueduct OT-A 1, Partial Collapse at southern end of Section C

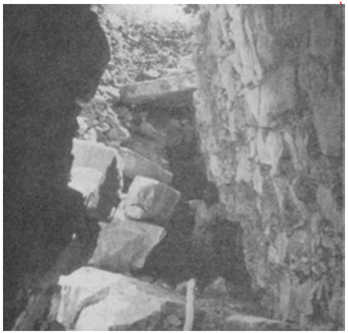


Figure 5.116: Palenque, Palace Aqueduct (OT-A1). (a) (source: French 2009: Figure 7.11); (b) source: French 2009: Figure 7.12); (c) (source: French 2009: Figure 7.9); (d) (redrawn after French 2009: Figure 7.10); (e) (source: French 2009: Figure 7.0); (f) (source: French 2009: Figure 7.8).

After passing the alligator figure, the stream flows slightly to the east, passes the ball court and approaches the Otolum Bridge (OT-B1) (French 2009: 131, 145; see Figures 5.116a, 5.116b, 5.116c and 5.116e). This remarkably well-preserved bridge measures 10.25 m x 10.25 m and features a 1 m wide corbelled arch in the construction's middle that allowed the Otolum to pass beneath it (French 2009, 131, 145; see Figure 5.116e). After passing through the bridge, the water cascades over several waterfalls and flows into the Queen's Bath (French 2009: 145, see Figure 5.117b).

After passing the Queen's Bath, located at an elevation of 110 m, the Otolum forms a shallow natural pool and then enters a set of parallel aqueducts: OT-A2 and OT–A3 (French 2009: 145, see Figures 5.117b, 5.117d and 5.117f). Both aqueducts have similar dimensions of 1.10 m in height and 80 cm in width (French 2009: 149). The OT-A2 travels north at a bearing of 27° before exiting into the natural streambed (French 2008: 145, see Figure 5.117d). The OT-A 3 is heavily calcified and partially collapsed (French 2009: 145). The left margin of Figure 5.116f indicates that the northern end of Aqueduct OT-A3 feeds into the OT–A2 section. After joining to Aqueduct OT–A2, the water passes underneath the modern road and through the museum group before flowing into the Michol River (French 2009: 149; see Figure 5.117b).

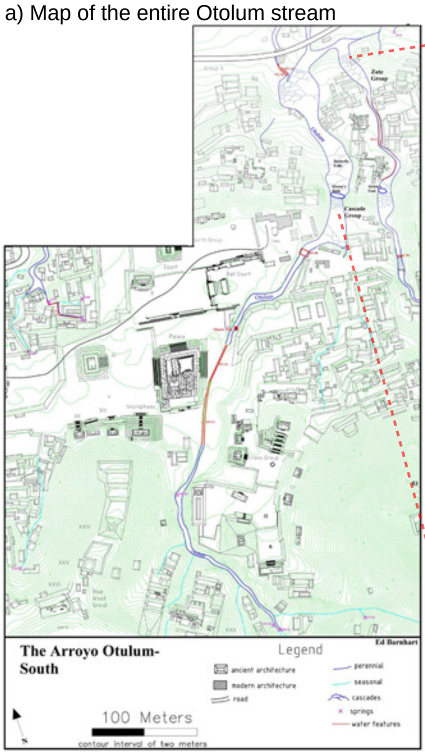
In conclusion, French (20098: 158) argued that the Palace Aqueduct (OT-A1) could have been used both to prevent the flooding of plazas during heavy rains and to store water during times of drought. Furthermore, the construction of the aqueduct resulted in more habitable space. Thus, French (2009: 72) calculated that the land produced by the aqueduct and the level terrain east of the Otolum would have increased the size of the main plaza by 23%. The original benefits of the Palace Aqueduct are obvious today, as the Otolum currently passes directly through the main plaza and divides it due to the southern portion of the aqueduct's collapse (French 2009: 72). However, when the Palace Aqueduct was intact and functional, the installation of this feature would have enabled unhindered activity along the entire main plaza.

Another unique element of Palenque's hydraulic system is the application of a pressure conduit in the Piedras Bolas Aqueduct 1 (PB-A1), which passes close to the Piedras Bolas site (French 2009: 160; see Figure 5.118a). This aqueduct differs from the other hydraulic constructions in the site, which vary in overall size, but always maintain a consistent cross-sectional area of the pipe from inlet to outlet with a relatively flat slope (< 1/100) (French 2009: 160). However, the Piedras Bolas Aqueduct exhibits a closed conduit with a cross-sectional area of 1.2 m x 0.8 m and shows a consistent inclination of 5% over its entire length of 66 m (French 2008: 162). Near its bottom end however, the size of the conduit decreases abruptly to 20 x 20 cm over a length of 1 m (French 2008: 162; see Figures 5.118b and 5.118c). Due to this reduction, the cross-sectional area of the aqueduct was reduced from 0.96 m^2 to 0.04 m^2 (French 2009: 162). Since the inlet of PB-A1 is at an elevation of 196 m and the outlet is at an elevation of 190 m, the aqueduct had a hydraulic head of 6 meters, which, together with the reduced cross-section near the outlet, would have created a considerable amount of pressure (see Figure 5.118c). According to French (2009: 162), the hydraulic pressure generated by PB-A1 could have been used for a number of purposes, which have not been fully identified as of yet.

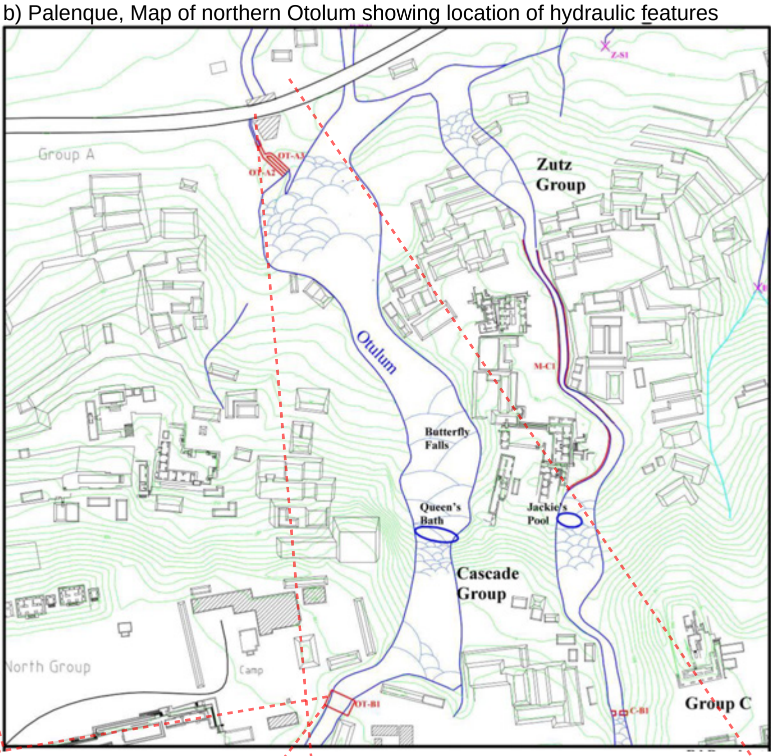
Apart from creating hydraulic pressure, the Piedras Bolas Aqueduct also would have resulted in approximately 200 m^2 more settlement area. Thus, sealing the water course also bridged several household groups (French 2009: 162). In times of water scarcity, the pre-Hispanic inhabitants could have also sealed the outlet, which would have enabled them to store about 68,000 liters of water (French 2009: 162).

The functionality of these features show that, in comparison to the hydraulic systems presented in Chapter 5.7, the main purpose of Palenque's hydraulic system was the protection of the urban landscape and the public infrastructure, which were seriously endangered by the streams and torrents of the rainy season (French 2009: 63). In order to minimize land loss from erosion and to increase the surface of habitable land, the city planners decided to canalize all nine waterways of the site in the form of public works (French 2009: 63). Based on these observations, French (2009: 158) argued that the pre-Hispanic inhabitants of Palenque had gradually developed an empirical understanding of hydrological engineer-

a) Map of the entire Otolum stream

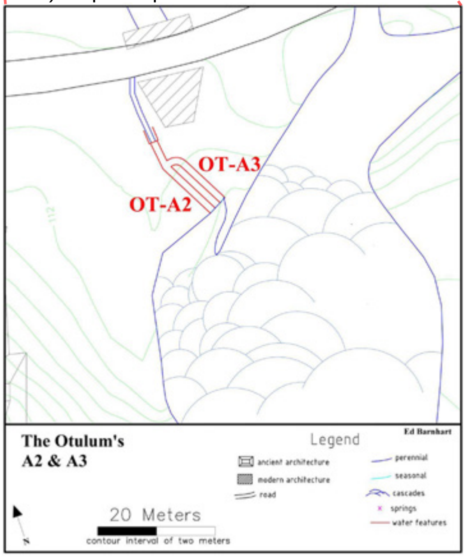


b) Palenque, Map of northern Otolum showing location of hydraulic features

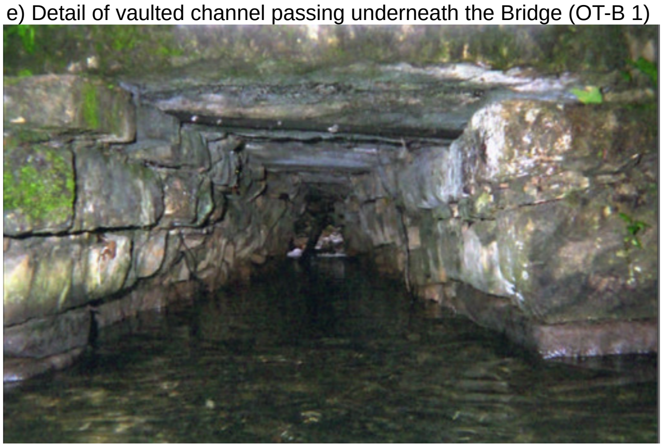


c) North view of Bridge (OT-B 1) crossing the Otolum stream

d) Map of aqueducts OT - A 2 and OT- A 4



e) Detail of vaulted channel passing underneath the Bridge (OT-B 1)

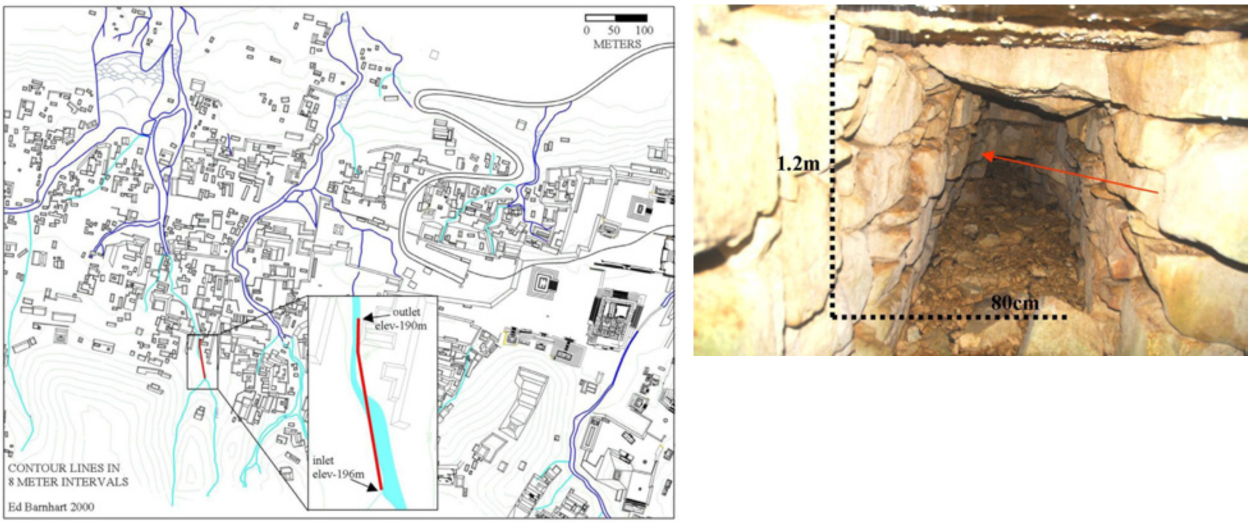


f) Detail view of the interior of aqueduct A 2

Figure 5.117: Palenque, Otolum Bridge (OT-B19) and aqueducts A2 and A3. (a) (source: French 2009: Figure 7.1); (b) (source: French 2009: Figure 7.0); (c) (source: French 2002: Figure 3.14); (d) (source: French 2009: Figure 7.13); (e) (source: French 2002: Figure 3.15); (f) (source: French 2002: Figure 3.14). Reproduced with kind permission of Kirk D. French.

ing. Over time, experience in the construction of aqueducts even enabled them to manipulate water pressure and use it to their advantage. Ultimately, this experience also enabled the construction of sophisticated pressure conduits (French 2009: 166).

In conclusion, the location, layout and interaction of the different hydraulic features indicate that Palenque's hydraulic system served both to prevent inundations and to retrieve water in times of drought (French 2009: 170). During times of water scarcity, the outlets of the aqueducts could have been temporarily dammed in order to impound water. In this case, the stucco applied to the interior walls of the aqueduct would have drastically reduced seepage (French 2009: 170). Along with this, the damming of the Palace aqueduct would have impounded a daily volume of 225 m^3, while still allowing enough overflow for crop irrigation in the plains north of the site (French 2008: 170). In consideration of the reconstructed pre-Hispanic population of the site (4,147-6,220 people estimated by Barnhart 2001), and the available paleoclimatic data for the site, French (2009: 170) argued that Palenque had surely not been abandoned due to droughts or famine.


a) Palenque, Site map showing the location of the Piedras Bolas Aqueduct 1 (PB-A 1)

b) Interior view of PB-A 1 showing the abrupt reduction of conduit size

c) Isometric reconstruction drawing of Piedras Bolas pressure conduit

d) Interior view of PB-A 1

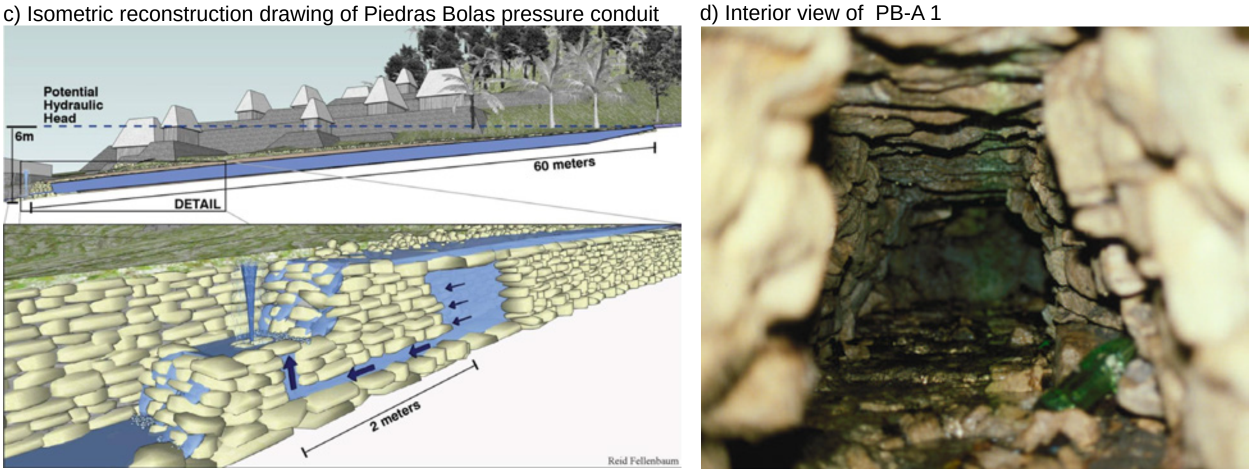


Figure 5.118: Palenque, Piedras Bolas pressure conduit (PB-A1). (a) (source: French 2009: Figure 8.0); (b) (source: French 2009: Figure 8.1); (c) (source: French 2009: Figure 8.3); (d) (source: French 2002: Figure 3.6). Reproduced with kind permission of Kirk D. French.

5.8.4 Hydraulic system of Cancuén

Cancuén is situated along the banks of the Río Pasión and was populated for a rather short period between AD 650 and 800 (Alvarado Najarro 2013: 126; Crandall 2009). The site features a very complex hydraulic system based primarily on canals and artificial reservoirs in the site center (Alvarado Najarro 2013: 126). According to Alvarado Najarro (2013: 126), the water level of the Río Pasión can fluctuate up to five meters over the course of the year, leading to extended inundations during the rainy season. A very peculiar landscape feature of Cancuén are a series of natural bays along the course of the Río Pasión, which, according to Alvarado Najarro (2013: 129), were used as ports with landing docks for canoes. Barrientos (2003: 21) speculated that these landing docks might have served as entryways to Cancuén or as means of transport-control for products traded between the Highlands and the Lowlands. According to Alvarado Najarro (2013: 129), the recurring floods had been the driving factor for Cancuén's population to develop a hydraulic system. This hydraulic system was designed to fulfill three different functions:

(1) Controlling the fluctuations of the Río Pasión and protecting the settlement from inundations caused by runoff,

(2) Transforming the Río Pasión into a more usable transport route, and

(3) Creating convenient access to reservoirs with potable water (Alvarado 2013: 129).

At the current state of research, the investigations in Cancuén resulted in the discovery of four reservoirs, a system of canals, artificially sloped surfaces and modified correntales, which had been carefully planned and adjusted to adhere to the local landscape (Alvarado Najarro 2013: 129, see Figure 5.119). As Alvarado Najarro (2013: 129) noted, Cancuén's hydraulic system can be subdivided into three different sectors: The southern sector (1), the northern sector (2) and the northwestern sector (3) (see Figure 5.119). In order to provide a better understanding of the adaptation strategies of Cancuén's pre-Hispanic inhabitants, these different sectors are described in greater detail in the following sections.

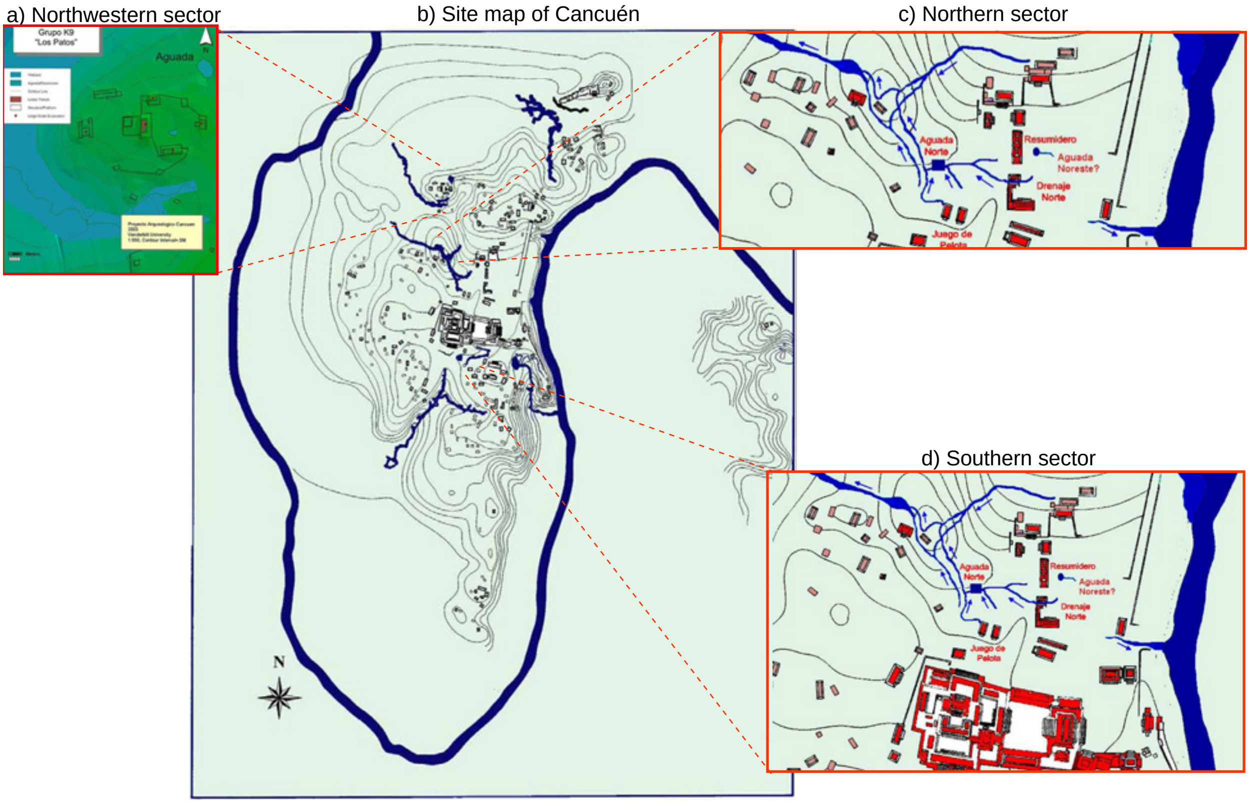


Figure 5.119: Cancuén, Map of the site showing the location of hydraulic features. (a) (source: Barrientos 2008: Figure 7); (b) (modified from Barrientos 2008: Figure 4); (c) (source: Barrientos 2008: Figure 9); (d) (source: Barrientos 2008: Figure 32). Reproduced with kind permission of Tomás Barrientos.

5.8.4.1 Hydraulic system in Cancuén's southern sector

The hydraulic system in Cancuén's southern sector is centered around the southern reservoir or *Royal Pool* near the southern access point to the Royal Palace (Alvarado Najarro 2013: 129; see Figures 5.120a and 5.120c). To the east of the reservoir lies an old modified corriental called *drenaje sur*, which was converted into a canal to drain excess water from several major structures, such as L 7-27; K 7-38 and M 7-5, into a small arroyo to the south of the reservoir (Alvarado Najarro 2013: 129; Barrientos *et al.* 2006; see Figures 5.120a and 5.120b).

Due to its situation at the palace entrance, the southern reservoir could only be used by members of the elite living inside the palace compound (Alvarado Najarro 2013: 129, see Figure 5.120d). According to Alvarado Najarro (2013: 129), the form of this reservoir also indicates that it had been built as a representation of the quatrefoil – an important element in water imagery (Barrientos 2008; Fash 2005; Scarborough 1998). The reservoir was fed by a spring that dries up in the summer and features a north-south length of 7.76 m, an east-west width of 9.29 m and a depth of approximately 2 m (Alvarado Najarro 2013: 130, see Figures 5.120c and 5.120f). These dimensions indicate that the reservoir originally had a storage capacity of approximately 144.18 m^3 (Alvarado Najarro 2013: 130). As Figures 5.120c, 5.120e, and 5.120f indicate, the base of the reservoir was clad with large and flat stone slabs featuring lengths of up to two meters near the bench. In the lowermost part of the reservoir, the stone slabs are rounded.

To the west and east, the reservoir basin was bordered by two platforms that facilitated easier access and were clad with medium-sized limestone slabs (Alvarado Najarro 2013: 130). As the sidewalls of the reservoir had already collapsed, Alvarado Najarro (2013: 130) was unable to determine any form of drainage device or water outlet that might indicate that the reservoir was constantly interchanging water through an inlet and outlet. However, as the surrounding landscape was sloped towards the south, Alvarado-Najarro (2013: 130) speculated that the water of this reservoir was drained in this direction. According to Alvarado Najarro (2013: 131), the palace inhabitants used the reservoir for domestic purposes. However, access might have been restricted due to the source drying up in the summer and the flow-rate varying from year to year. Due to the fact that the human remains of 38 individuals[174] were documented in the interior of the reservoir, Alvarado Najarro (2013: 133) speculated that it had also been used for ritual purposes.

However, Alvarado Najarro (2013: 133) assumed that the southern reservoir originally had a purely domestic use and would have been related to Group L-6, a group identified as the "kitchen area" of the palace compound. During the later reign of *Taj Chan Ahk*, however, the reservoir underwent several modifications and a finer and more delicate structure was built around the water source (Alvarado-Najarro 2013: 133). In contrast to other reservoirs, this feature was not connected to drainage or irrigation canals. It is not certain, but probable that excess water was drained to the south by means of the surrounding sloped surface. In the author's opinion, this reservoir is one of the few examples of hydraulic features in the Maya Lowlands that does not have the singular purpose of supplying water, but can also be interpreted as a luxury.

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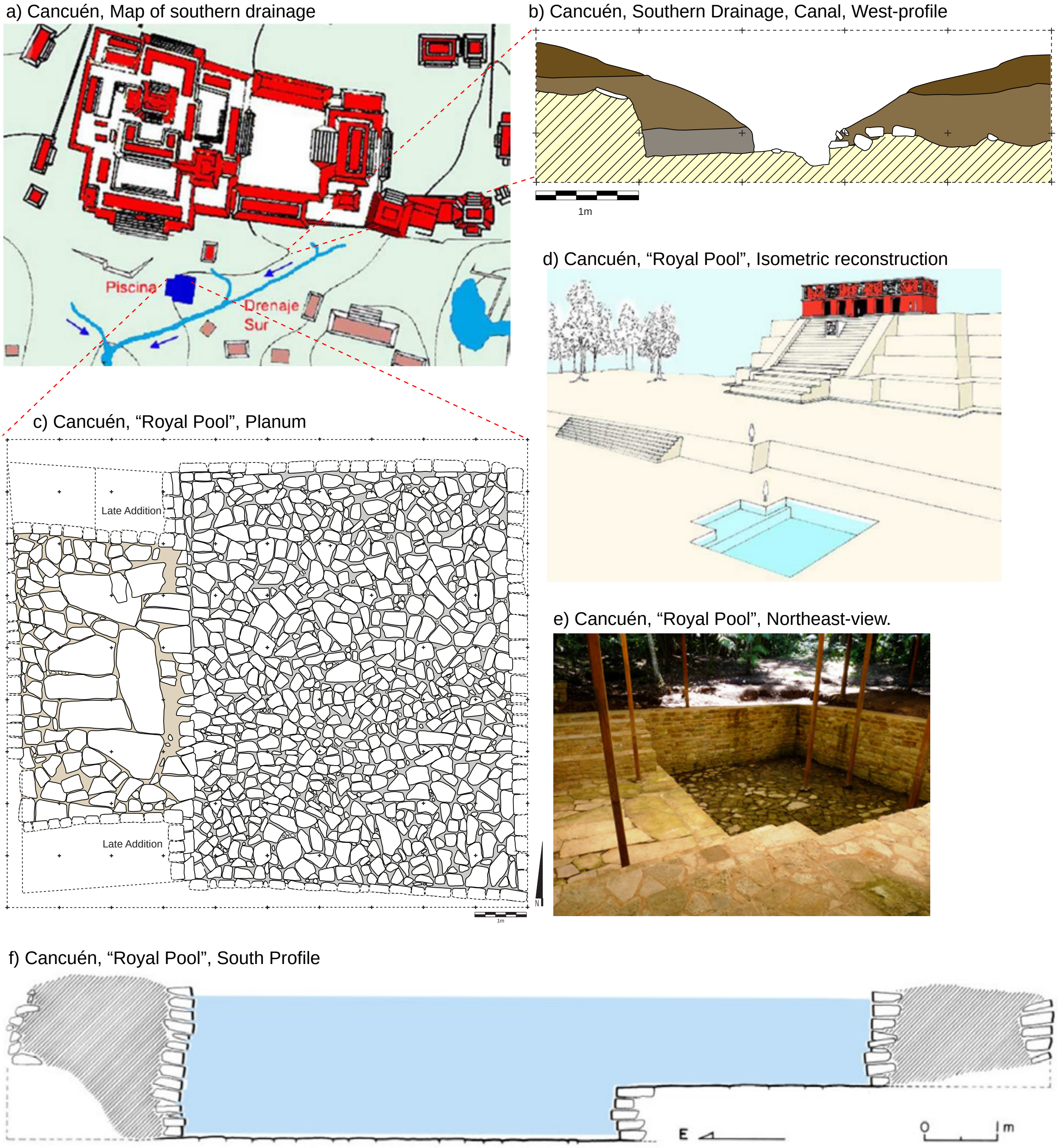
[174] According to the osteological analysis, these individuals had been victims of a violent death (Suasnavar *et al.* 2007: 26-27) and were later on thrown into the interior with all their adornments. The hypothesis of a violent death is furthermore supported by the presence of 11 chert arrowheads, which were found in association with these remains (Alvarado Najarro 2013: 131) The form of deposition is remarkably similar to the deposition of individuals within the artificial cave of Uxul (Seefeld 2013b; see Chapter 6.3.4).


a) Cancuén, Map of southern drainage

b) Cancuén, Southern Drainage, Canal, West-profile

c) Cancuén, “Royal Pool”, Planum

d) Cancuén, “Royal Pool”, Isometric reconstruction

e) Cancuén, “Royal Pool”, Northeast-view.

f) Cancuén, “Royal Pool”, South Profile

Figure 5.120: Cancuén, Hydraulic features in the southern drainage. (a) (source: Barrientos 2008: Figure 32); (b) (modified from Barrientos 2008: Figure 34); (c) (redrawn after Barrientos 2014: Figure 9.254); (d) (modified from Barrientos 2008: Figure 47); (e) (Photo: Courtesy of J. Szymanski); (f) (modified from Barrientos 2014: Figure 9.256). Reproduced with kind permission of Tomás Barrientos.

5.8.4.2 Hydraulic features in the northern section of Cancuén

The northern section of Cancuén is composed of various residential structures that were presumably inhabited by members of the city's middle class (Alvarado Najarro 2013: 134). The largest hydraulic feature of this section is the northern reservoir, located close to the palace group and loosely associated with an elite residential group that features some of the earliest structures of the site (Alvarado Najarro 2013: 134; see Figure 5.121b). In the south, the reservoir is delimited by the palace ballcourt, which was built over a water source. Furthermore, the reservoir is connected to a small canal that drains the water into a corriental (Alvarado Najarro 2013: 134; see Figure 5.121b).

In many respects, the northern reservoir resembled the Royal Pool. It measures 6.00 m north-south by 7.30 m east-west with a height of 2.27 m and had a storage capacity of 136.66 m^3. Like its counterpart in the south, the basin of the reservoir was delimited by two platforms with heights of 85 cm, which were clad with large stone slabs with smooth surfaces (Alvarado Najarro 2013: 137). The bottom of the basin had been sealed in the same manner (see Figure 5.121d). Furthermore, Alvarado-Najarro (2013: 141) documented remains of a stucco covering that increased the quality of the stored water and the permeability of the reservoir. Alvarado Najarro (2013: 136) highlighted that the reservoir was originally rectangular and featured some sort of access on the eastern side. It was fed with water by an interior spring that had a higher inflow rate than the southern reservoir. Therefore, the northern reservoir does not dry up during the dry season (Alvarado-Najarro 2013: 126). Inside of the reservoir, the excavations also documented human remains of at least 15 individuals (Alvarado Najarro 2013: 137).[175]

According to Alvarado Najarro (2013: 241), the location of this reservoir is slightly unusual, as it lies relatively far from other structures. Therefore, the feature was interpreted as a domestic water source used by the palace inhabitants and the inhabitants of Group L-8. Based on the findings of domestic storage vessels and the abundance of grinding stones, Alvarado Najarro (2013: 141) assumed that the inhabitants of the L-8 Group used it for domestic purposes between AD 650 and 760. During the reign of *Taj Chan Ahk* (AD 760-800), however, the construction of a ballcourt and a stone structure around the source suggest that the reservoir was also used for ritual purposes (Alvarado Najarro 2013: 141).

In addition to the northern reservoir, several other hydraulic features were documented in connection with the northeastern plaza, which is located to the west of a sacbe (Alvarado Najarro 2013: 135; see Figures 5.121 a, and 5.121b). This northeastern plaza was complemented by a drainage canal that directed runoff towards a drainage feature composed of worked sandstone blocks (Alvarado-Najarro 2013: 135).

Further to the south, the pre-Hispanic inhabitants constructed a very elaborate canal, the northern drainage (see Figures 5.121b, 5.121c and 5.121e), which flowed through Structures L 8-6 and L 8-7 and ended in the northern reservoir (Alvarado Najarro 2013: 135). As Figure 5.121e indicates, this canal was delimited on both sides by stone slabs with smooth surfaces (Alvarado Najarro 2013: 135). At the end of the canal, Alvarado Najarro (2013: 135) also documented a dike feature, which presumably served to minimize the rate of flow during the rainy season.

To the west of the northern reservoir, Alvarado Najarro (2013: 135) documented another smaller canal, which fed into a corriental that drained into the Río Pasión. It had a depth of approximately 50 cm, an orientation of 255° northwest and a length of 27 m from the western edge of the reservoir to the bank of the corriental (Alvarado Najarro 2013: 136; see Figure 5.121b). The canal floor was formed with smooth, medium-sized and rectangular stone slabs. As Alvarado Najarro (2014: 135) noted, this canal also merged with the canal that began in the extreme northeast of the palace's ballcourt (Alvarado Najarro 2013 135, see Figure 5.121b). Presumably, the construction of these two canals was required to drain the northern reservoir of the excess water produced by the local spring and the northern main drainage (Alvarado Najarro 2013: 135).

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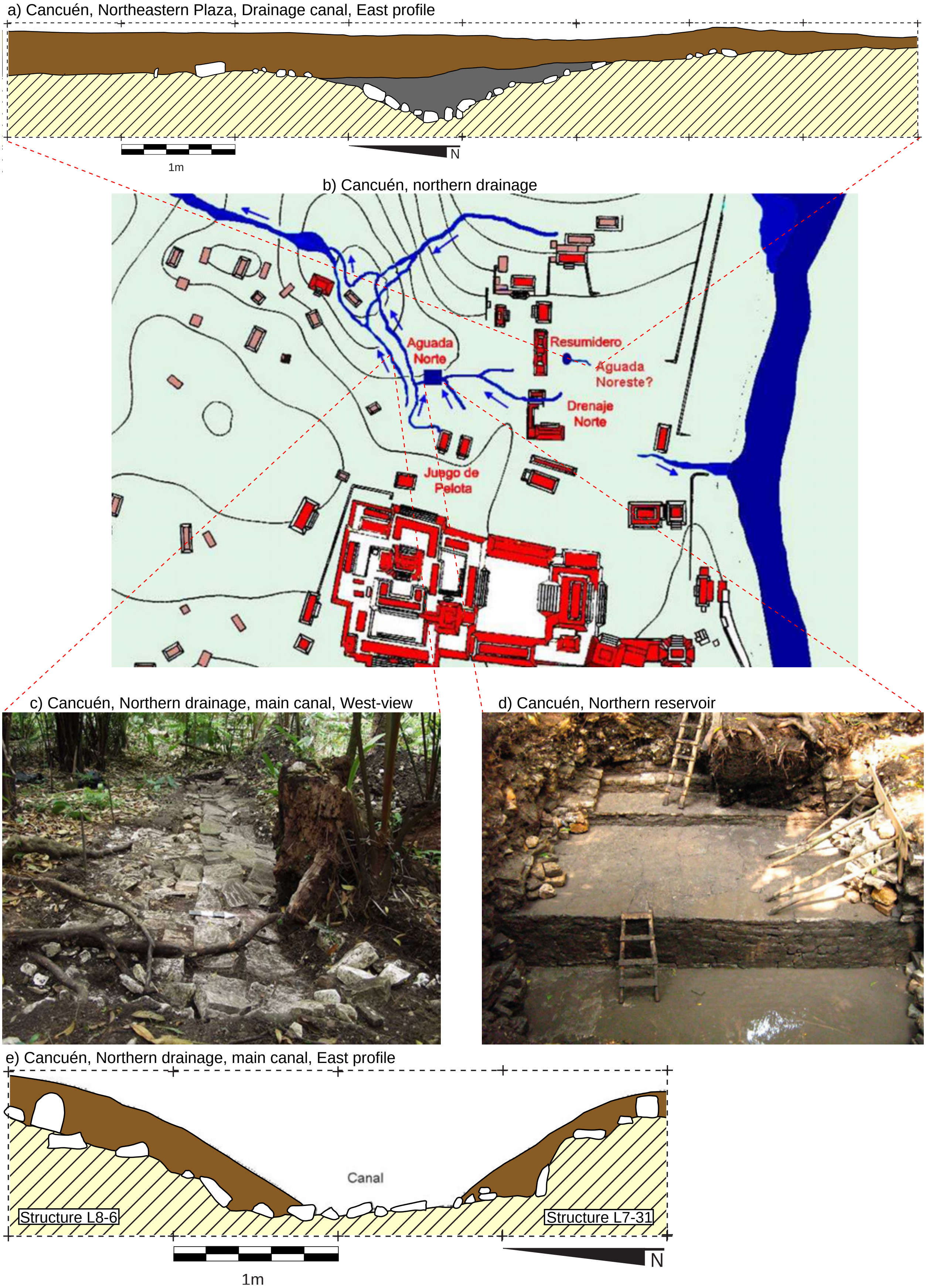
[175] According to Alvarado Najarro (2013: 137), it can be assumed that these individuals had died a violent death and were later on thrown into the reservoir. The form of deposition is very similar to the human remains in the southern reservoir, and the artificial cave of Uxul (Seefeld 2013b, see Chapter 6.2.5).


a) Cancuén, Northeastern Plaza, Drainage canal, East profile

b) Cancuén, northern drainage

c) Cancuén, Northern drainage, main canal, West-view

d) Cancuén, Northern reservoir

e) Cancuén, Northern drainage, main canal, East profile

Figure 5.121: Cancuén, Hydraulic features in the northern drainage. (a) (redrawn after Barrientos 2008: Figure 26); (b) (source; Barrientos 2008: Figure 9); (c) (source: Barrientos 2008: Figure 25). Reproduced with kind permission of Tomás Barrientos; (d) (source: Alvarado Najarro 2013: Figure 8. Reproduced with kind permission of Silvia Alvarado Najarro). (e) (redrawn after Barrientos 2008: Figure 26. Reproduced with kind permission of Tomás Barrientos).

5.8.4.3 Hydraulic features in the northwestern section of Cancuén

The K-9 or "Los Patos" Group is located approximately 500 m to the north and 1,000 m to the west of the palace (Alvarado Najarro 2013: 141, see Figures 5.118 and 5.122a). It included two adjacent patios surrounding the principal structure K 9-1 (Alvarado Najarro 2013: 141). In order to provide an effective drainage for the patio, its pre-Hispanic builders designed it with a gradual slope towards the Río Pasión (see Figure 5.122a). In the small residential group, which may have been inhabited by members of the local elite, Alvarado Najarro (2013: 141) located two aguadas: One medium sized reservoir in the northeast of the group and a small feature in the center.

The northeastern aguada features a rectangular form, an area of 10 x 12 m with a depth of 2 m, and originally would have been able to store 240 m^3 of water (Alvarado Najarro 2013: 142, see Figure 5.122a). Underneath a large fragmented ceramic sherd, excavations revealed the lower jaw of a human[176] (Tomasic 2003: 348), which suggested a termination ritual for the use of the aguada as a source for drinking water (Alvarado Najarro 2013: 143). In its southwestern corner, the reservoir was connected to a narrow canal that drained the water of the eastern patio of Group K 9 towards the aguada (Alvarado Najarro 2013: 142; Tomasic 2003: 351). This drainage featured an orientation of approximately 18.5°, a width of 40-60 cm and a depth of 50 cm (Ohnstad *et al.* 2004: 222).

The smaller aguada is located in the south-central portion of the eastern patio, between the structures K 9-5 and K 9-7 (Alvarado Najarro 2013: 143; see Figure 5.122a). In its northwestern corner, the reservoir was also connected to a small drainage canal. The reservoir featured an area of 4.2 x 3.2 m, a depth of 2 m and a conical form, and once had a storage capacity of approximately 26.88 m^3 (Alvarado 2013: 143, see Figure 5.122b). Because the eastern patio was slightly sloped towards the small aguada in a funnel-like fashion, it was fed by substantial amounts of runoff (Alvarado Najarro 2013: 143). No architectonical features were documented in the immediate vicinity of the reservoir (Alvarado Najarro 2013: 143; Ohnstad *et al.* 2004: 223).

Even though both aguadas of the "Los Patos" Group showed no association to architectonical structures, Alvarado Najarro (2013: 144) stressed that they had originally been used for domestic purposes between AD 650 and 760. Later on, the surrounding plazas would have been paved and artificially sloped, and connected to canals in order to avoid inundations (Alvarado Najarro 2013: 144). In this later period, the small reservoir might have also been used for ritual purposes.

Relating to the general development and functionality of Cancuén's hydraulic system, Alvarado-Najarro (2013: 133) concluded that all major hydraulic features, including the southern and northern reservoir, had originally been used exclusively for domestic purposes. During the reign of *Taj Chan Ahk,* however, the original purpose of the hydraulic system had been modified, because the ruler had visibly tried to use water related rituals as an instrument of power (Alvarado-Najarro 2013: 133).

After this extensive review of hydraulic features in the Maya Lowlands, the upcoming chapter will focus on the third main research issue of this work: the results of the archaeological investigation of Uxul's hydraulic features.

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[176] The pattern of a detached human lower jaw shows another similarity to the deposition of human remains in the artificial cave of Uxul (Seefeld 2013b, see Chapter 6.2.5).

a) Cancuén, Map of northwestern drainage

b) Cancuén, Grupo Los Patos, small reservoir, north profile

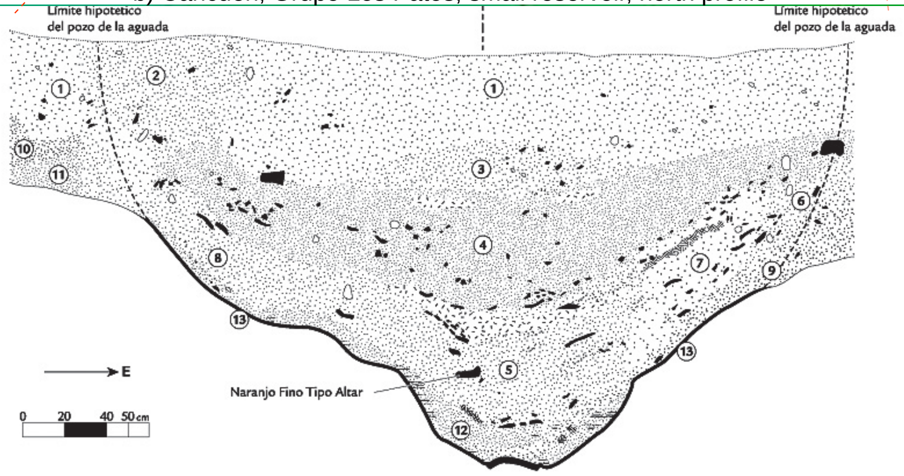

Figure 5.122: Cancuén, hydraulic features in the northwestern drainage. (a) (source: Barrientos 2008: Figure 7. Reproduced with kind permission of Tomás Barrientos); (b) (source: Alvarado Najarro 2013: Figure 14. Reproduced with kind permission of Silvia Alvarado Najarro).

6 Archaeological investigation of Uxul's hydraulic system

Uxul is a medium-sized Classic Maya city in the extreme south of the Mexican state of Campeche. It is located 34 km southwest of Calakmul and 4 km north of the border between Mexico and Guatemala (Grube *et al.* 2012: 11). Nowadays, the site is located within the Calakmul Biosphere Reserve, one of the largest nature reserves in Mexico featuring an extension of 721,957 ha (Grube and Delvendahl 2015: 1). In geological respects, Uxul is located in the core of the Elevated Interior Region (see Chapter 2.4.3.3) and lies on the western side of a karstic ridge running from the northern Petén into eastern Campeche (Grube *et al.* 2012: 14; see Figure 6.1).

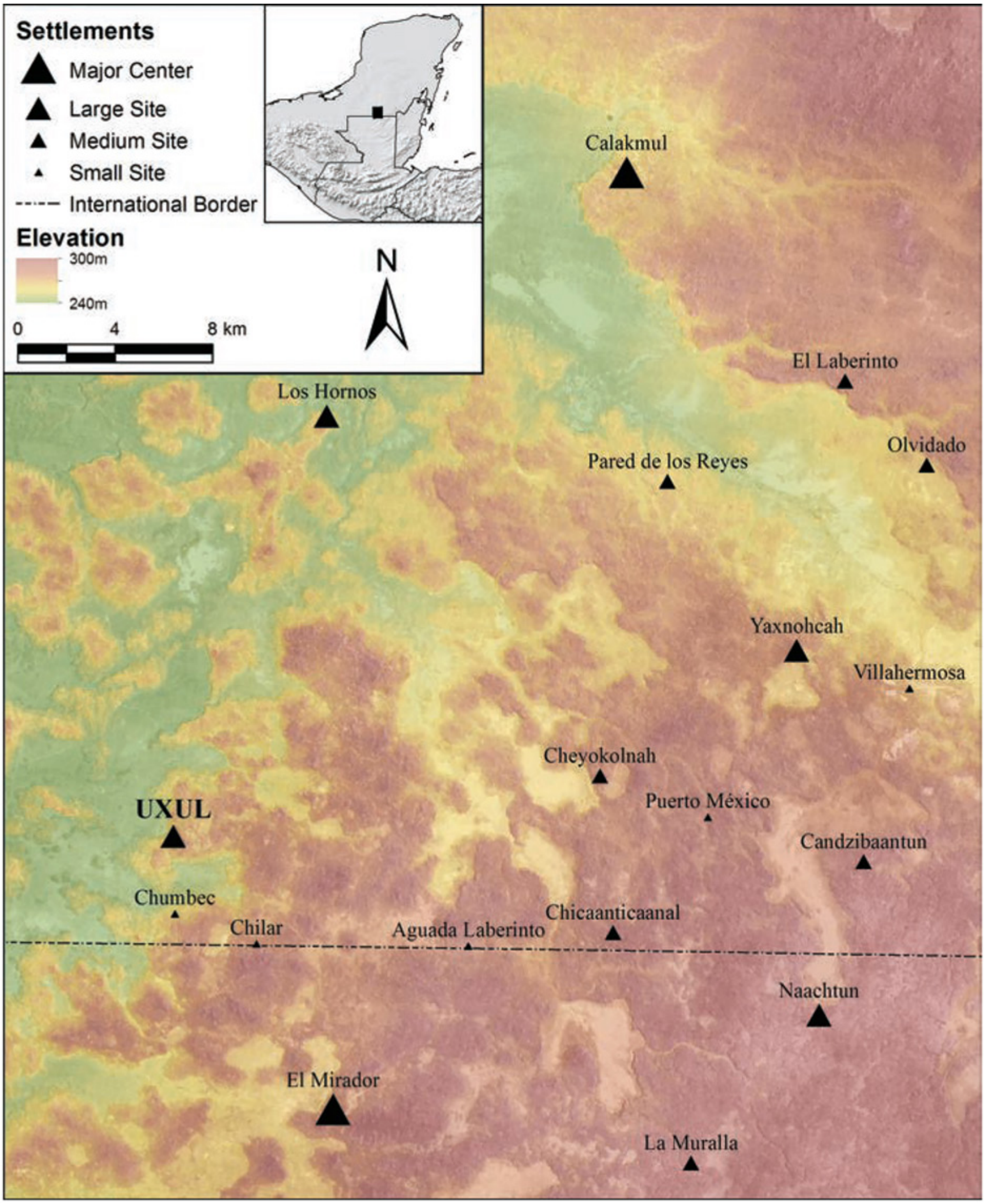

Figure 6.1: Regional Map of the northern Petén and southeastern Campeche (Map produced by B. Volta. Originally published in Grube *et al.* 2012: Figure 1. Reproduced with kind permission of Benjamino Volta).

6.1 History of discovery and research

The site was discovered, examined and mapped in 1934 by Karl Ruppert and John Denison during the third Carnegie Institution of Washington expedition to Campeche (Grube *et al.* 2012: 13; Ruppert and Denison 1943: 74). Ruppert and Denison (1943: 15) also named the site Uxul ("*the end*") "as it was the last one visited during the 1934 season". During their short stay of only nine days, Ruppert and Denison (1943) were nonetheless able to produce a preliminary map of the site that failed to include a number of major structures, but displayed the location of most documented structures with remarkably high accuracy (see Figure 6.2 and compare with Figure 6.3).

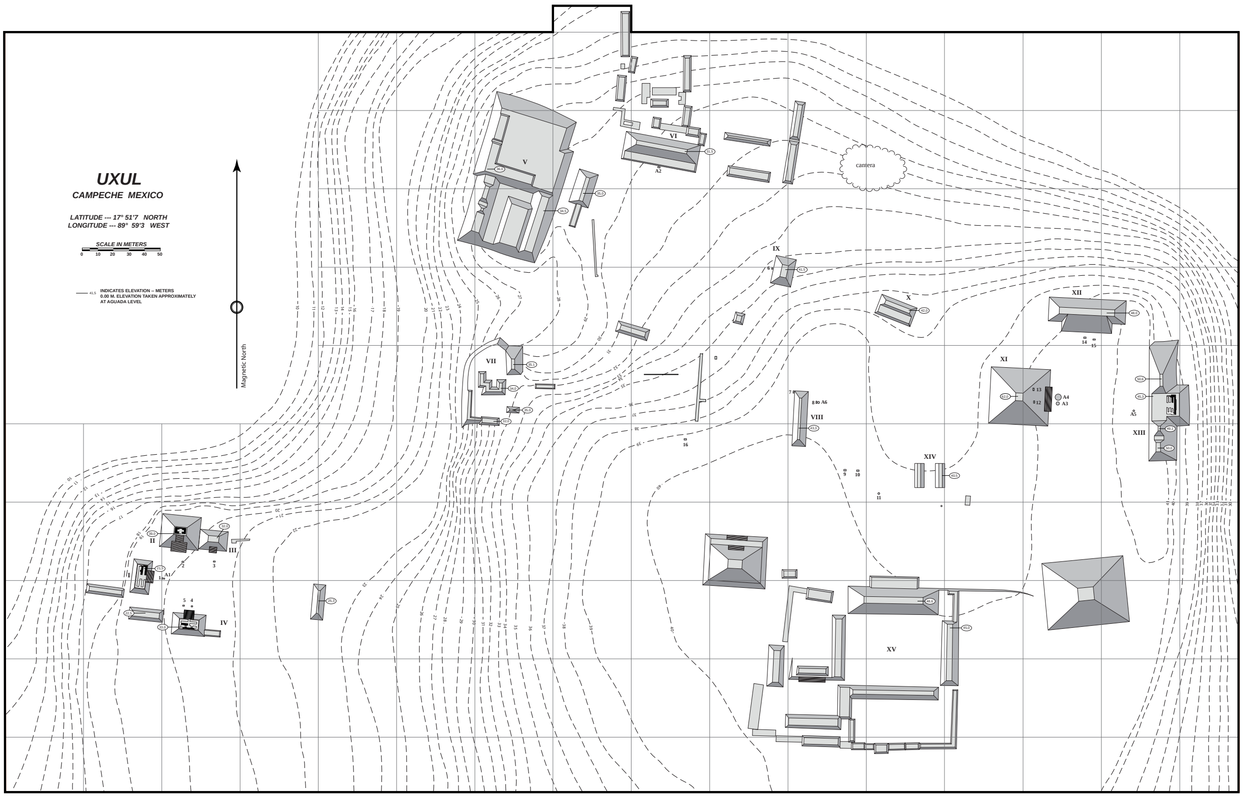

Figure 6.2: Map of Uxul produced by Karl Ruppert and John Denison (source: Ruppert and Denison 1943: Plate 70). Reproduced with kind permission from the Carnegie Institution of Washington.

After Ruppert and Denison published their observations, the exact location of Uxul was unknown to the scientific community for almost 70 years (Grube and Delvendahl 2015: 2). In 2005 however, the site of Uxul was scientifically rediscovered by an expedition led by Iván Šprajc after he identified the site in aerial photos (Grube and Delvendahl 2015: 3; Šprajc 2008: 13). In March 2006, a joint team of Antonio Benavides of the Centro INAH Campeche, Nikolai Grube, Iken Paap and the author (all from the University of Bonn), as well as a group of Mexican workers returned to Uxul in order to record some of the architectonic structures not recorded by Ruppert and Denison.

In 2007, Nikolai Grube, Iken Paap, and Antonio Benavides along with Margit Dauner from the department of archaeological investigation of Basel, Switzerland, carried out an extensive topographic survey of Uxul's central portion that resulted in the first updated map of the site (see Figure 6.3). The system of fixpoints (datums) defined in this field season was also used as a reference for the measurements in all subsequent mapping processes. During this field season, the team was able to identify a large number of previously unknown architectonic groups (Grube and Paap 2008).

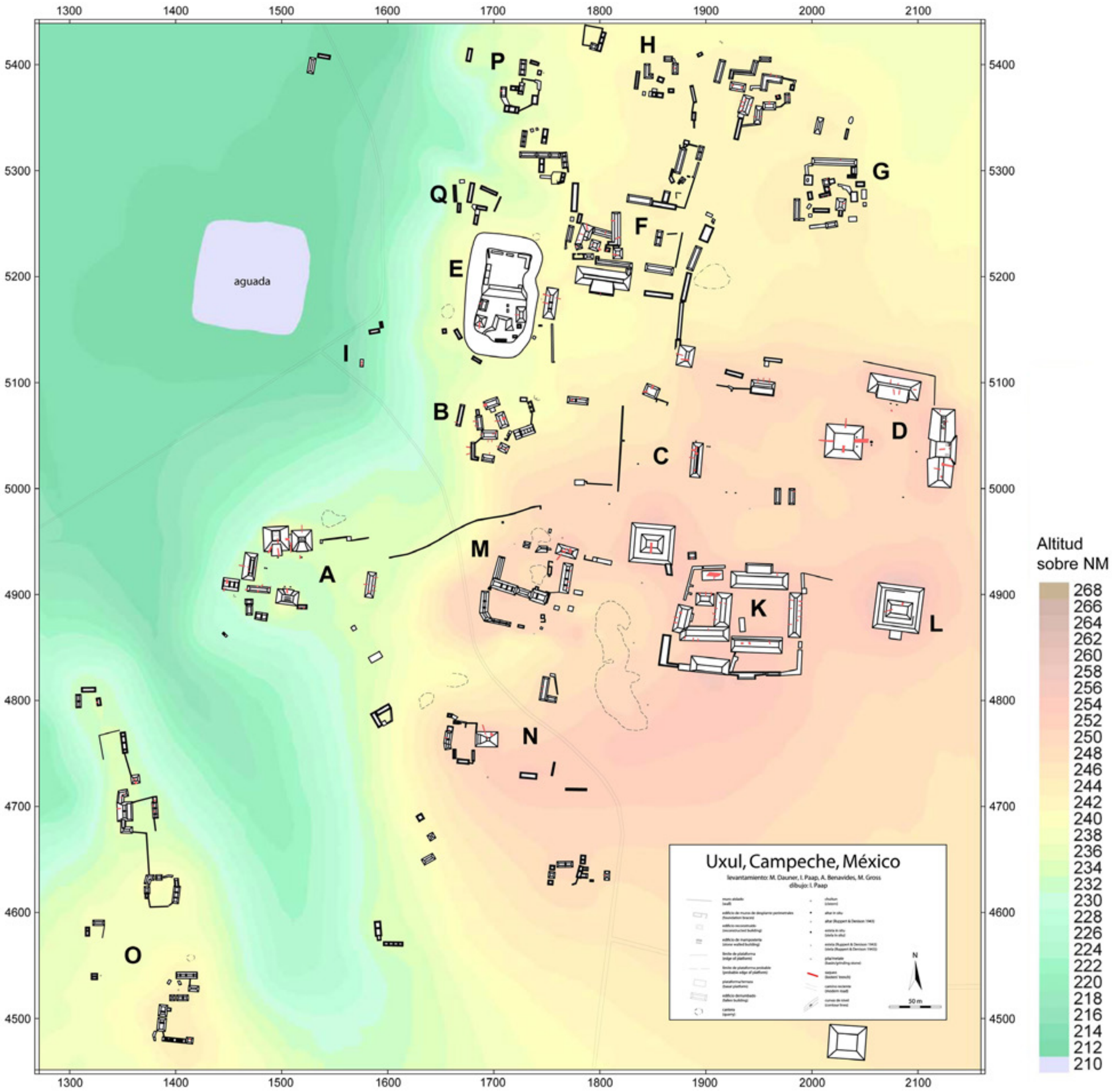

Figure 6.3: Map of Uxul generated during the survey in 2007 (Map produced by Iken Paap for the Uxul Archaeological Project. Orginally published in Grube and Paap 2008: Figure 4. Reproduced with kind permission of Iken Paap).

In 2009, the first archaeological excavations of the site began. These were carried out in collaboration with the Mexican Institute of Anthropology and History (INAH) and under the general direction of Prof Dr Nikolai Grube. Altogether, seven field seasons were conducted between 2009 and 2015.

During the 2009 and 2010 field seasons, Dr Iken Paap held the position of the field director of the Uxul Archaeological Project. From 2011-2015, the position was held by Dr Kai Delvendahl. From 2009-2013, Dr Antonio Benavides Castillo of the Centro INAH Campeche was the Mexican co-director of the project. Throughout the entire duration of the project, funding was provided by the German Research Foundation (DFG).

Over the course of these seven field seasons, the original map of 2007 was gradually complemented by a number of researchers. During the 2009 field season, the topographic survey focused on the northeastern section of the site and was carried out by the author and Sven Bayer from the University of Bonn. This process also led to the discovery of the Aguada Oriental, which had previously been unknown. In 2010, the topographic survey focused on the eastern section of the site and was carried out by the author, Sven Bayer and Benjamino Volta of the University of California, San Diego. During the 2011, 2012, and 2013 field seasons, the topographic survey was carried out by Benjamino Volta. This process led to the discovery of a large number of additional architectonic groups and a better understanding of the local topography and the settlement patterns of Uxul's pre-Hispanic inhabitants.

6.1.1 Research questions of the Uxul Archaeological Project

The goal of the project was to investigate the expansion and disintegration of hegemonic power in the Maya area, concentrating in the core area of the Maya Lowlands (Grube and Delvendahl 2011: 66; Grube *et al.* 2012). As an example for the overarching question, the medium-sized Maya city of Uxul was chosen in order to analyze the effects of its loss of political autonomy. The data gathered during the seven field seasons indicate that Uxul was under the hegemonic power of the regional capital Calakmul, one of the largest Maya cities of the Lowlands and seat of the influential Kaan dynasty (Grube and Delvendahl 2015: 1). Furthermore, the data gathered in Uxul also suggest that Calakmul's hegemony did not only affect the royal class and the high-ranking elites, but all strata of the local society. Therefore, the Uxul Project was interested in the extent to which the transformations in the political structure and the ruling system affected the society in general and how the different social strata were affected by these processes (Grube an Delvendahl 2015: 1). In this context, the Uxul project was focused on two main aspects:

(1) A refinement of the city's chronology in order to analyze the processes of centralization and disintegration of hegemonic states. In order to accomplish this objective, the thorough archaeological excavation of architectonic structures from different complexes of the site were used to produce a micro-chronology of the different architectonic phases, which could also be correlated with historic data.

(2) The investigation of the effects of Uxul's integration into the hegemonic rule within the different social strata. To this end, the excavations were initially concentrated on medium-sized residential areas located between the residential areas of the elite and the commoner population. On this basis, further excavations were carried out in the residential areas of the elite, the ruling elite and the palace complex (Delvendahl and Grube 2011; Grube and Delvendahl 2011; Grube *et al.* 2012).

6.1.2 Settlement patterns

Thanks to the intensive topographic surveys, the Uxul Archaeological Project was able to develop a fairly deep understanding of the general topographic conditions and the extension of the settlement, which is spread over a series of three neighboring hilltops surrounded by inner bajo habitats (Grube and Delvendahl 2015: 1; see Figure 6.4). These hilltops are marked by fairly level surfaces ranging between 250 and 270 m above sea level and are situated at an average of 30 m above the surrounding terrain marked by the inner bajos (Grube *et al.* 2012). As Figure 6.4 indicates, the relatively level surfaces of these hilltops are cut by a number of *corrientales* that drain runoff toward less elevated areas. In this respect, the drainage characteristics of the local topography are quite similar to those of Tikal (Silverstein *et al.* 2009: 50), as the discharge rates along the slopes of Uxul are surprisingly low. Figure 6.4 also indicates that the deepest of these *corrientales* is the northern *corriental*, which forms a steep canyon and thus creates a pronounced topographic division between the central and the northern hilltops of Uxul (Grube *et al.* 2012: 14).

At the current state of research, a total of 77 architectonical groups with 758 structures have been mapped within the site that originally had an extension of 5 km^2 (Grube and Delvendahl 2015: 1; Grube *et al.* 2012: 20). Furthermore, the topographic survey and archaeological excavations have resulted in the location of more than 110 chultunes. Based on these results, it has been estimated that Uxul had a

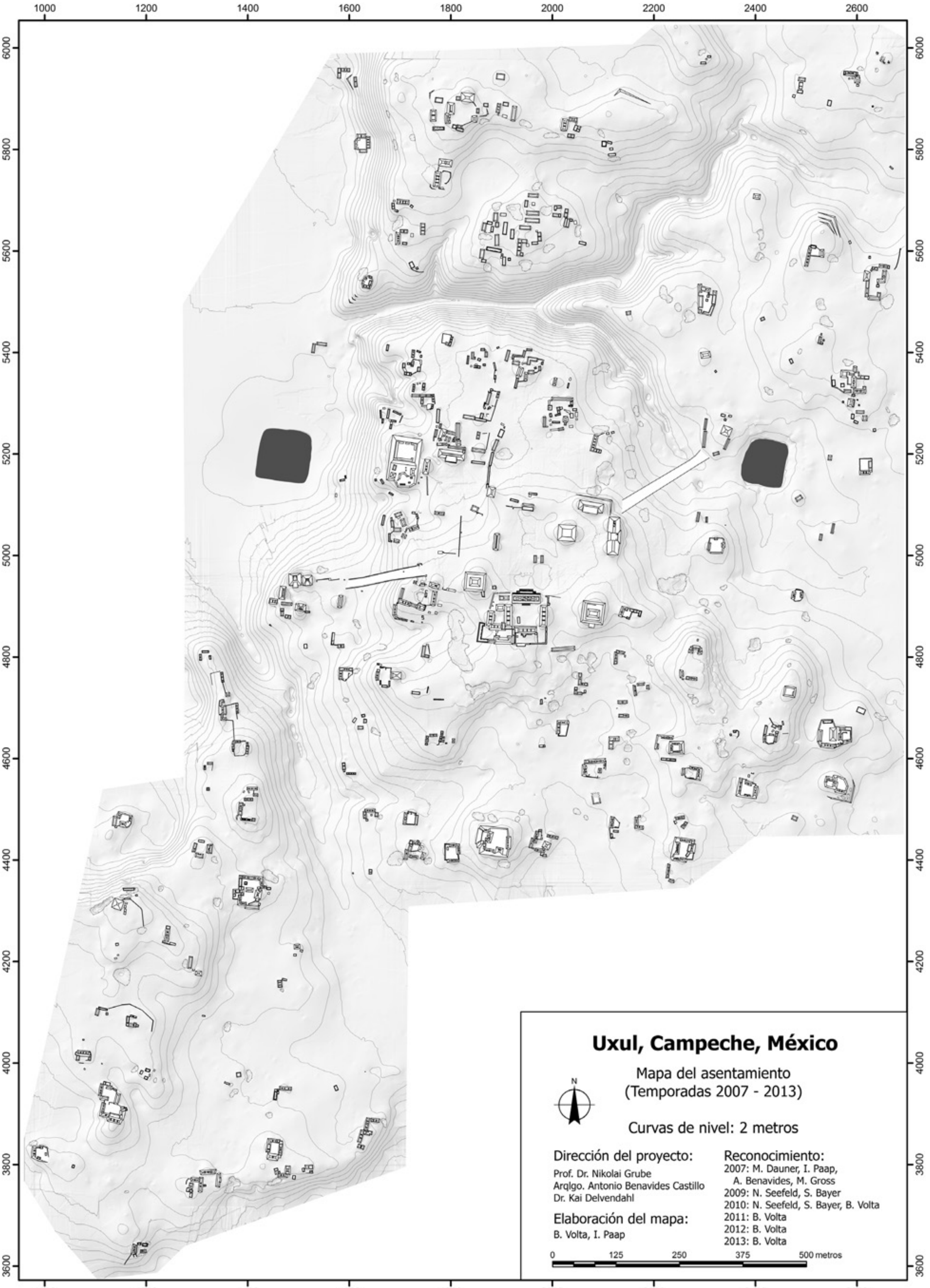

Figure 6.4: Map of Uxul (Source: N. Seefeld). Map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

population of approximately 5,000-7,000 people[177] in pre-Hispanic times (Grube and Delvendahl 2015: 2; Grube *et al.* 2012: 20).

For the most part, the distribution of the residential structures in Uxul indicates a general principle in Maya architecture – the preference for elevated terrain. This pattern becomes apparent in the general lack of architectonical structures in sloped areas, or areas of low elevation (see Figure 6.4). Most of all however, it is indicated by the fact that the highest density of occupation can be found in the site core of the central hilltop. Although there are some smaller residential structures in low-lying areas, larger architectonic assemblages are clearly associated with elevated portions of the site.

To the west and the east, this central hilltop is flanked by the two reservoirs: the Aguada Occidental to the west and the Aguada Oriental to the east (see Figure 6.4). Important elements of the infrastructure are the two sacbe'ob emanating from the site core. As Figure 6.4 indicates, the western sacbe, named Ruppert sacbe, features a length of 150 m and leads from the western edge of the main plaza to Group A (Grube *et al.* 2012: 17; Haug 2010). The eastern sacbe, named Denison sacbe, begins in the northeastern edge of Group D and extends 200 m to the northeast where it connects to the southern edge of Group R and thus creates a formal connection to the Aguada Oriental (see Figure 6.4). The location of the two aguadas and the orientation of the two sacbe'ob create a fairly symmetrical east-west layout of Uxul's site core that may have been partially intended by the planners of the building programs.

The available chronological information suggests that the site was already colonized during the Late Preclassic and continued to be occupied into the early Terminal Classic (Grube *et al.* 2012). However, Uxul's political and demographic climax was during the 7th and 8th centuries AD. The results of the excavations indicate that before losing its autonomy during the expansion of Calakmul, Uxul was the seat of an independent royal dynasty that erected a number of stelae in the plaza of Group A (Grube and Delvendahl 2015: 2). By the mid 7th century however, Uxul obviously fell under the ruler of the Kaan dynasty of Calakmul (Grube *et al.* 2012: 23). According to Grube *et al.* (2012: 23), the "overlordship of Calakmul is most obvious during the reign of Uxul's King Muyal Chaak ("Cloud Chaak") who acceded to power on April 11, 660 AD." The most obvious evidence for Calakmul's domination of Uxul comes from a series of hieroglyphic panels found in the stairways of Structure K2, which display the kings of the Kaan dynasty in the ballgame (Grube *et al.* 2012: 26). These hieroglyphic panels bear dates of 695 and 705 AD (Grube *et al.* 2012: 26).

All of the available chronological data and the observations made during excavations suggest that the occupation of Uxul originated along the eastern edge of the Aguada Occidental (Grube *et al.* 2012: 27). This is hardly surprising given the fact that the earliest inhabitants were necessarily dependent on a natural water source for permanent settlement. In the ensuing centuries, a series of residential structures was built on all three defined hilltops of Uxul. The climax of occupation and building activity occurred during the Late Classic Period (Grube *et al.* 2012: 44). However, around 750 AD, the city experienced a tremendous decline. This is indicated by the fact that only 1% of all ceramics in Uxul belong to the Terminal Classic Period (Grube *et al.* 2012: 37).

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[177] The calculation of Uxul's pre-Hispanic population is based on an average of 5 inhabitants per structure (Grube *et al.* 2012: 20).

6.1.3 Topographic location of Uxul's hydraulic features

In the hitherto surveyed landscape, three major hydraulic features were identified: Aguada Occidental (1), a feeding channel to the Aguada Occidental (2) and the Aguada Oriental (3) (see Figure 6.5). Another smaller water storage feature is the artificial cave in the north of Group E, which received a thorough archaeological investigation in 2013 and 2014 (see Figure 6.5). The two aguadas are situated to the west and east of the site core. Surprisingly, these reservoirs do not only share the same size, form and extension, but they are also situated on the same north-south axis. It therefore appears that the two reservoirs served as the eastern and western boundaries of the settlement since the density of structures markedly drops off to the west of the Aguada Occidental and to the east of the Aguada Oriental. The major difference between the two aguadas is that they are located in very different topographic surroundings.

The Aguada Occidental, discovered and first mentioned by Ruppert and Denison[178] (1943: 15), lies to the west of the central hilltop of Uxul in a naturally low elevation section that merges with a bajo further to the west. During the survey campaign of 2007 and during the 2012-2015 field seasons, standing water was still visible in the aguada during the dry season. Due to its low elevation, the Aguada Occidental exhibits an extensive catchment area and is fed with substantial amounts of runoff through numerous corrientales. It has an extension of approximately 100 x 100 m and is perennially overgrown by shoulder-high sedge vegetation (Seefeld 2011: 310).

By contrast, the Aguada Oriental, discovered by the author and Sven Bayer in March 2009, sits on the crest of an elevated plain in the northeast portion of the settlement. Due to this location, it exhibits a small water catchment area of at most 4 ha (see Figure 6.5). Owing to these factors, the aguada did not contain standing water during each field season.While the reservoir was entirely dry during the 2009, 2010, and 2011 field seasons, it was water filled during the 2012, 2013, 2014 and 2015 seasons (see Figure 6.6). These observations bear witness to the drastic extent of climatic variations in the Maya Lowlands and their effect on the availability of water during the dry seasons. As Figure 6.6 indicates, the water level during the dry season still showed a depth of approximately 60 cm, despite the fact that the Aguada Oriental was infilled with a 1.10-1.40 m deep layer of vertisol clay (see Chapter 6.2.2).

An interesting peculiarity of the Aguada Oriental is a linear depression 15 m in length in the middle of the southern bank, which apparently served to direct rainfall from the southern catchment area to the interior. In the current landscape, this "canal" features a width of 0.5-4 m (see Figures 6.7a and 6.7c). As mentioned above, the Aguada Oriental is also formally connected to the site center by means of the Denison sacbe, which features a length of 200 m and a width of approximately 20 m (see Figures 6.7a and 6.7b). The aguada has a distinct rectangular shape with a north-south extension of 105 m, and an east-west extension of 95 m (see Figure 6.6).

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[178] Ruppert and Denison (1943: 15) described the Aguada Occidental as follows: „The aguada is large, partially covered with lechuga, and furnishes an ample supply of good water".

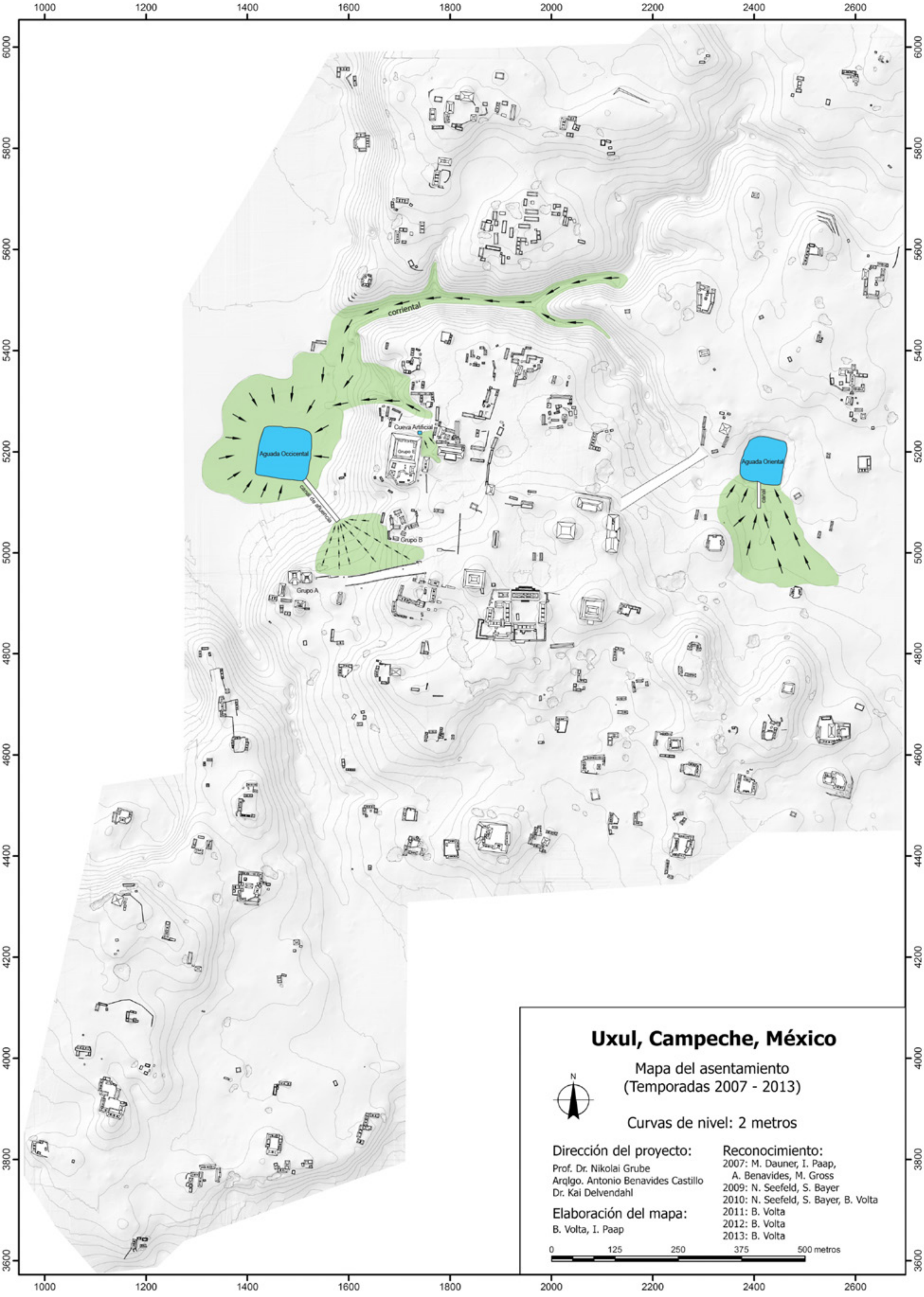
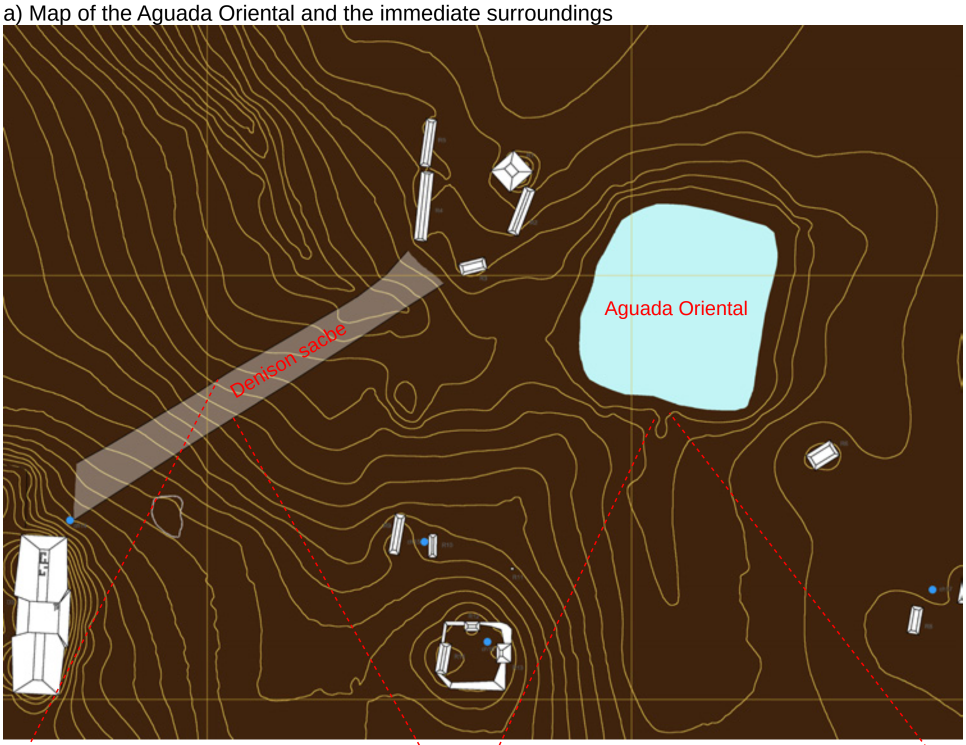


Figure 6.5: Map of Uxul showing the location of hydraulic features and their respective catchment areas (modified from Seefeld 2016: 67, Figure 2). Base map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

Figure 6.6: Uxul, Aguada Oriental with standing water in April 2012 (Photo: N. Seefeld).

The feeding canal to the Aguada Occidental, which was initially observed in 2010, connected the southeastern corner of the Aguada Occidental with the elevated terrain between Groups A and B (see Figure 6.5). Essentially, this feature only consisted of two simple, but parallel stone alignments, which crossed the camp of the archaeological project. Despite its extensive length, the feature could only be verified in archaeological investigations due to its low height. The artificial cave of Group Q, a small reservoir with an extremely small catchment area, is situated at the northwestern margin of Uxul's site core and was obviously interconnected with the residential area in its vicinity.

a) Map of the Aguada Oriental and the immediate surroundings



b) Denison Sacbe, East view

c) Influx canal to Aguada Occidental, North view

Figure 6.7: Uxul, Aguada Oriental in the context of the local topography (Map and Photos: N. Seefeld).

6.2 Results of the archaeological investigation of Uxul's hydraulic features

As pointed out in Chapter 1, the primary aim of this book was the identification of the adaptation strategies that enabled a constant supply of water for Classic Maya polities during the critical dry seasons. In order to systematically reconstruct these adaptation strategies, the third main approach of the author was to analyze the function and development of Uxul's hydraulic system as well as its integration into the local landscape, the urban infrastructure and the different residential areas of the settlement.

6.2.1 Methodology for the archaeological investigation of Uxul's hydraulic system

The methodology used during the investigation of Uxul's hydraulic system consisted of two basic methods:

(1) A topographic survey of the settlement landscape conducted to locate landscape modifications that served to divert and accumulate precipitation.

(2) The archaeological investigation of these landscape modifications/hydraulic features in order to obtain data on the technology, chronology, and social implications of these modifications (Seefeld 2013a: 63).

In order to thoroughly evaluate the adaptation strategies of Uxul's pre-Hispanic inhabitants, the observations of the topographic surveys were continuously consulted for a better understanding of the characteristics of the local landscape and the cultural modifications. In the same way, the increased awareness of the drainage characteristics of the landscape, previous observations of the functionality of hydraulic features in other Maya sites and an increasing understanding for the requirements of Uxul's hydraulic system all played a decisive role in defining the location of specific excavation units.

6.2.1.1 Chronology of the archaeological investigation of Uxul's hydraulic system

The investigation of Uxul's hydraulic system was carried out over the course of six field seasons between 2009 and 2014. However, not all six field seasons were focused entirely on the investigation of hydraulic features.

During the 2009 field season, the author and Sven Bayer were responsible for the topographic survey of the previously unmapped northeastern section of Uxul, which resulted in the discovery of the Denison sacbe and the Aguada Oriental. At the end of the 2009 field season, the Aguada Oriental was archaeologically investigated over a period of ten days by means of two archaeological trenches.

During the 2010 field season, the author and Sven Bayer were also responsible for the topographic survey in the previously unmapped eastern section of Uxul. During the second half of this field season, Benjamino Volta participated in the topographic survey as well. At the end of the 2010 field season, the termination of the mapping process and the particularly dry conditions enabled the author to excavate one archaeological trench in the Aguada Occidental over a period of 15 days.

The 2011 field season was the first field season that was entirely focused on the issue of water supply and enabled the author to carry out an extensive archaeological investigation of the Aguada Oriental. The excavation of this reservoir was carried out over 56 days in collaboration with a team of five excavation workers from the villages of Constitución and Pablo García, Campeche, Mexico – a collaboration that proved to be so fruitful and productive that the same team of workers assisted the author in all successive field seasons. During the 2012 field season, the research focus was on the influx canal to the Aguada Occidental, which had been discovered in the same year. As in the 2011 season, the investigation of this complex feature was carried out over 56 days. The 2013 field season was focused on the identification of potential modifications of Aguada Occidental's watershed, a process that resulted in the discovery of the small reservoir of the artificial cave in Group Q. The archaeological investigation of this feature was carried out over 49 days. As the complexity of the artificial cave did not allow for a complete investigation of this feature, the excavation of this small reservoir was continued in the 2014 field season.

6.2.2 Aguada Oriental

The Aguada Oriental is located on the top of a plateau to the east of Uxul's central hilltop. As the landscape type can be defined as a "well-drained upland area" (see Chapter 2.4), it is obvious that the aguada could not have been formed through natural processes. The Aguada Oriental has a north-south extension of 105 m and an east-west extension of 95 m. Thus, it is the largest culturally modified reservoir in Uxul apart from the Aguada Occidental. Interestingly, no large architectonical groups were located in the vicinity of the reservoir. However, close to the northeastern border of the Aguada lies Group R, a compound of four small platforms and a low pyramid. The Denison sacbe connected the southwestern corner of Group R to the northeastern corner of Group D (see Figure 6.7).

In contrast to the very homogenous vegetation within the Aguada Occidental, the vegetation in and around the Aguada Oriental was marked by three distinct belts of plant associations, which are derived from the differing elevations and the variation of the associated moisture levels (see Figure 6.8a). These are the central zone (1), the transition zone (2), and the outer zone (3).

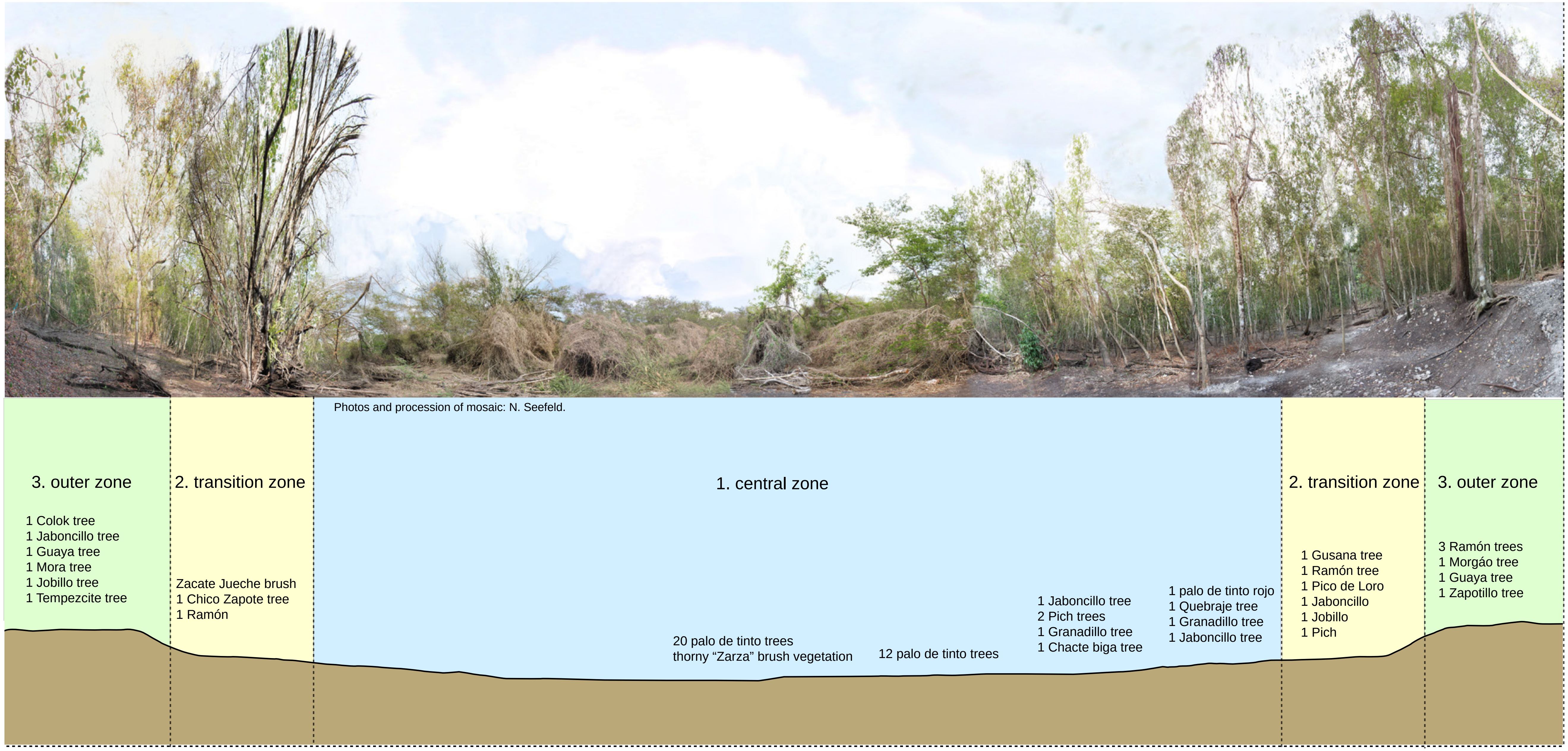
(1) The central zone extends from the reservoir's center to 10 m from the slope of the aguada's embankment. This area is dominated by "palo de tinto" (*Haematoxylum campechanium*) and a shoulder-high brush (see Figures 6.8a and 6.8d). Furthermore, the surface of this central zone is covered by many *Pomacea* snail shells, indicating that the area was saturated with water in recent times (see Figure 6.8.e).

(2) The transition zone extends from a 10 m distance to the embankment to the middle of the embankment. This area features a greater variety of plant species (see Figures 6.8a and 6.8b).

(3) The outer zone extends from the middle of the embankment into the area beyond the aguada. The vegetation within this ring coincides with the general "high bush" vegetation prevailing in the more elevated areas of Uxul (see Figure 6.8a).

In many respects, these different plant associations resemble the vegetation patterns observed in outer bajo landscapes (Jacob 1995: 177; see Chapter 2.4.4). During the 2011 field season, the author determined the composition of these different vegetation associations with the assistance of Daniel Cruz, a resident of Constitución, Campeche, Mexico. In accomplishing this, the author and Daniel Cruz followed the line of excavated trenches and extended it to the north and south. This process resulted in an east profile of the vegetation associations (see Figure 6.8a).

a) Aguada Oriental, Vegetation profile, Photo mosaic



Photos and procession of mosaic: N. Seefeld.

b) Vegetation in the northern transition zone of the Aguada Oriental

c) Brush vegetation in the center of the Aguada Oriental

d) Palo de tinto vegetation in the center of the Aguada Oriental

e) *Pomacea* snail shell in the center of the Aguada Oriental

Figure 6.8: Uxul, Vegetation in the Aguada Oriental (Photos and Graphics: N. Seefeld).

6.2.2.1 Excavations during the 2009 field season

Shortly after the Aguada Oriental's discovery, the primary interest was to gain an understanding of the depth of the washed in sediments and the stratification. To this end, two trenches were excavated within the reservoir. A 4 x 2 m trench in the center of the reservoir and a 2 x 2 m trench close to its northern edge (see Figure 6.9).

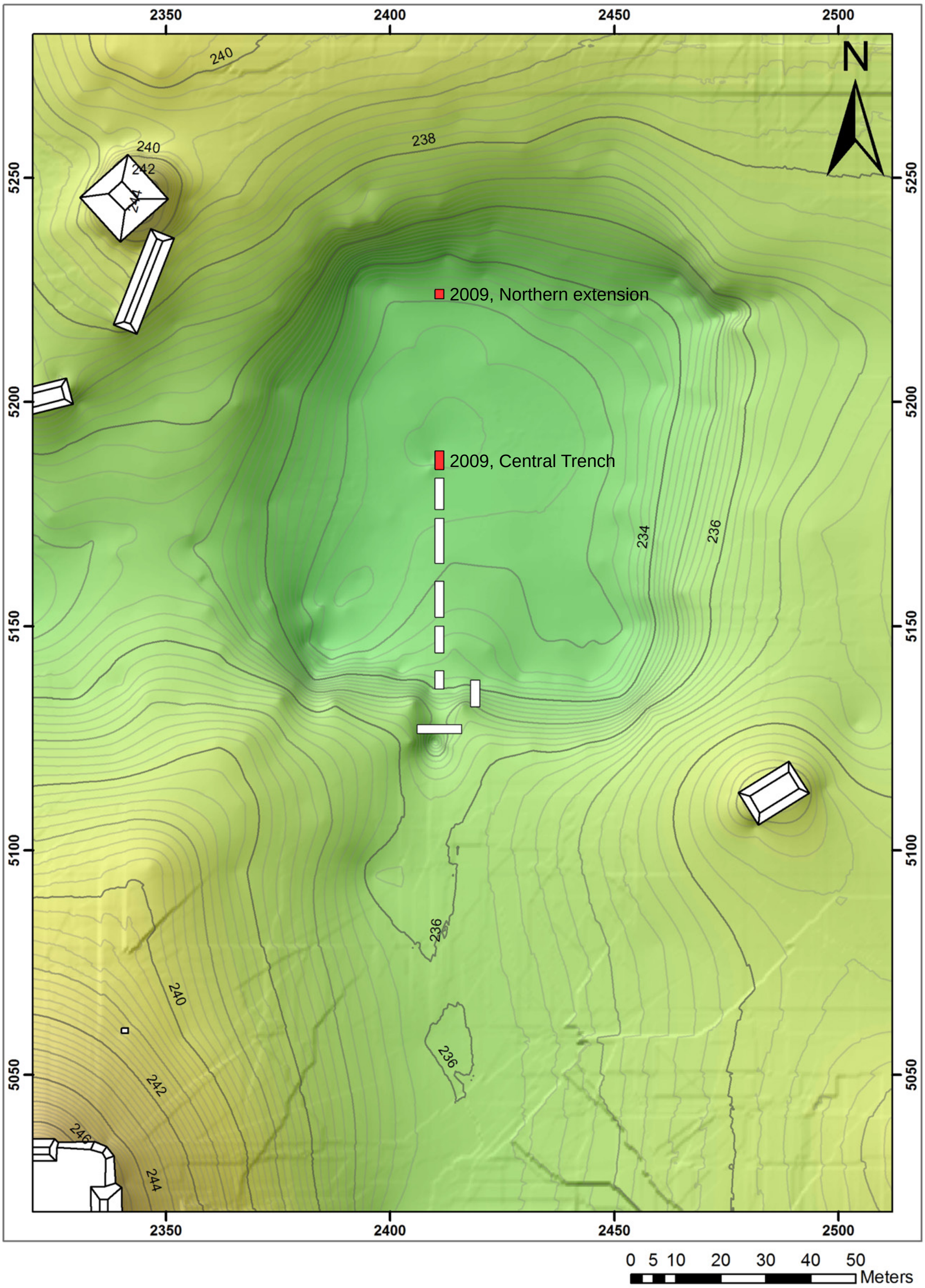


Figure 6.9: Uxul, Aguada Oriental, Location of the trenches excavated during the 2009 field season (Map: Courtesy of B. Volta 2011. Reproduced with kind permission of Benjamino Volta).

After the removal of the humus layer (Lote 700), the excavations in the central trench revealed a fairly uneven surface of a very thick clayey layer (Lote 701; see Figure 6.10b). The uneven character of the surface could easily be identified as the result of expansion and contraction processes that have frequently been observed in inner bajo landscapes (see Chapter 2.4.3.1). Indeed, the later excavations showed that the clay sediment that was washed into the Aguada Oriental shared many similarities with the vertisol clays of inner bajo habitats. The clay (Lote 701) had a very hard and sticky consistency. During the excavation process however, no cultural features could be documented.

a) Central trench of 2009 before excavation

b) Central trench of 2009 after extraction of the humus layer

Figure 6.10: Uxul, Aguada Oriental, Central trench of 2009 before the excavation and after extracting the humus layer (Photos: N. Seefeld).

At a depth of 1.4 meters, the excavations led to the discovery of a homogenous layer of limestone slabs (Lote 702) (see Figure 6.11). The individual stones measured between 8 x 10 cm and 40 x 30 cm. As the gaps between the different stones were very even and no stone superimposed another, it became apparent that these stones had not been piled up as a consequence of natural (e.g. alluvial) processes, but that they had been deliberately deposited by Uxul's pre-Hispanic inhabitants. In some gaps between these stone slabs, a high concentration of ceramic sherds could be observed (see Figure 6.11a). After documenting this "pavement", the stone slabs could be removed.

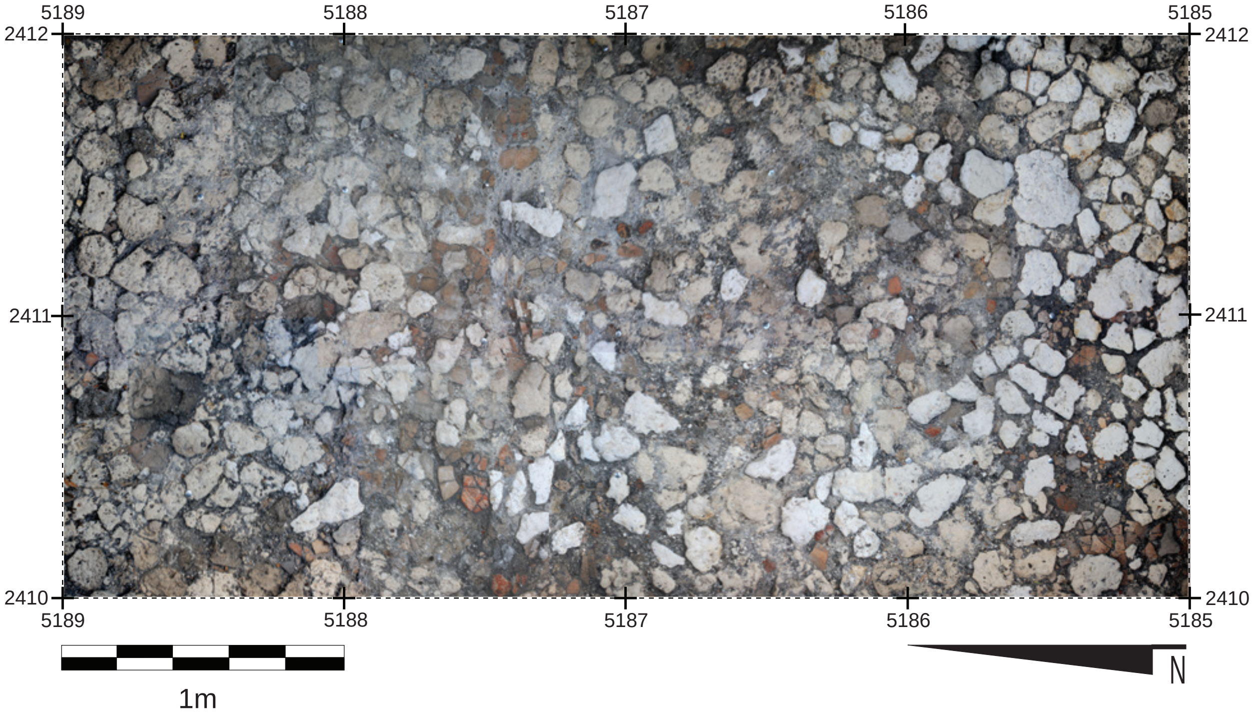


Figure 6.11: Uxul, Aguada Oriental, Central trench of 2009, Photo mosaic of limestone pavement (Photos: N. Seefeld).

During the careful removal of these slabs, an even higher concentration of ceramic sherds (Lote 703) was observed immediately underneath the limestone slabs, which was subsequently exposed as carefully as possible (see Figure 6.12). This even surface covered with hundreds of individual sherds was a unique discovery, which was not only impressive due to the sheer number of sherds, but also due to their careful deposition. During the documentation process, it became apparent that none of the fragments were superimposing each other. This detail showed that these ceramic sherds had not simply been piled up, but deliberately placed next to one another in order to form a tight bond.

Upon closer observation of this surface, also it became apparent that many fragments had actually been broken in situ. Apart from that, the documentation revealed that the builders had selected specific ceramics before depositing them on the ground. The majority of the fragments shows a very low inclination of the vessel walls – in fact, they corresponded to fragments of ancient plates or low bowls. This selection was essential in order to create a preferably even surface.

The desire to create an even surface also became apparent in the next constructional element. Gaps in the ceramic layer (see Figure 6.11c) already disclosed hints of the underlying bedrock. After the documentation and removal of the ceramic layer, the excavations revealed the top edge of the natural bedrock (Lote 704), which had evidently been leveled with stone tools in order to create an even base for the previously mentioned constructional elements (see Figure 6.11b).

The east profile of this trench clearly shows the separation of these two elements (see Figure 6.11d). Furthermore, the homogenous clay deposition above the limestone pavement, and the absence of soil layers between the bedrock and pavement revealed that the builders had evidently removed the natural sediment covering the bedrock surface.

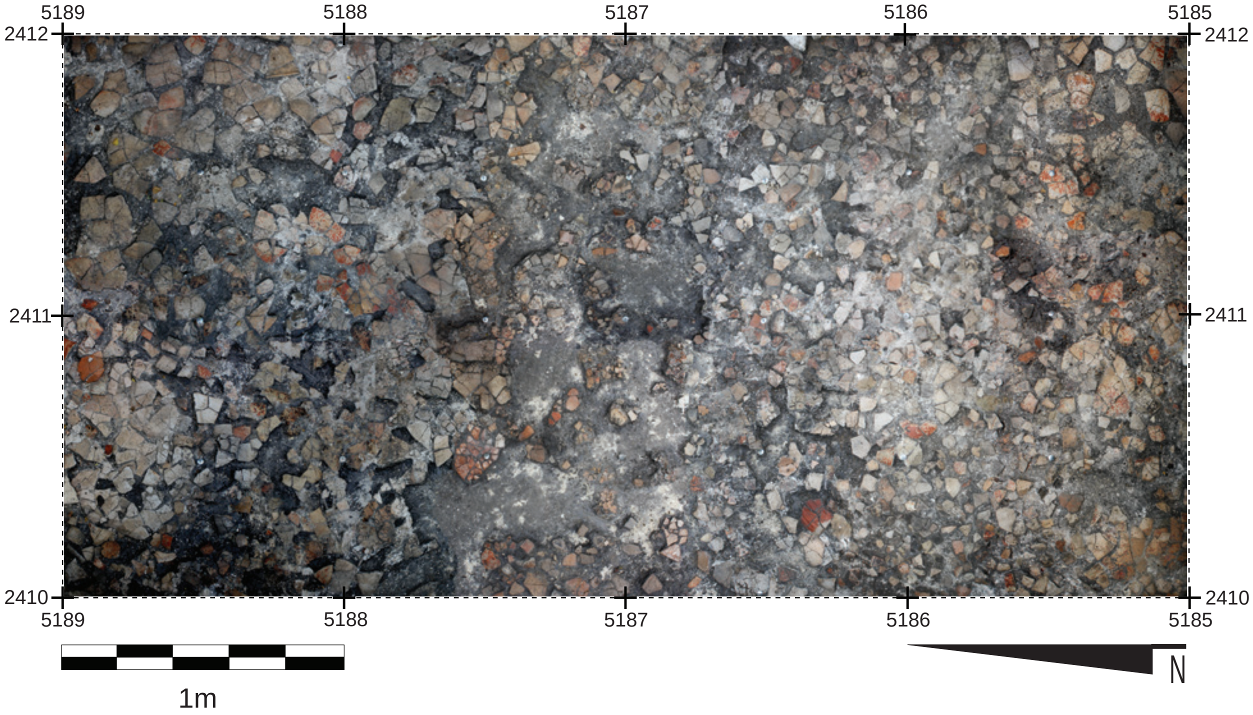
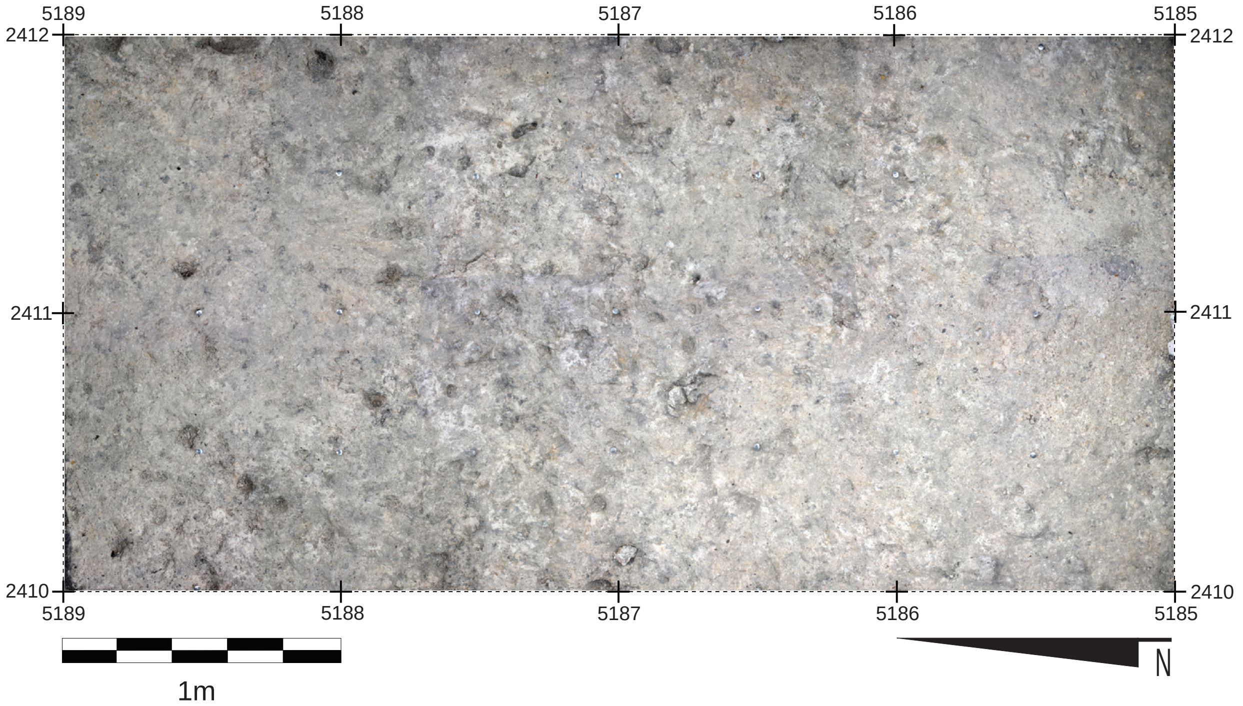


Figure 6.12: Uxul, Aguada Oriental, Central trench of 2009, Photo mosaic of ceramic layer (Photos: N. Seefeld).

a) Bedrock surface, Photo mosaic



b) East profile, Photo mosaic

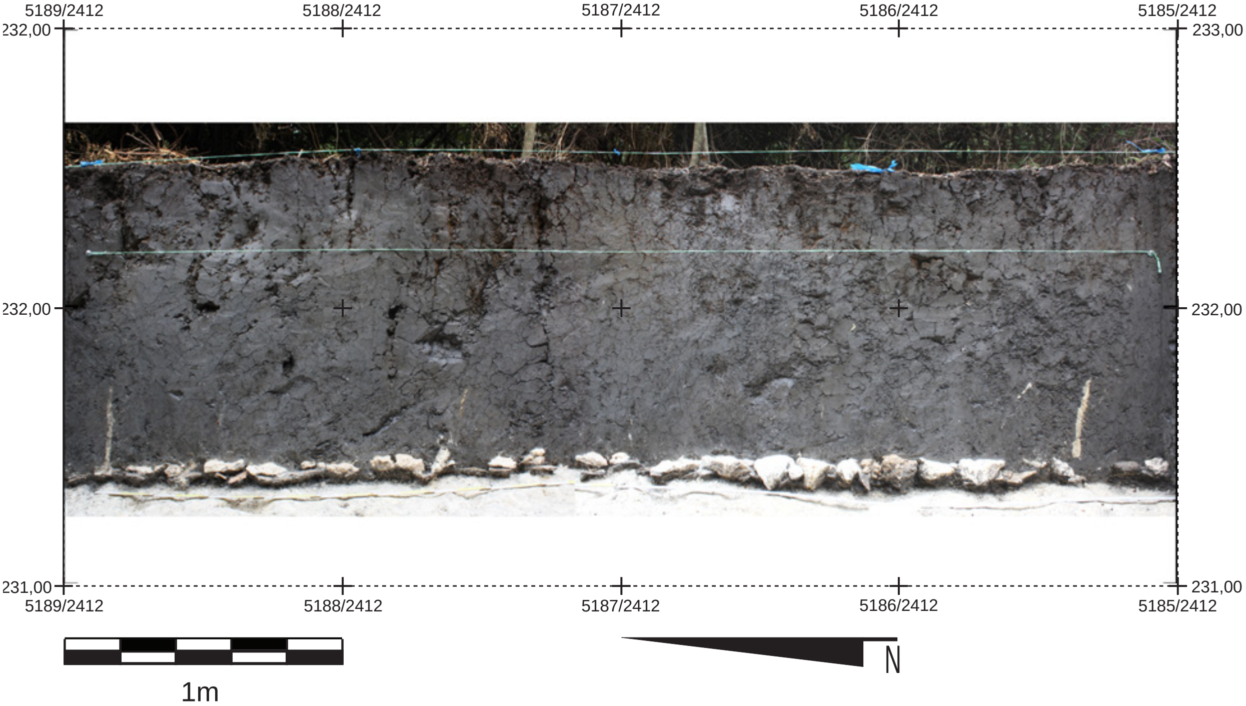
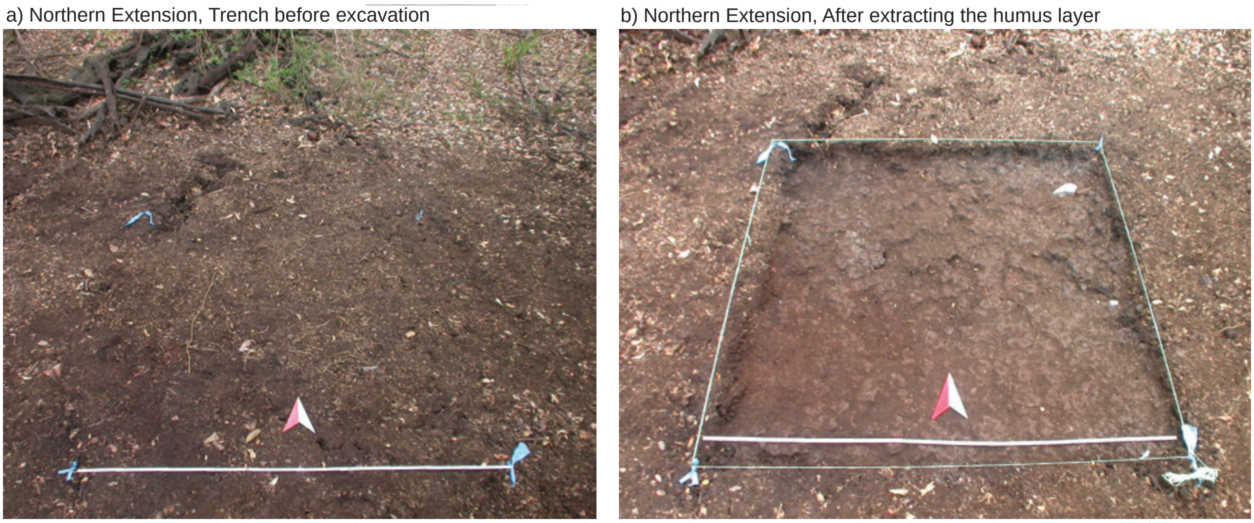


Figure 6.13: Uxul, Aguada Oriental, Central trench of 2009, Bedrock surface and east profile (Photos and Graphics: N. Seefeld).

After exposing the cultural features in the center of the aguada, the interest shifted towards determining whether or not these base modifications had been applied to the bottom of the whole reservoir. Therefore, a 2 x 2 m unit was defined close to the northern border of the reservoir, 34 m north of the central trench (see Figure 6.15a). Due to the slightly higher elevation, the surface of the humus layer (Lote 750) already indicated lower moisture levels (see Figure 6.14a). After the removal of the humus layer, the excavations exposed the same rugged and uneven surface of a vertisol clay layer (Lote 751) that was documented in the center of the aguada (see Figure 6.14b). Just like in the center, no cultural features could be identified in this clay layer.

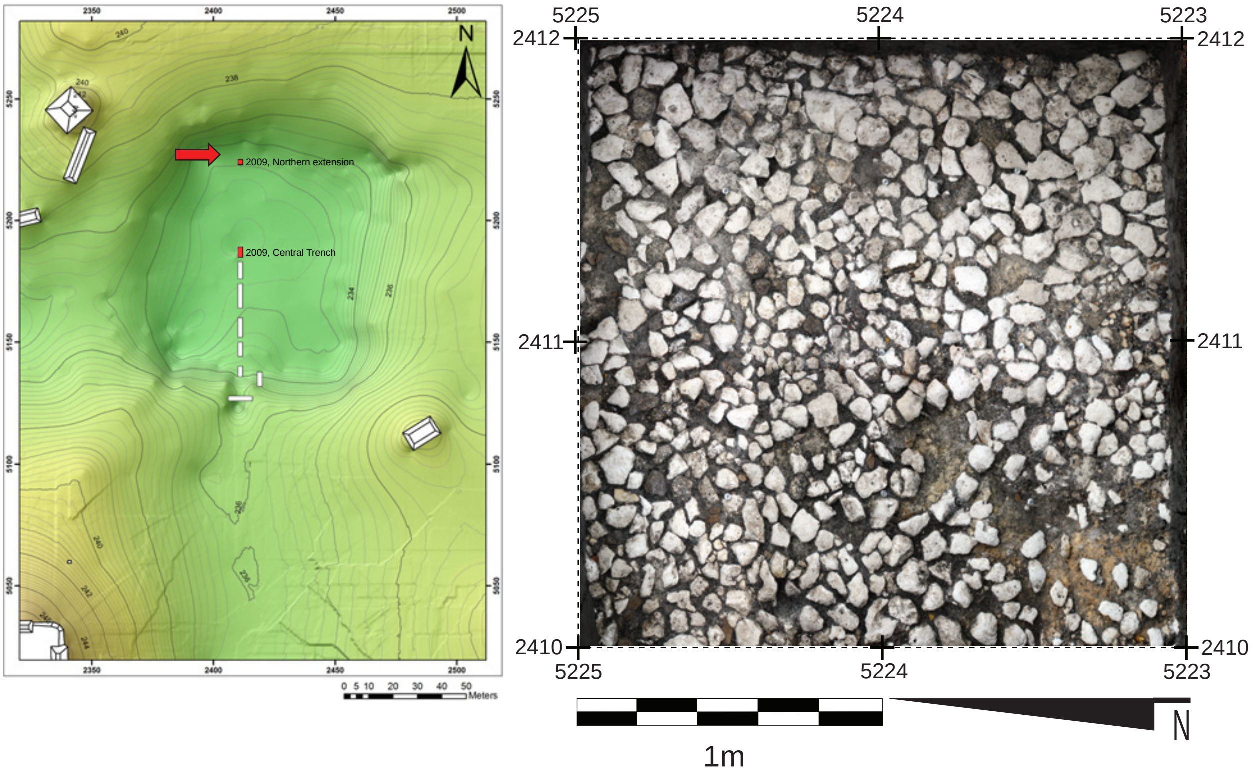
At a depth of 80 cm, however, we exposed a pavement consisting of limestone slabs (Lote 752; see Figure 6.15b). Although this pavement consisted of smaller stones, the general character was more homogenous and denser than the pavement in the reservoir's center. However, no ceramic concentration could be documented underneath this pavement. As the documentation of the pavement's surface indicated, this constructional element sat immediately on the natural bedrock (Lote 753). After documenting and removing the pavement, the ongoing excavations revealed the top edge of the natural bedrock (see Figure 6.15d). Similar to the center of the reservoir, its surface has been artificially leveled with stone tools. However, only a handful of ceramic fragments could be documented on its surface.

Just as in the reservoir's center, the east profile of this northern extension clearly showed the constructional elements (see Figure 6.15c). This made it clear that the construction process and the composition of the base modification of the center were almost identical to the area close to the northern edge of the reservoir. However, the prominent difference was that no ceramic layer could be documented in the northern extension. Another trait that could not be discerned by surface observation is the clear inclination of the pavement towards the south. As Figure 6.14f indicates, the pavement shows a level difference of 20 cm over the length of the 2 m profile. Furthermore, the east profile also shows the drier conditions at the northern border of the reservoir that were already observed on the surface. The broad and long fissures visible in Figure 6.14f can be identified as gilgai formed during the desiccation process of the vertisol clay within the Aguada Oriental. Due to the higher concentration of moisture in the center of the aguada, the fissures are less pronounced than on the northern margins.


a) Northern Extension, Trench before excavation

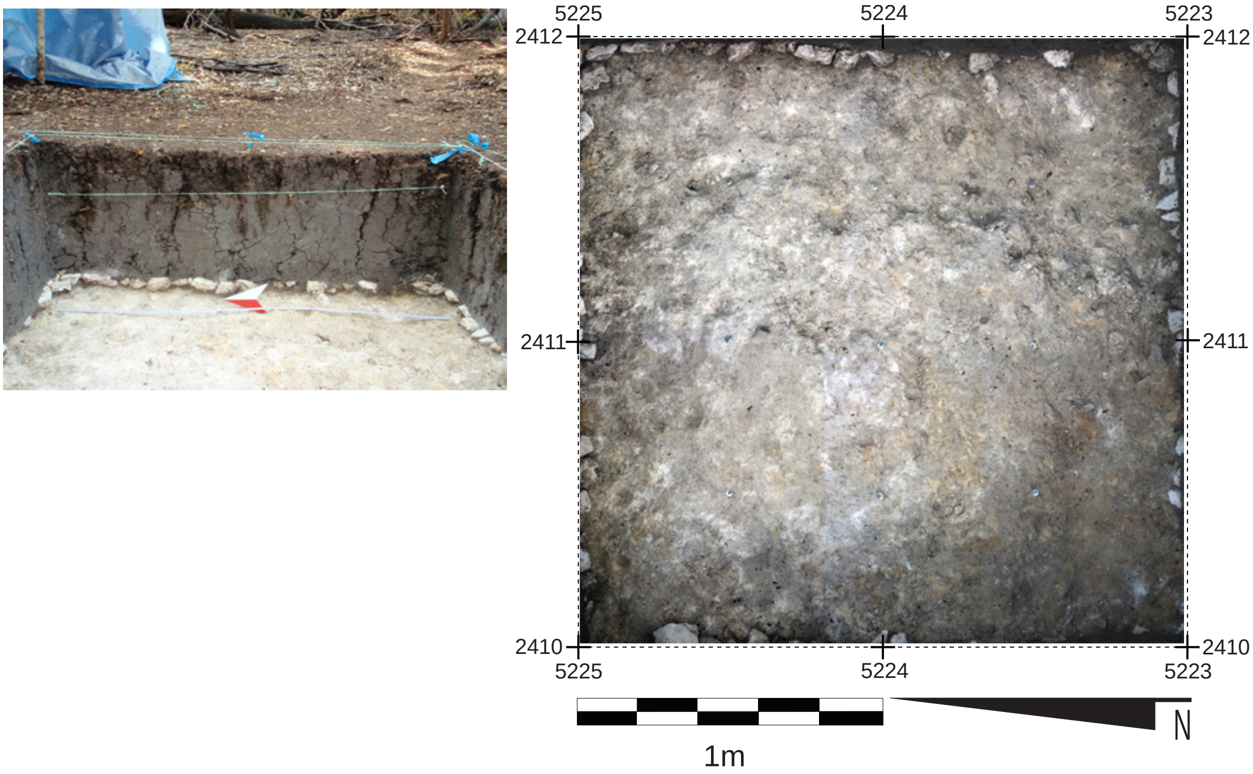
b) Northern Extension, After extracting the humus layer

Figure 6.14: Uxul, Aguada Oriental, Northern extension before the excavation and after extracting the humus layer (Photos: N. Seefeld).



a) Map showing the location of the northern extension

b) Northern Extension, Limestone pavement



c) Northern Extension, East profile

d) Northern Extension, Bedrock surface

Figure 6.15: Uxul, Aguada Oriental, Northern extension. (a) (Map: Courtesy of B. Volta 2011. Reproduced with kind permission of Benjamino Volta); (b-d) (Photos: N. Seefeld).

6.2.2.2 Excavations during the 2011 field season

The excavations of the 2009 field season provoked a number of questions regarding the construction methods and the extension of the base modifications at the bottom of the Aguada Oriental. Therefore, the excavations of the 2011 field season were planned in order to explain a number of these open questions.

A primary aim was to determine the function of the ceramic layer at the reservoir's center and verify if it covered the entire level base of the aguada. Another open question concerning the base modification of the Aguada Oriental was whether the limestone pavement covered the entire base of the reservoir. Considering the general technical layout of the reservoir, the author was also interested to determine in which manner the sloped border areas had been modified or protected in order to circumvent erosion. In order to gain a better understanding of the incorporation of the reservoir into the settlement landscape, the author also wanted to investigate if the southern influx canal of the aguada featured any form of formal construction or sophisticated cultural modifications. Last of all, the author aimed to determine the overall storage capacity of the reservoir and thus reconstruct its importance for the pre-Hispanic inhabitants of Uxul.

Ever since the planning process of the 2009 excavations, importance was given to the option of being able to extend the 2 x 4 m trench towards the north and south in future excavations. Consequently, the central trench of 2009 was planned in such a manner that an extension towards the north and south would also meet the southern influx canal (see Figure 6.16). This anticipatory planning enabled the positioning of the 2011 excavations in such a way that they would both cut through the southern influx canal and create an almost uninterrupted east profile of the Aguada Oriental (see Figure 6.16). The general purpose of this planning was to allow for a calculation of the total storage capacity of the reservoir. In order to advance the understanding of these open questions, seven distinct trenches were planned in preparation for the 2011 field season (see Figure 6.16). Trenches 1 to 5 were situated upon the same axis as the trenches excavated during the 2009 field season and formed a line from the reservoir's center to its southern margin. Trench 6, which perpendicularly cuts the southern influx canal, was excavated in order to create south and north profiles encompassing the canal's basin, its embankment and the upper edge of the current level of the surrounding terrain. Trench 7, which runs perpendicular to the aguada's southern embankment, was planned in order to create a profile encompassing the aguada's basin, the transition to the sloped embankment, the sloped embankment and the upper edge of the current level of the surrounding terrain.

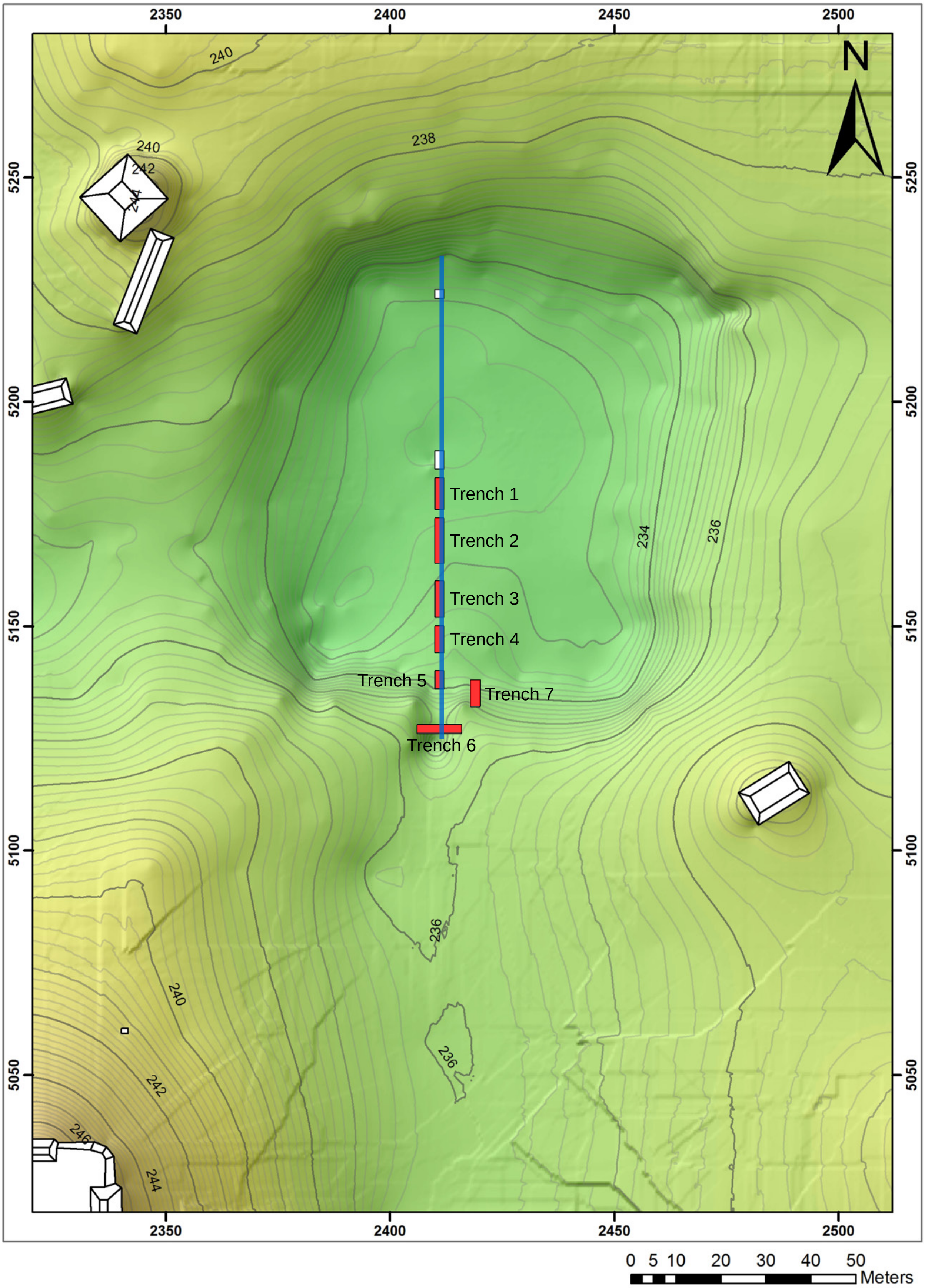


Figure 6.16: Uxul, Aguada Oriental, Location of the trenches excavated during the 2011 field season (Map: Courtesy of B. Volta 2011. Reproduced with kind permission of Benjamino Volta).

Trench 1

Trench 1 measures 2 x 7 m, encompasses the quadrants 5178 to 5182 and is situated two meters south of the central trench of the 2009 field season (see Figure 6.17d). As was expected, the features documented during the excavation resembled those of the central trench of 2009 in almost every detail:

At a depth of 130 cm, a homogenous pavement of limestone slabs was documented (see Figures 6.17a and 6.17b). The stones featured almost uniform dimensions of 10 x 15 cm and their top edges formed a surface without marked height differences. In the entirety of Trench 1's exposed surface, it became apparent that the stone slabs had been deposited intentionally in order to create an even and closed surface. This intention is apparent in the fact that the gaps between bigger stones had been carefully filled with smaller stones. The smooth surface of the limestone bedrock indicates that the available stone material had been carefully selected before its deposition. Furthermore, residues of a very hard stucco matrix were observed in the remaining seams, which had been applied in order to seal the pavement. In the few gaps of this pavement not filled with smaller stones, a dense concentration of ceramic sherds was observed. Generally, this pavement showed a higher quality than the pavement of the central trench of the 2009 field season (see Figure 6.17a). In the quadrants of 5179-5179/2410-2411, some of the stone slabs featured larger dimensions of up to 30 x 50 cm. Another peculiarity was an obvious linear patterning of these limestone slabs at the transition between quadrants 5178 and 5179. While the remaining stones of Trench 1's pavement were assembled without any recognizable pattern, two parallel lines of larger stone slabs could be documented in the center of the trench (see Figure 6.17a). During the extraction of the limestone slabs, it became apparent that they all had a uniform thickness of 4-6 cm. Furthermore, all stone slabs showed processing marks on their upper and bottom sides, which proved that these slabs had been produced specifically for this purpose and had been cut with a uniform thickness.

Underneath the pavement of limestone slabs, excavations revealed a dense concentration of ceramic sherds, which had apparently been deposited intentionally (see Figures 6.17c, 6.17e and 6.17f). A close examination of the deposit showed that many of the larger ceramic fragments had apparently broken in situ. Moreover, parts of vessels with only slightly inclined walls had been deposited for the most part. This pattern once again displayed the intention to create an even base for the overlying pavement. Although the ceramic layer was generally distributed rather densely, some gaps of up to 20 x 20 cm could be documented (see Figure 6.17e).

None of the sherds in the exposed deposition superimposed another. Instead, each individual sherd had been deposited individually. Since these ceramic sherds could no longer be moved after their deposition and covering them with a pavement, the builders of this feature had intentionally left gaps in the deposition.

Interestingly, the deposition of ceramic fragments features a 2 m long and 10 cm wide gap running east to west, which was located precisely underneath the two parallel lines of limestone slabs (see Figure 6.17e). Furthermore, it could be observed that the ceramic layer to the north of this linear gap was 8 cm lower than the ceramic layer to the south. A more detailed examination revealed that the gap created a step-like height difference. Interestingly, both areas featured entirely even surfaces. However, this gap consisted of a pronounced linear bulge in the bedrock surface with a height of 6 cm and a width of 8 cm. This finding clarifies that the builders wanted to avoid any inclination of the deposited sherds. Generally, this observation stands in contrast to the overlying limestone pavement, where a mild inclination of the stone slabs was obviously not perceived as problematic by the builders.

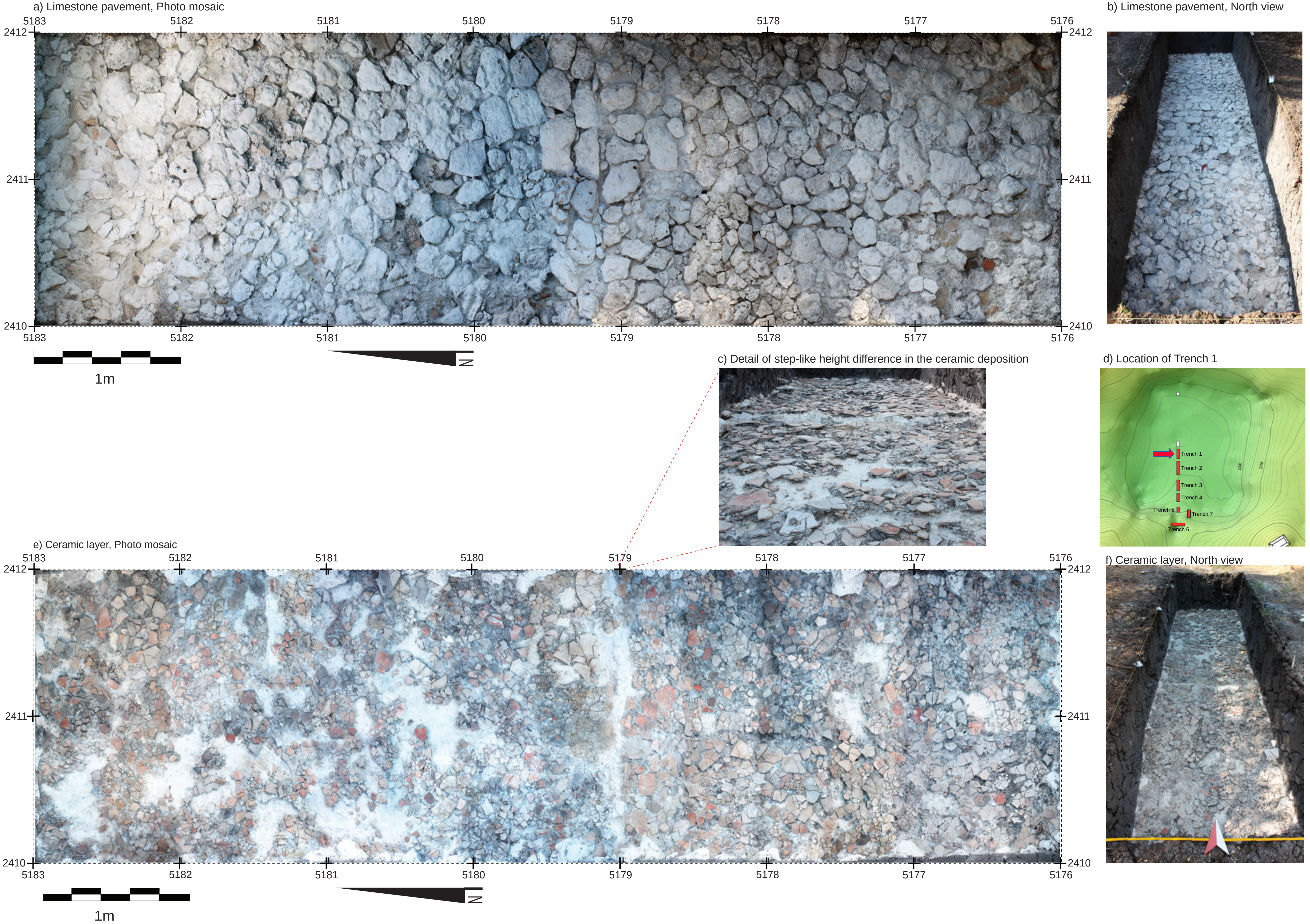
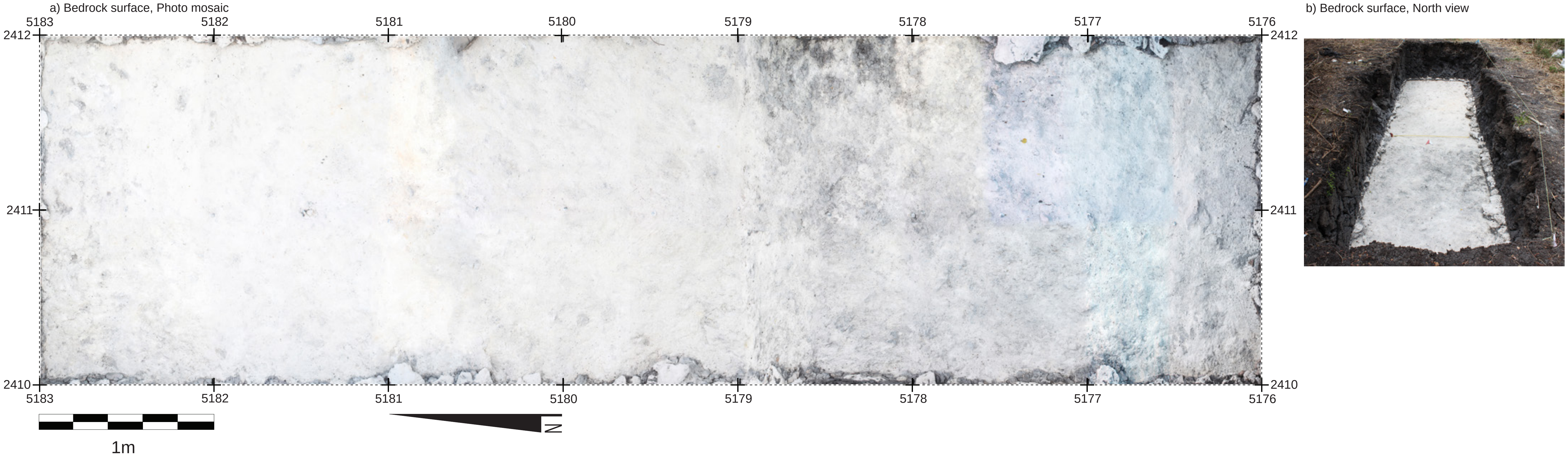


Figure 6.17: Uxul, Aguada Oriental, Trench 1, Limestone pavement and ceramic layer. (a-c) (Photos and graphics: N. Seefeld); (d) (Map: Courtesy of B. Volta. Reproduced with kind permission of B. Volta); (e-f) (Photos and graphics: N. Seefeld).


a) Bedrock surface, Photo mosaic

b) Bedrock surface, North view

c) East profile, Photo mosaic

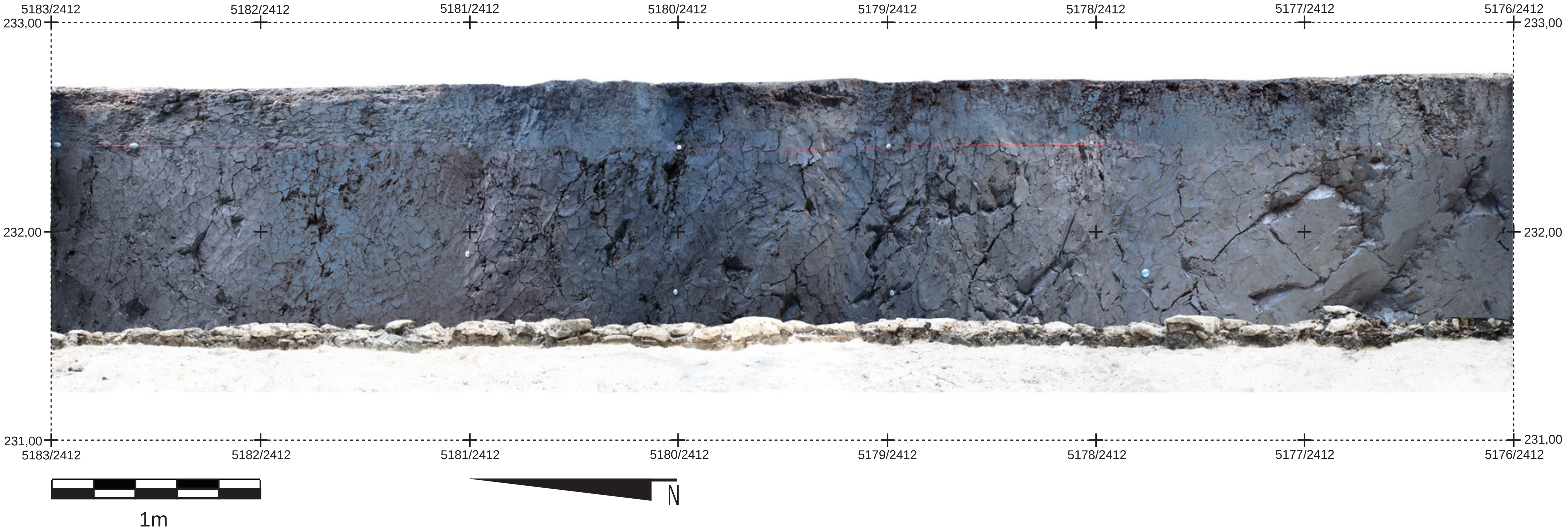


Figure 6.18: Uxul, Aguada Oriental, Trench 1, Bedrock surface and East profile (Photos and Graphics: N. Seefeld).

Underneath the ceramic layer (Lote 548), the ongoing excavations exposed the surface of the natural bedrock (see Figures 6.18a and 6.18b). Similar to the central trench of the 2009 field season, the bedrock's surface had been artificially leveled. The step, which had become visible in the overlying ceramic layer and the limestone pavement, can be traced back to a row of stone blocks naturally embedded in the bedrock. This observation illustrates that irregularities in the natural bedrock material had forced the builders of the Aguada Oriental to develop specialized solutions of both the ceramic layer and the overlying limestone slabs. Similar to the trench excavated in the 2009 field season, the east profile indicated a very homogenous deposition of clay above the limestone pavement (see Figure 6.18c). Furthermore, the east profile vividly illustrated the clear separation of the different constructional elements and the level surfaces of the ceramic layer and the limestone pavement. Over a length of 7 m, the height level of the pavement only varied by 7 cm (231.53 m above sea level in the north and 231.60 m above sea level in the south; see Figure 6.18c).

Trench 2

Trench 2 measures 10 x 2 m, encompasses the quadrants 5162-5172/2410-2411 and is located two meters to the south of Trench 1 (see Figure 6.19). The documented features resemble those of Trench 1 in almost every detail:

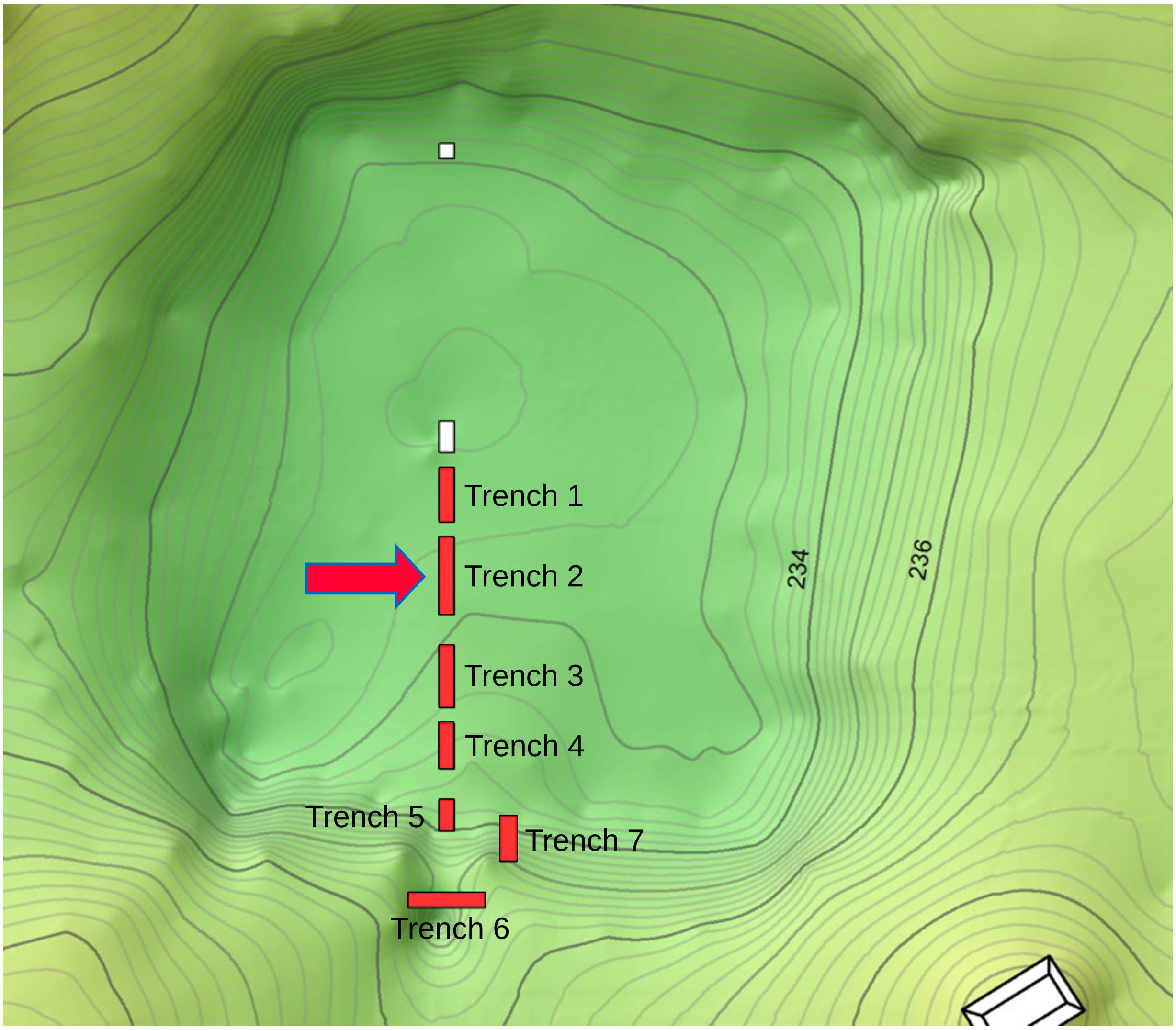


Figure 6.19: Uxul, Aguada Oriental, Location of Trench 2. (Map: Courtesy of B. Volta. Reproduced with kind permission of Benjamino Volta).

At a depth of 110-130 cm, excavations exposed a perfectly level pavement of limestone slabs (Lote 540) that featured the most homogenous character of all trenches. On a surface of 20 m^2, neither gaps in the pavement nor differences in form and size of the stones could be observed (see Figures 6.20a and 6.20b). In every section of this surface, it became apparent that all stones featuring dimensions of approximately 20 x 20 cm had been carefully fitted into this pavement. In some instances, isolated ceramic fragments were found on the limestone pavement and assigned a specific feature number (Lote 546) for chronological differentiation.

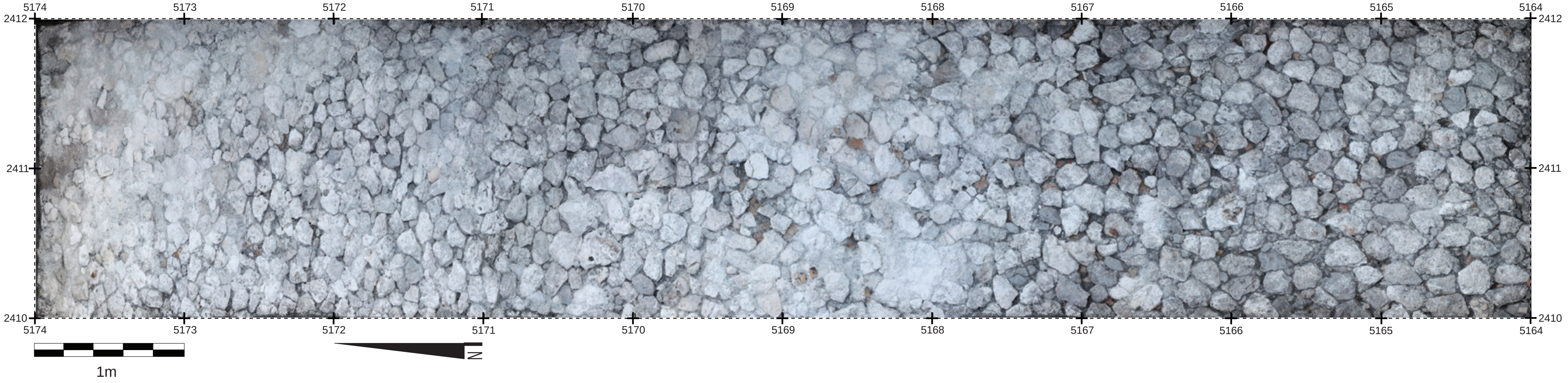
In the quadrants 5168/2410 and 5168/2410, the pavement showed a linear deposition of narrow stones that visibly differed from the remaining part of the pavement, which did not follow a specific pattern. In some sections, single stone slabs and/or the seams between them had been filled or covered by a very hard stucco matrix.

Immediately underneath the limestone pavement (Lote 540), the author documented an intentional deposition of ceramic fragments arranged less densely than the previously exposed concentrations.In the four southernmost quadrants (5164-5165/2410-2411), exceptionally large ceramic fragments were deposited in a very loose pattern featuring many gaps (see Figure 6.20e). The four quadrants located north of these large ceramic fragments (quadrants 5166-5167/2410-2411) featured a denser deposition of ceramic fragments. On the other hand, the northernmost 12 quadrants of Trench 2 (5168-5173/2410-2411) were covered with a very loose layer of ceramic sherds. In this section, many quadrants were devoid of ceramic sherds (see Figure 6.20e). Interestingly, the deposition of sherds showed a distinct linear demarcation line to the north, which coincided with the location of the linear stone deposition in the overlying pavement. A slight, 30 cm wide and 5 cm high linear elevation in the form of a narrow bulge in the underlying bedrock surface coincided perfectly with the overlying line of narrow stone blocks. To the north of this feature, the limestone blocks were generally deposited immediately on the bedrock surface.

After the documentation and extraction of the ceramic layer, the surface of the natural bedrock could be exposed. Apart from the small linear elevation, this surface had been perfectly leveled (see Figures 6.21a and 6.21b).

Similar to Trench 1, the east profile showed that the washed-in sediment had a homogenous composition and coloration (see Figure 6.21c). Likewise, the separation of the different constructional elements was very distinct. An obvious difference to the east profile of Trench 1 was the pronounced slickenslides or gilgai that originated at the surface and reached lengths of up to 90 cm. The more severe desiccation of the washed-in vertisol clays had already been observed during the extraction of the sediment and showed that the clay of Lote 539 was far dryer and less sticky than the clay in Trench 1. In the author's opinion, the more pronounced desiccation of the washed-in soils can be explained by the fact that during the dry season, remaining moisture tends to concentrate in the center of the reservoir and steadily decreases towards the edges. This relationship is also apparent in the comparatively long profile of Trench 2. Here, the slickenslides near the northern end of the trench (closer to the reservoir's center) are less pronounced than the slickenslides near the southern end (closer to the reservoir's edge) (see Figure 6.21c). Similar to Trench 1, the east profile of Trench 2 also reveals that the base modification only had a slight inclination. Over its length of 10 m, the height level of the pavement only varied by 11 cm (231.66 m above sea level in the north, and 231.77 m above sea level in the south; see Figure 6.21c).

a) Stone pavement, Photo mosaic

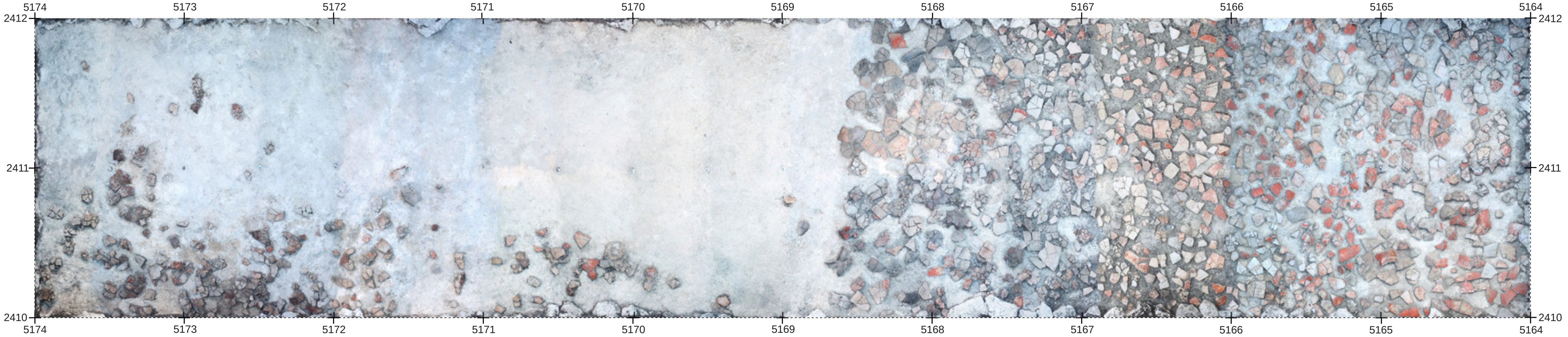


b) Stone pavement, South view

c) Stone pavement, Detail view

d) Detail of ceramic layer

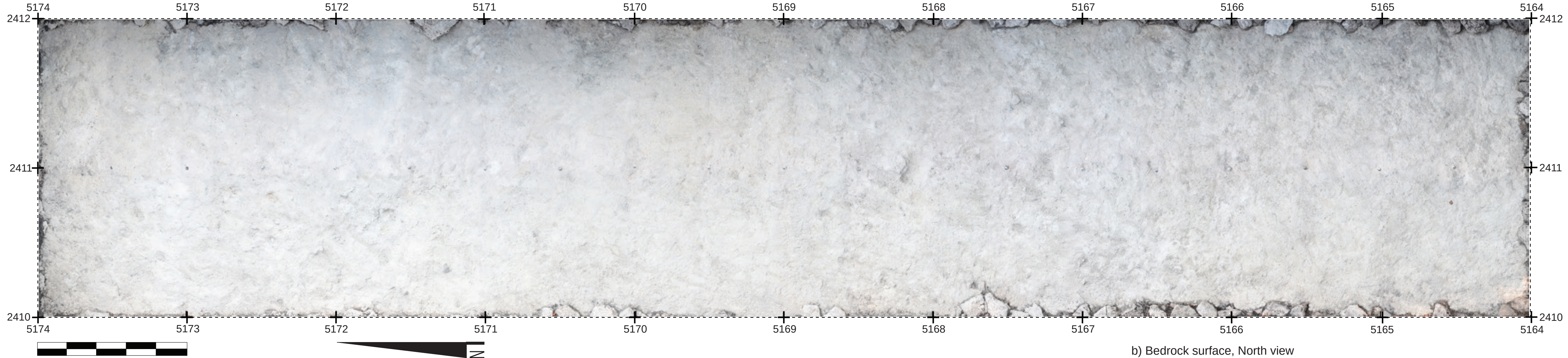
e) Ceramic layer, Photo mosaic



f) Ceramic layer, North view

Figure 6.20: Uxul, Aguada Oriental, Trench 2, Limestone pavement and ceramic layer. (a-f) (Photos and Graphics: N. Seefeld).

a) Bedrock surface, Photo mosaic



b) Bedrock surface, North view

c) East profile, Photo mosaic

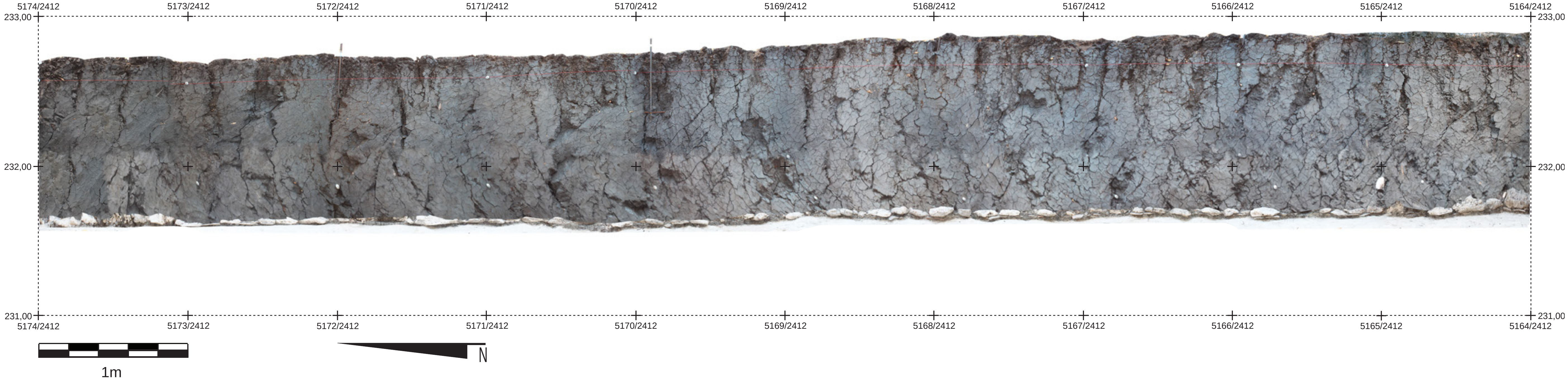


Figure 6.21: Uxul, Aguada Oriental, Trench 2, Bedrock surface and East profile (Photos and Graphics: N. Seefeld).

Trench 3

Trench 3 measures 8 x 2 meters, encompasses the quadrants 5152-5158/2410-2411, and is located four meters to the south of Trench 2 (see Figure 6.22). For the most part, the documented features resemble those of Trenches 1 and 2.

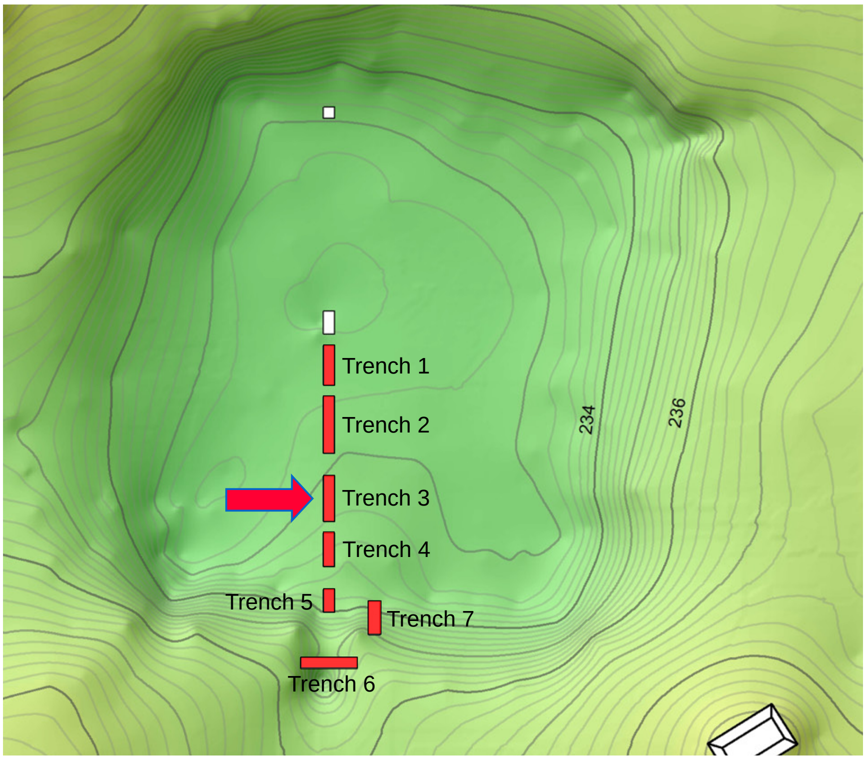


Figure 6.22: Uxul, Aguada Oriental, Location of Trench 3 (Map: Courtesy of B. Volta. Reproduced with kind permission of B. Volta).

At a depth of 120-130 cm, excavations revealed a pavement of limestone slabs (Lotw 540) with a less homogenous character than that of Trench 1 and Trench 2 featuring several gaps in the stone deposition at its surface (see Figures 6.23a and 6.23b). However, the pavement still formed a very firm compound with an easily walkable surface. In several examples, residues of a hard stucco matrix were observed in the seams between individual stone slabs. An interesting peculiarity was observed in quadrant 5158/2411. As Figure 6.23a indicates, the pavement showed a small, but visible gap in the surface surrounded by a circular depression of stones. The base of this hole was filled with gray sediment (Lote 539).

Another interesting peculiarity was documented in quadrant 5158-5159/2411. While the pavement in the northern half of Trench 3 formed a very dense surface, the southern half was more irregular. In quadrants 5152-5153/2410-2411, a linear depression runs diagonally through the trench's surface. Interestingly, the base of this depression was not covered with a stone pavement. Instead, small stones and ceramic fragments were applied to a sascab matrix, which exhibited a surprisingly hard consistency during excavation (see Figure 6.23a).

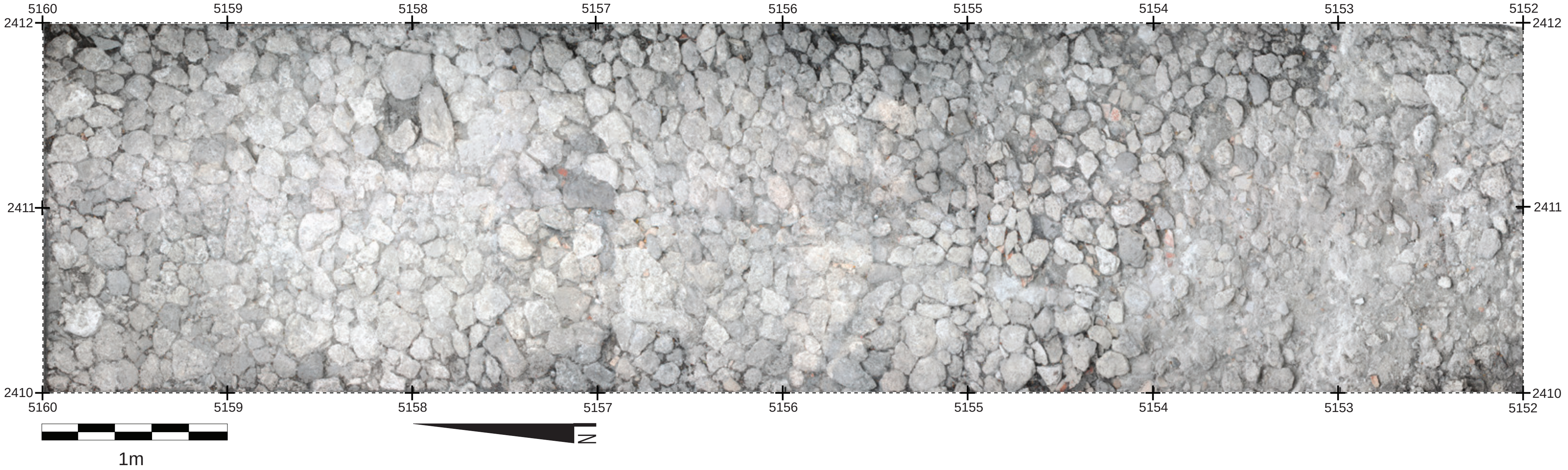
After the documentation and removal of the limestone pavement, the ongoing excavations again revealed a dense ceramic layer with a very homogenous character (see Figures 6.23e and 6.23f). The top edges of the individual sherds form an almost even surface. Apart from the special sealing technique in the four southernmost quadrants (5152-5153/2410-2411) where the ceramic sherds were deposited in a very heterogenous manner, the density of the ceramic layer is markedly high in the remaining quadrants. Interestingly, the ceramic depistion is divided by a narrow and linear gap that runs diagonally through the trench with a lenght of 6 m, a height of 10 cm and a width of 10 cm (see Figures 6.23e and

6.23f). As Figure 6.23d indicates, this gap is the result of a rise in the underlying bedrock surface. The density of ceramic deposition to the west of this ridge-like elevation is higher than it is to the east and also represents the highest density of the entire Aguada Oriental (see Figure 6.23d).

The natural bedrock exposed immediately underneath the ceramic layer featured a very even surface in quadrants 5155-5159/2410-2411 (see Figures 6.24a and 6.24b). In the six southern quadrants however, a canal-like, linear depression was observed, the base of which was clad with a matrix of stucco with stones and ceramic fragments still adhering to it. During the documentation of the bedrock surface, it also became apparent that the circular depression observed in both the limestone bedrock and the ceramic layer in quadrant 5158/2411 originated from a circular, 30 cm wide depression in the bedrock material (see Figure 6.24d). The regular shape of this circular depression indicated that it had been intentionally excavated from the bedrock material.

However, the linear, ridge-like elevation in the bedrock surface appeared to be a portion of the natural limestone that had a harder consistency than that of the surrounding bedrock and thus could not be excavated by the pre-Hispanic builders. In order to ensure that the resulting surface o the limestone bedrock was smooth, the builders left this ridge in place, while the areas to the west and east were covered with a higher concentration of ceramic fragments. Presumably, this was done in order to deposit the layer of limestone slabs on a firm and even subsurface. From the technological perspective, this pattern bears similarities to the ridge-like elevation documented in the center of Trench 1. In both cases, the harder consistency of the bedrock material caused an irregularity in height of the modified bedrock surface. Apparently, the stone tools of the pre-Hispanic builders could not remove these harder fractions of the natural bedrock. In order to level out these height differences, the Aguada Oriental builders had to modify the pattern of deposition in the ceramic layer.

As the east profile of Trench 3 indicates, the washed-in sediment shows an even more pronounced development of slickensides than in Trench 2, which can be explained by the greater distance from the reservoir's center (see Figure 6.24c). The proximity to the reservoir's edge might also explain the presence of some medium-sized stone blocks, which apparently washed in after the abandonment of the site (see Figure 6.24c). Furthermore, the effects of the lower moisture levels outside of the reservoir's center are also apparent in the vegetation cover. As Figure 6.24c indicates, the southern edge of Trench 3 had a higher elevation than the areas located further to the north. The higher elevation apparently reduced the duration of inundations enabling the growth of taller tree species (see Figure 6.24c). Figure 6.24c also shows that the pavement of Trench 3 has a greater degree of inclination than those of Trenches 1 and 2. Over its length of 8 meters, the height level of the pavement varied by 26 cm (231.85 m above sea level in the north and 232.11 m above sea level in the south; see Figure 6.24c).

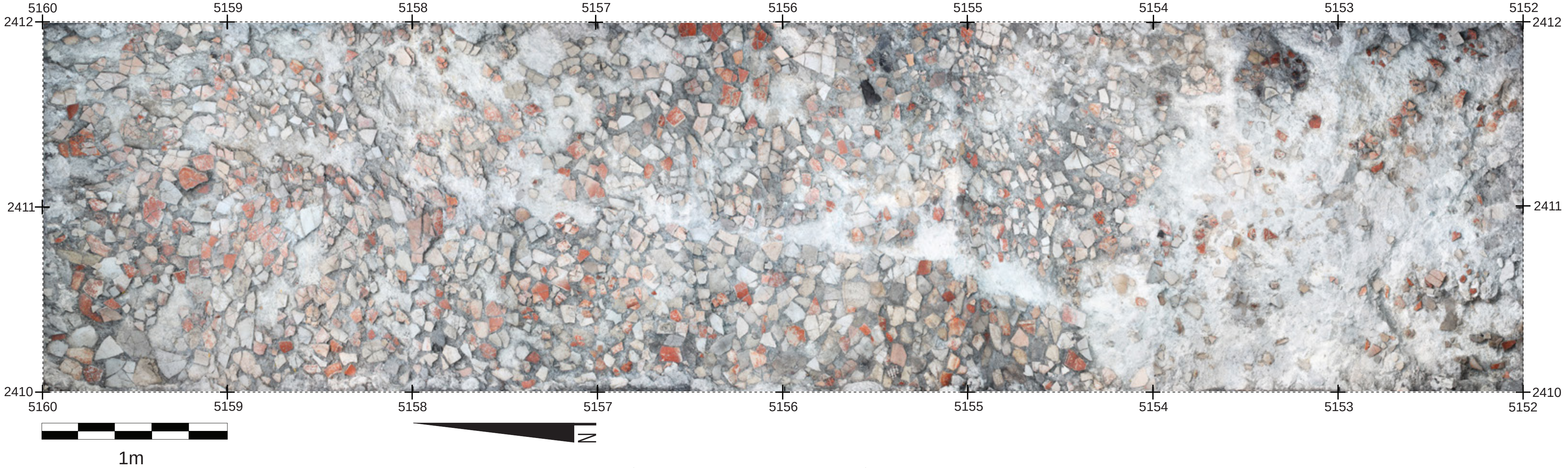


a) Limestone pavement, Photo mosaic

b) Limestone pavement, North view

c) Ceramic layer, circular gap of ceramic layer

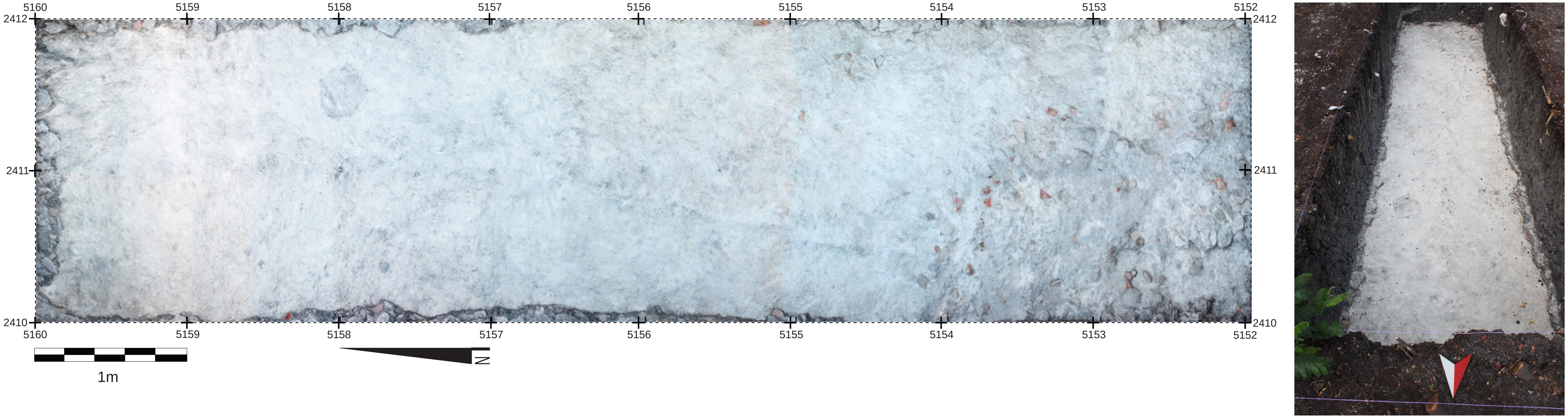
d) Ceramic layer, Detail of ridge-like elevation in the bedrock surface, North view



e) Ceramic layer, Photo mosaic

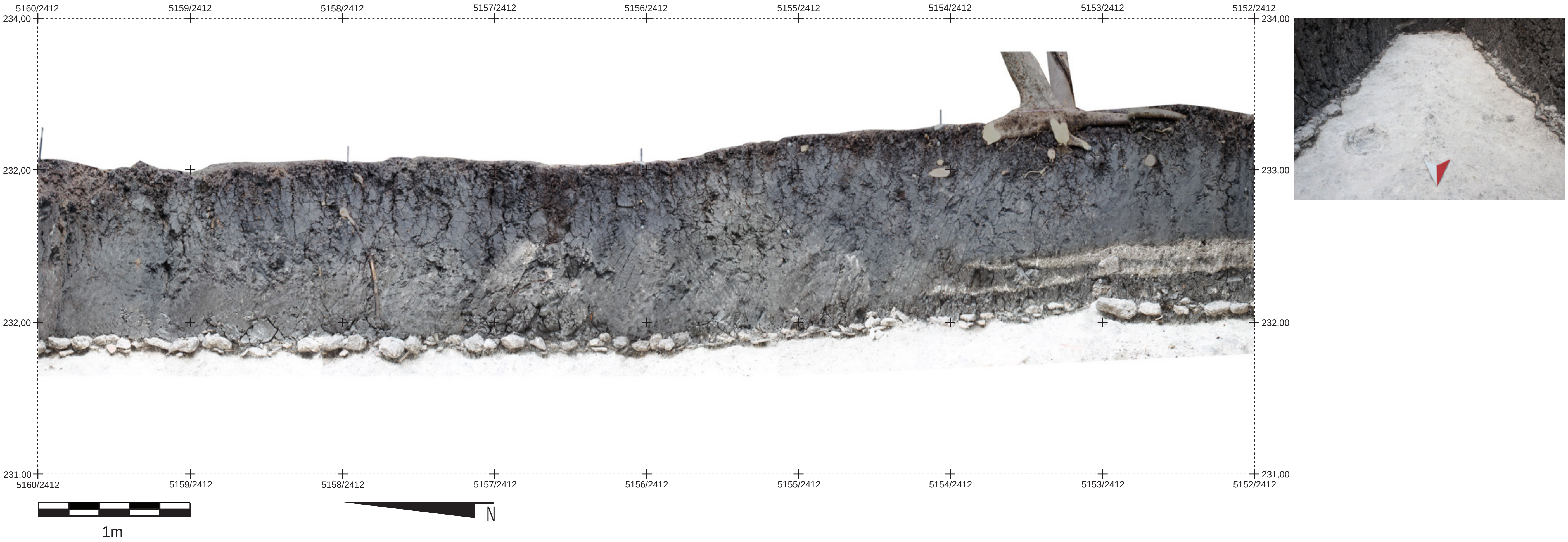
f) Ceramic layer, South view

Figure 6.23: Uxul, Aguada Oriental, Trench 3, Limestone pavement and ceramic layer (Photos and graphics: N. Seefeld).



a) Bedrock surface, Photo mosaic

b) Bedrock surface, South view



c) East profile, Photo mosaic

d) Bedrock surface, Detail of circular depression

Figure 6.24: Uxul, Aguada Oriental, Trench 3, Bedrock surface and east profile (Photos and graphic: N. Seefeld).

Trench 4

Trench 4 measures 6 x 2 meters, encompasses quadrants 5144-5149/2410-2411 and is situated two meters to the south of Trench 3 (see Figure 6.25). The features documented in this trench only resemble those of Trench 3 to a limited degree.

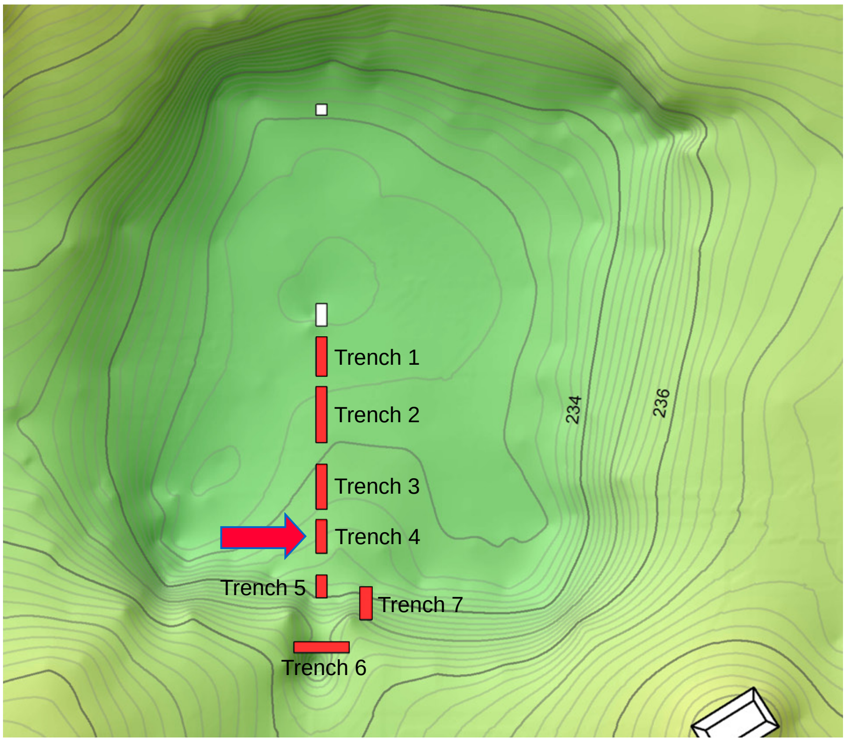


Figure 6.25: Uxul, Aguada Oriental, Location of Trench 4 (Photos and graphic: N. Seefeld). (Map: Courtesy of B. Volta. Reproduced with kind permission of Benjamino Volta).

During the extraction of the washed-in clay sediment (Lote 539), the author documented a large number of unworked limestone blocks with heterogenous dimensions that had obviously washed in. As Figure 6.20a illustrates, these stone blocks were largely concentrated at the southern end of Trench 4, which indicates that they most likely originated from the area south of the Aguada Oriental.

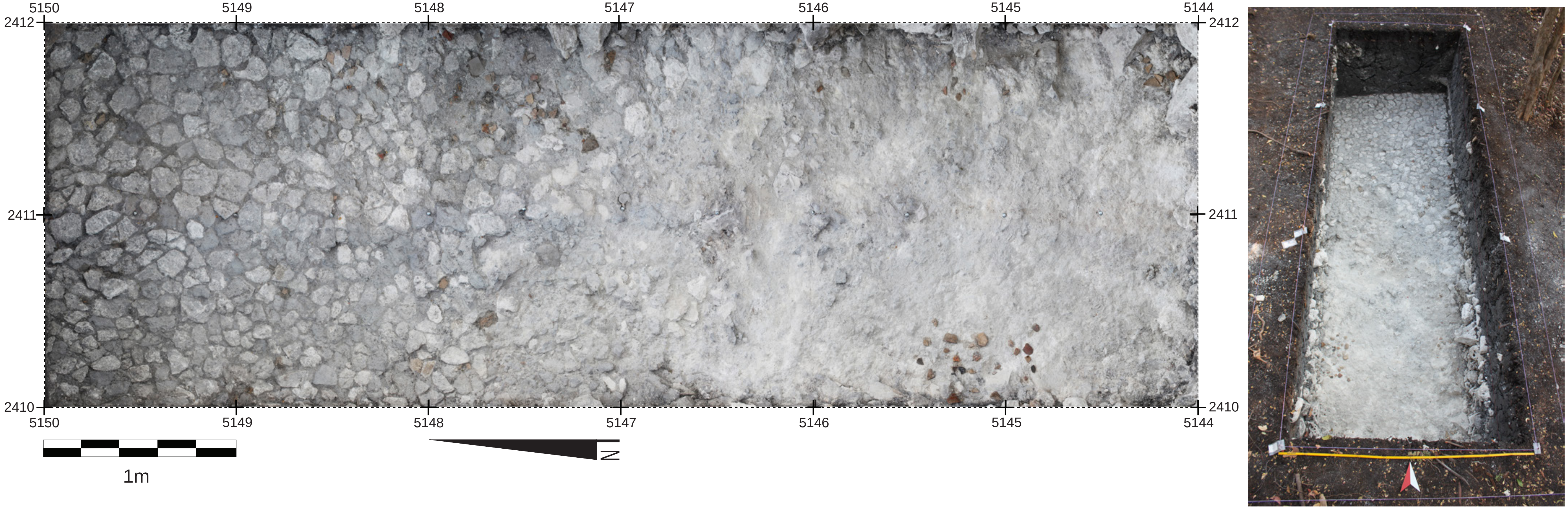
At a depth of approximately 100 cm, the excavations encountered a pavement of limestone slabs, which represented an intentional stone deposition in the northern portion of the trench (quadrants 5147-5149/2410-2411) (see Figures 6.26a and 6.26b). Although the sizes of these stone slabs in this northern portion vary to a large extent, the pavement forms an almost perfectly closed surface. Generally, the stones are smaller than those documented in Trenches 1, 2 and 3. They feature heterogenous dimensions ranging between 10 x 8 and 25 x 25 cm and form a very firm compound with a smooth and easily walkable surface.

In the southern six quadrants of Trench 4 (Quadrants 5144-5146/2410-2411), there were no traces of a pavement on the natural bedrock surface. The bedrock surface of this section is intermingled with a few larger limestone blocks and very uneven. The transition from the closed pavement to the bedrock surface is gradual. No distinct, intentionally defined demarcation is visible (see Figure 6.26a).

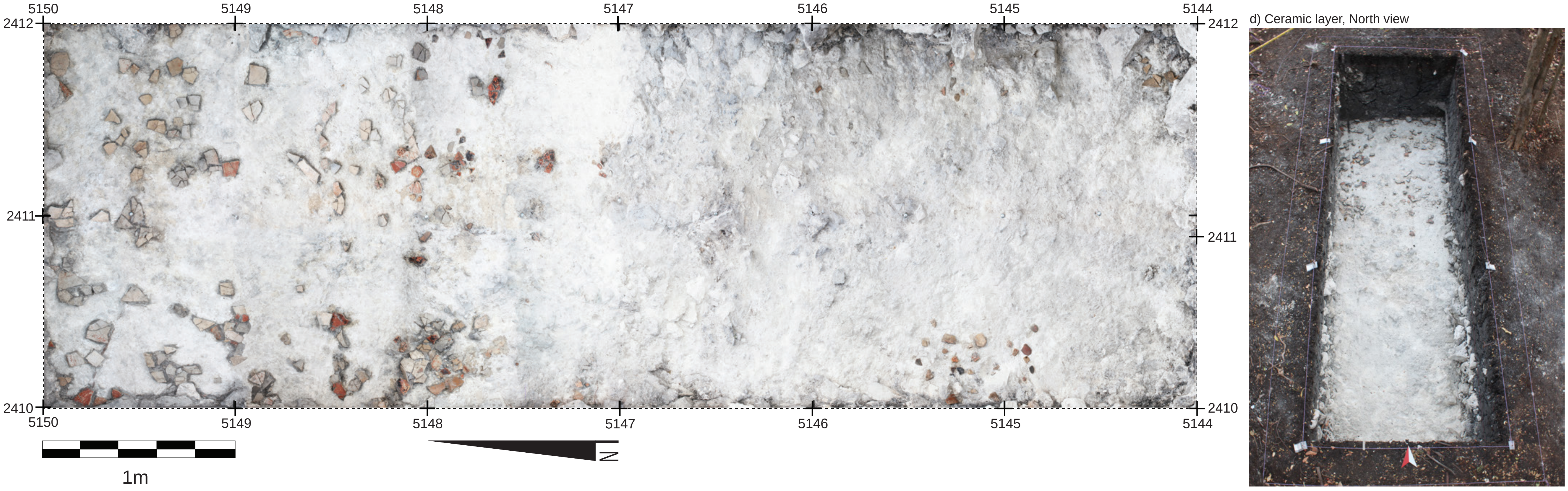
After extracting the limestone slabs in the northern half of Trench 4, only a relatively small number of ceramic fragments could be documented underneath the pavement (see Figures 6.26c and 6.26d). The density of deposited sherds is in fact so low that, in contrast to Trenches 1, 2 and 3, it could no longer be defined as a ceramic layer. A reasonably dense ceramic deposition could only be observed in the quadrants 5147-5149/2410-2412. The extension of this layer largely coincides with the extension of the overlying limestone pavement (see Figures 5.26a and 5.26b).

After removing this small amount of ceramic sherds, the surface of the natural bedrock could be documented. As Figures 6.27a and 6.27b indicate, this surface had only been artificially leveled in the northern section of the trench (quadrants 5147-5149/2410-2411). In the southern half however, the excavations exposed a rough bedrock surface that had been leveled to a much lesser degree.

As the east profile (see Figure 6.27c) indicates, the washed-in sediment (Lote 539) has a very dry and brittle consistency, a pattern that can be explained by the close proximity to the southern edge of the Aguada Oriental. The density of washed-in material prevents the clear differentiation of the various constructive elements, which were easily distinguishable in the cases of Trenches 1, 2 and 3. Due to the slight inclination of the bedrock surface, and particularly due to the lack of a ceramic layer, the constructive elements documented in Trench 4 mostly resemble those documented in the northern extension of the 2009 field season. As the east profile of Trench 4 illustrates, no eroded flat limestone slabs could be documented above the intact pavement in the northern section of the trench. This observation illustrates that the more sloped southern half of the trench had never been sealed off with a pavement. Instead, the builders of the Aguada Oriental had apparently decided to delimit the extension of the pavement to the level base of the reservoir. Furthermore, the east profile reveals that the base modification of Trench 4 has a similar inclination to that of Trench 3. Over its length of 6 m, the bedrock surface shows a height difference of 29 cm (232.06 m above sea level in the north and 232.33 m above sea level in the south).


a) Limestone pavement, Photo mosaic

b) Limestone pavement, North view


c) Ceramic layer, Photo mosaic

d) Ceramic layer, North view

Figure 6.26: Uxul, Aguada Oriental, Trench 4, Limestone pavement and ceramic layer (Photos and graphics: N. Seefeld).


a) Bedrock surface, Photo-mosaic

b) Bedrock surface, North view

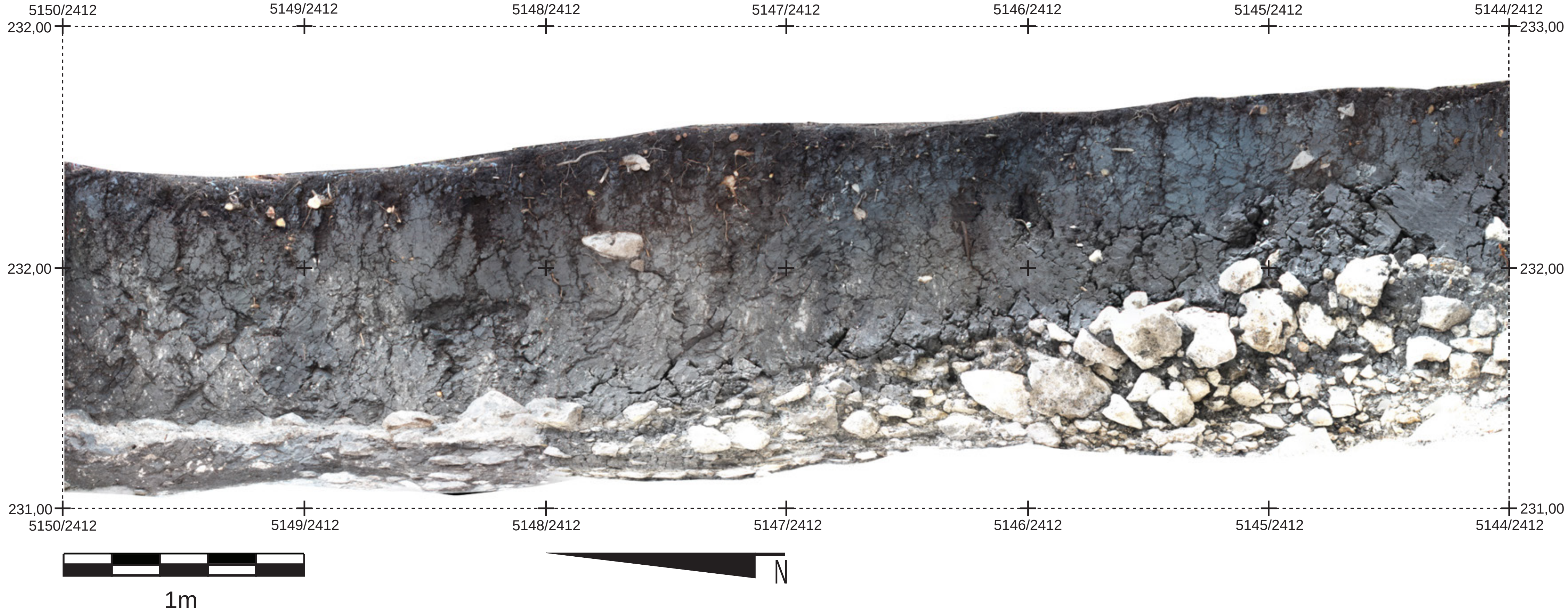

c) East-profile, Photo mosaic

Figure 6.27: Uxul, Aguada Oriental, Trench 4, Bedrock surface and east profile (Photos and Graphics: N. Seefeld).

Trench 5

Trench 5 measures 4 x 2 m, encompasses quadrants 5136 to 5139 and is located four meters to the south of Trench 4 (see Figure 6.28b). The features documented in this trench differed entirely from those documented in Trenches 1-4. A pavement of limestone slabs could not be documented in this trench. Instead, the excavations revealed a peculiar mass of stone rubble and blocks at a depth of 74 cm, which was carefully documented due to its uncertain origin and function at the time (see Figure 6.28c). In the first planum, the excavations revealed that the surface of the natural bedrock was at the surprisingly shallow depth of 45 cm (see Figure 6.28a). This observation was an important indicator that the Aguada Oriental did not represent a natural depression but that the majority of the reservoir's basin had been artificially carved out.

a) Uxul, Aguada Oriental, Trench 5, Planum 1, West view

b) Aguada Oriental, Location of Trench 5

c) Uxul, Aguada Oriental, Trench 5, Planum 1, Photo mosaic

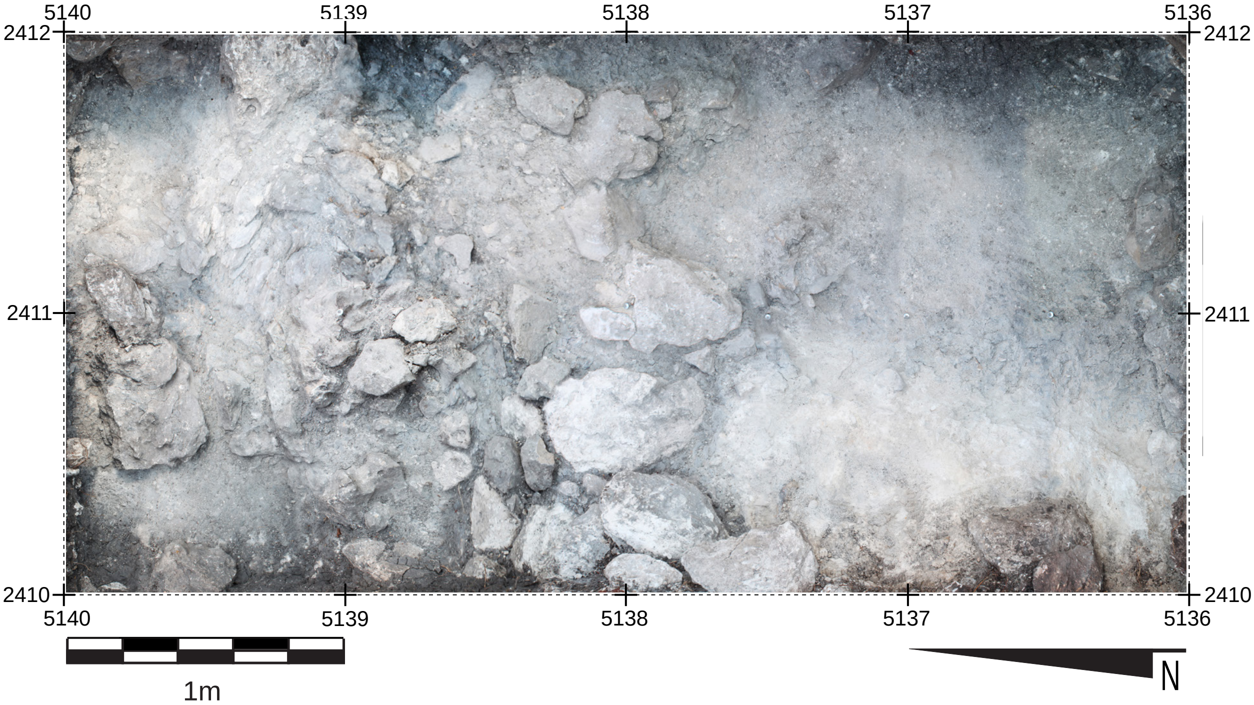


Figure 6.28: Uxul, Aguada Oriental, Trench 5, Planum 1. (a) (Photo: N. Seefeld); (b) (Map: Courtesy of B. Volta. Reproduced with kind permission of Benjamino Volta); (c) (Photos and graphics: N. Seefeld).

In order to retain the potential significance, the height and position of each different stone block was documented in drawings and photos. In this way, the excavation process was documented with eight different plana (see Figures 6.28-6.34). In the course of this careful documentation process, it became apparent that not all of the observed stone blocks had been washed in from the southern catchment area. Instead, the documentation revealed that some of these stone blocks formed part of a wall. During the documentation of Planum 2 and Planum 3, it became apparent that some of these stone blocks were still in situ (see Figure 6.29). In succession, we extracted the eroded material to the north and south of these original stones and exposed the entire intact portion of the construction. While carefully extracting the loose stone blocks, the excavation process showed that this stone wall had an exact east-west orientation and originally consisted of at least four layers of stone (see Figures 6.29 and 6.30).

a) Uxul, Aguada Oriental, Trench 5, Planum 2, South view

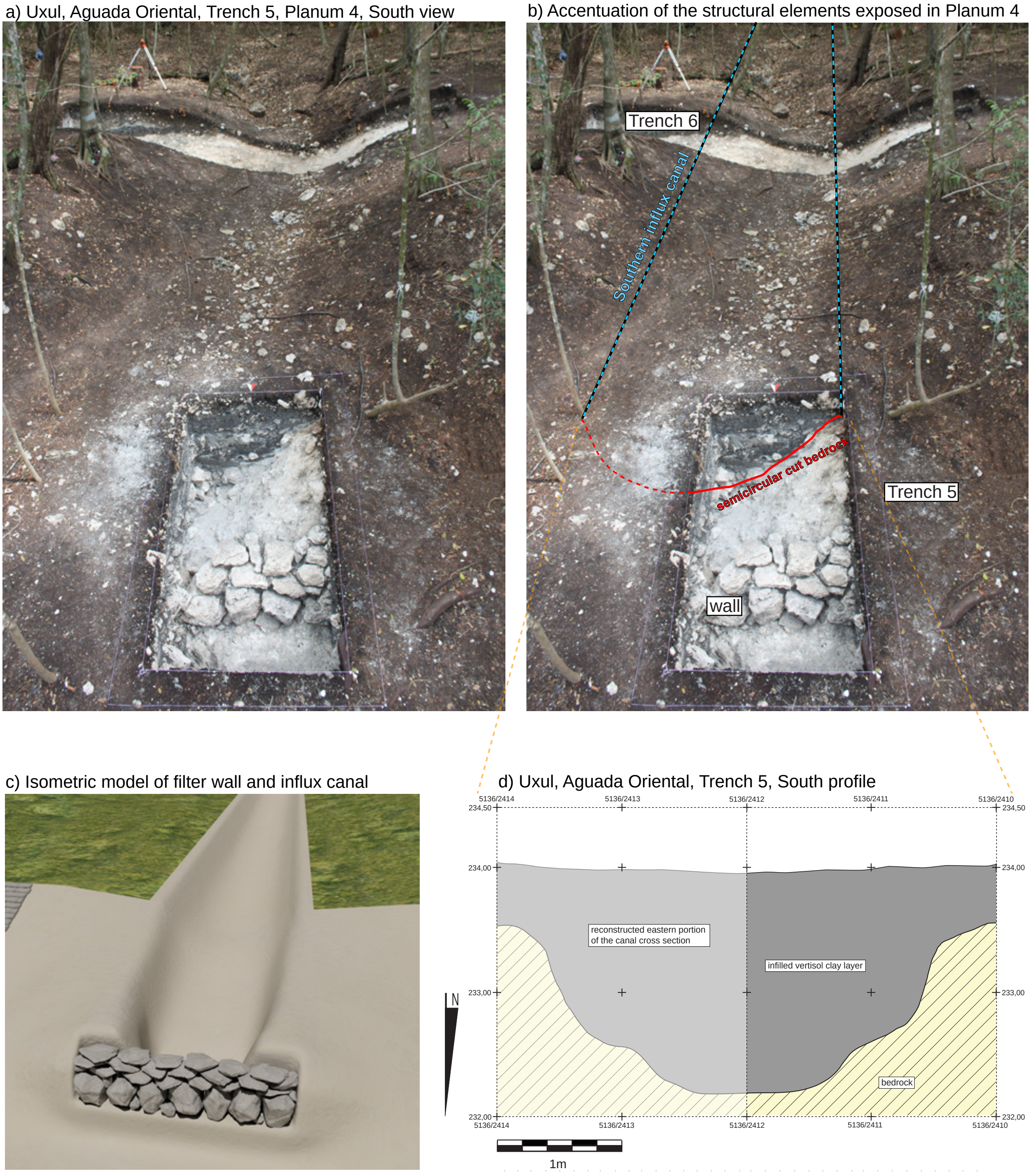
b) Uxul, Aguada Oriental, Trench 5, Planum 2, North view

c) Uxul, Aguada Oriental, Trench 5, Planum 3, South view

d) Uxul, Aguada Oriental, Trench 5, Planum 3, North view

Figure 6.29: Uxul, Aguada Oriental, Trench 5, Planum 2 and Planum 3 (Photos: N. Seefeld).

During the documentation of Planum 4, it also became apparent that the natural bedrock surface to the south of this wall had been carved out in a semicircular form (see Figure 6.30a). By considering the location of this trench in relation to Trench 6, the semicircular depression in the bedrock surface was soon identified as the northern extension of the influx canal to the Aguada Oriental (see Figure 6.30b). This southern influx canal and the semicircular depression documented to the south of the wall directed runoff in the direction of the documented wall.


a) Uxul, Aguada Oriental, Trench 5, Planum 4, South view

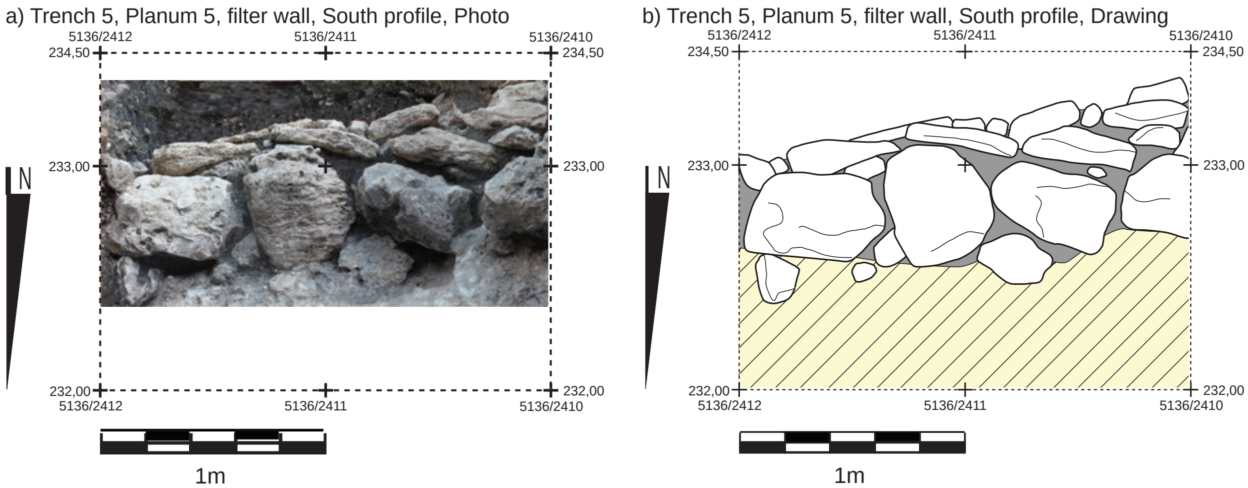
b) Accentuation of the structural elements exposed in Planum 4

c) Isometric model of filter wall and influx canal

d) Uxul, Aguada Oriental, Trench 5, South profile

Figure 6.30: Uxul, Aguada Oriental, Trench 5, South profile. (a-b) (Photos: N. Seefeld); (c) (Model: M. Lyons. Courtesy of Michael Lyons); (d) (Drawing: N. Seefeld).

In Planum 5, the south view of the exposed wall construction revealed that the stones were quite large. Furthermore, the lowermost stone alignment quite obviously featured larger dimensions than the upper alignments. As Figure 6.31 illustrates, the stone blocks of the lowermost alignment feature heights between 35 and 55 cm, whereas the stones of the overlying alignments feature heights between 10 and 21 cm. While the lower alignment was formed of cuboid blocks, the upper alignments rather resembled slabs (see Figures 6.31 and 6.32).


a) Trench 5, Planum 5, filter wall, South profile, Photo

b) Trench 5, Planum 5, filter wall, South profile, Drawing

Figure 6.31: Uxul, Aguada Oriental, Trench 5, Filter wall, South profile (Photos and Graphics: N. Seefeld).


Figure 6.32: Uxul, Aguada Oriental, Trench 5, Planum 5, Filter Wall, East view (Photo: N. Seefeld).

Furthermore, the north view of this filter wall indicates that the natural bedrock to the south of this wall had been removed with stone tools in such a way that the entire construction was left resting upon a small bedrock pedestal that was deliberately left during the hollowing out of the Aguada Oriental (see Figure 6.33).

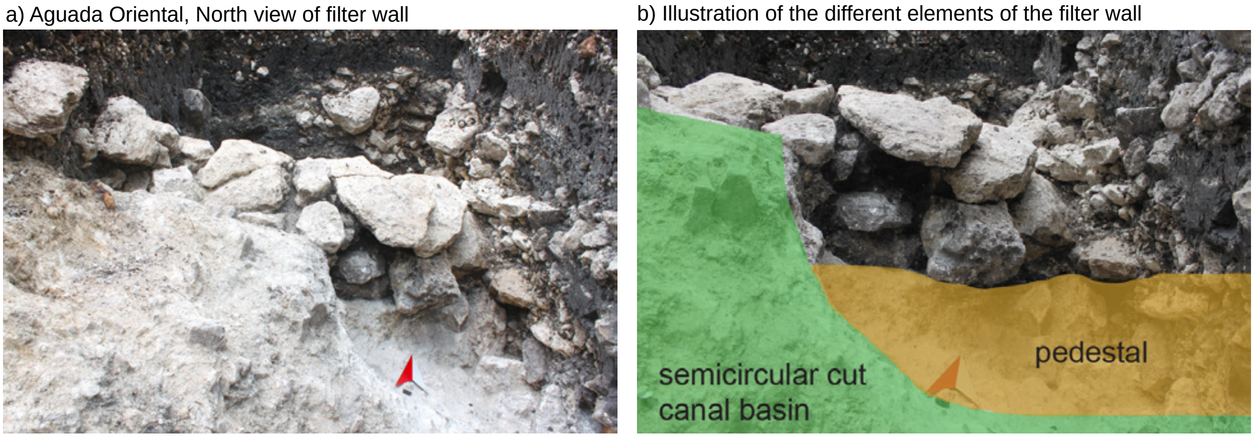


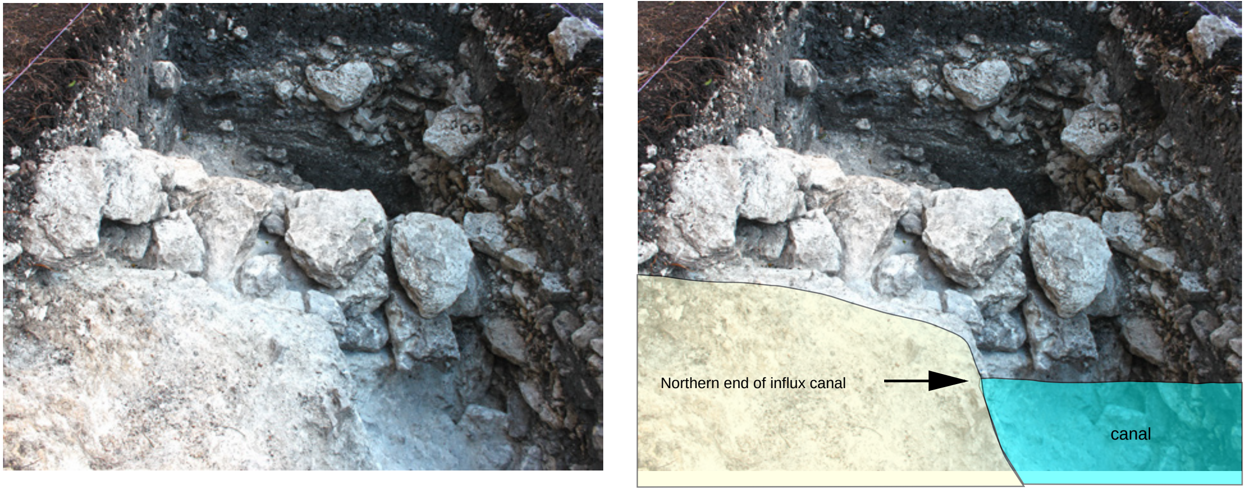
Figure 6.33: Uxul, Aguada Oriental, Trench 5, North view of filter wall (Photos and Graphics: N. Seefeld).

In Planum 7, the south and north views of the wall (see Figures 6.33a and 6.33b) indicated that the lowermost stone alignment had been firmly anchored in cavities carved from the parent bedrock material specifically for this purpose. Furthermore, it could be documented that the wall formed a clear northern barrier for the influx canal. As Figures 6.34c, 6.34d and 6.35 indicate, the wall was wider than the southern influx canal and had been installed in order to impound the inflowing rainwater. In Planum 8, the careful construction of the wall's foundation became even more evident. The lowermost stone blocks featured dimensions of up to 80 x 50 cm. Presumably, the foundation's large dimensions are the reason why most stone alignments were still in situ. Another factor for the good state of preservation was the fact that the wall had been built on a small pedestal (see Figures 6.34a and 6.34g).

Based on these observations, the author arrived at the conclusion that this feature represented a "filter wall" that would have served to purify the water flowing in through the southern influx canal by filtering out large dirt particles and thus ensuring the storage of decontaminated water to the north of this barrier. The elevated position of the wall would have also facilitated the deposition of coarse material. If the washed in and dammed up coarse material would have been removed on a regular basis, this constructional element would have significantly improved the general cleanliness of the stored water.

a) Aguada Oriental, Trench 5, Planum 7, Filter wall, North view

b) Aguada Oriental, Trench 5, Planum 7, Filter wall, South view



c) Aguada Oriental, Trench 5, Planum 7, Filter wall, North view

d) Technical implementation of the filter wall

e) Aguada Oriental, Trench 5, Planum 8, Filter wall, North view

f) Aguada Oriental, Trench 5, Planum 8, Filter wall, South view

g) Aguada Oriental, Trench 5, Planum 8, Filter wall, Top view

Figure 6.34: Uxul, Aguada Oriental, Trench 5, Planum 7 and Planum 8 (Photos and Graphics: N. Seefeld).

Figure 6.35: Uxul, Aguada Oriental, Trench 5, Planum 8, South view (Photo: N. Seefeld).

Trench 6

Trench 6 measures 10 x 2 m, runs perpendicular to the course of the southern influx canal and encompasses quadrants 5126-5127/2406-2416 (see Figure 6.36a). As mentioned before, the main objective for the definition of this trench was to determine the technical layout of the southern influx canal.

Before the excavation process, the surface of Trench 6 only revealed a number of small, unworked cobbles which had apparently washed in as recent alluvial deposits from the southern catchment area. In the ensuing excavation process, these cobbles were also documented in the humus layer (Lote 576). Towards the north and the south of the canal bottom, the excavations only revealed a deposition of vertisol clays that partially resembled the clay layers in the interior of the aguada (see Figure 6.36d). However, no worked stones or remains of potential former floors could be observed during the excavation process. As Figure 6.36d indicates, the south profile of Trench 6 is only marked by lenticular depositions of different soil layers which seem to be entirely the result of alluvial processes. The stones visible in Figure 6.36d appear to be alluvial deposits because they do not have processing marks and feature very heterogeneous dimensions. Thus, the only clear traces of cultural modification could be observed on the surface of the bedrock.

As Figure 6.36c indicates, the surface of the natural bedrock had been perfectly leveled. Furthermore, the southern profile indicates that the bedrock had been extracted to form a semicircular canal in order to facilitate the flow of water. In the author's opinion, it is plausible that the builders of the Aguada Oriental had also sealed the bottom of this canal with a stucco layer and reinforced the terrain to the north and south with stone constructions. However, the inflow of water from the southern catchment area over many centuries and the ensuing erosion have destroyed all traces apart from the modified bedrock surface.

a) Location of Trench 6

b) Trinchera 6, Bedrock surface, South view

c) Bedrock surface, West view

d) South profile, Photo mosaic

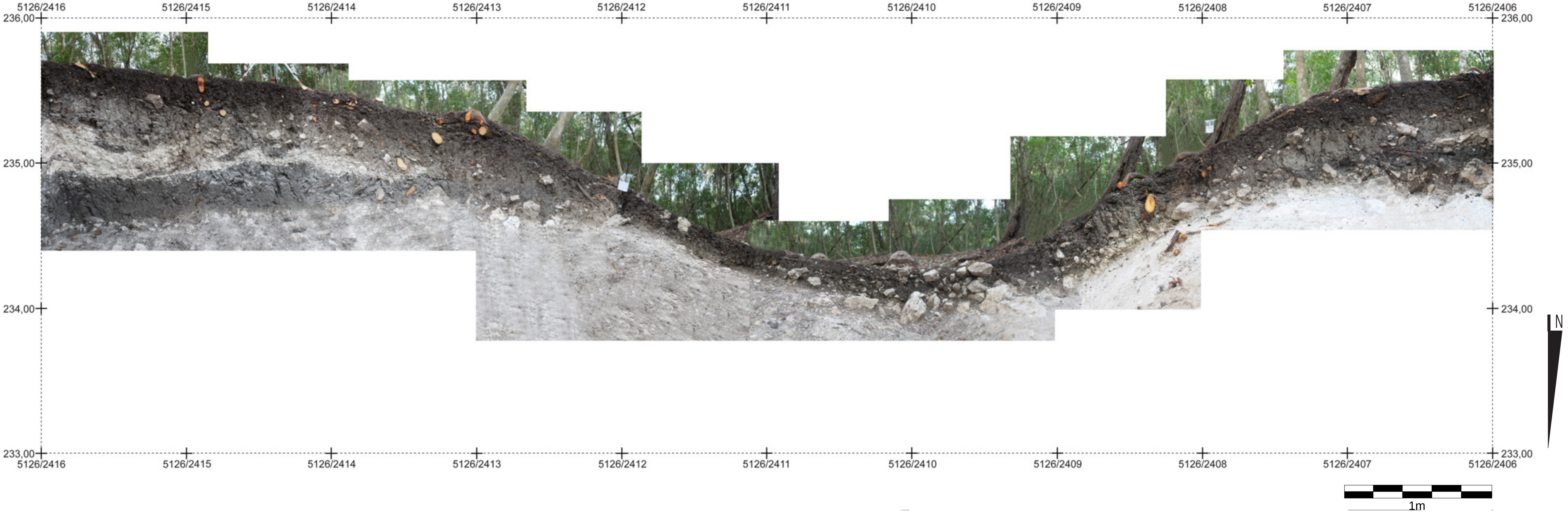


Figure 6.36: Uxul, Aguada Oriental, Trench 6 (a) (Map: Courtesy of B. Volta. Reproduced with kind permission of Benjamino Volta); (b-d) (Photos and graphics: N. Seefeld).

Trench 7

Trench 7 measures 6 x 2 m, cuts through the entire sloped southern embankment of the reservoir, and encompasses quadrants 5132 to 5137 (see Figure 6.37). As mentioned before, the main objective for the excavation of this trench was to determine if the embankment of the reservoir had been supported by a stone construction. Prior to the commencement of the excavations, the surface of Trench 7 was only marked by a small accumulation of medium-sized stones in the upper section of the southern slope (see Figure 6.38a). After extracting the humus layer (Lote 575), this small stone cluster proved to be the top edge of a larger stone accumulation that extended over the entire surface of Trench 7 (see Figures 6.38b, 6.39 and 6.40a). Even though none of these stone blocks seemed to be in their original position, some stones were clearly dressed. Because the stones had fairly homogenous dimensions and the east profile of the trench indicated a certain amount of regularity in their deposition, it seems probable that the southern embankment had been reinforced by a step-like paneling with medium-sized stone slabs (see Figure 6.40a).

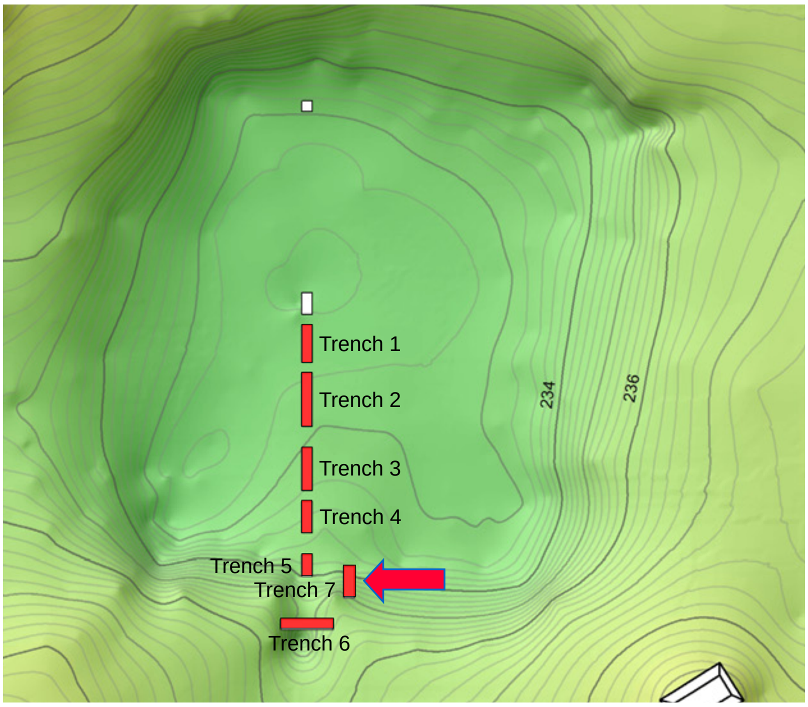
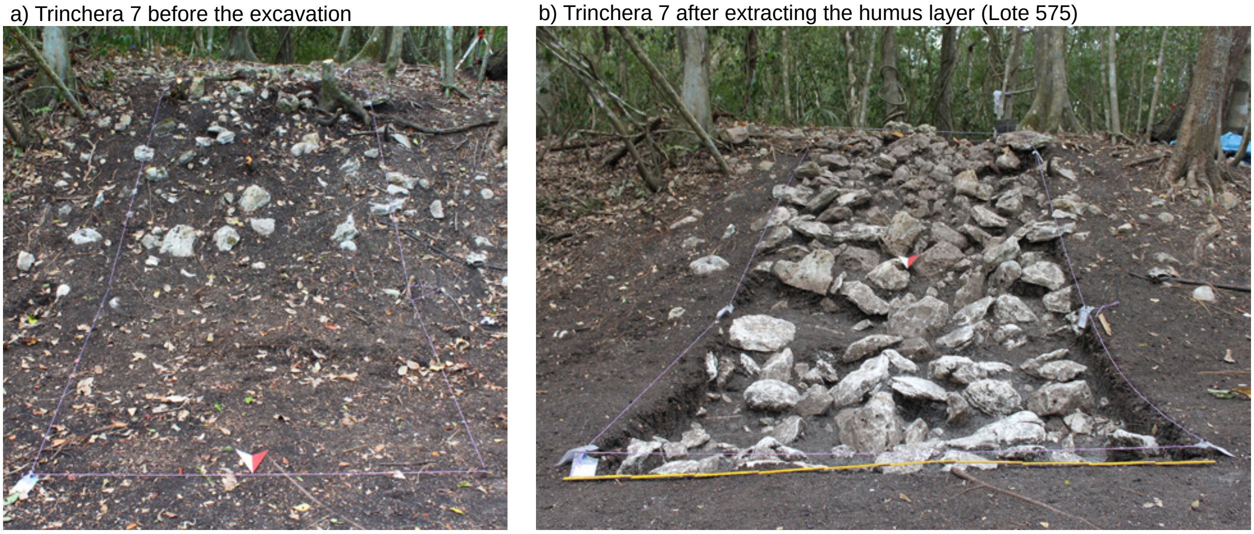


Figure 6.37: Uxul, Aguada Oriental, Location of Trench 7 (Map: Courtesy of B. Volta. Reproduced with kind permission of Benjamino Volta).


a) Trinchera 7 before the excavation

b) Trinchera 7 after extracting the humus layer (Lote 575)

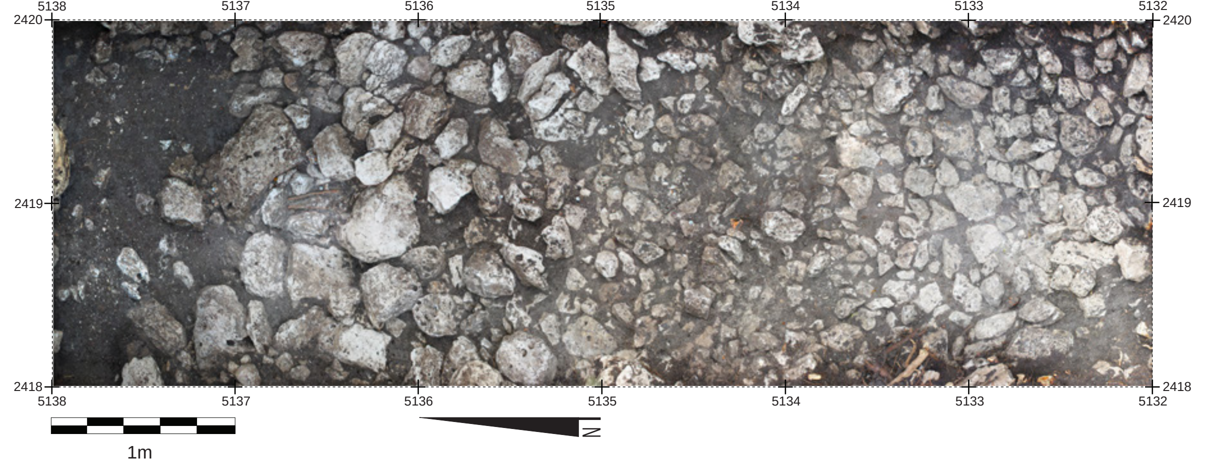
Figure 6.38: Uxul, Aguada Oriental, Trench 7 before the excavation and after extracting the humus layer (Photos: N. Seefeld).

After extracting this accumulation of stone slabs, the excavations revealed the surface of the limestone bedrock, which was very smooth and had been canted off in the same angle (see Figures 6.40 and 6.41c). A more detailed examination of the planum (see Figure 6.41b) indicates that the pavement begins precisely at the transition from the sloped embankment of the reservoir to the flat bottom. The fact that the deposition of stone blocks had not been documented above this pavement further indicates that this deposition had originally formed part of a support for the southern embankment (compare Figures 6.40 and 6.41c).

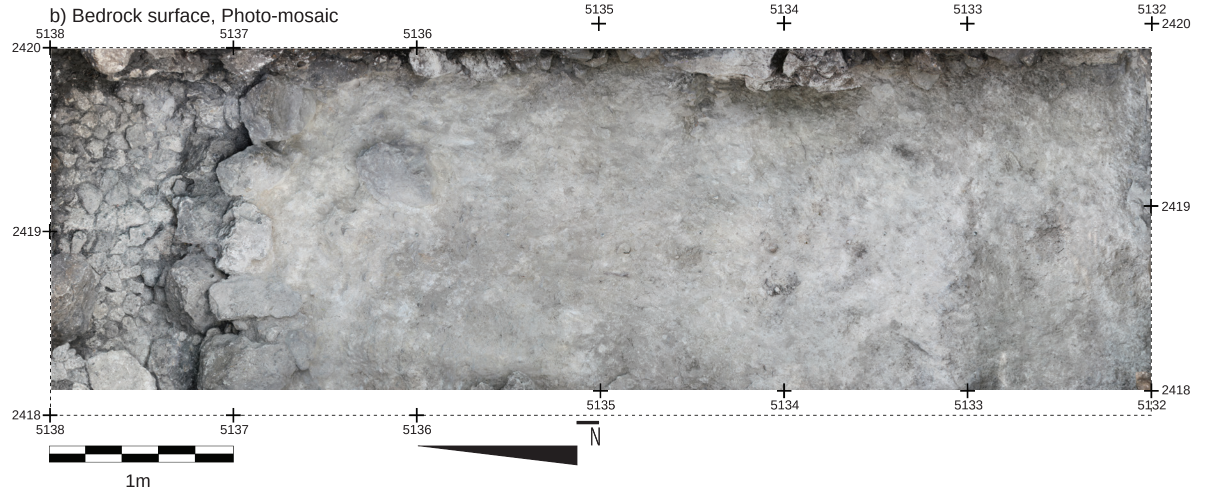
Figure 6.39: Uxul, Aguada Oriental, Trench 7, Stone deposition, Southeast view (Photos: N. Seefeld).

Figure 6.40: Uxul, Aguada Oriental, Trench 7, Bedrock surface, Southeast view (Photos: N. Seefeld).

a) Stone deposition, Photo-mosaic



b) Bedrock surface, Photo-mosaic



c) East profile, Photo-mosaic

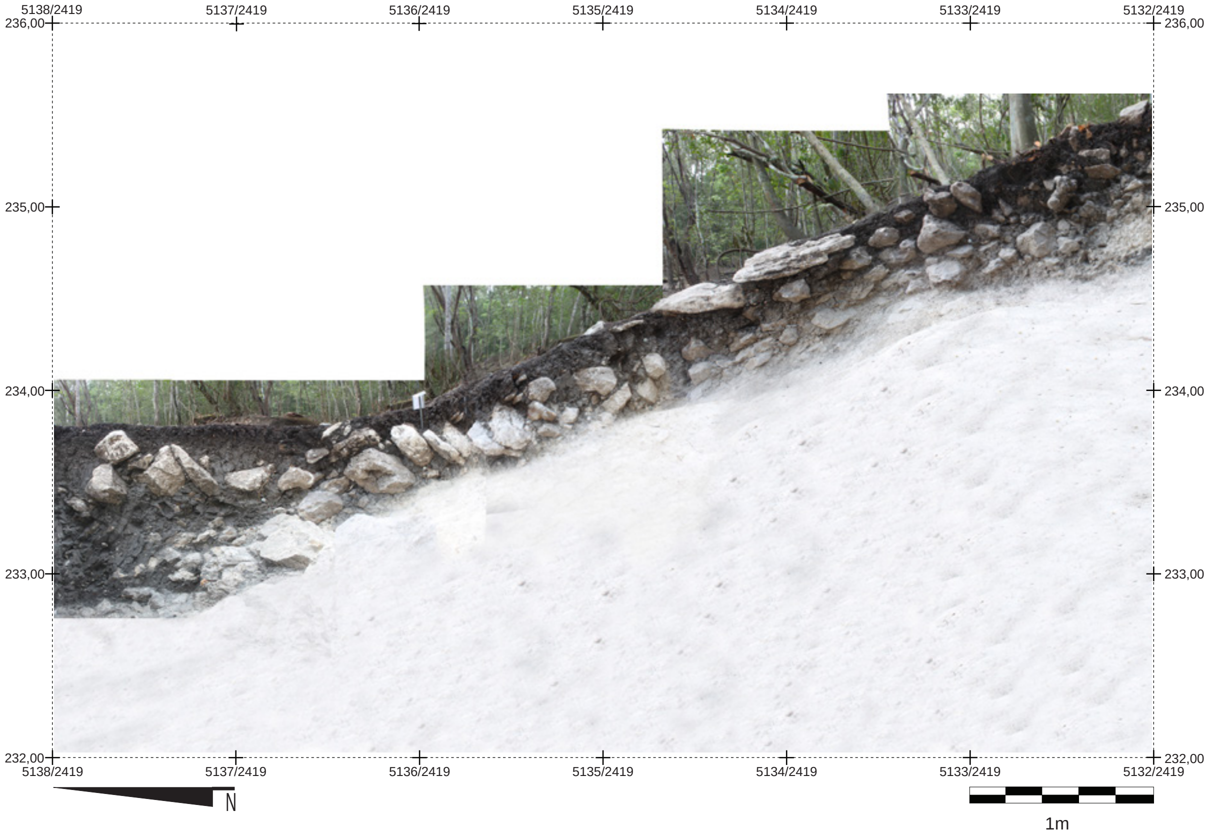
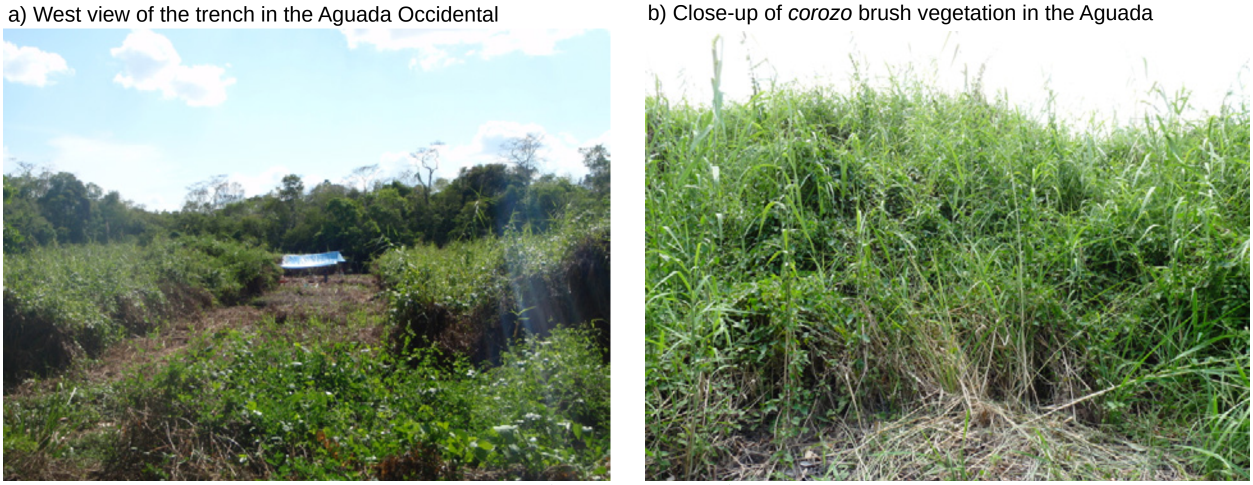


Figure 6.41: Uxul, Aguada Oriental, Trench 7, Bedrock surface and east profile (Photos and graphics: N. Seefeld).

6.2.3 Aguada Occidental

The Aguada Occidental lies to the west of Uxul's center hilltop in a naturally low-elevated section that receives substantial amounts of runoff. Owing to this situation, it was filled with water during most field seasons. Like the Aguada Oriental, it features a very distinct square shape and has extensions of roughly 100 x 100 m. Apart from the influx canal connected to its southeastern corner, no further architectonic features have been documented in its immediate vicinity so far. As Figures 6.42a and 6.42b indicate, the vegetation within the Aguada Occidental is very homogenous and dominated by shoulder-high *corozo* sedge.



a) West view of the trench in the Aguada Occidental

b) Close-up of *corozo* brush vegetation in the Aguada

Figure 6.42: Uxul, Vegetation in the Aguada Occidental (Photos: N. Seefeld).

Due to the large catchment area of the reservoir, only the extraordinarily dry conditions during the 2010 field season resulted in a complete desiccation of the Aguada Oriental. This enabled the first and only opportunity to carry out archaeological investigations thus far. These investigations focused on determining if this landscape feature represented a natural aguada or an artificial reservoir. Therefore, a 4 x 2 m trench encompassing quadrants 5192-5195/1476-1477 was defined in the very center of the reservoir (see Figures 6.43 and 6.44).

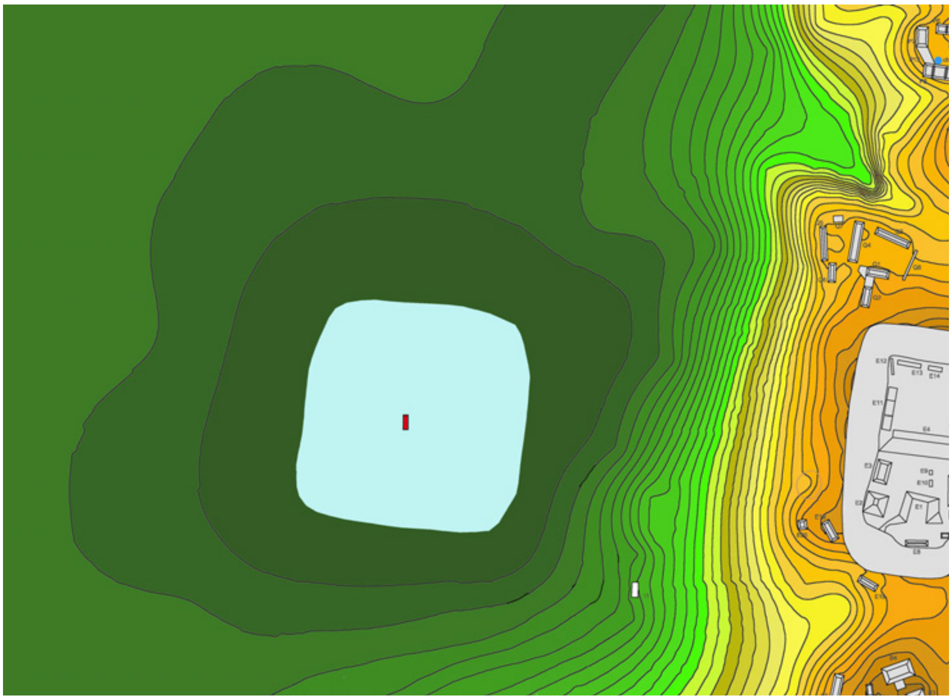


Figure 6.43: Uxul, Location of the Central Trench in the Aguada Occidental (Map: N. Seefeld).

After extracting the thin humus layer (Lote 472), the excavations exposed a hard and sticky vertisol clay layer (Lote 473) that showed an irregular surface with several gilgai formations (see Figures 6.44, 6.45 and Chapter 2.4.3). During the extraction of this vertisol clay layer, no cultural material or alterations in the soil could be documented.

Figure 6.44: Uxul, Aguada Occidental, Central trench before the excavation (Photo: N. Seefeld).

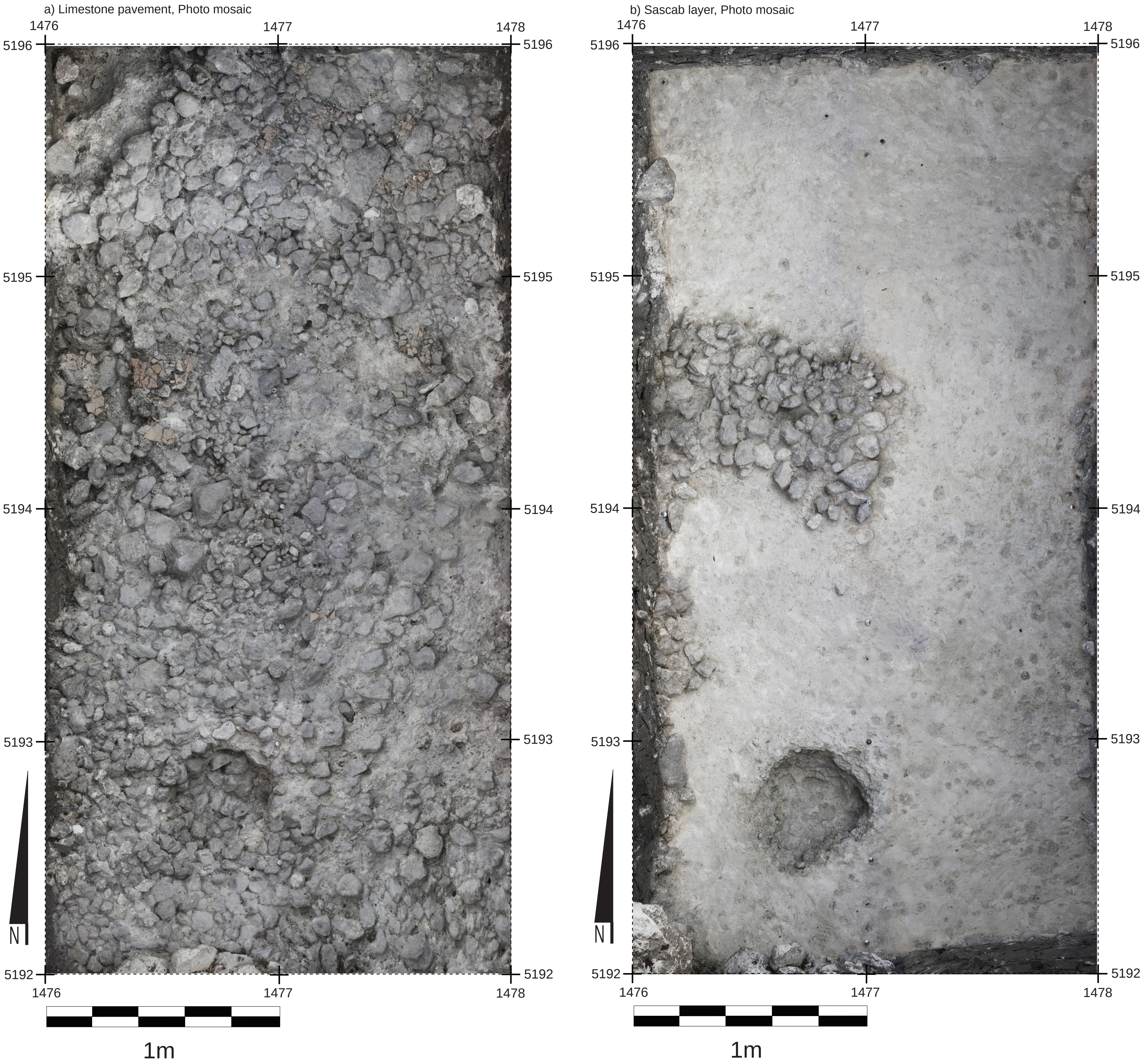
Figure 6.45: Uxul, Aguada Occidental, Central trench after the extraction of the humus layer (Photo: N. Seefeld).

At a depth of 170 cm, the excavations led to the discovery of a pavement composed of rough and small limestone blocks (Lote 501) whose upper edges formed an irregular surface (see Figure 6.46b). The mostly rounded stones featured heterogenous dimensions and were irregularly distributed over the surface. In a few instances, residues of a stucco layer could also be observed in the gaps between the different stones. Furthermore, some scattered ceramic fragments could be documented on the surface of the pavement.

A very peculiar feature of this modification was a small, circular depression with a diameter of approximately 35 cm in the southeastern corner of the exposed surface. As Figure 6.46d indicates, the bottom of this depression was also covered with the same limestone blocks as the rest of the exposed pavement. After documenting this surface, the upper stone layer of the exposed pavement was removed. In this process, it became evident that the pavement had been applied directly upon a compact sascab layer (see Figure 6.46c). Furthermore, this process also showed that the pavement of the Aguada Occidental partially consisted of two layers of stone slabs (compare Figures 6.46b and 6.46c). Due to the fairly hard consistency of the sascab layer, the builders of the pavement only needed to level the existing sascab layer and deposit the stones directly upon it. As Figure 6.46c indicates, these stones even left shallow imprints in the hard sascab layer.

As the function and origin of the small circular depression in the west of the planum could not be identified based on the exposed surface, the author decided to investigate this feature by excavating an artificial profile through its center. To accomplish this, an east-west cut was laid through the center of the depression. In the next step, the hard sascab layer north of this center line was excavated (see Figure 6.46d).

The resulting profile showed that this feature had been created long after the construction of the limestone pavement (see Figure 6.46e). While the pavement sits directly upon the dense layer of sascab, the depression was excavated up to a depth of 60 cm where it hit the bedrock. (see Figure 6.46e). In the author's opinion, the most likely explanation for this feature is that it is a buk'te' well (see Chapter 5.6.4.2). The partial destruction of an already existing pavement could be interpreted as a desperate attempt at acquiring small amounts of water in times of uttermost water scarcity.



a) Limestone pavement, Photo mosaic

b) Sascab layer, Photo mosaic

c) Close-up of circular depression in the southwestern section of the pavement

d) Planum of the east-west cur through the buk'te' feature

e) South view of the buk'te' feature

Figure 6.46: Uxul, Aguada Occidental, Limestone pavement, sascab layer and buk'te' feature (Photos and graphics: N. Seefeld).

As the west profile of the trench illustrates, the surface of the pavement shows some irregularities (see Figure 6.47). Furthermore, the clay layer above the pavement is marked by very pronounced slickensides, which indicate that the aguada has been subject to highly differing moisture levels after the abandonment of Uxul.

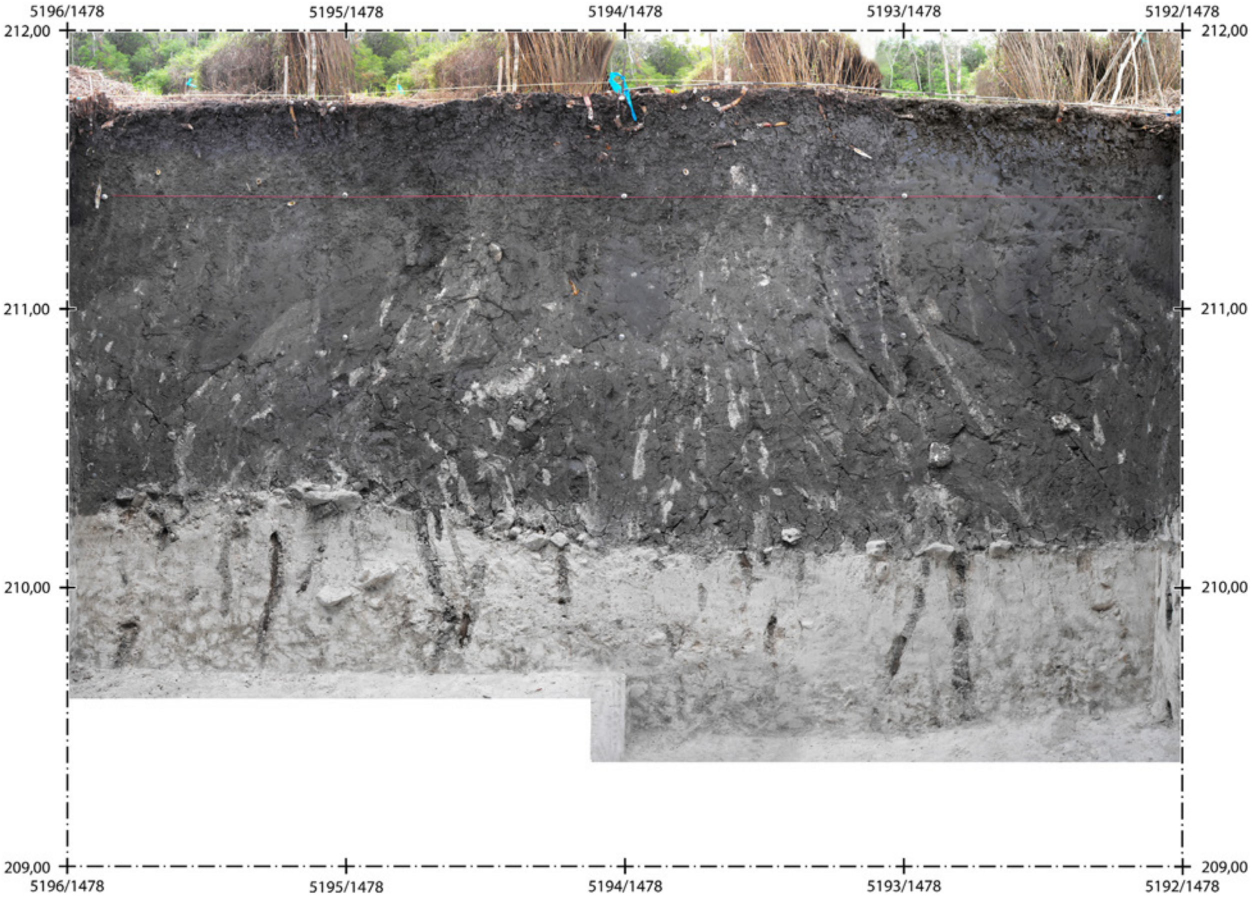


Figure 6.47: Uxul, Aguada Occidental, West Profile (Photo and Graphic: N. Seefeld).

6.2.4 Feeding canal to the Aguada Oriental

The feeding canal to the Aguada Oriental had already been observed by the author in 2010. Essentially, the only clue for the existence of this feature consisted of a simple stone alignment, which crossed the Uxul Archaeological Project's base camp.

The 2012 field season was focused on the identification of the potential modification of the catchment area of the Aguada Occidental and at the onset of the season, the author decided to determine if this stone alignment actually had a cultural origin. In the beginning, this stone line could only be observed over a distance of 10 meters. However, because the line of stones constituted the first indication of a modification of the watershed, it was initially cleared of loose leaves and other material leading to the discovery of a second stone line running parallel to the already known line at a distance of 2.5 m. In order to better understand the composition and function of these two stone lines, a central axis was defined between them (see Figure 6.48). While extending this axis towards the northwest, it also became apparent that the southeastern corner of the Aguada Occidental featured a linear depression with the same orientation as the two parallel stone lines (see Figure 6.49). Subsequently, three archaeological trenches were defined perpendicular to the central axis. Trenches 1 and 2 were placed next to the camp's kitchen and Trench 3 was placed in the linear depression at the southeastern corner of the Aguada Occidental (see Figure 6.50).

Figure 6.48: Uxul, Influx canal to Aguada Occidental, Southeastern limit of central axis (Photo: N. Seefeld).

Figure 6.49: Uxul, Influx canal to Aguada Occidental, Northwestern limit of central axis (Photo: N. Seefeld).

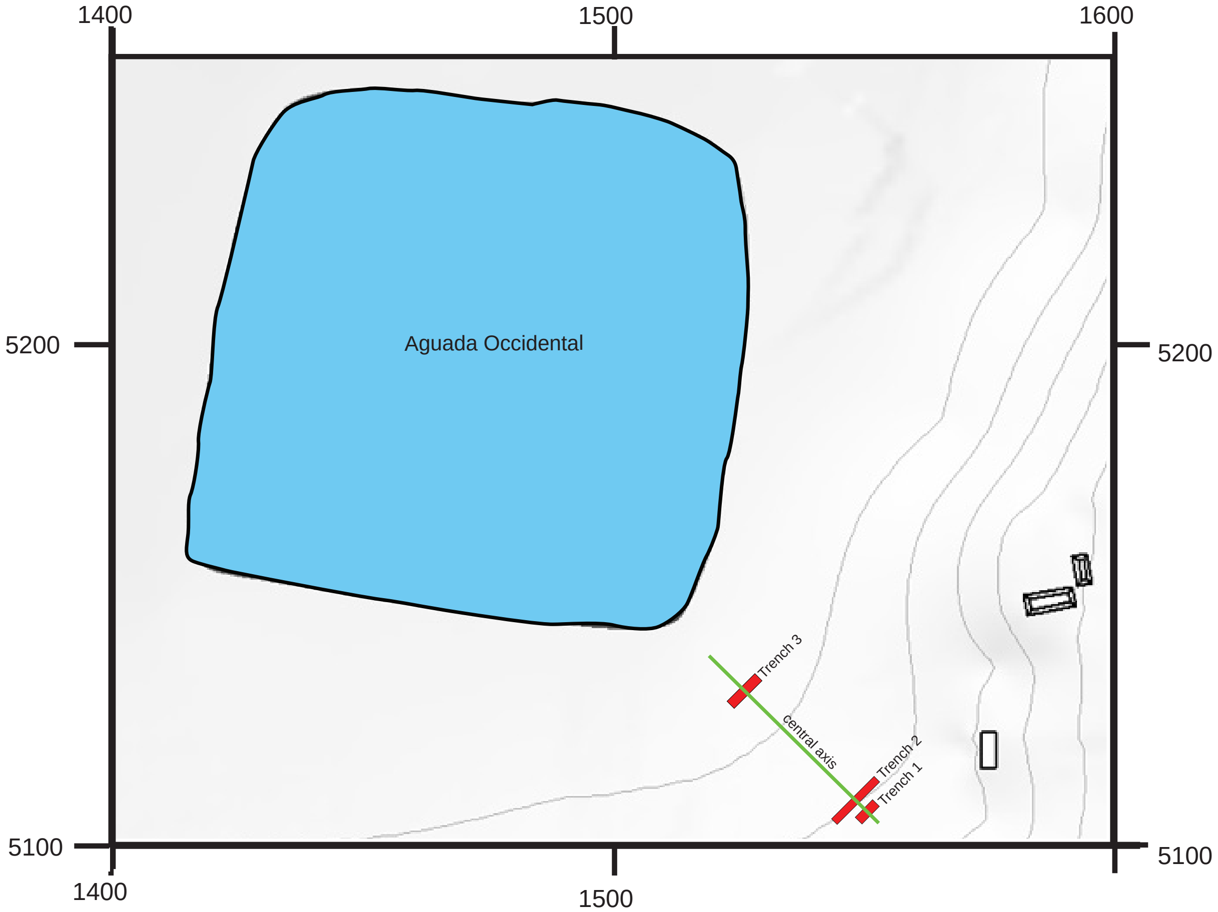


Figure 6.50: Uxul, Influx canal to Aguada Occidental, Location of excavation units (Map: N. Seefeld, modified from Seefeld 2016: Figure 2). Base map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

Trench 1 and Trench 2

In contrast to the other studied hydraulic features of Uxul, Trenches 1-3 were not oriented to the north, but perpendicular to the course of the canal. This decision was made in order to record the technical layout of a potential cultural feature as a distortion-free cross section. Trench 1 was defined as a 5 x 2 m unit while Trench 2 was defined as a 12 x 1.5 m unit. At the beginning, the excavations in Trenches 1 and 2 began with the extraction of a 5 cm thick loose humus layer (Lote 1082). The resulting Planum 1 clearly indicated that the two parallel stone lines were the result of human activity (see Figures 6.51a and 6.51b). Nevertheless, the exposed features still did not enable a clear interpretation. After the documentation of Planum 1, the fine-grained light brown sediment visible in Planum 1 (Lote 1084) was extracted, while the stone blocks remained unmoved.

Figure 6.51: Uxul, Influx canal to Aguada Occidental, Trenches 1 and 2, Planum 1, Photo mosaic (Photo: N. Seefeld).

Upon extracting a 5 cm thick layer of the sediment (Lote 1084), the excavations exposed the upper edge of a sediment layer with a harder consistency, a grey coloration and a higher content of small stones (Lote 1085). The surface of Lote 1085 was documented in Planum 2. As Figures 6.52a and 6.52b indicate, the stone alignments observed prior to the excavations now appeared to be two distinct bands of deposited stones at the northeastern and southwestern limits of Trench 1 and Trench 2. Particularly, the stone blocks in the southwestern portion of Trench 1 showed remarkably homogenous dimensions. At the same time, it became apparent that the central portions of the trenches were only marked by the accumulated gray sediment (Lote 1085). After the documentation of Planum 2, this sediment was extracted in the central portions of Trench 1, while the stone depositions at both ends were left in place.

Figure 6.52: Uxul, Influx canal to Aguada Occidental, Trenches 1 and 2, Planum 2 (Photos and Graphics: N. Seefeld).

After extracting a 10 cm thick layer of Lote 1085 in the central portions of Trench 1 and Trench 2, the excavations led to the exposure of a 2.80 m wide pavement composed of limestone slabs (Lote 1284) that had a good state of preservation (see Figures 6.53 and 6.54). The limestone slabs forming the pavement featured a homogenous thickness of 6-8 cm and had obviously been deposited in order to create an even and closed surface. While the pavement of Trench 2 was better preserved than that of Trench 1, both could still be defined as intact. The two parallel stone lines observed prior to excavation (as seen in Plana 1 and 2) could now be identified as lateral walls (Lote 1466 and Lote 1467) composed of worked stones with heights of 50 cm, widths of 25 cm and lengths of 20-60 cm, which delimited the pavement on both sides.

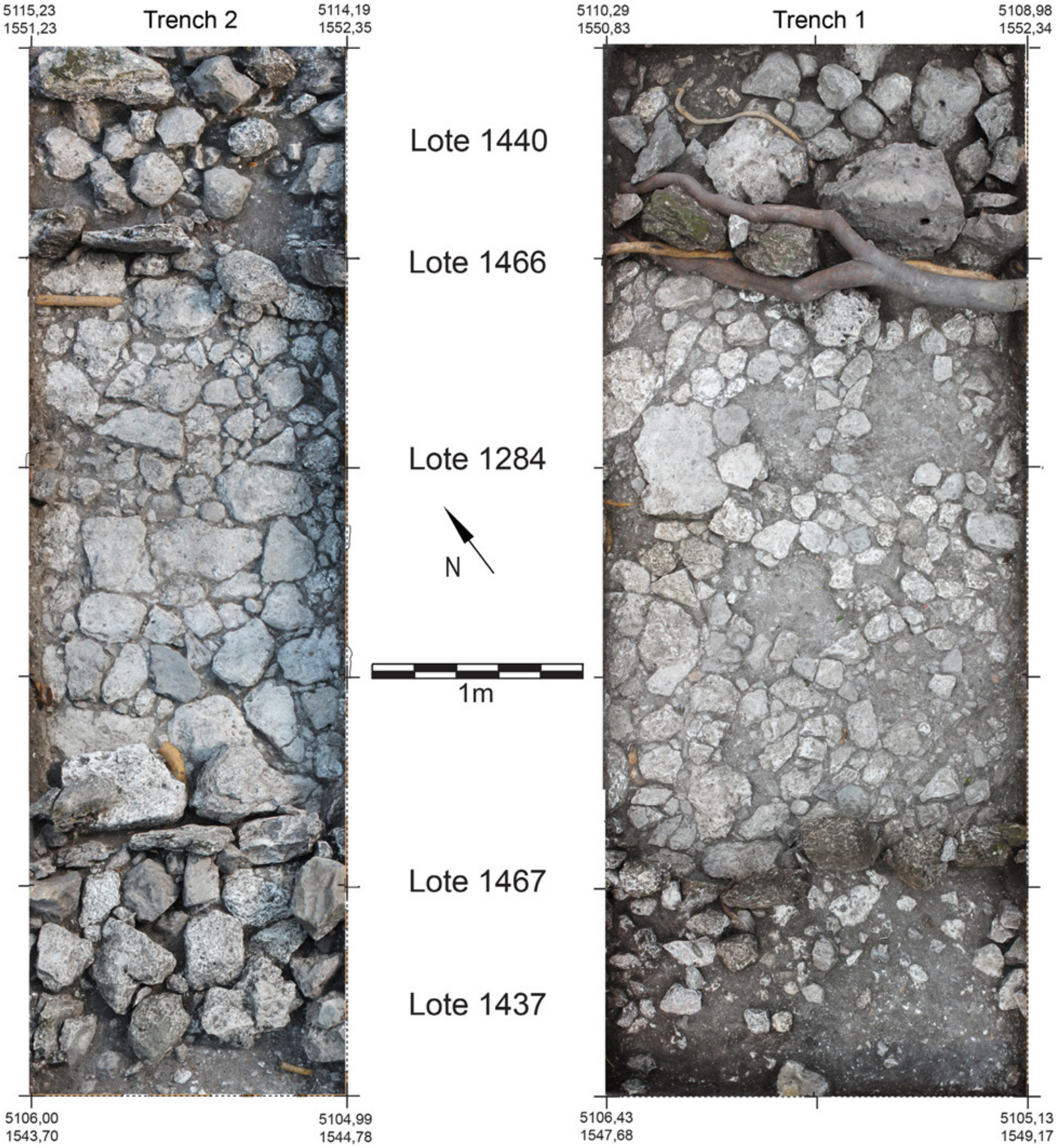


Figure 6.53: Uxul, Influx canal to Aguada Occidental, Trenches 1 and 2, Planum 3, Photo mosaic (Photo: N. Seefeld).

The walls were supported by stone embankments with widths of 80 cm and heights of 40 cm. One embankment (Lote 1437) is located southwest of the southern lateral wall (Lote 1467), while the other embankment (Lote 1440) is located northwest of the northern wall (Lote 1466; see Figures 6.53 and 6.54). Both embankments consisted of rough, unworked stone blocks with dimensions of 25 x 30 to 50 x 35 cm, which had obviously been constructed without the intention of creating a close bond. As the builders had placed these lateral walls tightly between the pavement and the exterior stone embankment, they could still be documented in their upright position (see Figures 6.53 and 6.54).

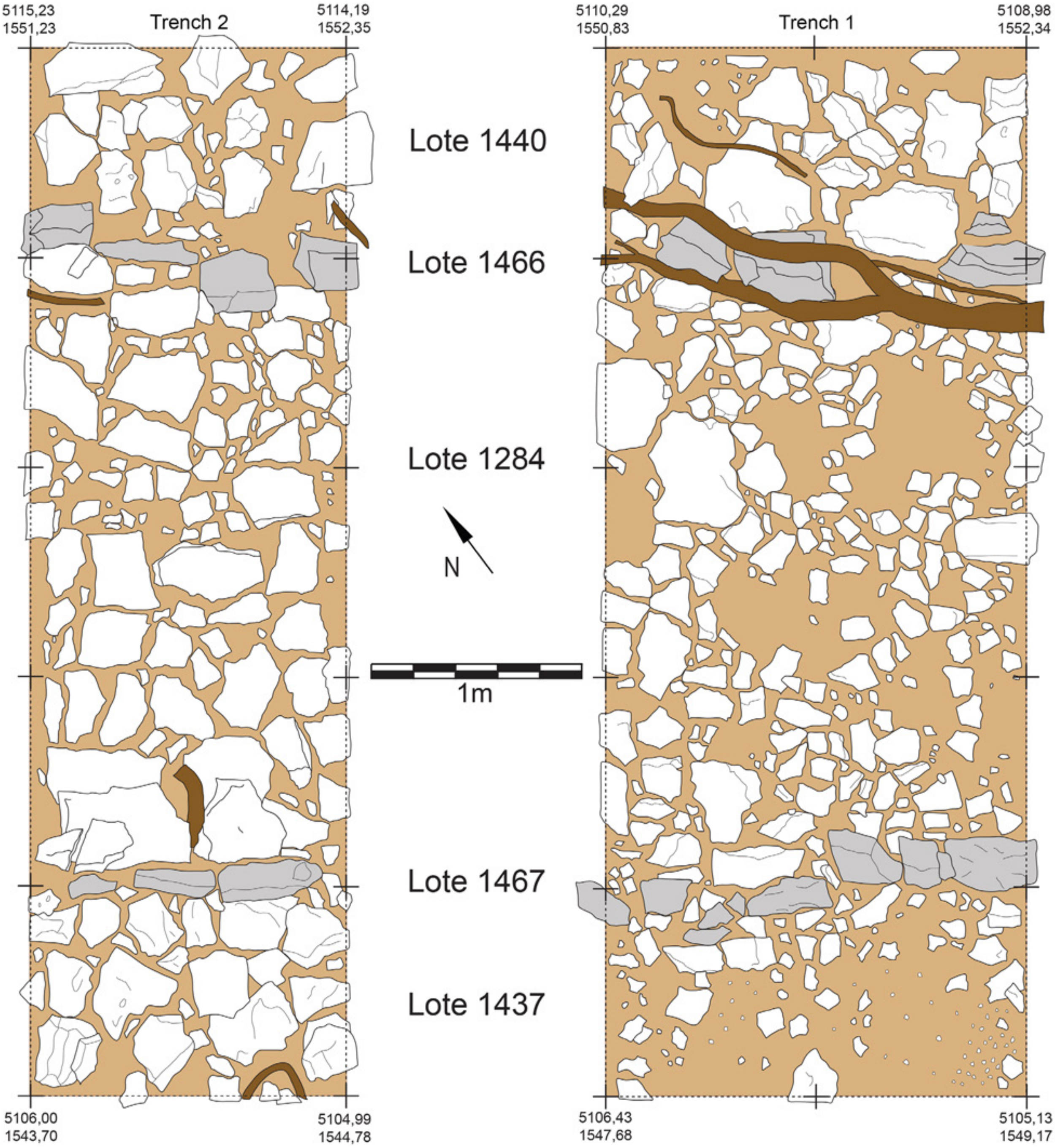


Figure 6.54: Uxul, Influx canal to Aguada Occidental, Trenches 1 and 2, Planum 3, Drawing (Drawing: N. Seefeld).

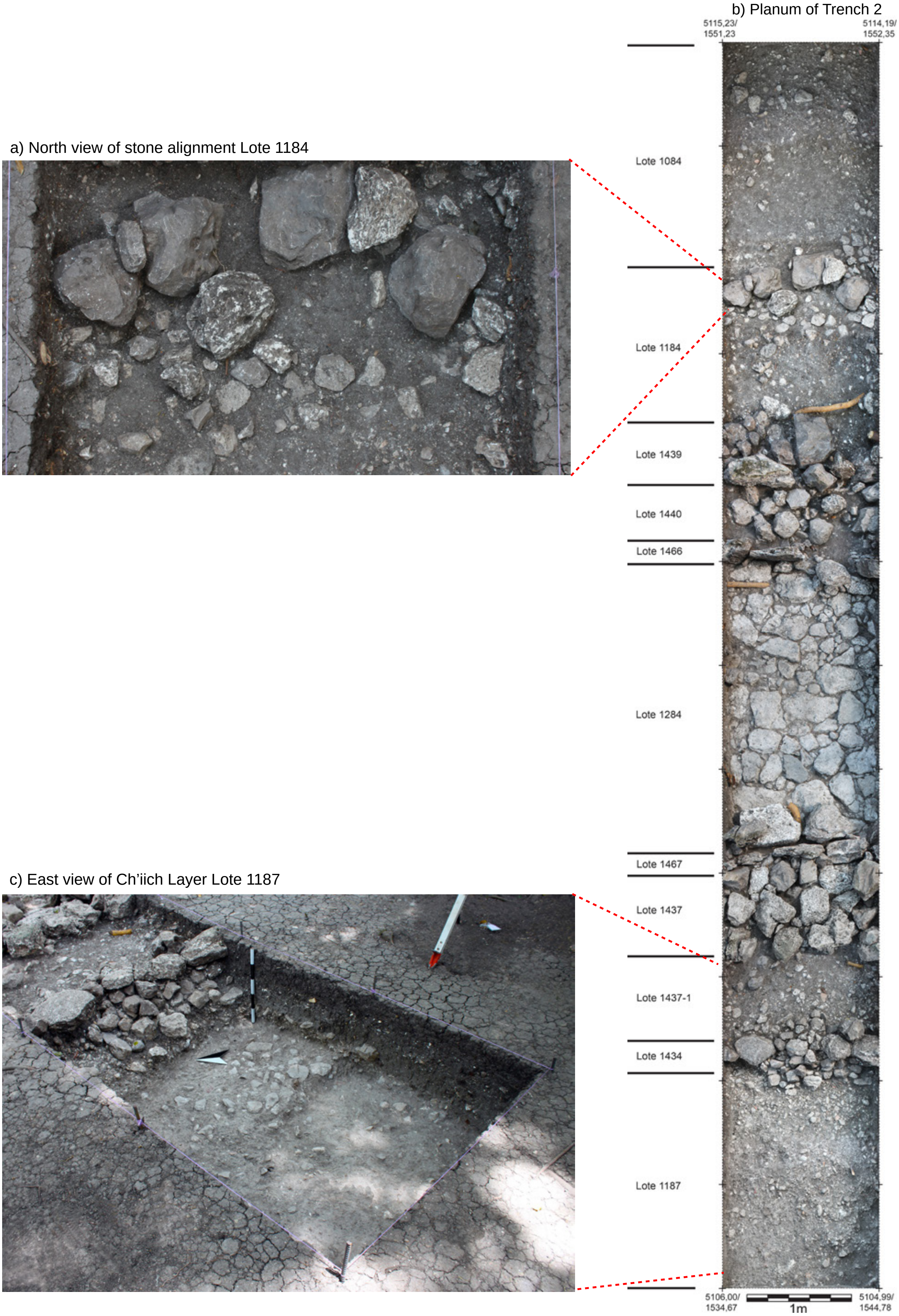
Because the extension of these exterior stone embankments could not be determined based on the exposed surface, the author extended Trench 2. It was extended three meters to the southeast and four meters to the northwest in order to investigate all horizontal features of the construction (see Figure 6.55b). The extension of Trench 2 showed that the stone embankments observed in Planum 3 consisted of several elements.

The southeastern embankment (Lote 1437) was delimited by a compact ch'iich layer (Lote 1437-1) bordered by another alignment of large stone blocks (Lote 1434; see Figure 6.55b). South of Lote 1434, the excavation exposed the surface of an additional compact ch'iich layer (Lote 1187; see Figure 6.55c).

The northwestern stone embankment (Lote 1440) was delimited by an alignment of large stone blocks (Lote 1439) that formed the end of the embankment and collided with a compact ch'iich layer (Lote 1184) and several medium sized stones (see Figure 6.55a and 6.55b). This ch'iich layer was bordered in the north by a homogenous and compact soil layer (Lote 1084), which was not a component of the construction.

Based on these observations, it could be determined that the canal construction had originally consisted of various constructional elements adding up to a total width of 8 m. Thus, the southeastern stone embankment (Lote 1434) could be identified as the southern limit of the canal construction, and the stone alignment of Lote 1184 as the northwestern limit of the canal. Consequently, the ch'iich layers, Lote 1084 and Lote 1187, were located at the same height, showed the same composition and consistency and could be identified as the occupation level around the canal construction in pre-Hispanic times. Furthermore, the exposed planum of Trench 2 also revealed that the different construction elements of the influx canal to the Aguada Occidental had been designed in a very symmetrical way. Thus, the lateral walls (Lote 1466 and 1467) bordering the central limestone pavement had been supported by an embankment consisting of three elements on both sides:

An accumulation of coarse stone blocks (Lote 1440 and Lote 1437) whose only purpose was the lateral support of the side walls, the two narrow ch'iich layers (Lote 1184 and Lote 1437-1) bordering these stone accumulations that formed a sloped transition zone and the narrow stone alignments (Lote 1184 and 1434) that ultimately delimited this transition zone (see Figure 6.55b).



a) North view of stone alignment Lote 1184

b) Planum of Trench 2

c) East view of Ch'iich Layer Lote 1187

Figure 6.55: Uxul, Influx canal to Aguada Occidental, Overview of constructional elements (Photos and graphics: N. Seefeld).

Figure 6.47: Uxul, Influx canal to Aguada Occidental, Overview of constructional elements (Photos and Graphics: N. Seefeld).

After determining the horizontal extension of the construction, we carried out a number of test pits within Trench 2 in order to determine on which subsoil the previously documented constructional elements had been erected. In this process it became apparent that the surface of the natural bedrock (Lote 1472) was at an unusually great depth of 4.05 m (see Figure 6.56e).

The resulting east profile of Trench 2 (see Figure 6.56d) shows the complete stratification of the construction and indicates that it evidently had a precursor. As Figure 6.56d illustrates, a semicircular depression was in-filled (Lote 1285) before the construction of the pavement (Lote 1284). This observation was also supported by the sequence of layers to the north and south of this semicircular depression, which were deposited in a horizontal manner. The semicircular depression, however, had obviously cut the natural stratification and could consequently be defined as a perturbation. During the excavation, the fill material (Lote 1285) documented within this perturbation proved to have a looser consistency. On one occasion, the material was so loose that it could be extracted with a brush and eventually revealed the original underlying semicircular canal basin (see Figure 6.56f).

After filling the original canal construction with fill, the builders of the documented feature were able to deposit the limestone slabs in order to create the pavement. As mentioned before, the canal's cross section revealed that the different elements had been designed symmetrically. Furthermore, the canal had been designed in such a way that it rose above the level of the surrounding terrain by approximately 40 cm and thereby resembled the form of a causeway (see Figure 6.56d). The embankments were made up of medium-sized stones (Lote 1184 and Lote 1434, see Figure 6.56c) delimited by elements designed to elevate the entire canal and produce a steady inclination. During the observation of the east profile, it also became evident that the stone flags forming the lateral walls had been inserted after the completion of the pavement (see Figure 6.56b). As a next step, the stone blocks forming the embankments were apparently piled up behind these stone flags in order to support them. As the east profile indicates, the stone flags of the lateral walls were set into the soil deeper than the pavement and thereby enhanced the stability of the construction. In the author's opinion, the careful lateral support of these sidewalls by these stone embankments indicates that the builders wanted to counteract lateral pressures. In general, the aim of this construction was to accelerate the flow of water and to enable more rainwater to reach the Aguada Occidental. Due to the discovery of this influx canal, it could be verified that the pre-Hispanic inhabitants of Uxul had modified the landscape in order to maximize the quantity of collected water.

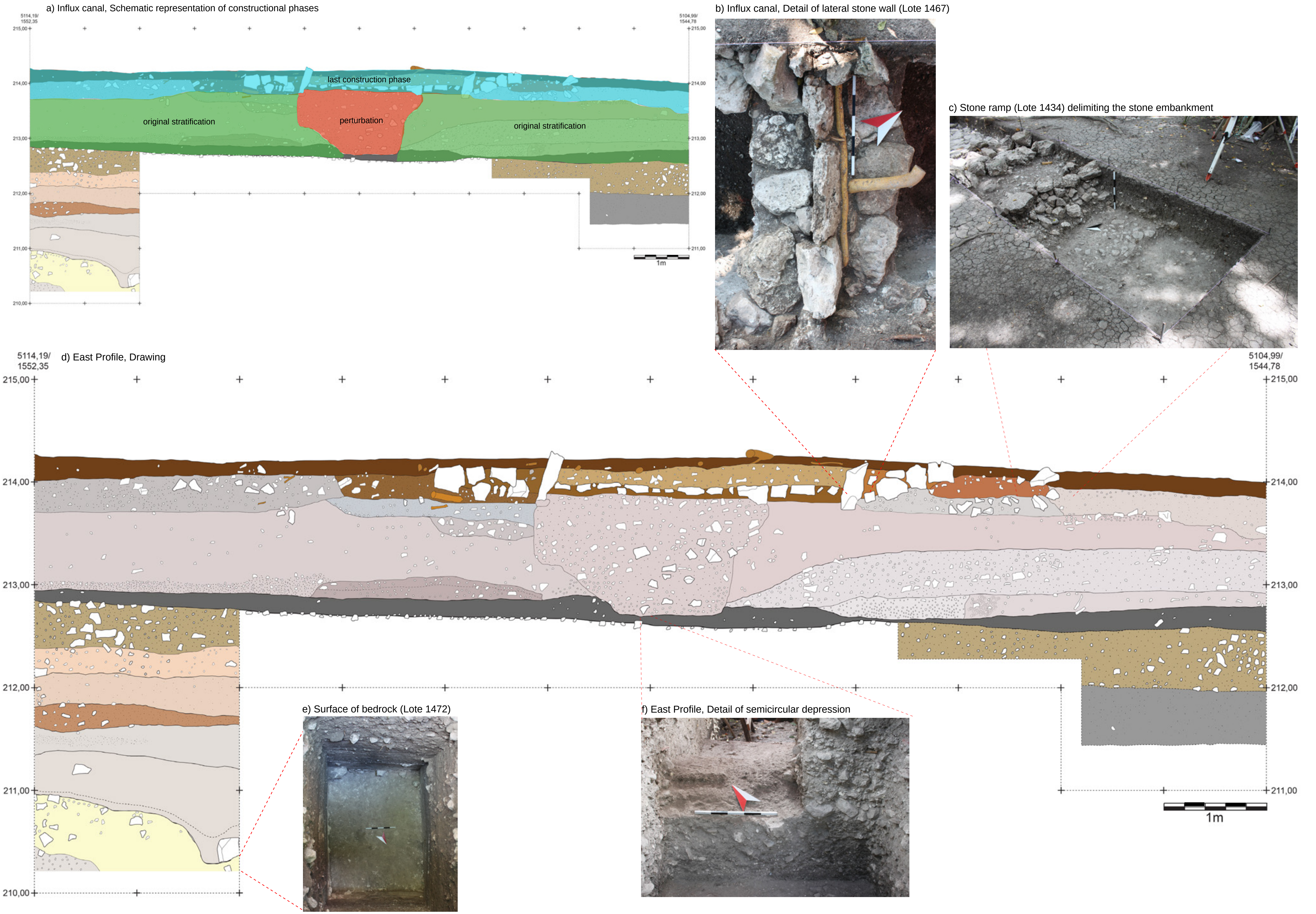


Figure 6.56: Uxul, Influx canal to Aguada Occidental, East profile and details of constructional elements (Photos and Graphics: N. Seefeld).

6.2.5 Artificial Cave of Group Q

After the investigations of the 2009-2012 field seasons, it became clear that the pre-Hispanic inhabitants of Uxul were able to create artificial reservoirs that could supply water for all inhabitants over the entire year. Essentially, the investigations of the Aguada Occidental, the Aguada Oriental and the influx canal to the Aguada Occidental proved that Uxul's inhabitants had come to understand that the key for sustaining the settlement was the storage of the rainy season's downpours. In conclusion, these excavations proved that Uxul's pre-Hispanic inhabitants had modified the majority of the settlement landscape in order to collect a maximum amount of rainwater. Although the capacity of these reservoirs would have facilitated the supply of water for each inhabitant throughout the entire year, they were located at the western and eastern limits of the settlement (see Figure 6.59a).

In this arrangement, the inhabitants of the residential areas of Uxul's central hilltop would not have had direct access to water for domestic use. This observation led the author to the hypothesis that Uxul's pre-Hispanic inhabitants had installed minor reservoirs in the vicinity of residential areas in the site's central hilltop, which could have been used by the local population for domestic purposes.

In order to verify this hypothesis, the author carried out a topographic survey in Group Q, located in the site's central hilltop (see Figure 6.59a). As Figure 6.59a illustrates, Group Q lies close to the steep western slope of Uxul's central hilltop, while at the same time being closely associated with the site core. The topographic survey of Group Q led to the discovery of a surface depression with a circular form located to the north of the monumental acropolis of Group E. The surface depression had a diameter of 8 m and a maximum depth of 1.50 m, and its form could not be attributed to geomorphological processes (see Figures 6.57 and 6.58). In order to determine the origin and function of this landscape feature, the author defined a 1 x 9 m trench through the center of the depression, Trench 2 of Group Q. As it became evident that this feature had a cultural origin, the trench was extended to a dimension of 22 x 14 meters during the 2013 and 2014 field seasons (see Figure 6.59b).

Figure 6.57: Uxul, Artificial Cave before the excavations, Northeast view (Photo: N. Seefeld).

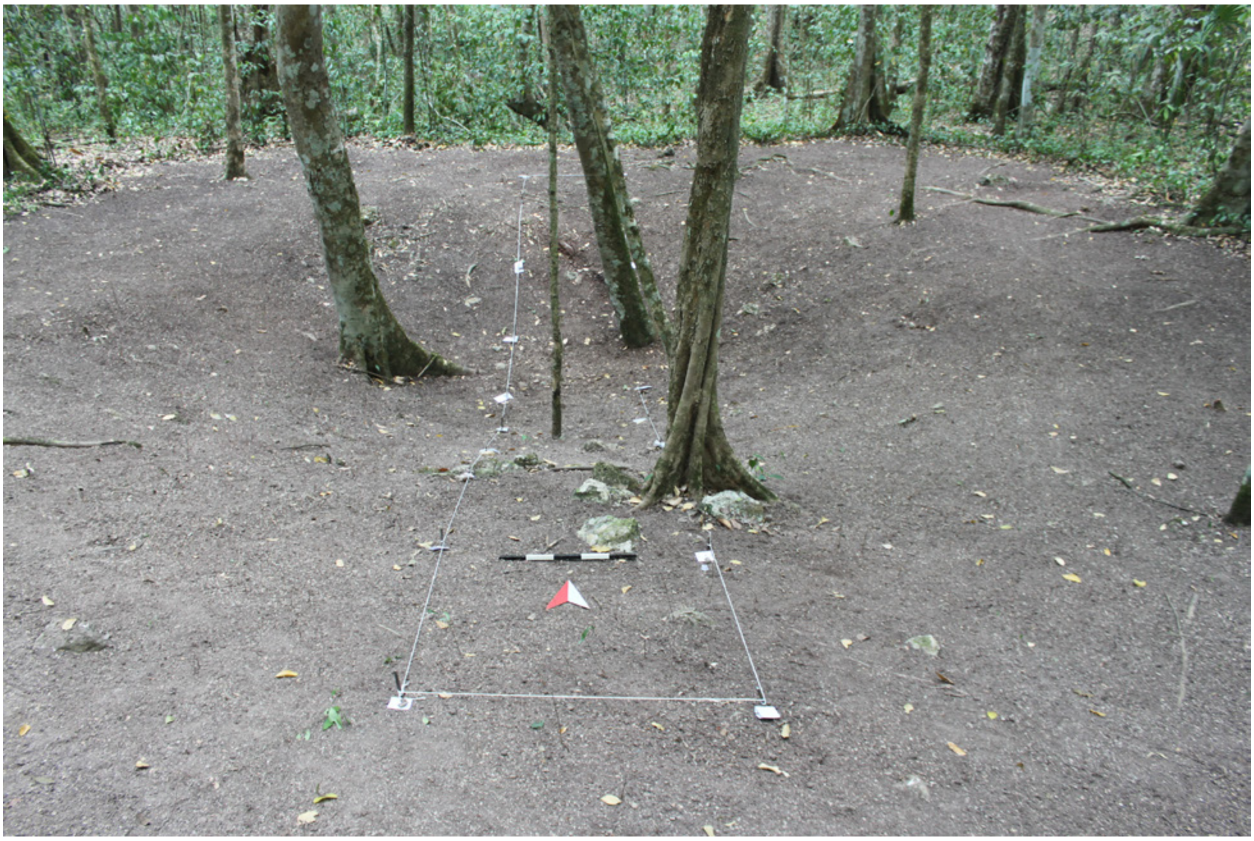
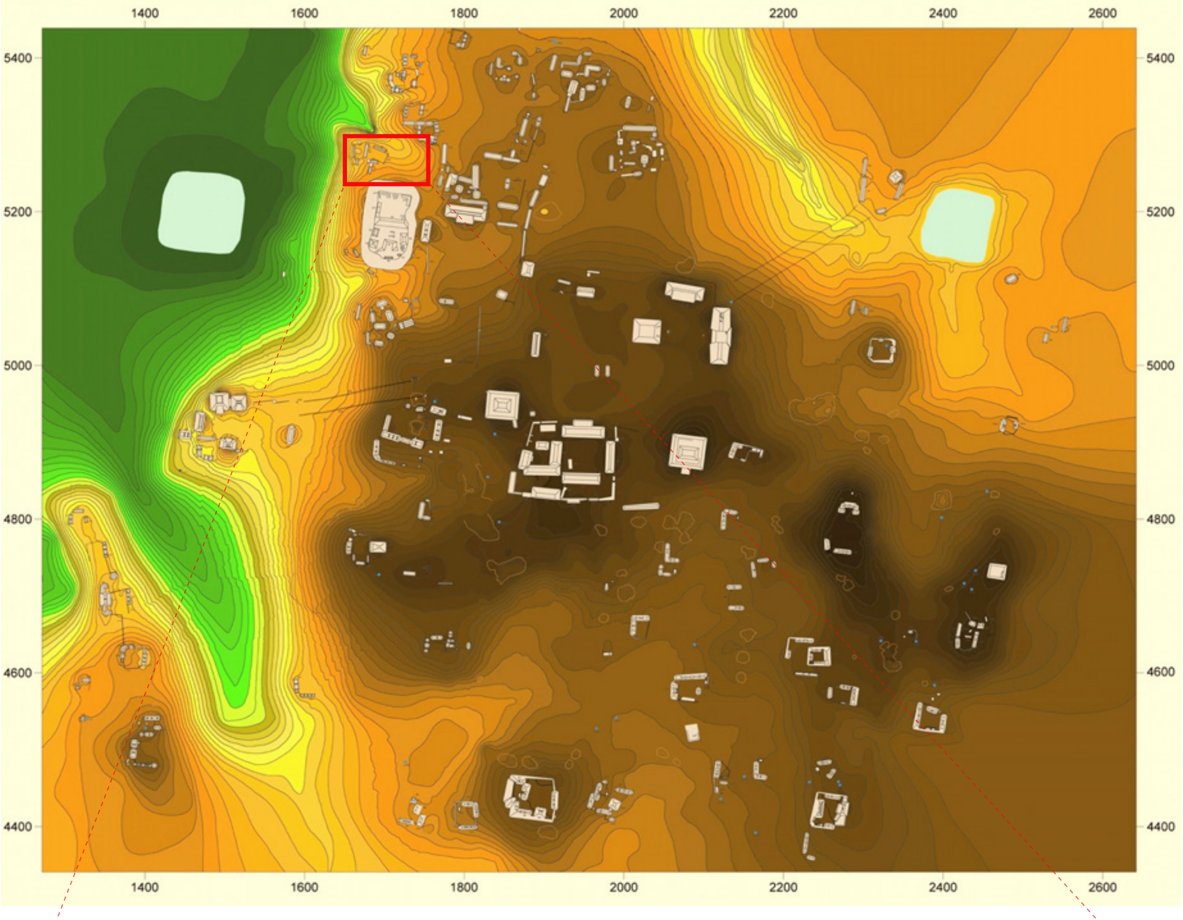


Figure 6.58: Uxul, Artificial Cave before the excavations, North view (Photo: N. Seefeld).

a) Location of Group Q in Uxul



b) Group Q, Location of excavation units

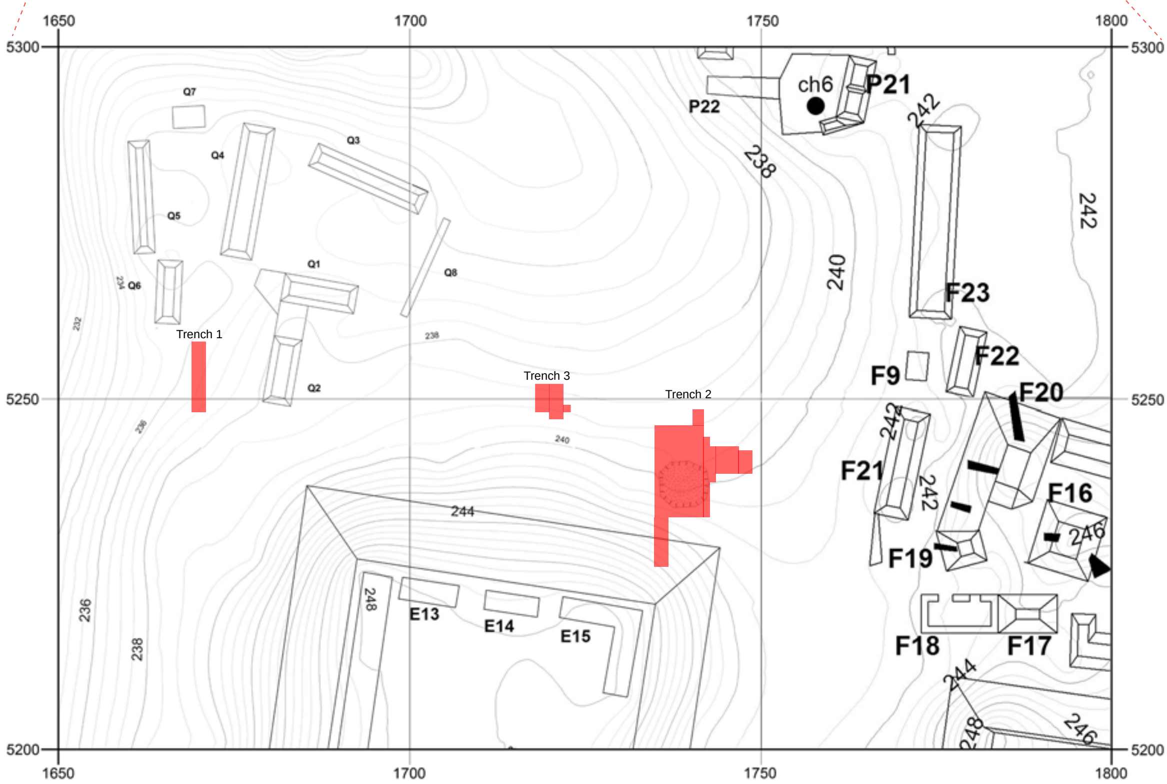


Figure 6.59: Uxul, Location of Group Q and the Artificial Cave. (a) (Map: N. Seefeld); (b) (Modified from Seefeld 2016: Figure 2). Base map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

Over the course of the excavation process, it could be determined that the origin of the circular depression was an artificial cavity that the builders had cut from the natural bedrock material. The circular rim of this cavity was surrounded on all sides by a stucco floor that descended towards the opening in the form of a funnel (see Figure 6.60).

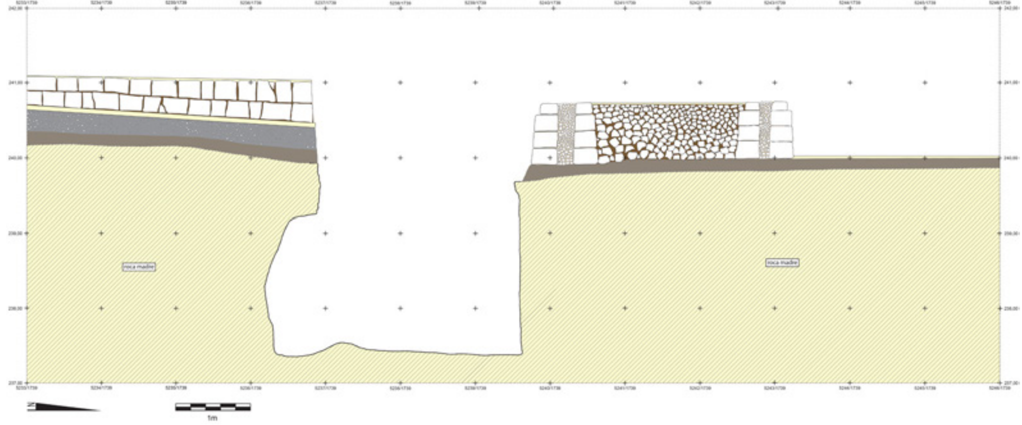

a) Artificial Cave, Final Planum, Photo Mosaic

b) Uxul, East view of the Artificial Cave and surrounding platforms

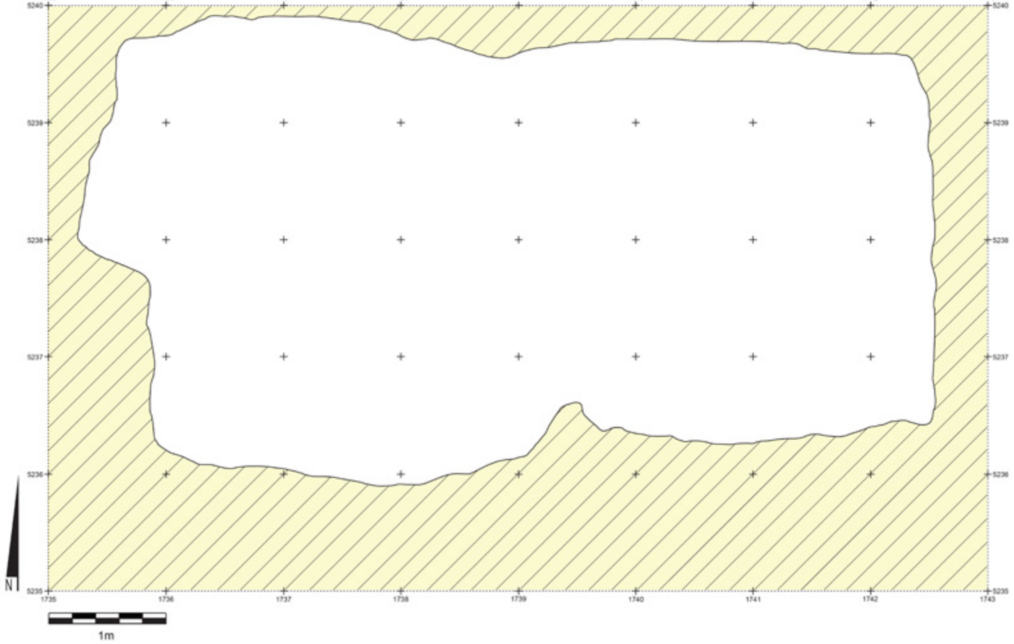
Figure 6.60: Uxul, Artificial Cave, Overview (Photos and Graphics: N. Seefeld).

The construction form of this cavity highly resembled the chultunes of the Puuc region, which were also surrounded by stucco floors that descended in a funnel-like fashion and demonstrably served as water storage features (Seefeld 2013b: 137; see Chapter 5.6.2). However, with its 3 m wide entrance, the cavity highly differed from the remaining chultunes of Uxul, which usually have diameters fluctuating between 70 and 100 cm. Owing to these characteristics, the exposed cavity was not defined as a chultun, but as an artificial cave. Based on the excavations of the 2013 and 2014 field season, the complete construction history of the artificial cave and its immediate surroundings could be retraced.

a) Uxul, Artificial Cave, Cross section, West view



b) Uxul, Artificial Cave, Planum of cave's interior



c) Uxul, Artificial Cave, North profile

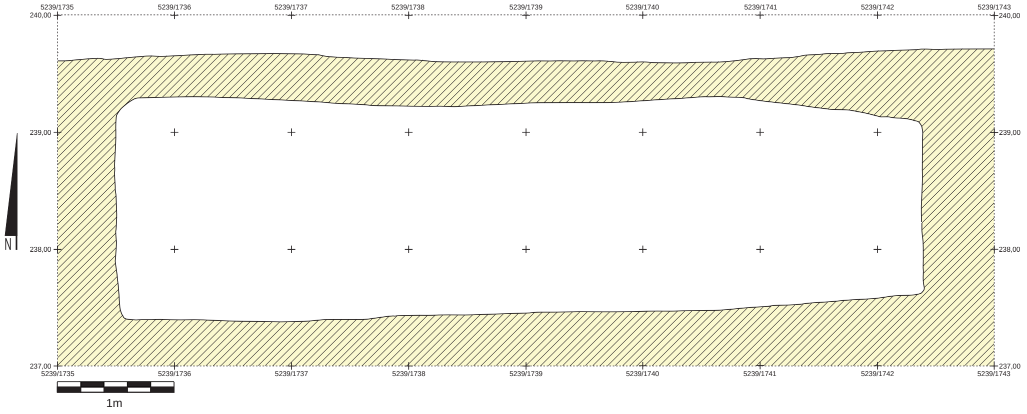


Figure 6.61: Uxul, Artificial Cave, Profiles and planum of the cavity (Photos and Graphics: N. Seefeld).

In construction phase 1, Uxul's inhabitants excavated the artificial cave from the natural bedrock material. After excavating the cavity, the surface around the entrance was sealed off by means of a stucco floor. The fact that this floor was inclined towards the entrance exemplifies that the artificial cave was originally constructed in order to serve as a reservoir. The floor of this reservoir was covered by a stucco layer and had a base of 8 x 4 meters. The cave also featured a rectangular interior with a uniform height of 1.85 m. Furthermore, the side walls had been shaped from the bedrock in a very homogenous manner. After excavating this cavity, a continuous stucco floor was built to the north and south of the entrance (see Figure 6.62).


a) Construction phase 1, Planum

b) Artificial Cave, East view illustrating the shape of the cavity and stucco floor

Figure 6.62: Uxul, Artificial Cave, Construction Phase 1 (Photo and drawing: N. Seefeld).

In construction phase 2, Platform 2 was erected to the south of the entrance (see Figure 6.51b). This platform showed the same orientation as the base of the acropolis of Group E and featured a height of only 60 cm (see Figure 6.63).


a) Construction phase 2, Planum

b) Artificial Cave, Platform 2, West view

Figure 6.63: Uxul, Artificial Cave, Construction Phase 2 (Photo and drawing: N. Seefeld).

In construction phase 3, the stucco floor to the north of the entrance was covered with a mortar layer with a very hard consistency. In this mortar layer, the builders set flagstones in order to form an influx canal that ended in the northwestern edge of the cave (see Figure 6.64b). This canal featured a width of 80 cm and the lateral flagstones featured homogenous heights of 40 cm (see Figures 6.64a and 6.64d). This construction element proves that the cave was utilized as a water storage feature up to this construction phase.

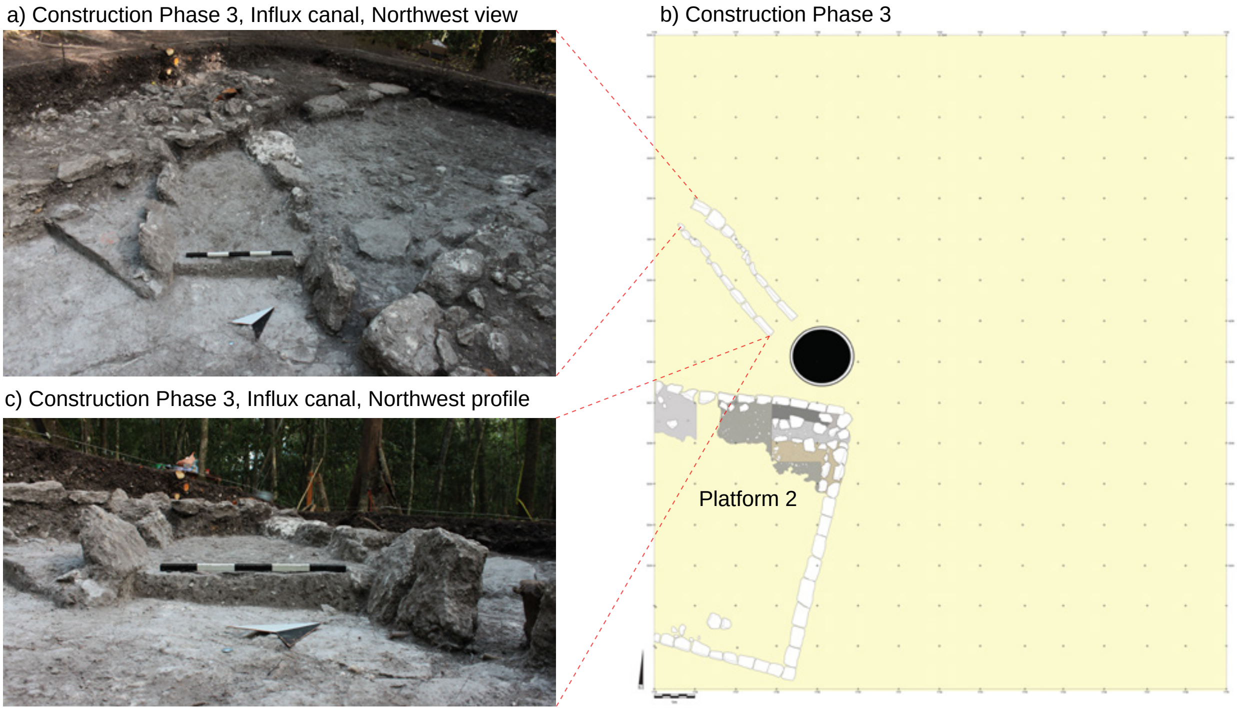


Figure 6.64: Uxul, Artificial Cave, Construction Phase 3 (Photo and drawing: N. Seefeld).

In construction phase 4, the artificial cave was no longer used as a water storage feature. After being used as a reservoir, the cave was transformed into a burial chamber. At the bottom of the cave, Uxul's inhabitants deposited the bodies of 27 individuals (see Figures 6.65b and 6.65c), which were subsequently covered by a voluminous stone layer (see Figure 6.65c; Seefeld 2013b, 2015). Afterwards, the local population no longer used the spacious interior of the cave.

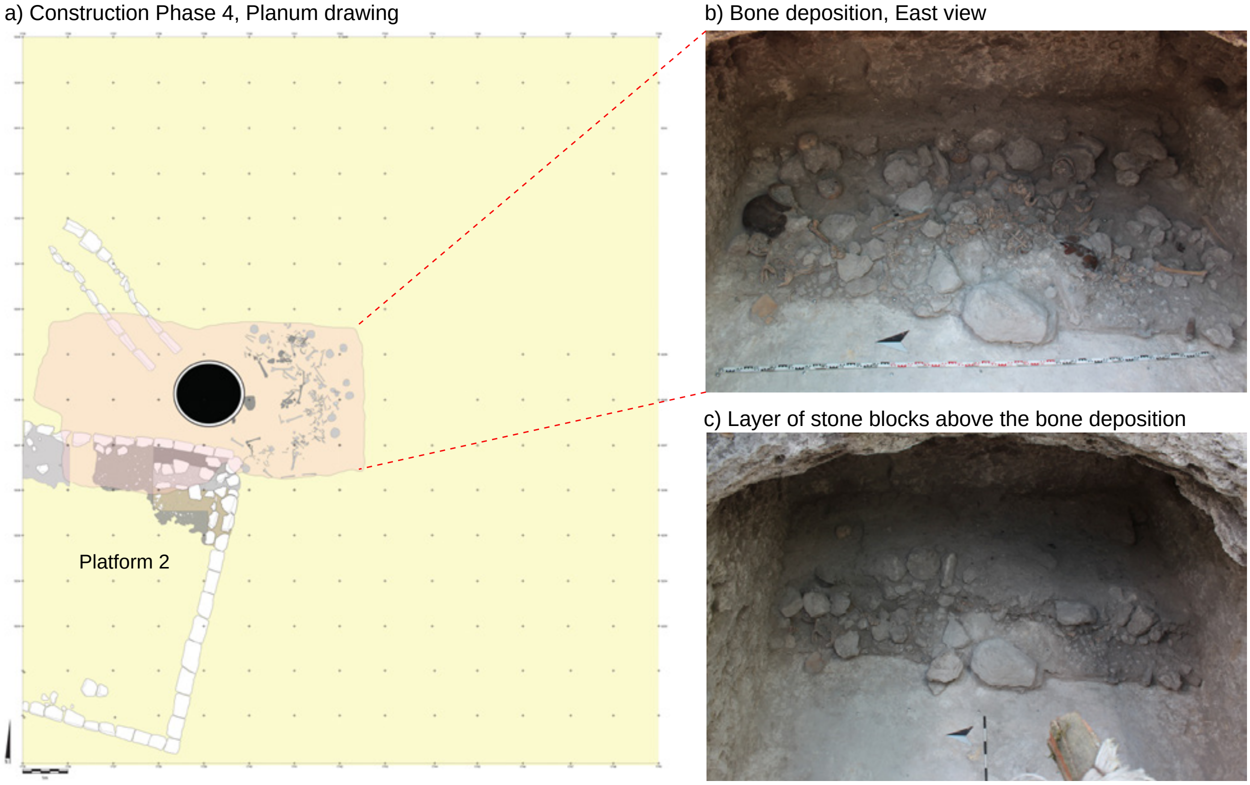
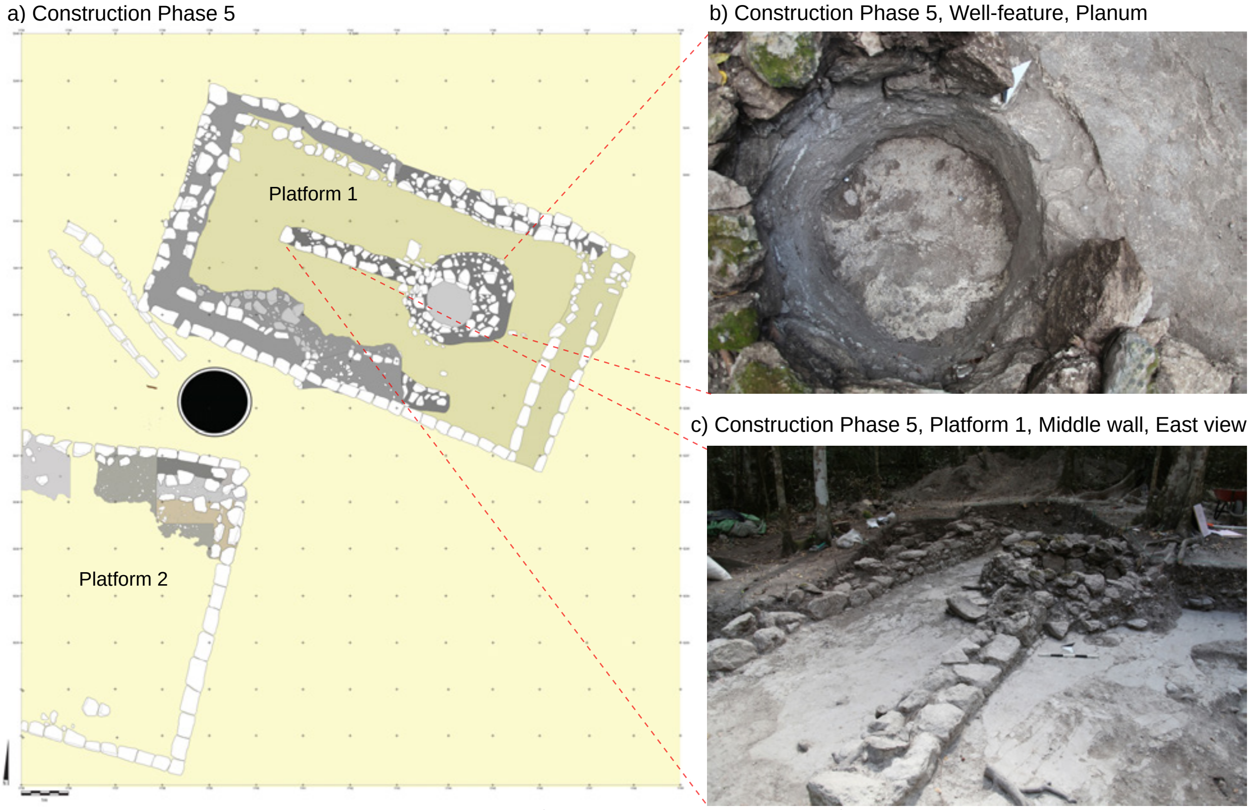


Figure 6.65: Uxul, Artificial Cave, Construction Phase 4 (Photo and drawing: N. Seefeld).

In construction phase 5, Uxul's inhabitants built Platform 1 to the north of the cave's entrance. The platform has a length of 10.5 m, a width of 6 m and a height of 60 cm (see Figure 6.66a). After sealing the artificial cave, the local population apparently wanted to create a new reservoir. Because of this, they built a well shaft on the stucco floor of construction phase 1 and sealed the interior wall with a stucco layer (see Figure 6.66b). In parallel, they erected a lateral wall in the middle of Platform 1 and sealed the interior space with a stucco floor. As Figure 6.57b indicates, this well featured a diameter of 95 cm and a depth of 130 cm. Curiously, Platform 1 also features a peculiar middle wall, which extends from this small cistern to the west (see Figures 6.66a and 6.66c). This middle wall forms a symmetrical axis and does not form part of a substructure. Consequently, it can be stated that Uxul's inhabitants deliberately constructed this middle wall during the same construction phase as the small well feature. The layout of Platform 1 has a quite irregular form and, so far, the author has been unable to trace any other documentation describing another building with a similar layout.


a) Construction Phase 5

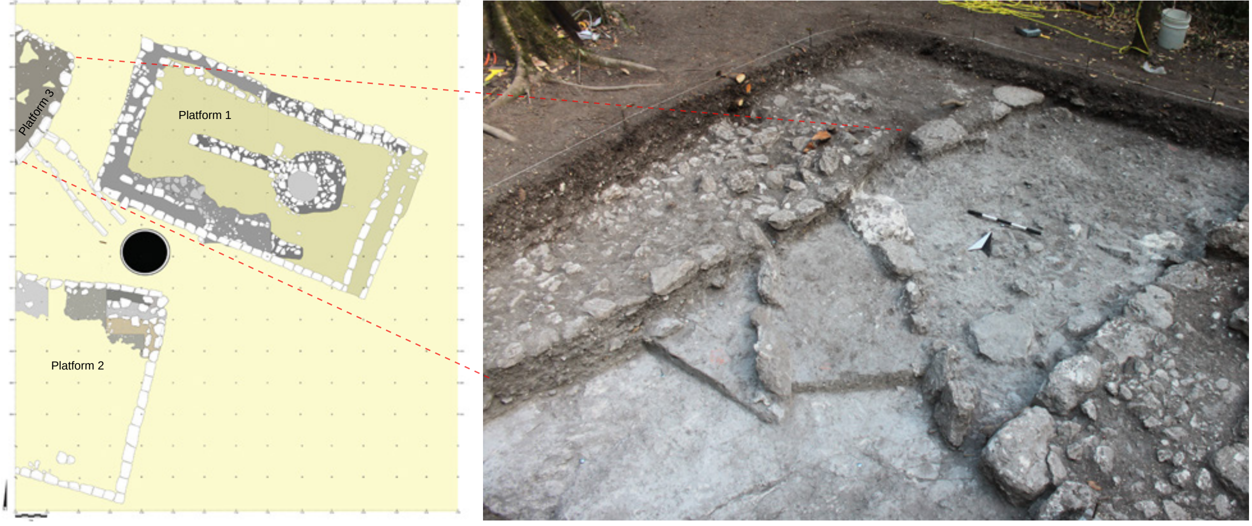
b) Construction Phase 5, Well-feature, Planum

c) Construction Phase 5, Platform 1, Middle wall, East view

Figure 6.66: Uxul, Artificial Cave, Construction Phase 5 (Photo and drawing: N. Seefeld).

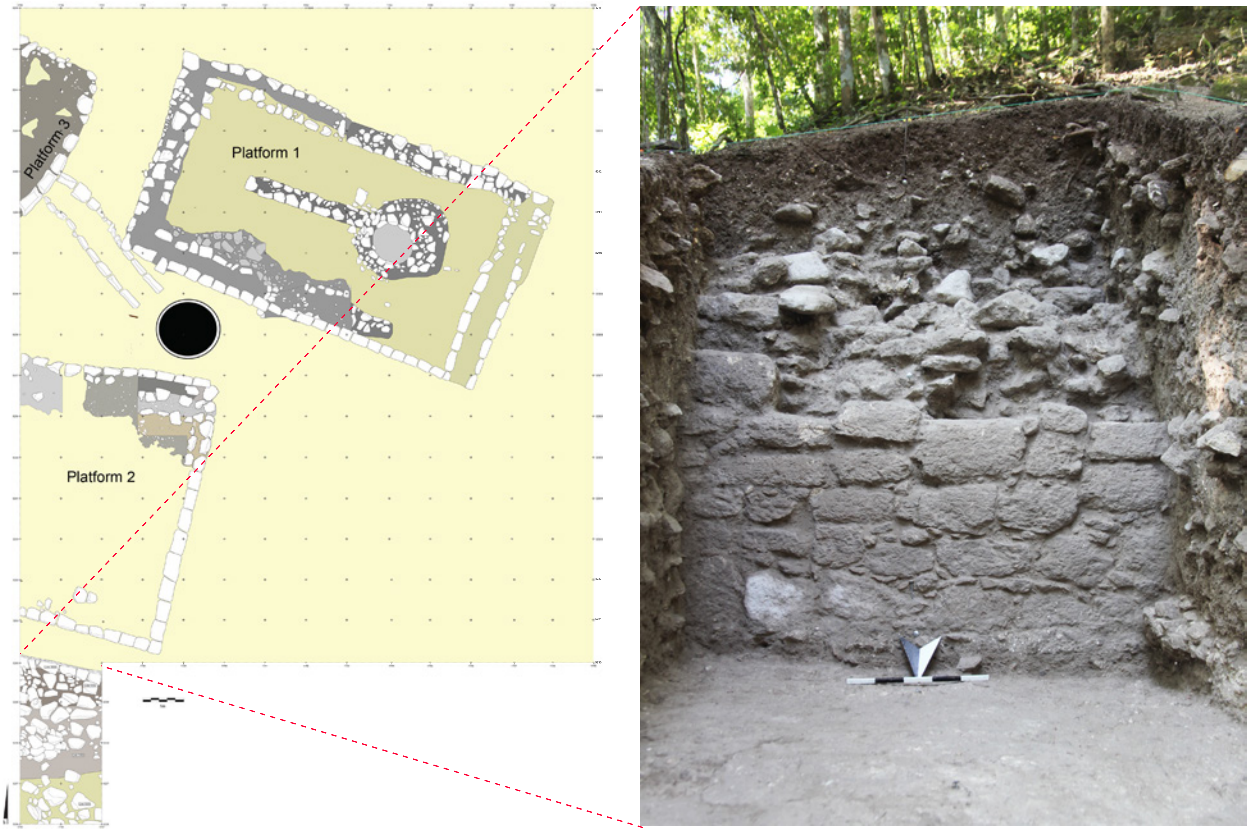
In construction phase 6, Uxul's inhabitants constructed Platform 3, which covered and partially destroyed the remains of the small influx canal, which by that time had already lost its original function (see Figure 6.67).

In construction phase 7, the local population constructed the base of Structure E (see Figure 6.68), which was evidently erected after the immediate surroundings of the artificial cave had already undergone their most intensive modifications.


a) Artificial Cave, Construction phase 6, Planum drawing

b) Artificial Cave, Platform 3, Northwest view

Figure 6.67: Uxul, Artificial Cave, Construction Phase 6 (Drawing: N. Seefeld).


a) Uxul, Group Q, Artificial Cave, Trench 2, Extension 3, Planum 4

b) Group Q, Trench 2,Northern base of Acropolis E, South view

Figure 6.68: Uxul, Artificial Cave, Construction Phase 7, Base wall of Group E (Photo: N. Seefeld).

As the description of the major elements of Uxul's hydraulic system has shown, the pre-Hispanic inhabitants applied a wide range of different technical approaches in order to store the maximum amount of water and to minimize the percolation of collected rainwater.

6.3 Functionality of Uxul's hydraulic features

The archaeological investigation of Uxul's hydraulic system resulted in the fundamental conclusion that the site's hydraulic features needed to be planned in all details prior to the actual construction (Seefeld 2013a: 74). Due to the evident adaption to the local landscape, the very calculated composition, and particularly due to its finely coordinated constructional elements, the sum of the individual components can be defined as a complex hydraulic system (Gunn *et al.* 2002: 298; Matheny *et al.* 1983; Seefeld 2013a: 74). Since the height of each component and various constructional elements had to be established prior to construction, it is evident that each expansion of the hydraulic infrastructure had been planned in advance. At the same time, the author is convinced that the high level of accuracy of these constructions indicates some amount of experience in the layout of such features, which suggests that the builders or planners had already undergone a long learning process (Seefeld 2013a: 74). Therefore, the upcoming chapter aims both to explain the functionality of these hydraulic features and identify the similarities to other hydraulic features of the Maya Lowlands that were presented in Chapter 5.

6.3.1 Function of the base modifications in Aguada Oriental and Occidental

As already pointed out in Chapters 6.2.1 and 6.2.2, the modifications of the Aguada Occidental and the Aguada Oriental bases essentially had the same purpose: the minimization of percolation and maximization of water storage. From a technological perspective, the base modifications of both aguadas are nearly identical. However, as previously mentioned, the main difference between these modifications consists in the quality and intricacy of execution. In Aguada Occidental's case, the builders of the base modifications simply applied a rather irregular limestone pavement on the surface of a hard sascab layer. The remaining gaps between the limestone slabs were then sealed with stucco. In Aguada Oriental's case, the builders of the base modification first had to level a surface out of the hard limestone bedrock, apply a dense layer of ceramic sherds, and finally seal the construction with a pavement of limestone slabs, which they sealed with a hard stucco matrix.

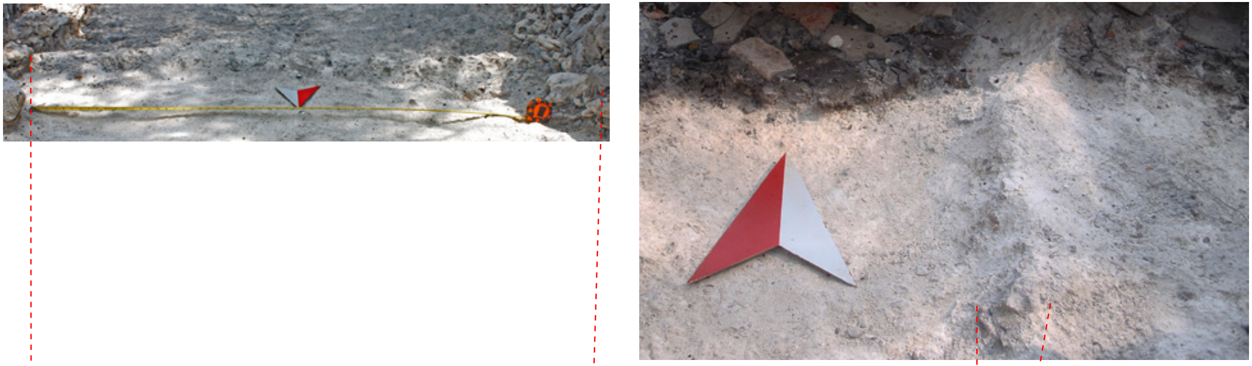
In the author's opinion, these differing modification techniques are largely the result of the different geological conditions at the bottom of both aguadas. While the base of the Aguada Occidental had a hard sascab layer with a certain level of plasticity, the base of the Aguada Oriental was made up of a very hard limestone bedrock. On the one hand, these conditions resulted in very different expenditures of effort in order to excavate the main basins of both reservoirs. More importantly however, the consistency of the bedrock (hard and plastic sascab vs. hard limestone) also seems to have defined the forms of the later base modifications.

As pointed out in Chapter 6.2.3, the hard yet plastic consistency of the sascab layer at the bottom of the Aguada Occidental enabled the limestone slabs of the pavement to be placed immediately upon the sascab, which had been artificially leveled prior to this deposition. Despite this rather simple solution, the surface of the pavement still showed a fairly homogenous composition. Furthermore, the various stone slabs left small imprints in the hard sascab layer (see Figure 6.69a). In the author's opinion, these small imprints indicate that the plastic consistency of the sascab layer had enabled Uxul's pre-Hispanic inhabitants to perfectly level it. During the deposition of the pavement, the consistency of the sascab still proved to be soft enough to accommodate the different stone slabs in such a way that they would not move after their deposition. The soft consistency of the sascab was also determined in the excavation process, where it could be easily cut with a trowel (see Figure 6.69b).

The geologic conditions at the bottom of the Aguada Oriental were dramatically different as the base of the reservoir consisted of very hard limestone bedrock. As was described in Chapter 6.2.2, the builders of this reservoir had evidently undertaken major efforts to create a perfectly smooth subsurface for the limestone pavement. However, the excavations revealed that, in many instances, the limestone bedrock apparently featured segments with a harder consistency, which prevented the creation of a perfectly flat basin (see Figures 6.69c and 6.69d). Thus, some of these sections of bedrock with a harder consistency could not be entirely removed with the tools available in pre-Hispanic times. This resulted in some remnant ridge-like elevations such as those observed in Trenches 1 and 3 (see Figures 6.69c and 6.69d). As pointed out in Chapter 6.2.2.2, these ridge-like elevations obviously had a far-reaching effect on the deposition of the ceramic layer because the builders of the Aguada Oriental tried both to avoid the deposition of ceramic fragments in sloped sections and form a flat surface. Therefore, the ridge-like elevation of Trench 1 later resulted in a step-like height difference in the deposition of the ceramic layer (see Figure 6.69e), while the ridge-like elevation in Trench 3 was simply not covered by ceramic fragments.


a) Aguada Occidental, Imprints of the pavement in the sascab layer

b) Aguada Occidental, Planum 9


c) Aguada Oriental, Trinchera 1, Detail of ridge-like elevation in the bedrock, South view

d) Aguada Oriental, Trinchera 3, Detail of ridge-like elevation in the bedrock


e) Aguada Oriental, Trinchera 1, Detail of step-like height difference in the ceramic layer

f) Aguada Oriental, Trinchera 3, Gap in the ceramic deposition to the east and west of the ridge-like elevation in the bedrock

Figure 6.69: Technical differences in the base modifications of the Aguada Occidental and the Aguada Oriental (Photos: N. Seefeld).

In the author's opinion, the fairly heterogenous pattern in the deposition of ceramic fragments in the Aguada Oriental suggests that it was not decided upon based on aesthetics[179], but was rather defined by the heterogenous consistency of the limestone bedrock, which forced the builders to customize the application of the ceramic floor to the specific location.

Figure 6.70: Ek' Balam, Structure 1, Ceramic floor at the bottom of Reservoir D-8 (adapted from Castillo Borges and Vargas de la Peña 2009: Photo 3). Reproduced with kind permission of Victor Castillo Borges and Leticia Vargas de la Peña.

This ceramic layer could be observed in the central trench of 2009 and in trenches 1-4 of 2011 and generally featured gaps of various sizes in each of the excavated trenches (see Figure 6.71). In some quadrants, the sherds were completely absent. This distribution already illustrated that the builders of the Aguada Oriental had only applied this ceramic layer to the level areas of the reservoir. Therefore, the ceramic layer is lacking in the northern trench of 2009 and the southern half of Trench 4. Because one can assume that these ceramic fragments could not dislodge after their deposition, the designers of the construction had quite obviously accepted these gaps. Since only 70% of the aguada's level ground is lined with ceramic sherds, the notion that they functioned as a sealing element must be expelled. However, the excavations had shown that the builders had only applied this ceramic layer in level areas. This pattern and the fact that there are step-like height differences in the ceramic layers of Trench 1 and Trench 3 (see Figure 6.69e) suggests that the ceramic layer had apparently been used as a pressure, water and age resistant leveling layer between the underlying bedrock and the limestone pavement (Seefeld 2013b: 75). So far, the only similar deposition of a ceramic layer that was published was at the bottom of Reservoir D-8, which integrated into Structure 1 of Ek' Balam (Castillo Borges and de la Peña 2009: 146; see Chapter 5.7.1 and Figure 6.70). In this reservoir, the ceramic layer was applied to a stone floor and then sealed with a plaster layer.

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[179] Even though the author had already explicitly explained in earlier publications that the ceramic layer of the Aguada Oriental was a leveling element (Seefeld 2013a: 75, 2013c), recent descripctions of this feature by other scholars have obviously misunderstood these earlier descriptions. This becomes obvious in a recent description by Brewer who writes that "At Uxul, Seefeld (2013) noted that the ceramic layer on one floor of the Aguada Oriental was discontinous, raising the question of whether this treatment was meant to enhance water retention or served another function. We speculate that such "tiling" may have been decorative?" (Brewer 2017: 163). In this respect, the author would also like to highlight that both the text and the figures included in the earlier article (Seefeld 2013a: 68 with Figure 7) made it clear that the limestone pavement entirely covered the ceramic layer. Consequently, Brewer's (2017: 163) interpretation of the ceramic layer as a "decorative element" is not expedient.

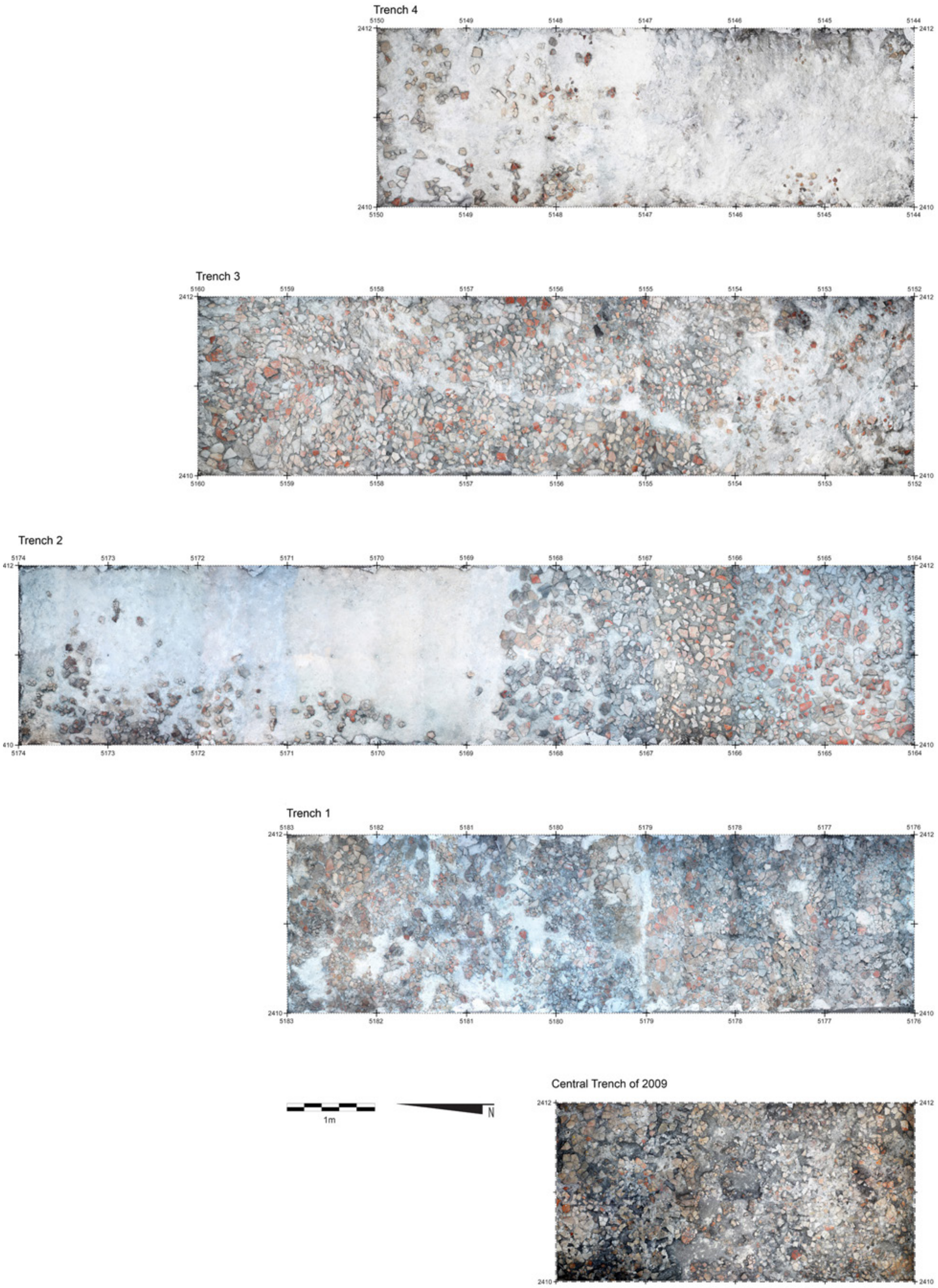


Figure 6.71: Uxul, Aguada Oriental, Overview of ceramic depositions (Photos and Graphics: N. Seefeld).

6.3.2 Size and extension of the limestone pavements in Aguada Occidental and Oriental

The results of the archaeological investigations in the Aguada Oriental and the Aguada Occidental suggest that the entire level base areas of the two reservoir basins were clad out with limestone pavements. Due to its extensive catchment area and the ensuing inundations, the Aguada Occidental could only be investigated with a single excavation trench during the particularly dry field season of 2010. Therefore, information regarding the extension of the limestone pavement in this reservoir is rather limited. However, observations from the investigation of the Aguada Oriental, a construction with a very similar layout, suggest that the entire level base of the Aguada Occidental was covered with a limestone pavement. Due to the square shaped layout of the Aguada Occidental, which has an extension of 100 x 100 m, it can be calculated that the level base of the reservoir basin had an extension of approximately 80 x 80 m (see Figure 6.72). Thus, it can be calculated that the pavement at the base of the Aguada Occidental originally had an area of approximately 6,400 m^2.

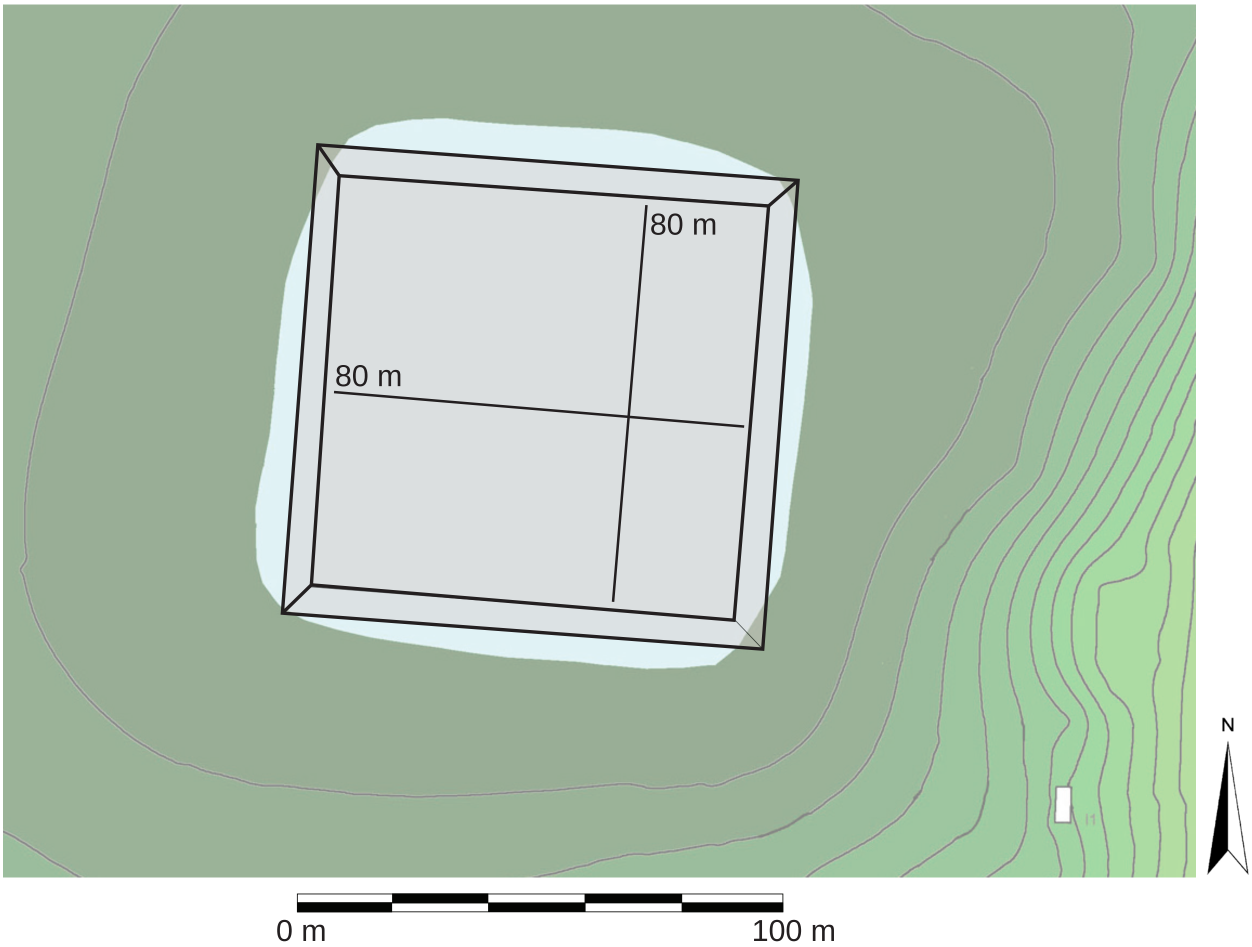
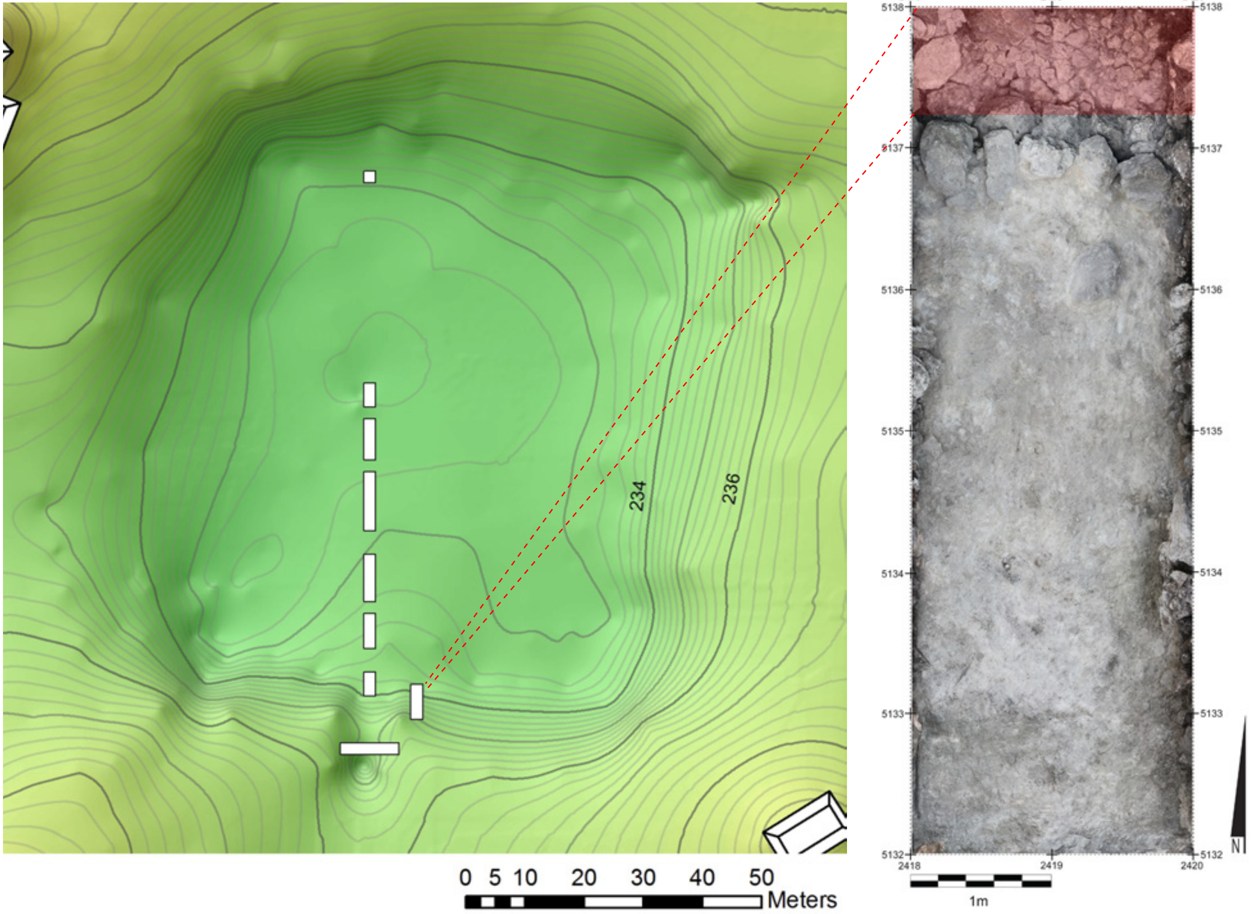


Figure 6.72: Uxul, Map illustrating the approximate extension of the pavement in the Aguada Occidental (Graphic and Map: N. Seefeld).

In Aguada Oriental's case, the excavation of the nine different trenches allows for a more substantiated reconstruction of the original extension of the pavement. A very revealing clue as to the original extension of the pavement was documented at the northern end of Trench 7 (see Figures 6.3a and 6.73b). In this location the pavement begins precisely at the transition from the slope to the reservoir's leveled zone, which exemplifies that the entire level base had been covered with limestone slabs (see Figure 6.73c).



a) Map showing the location of Trenches in the Aguada Oriental

b) Trench 7, Beginning of pavement

c) Approximate extension of the limestone pavement in the Aguada Oriental

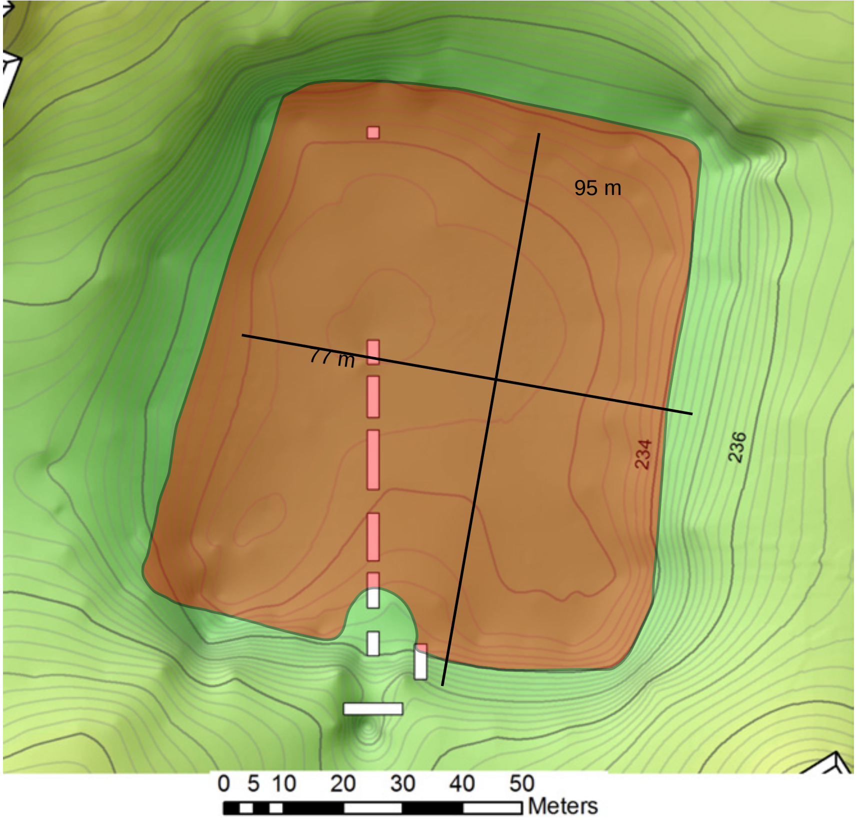


Figure 6.73: Uxul, Extension of pavement at the base of the Aguada Oriental. (a) (Map: Courtesy of B. Volta 2011); (b) (Photo: N. Seefeld); (c) (Graphic: N. Seefeld. Based on map produced by B. Volta 2011).

As Figure 6.73c indicates, the location of the pavement in the northern limit of Trench 7 and the rectangular layout of the reservoir suggest that the pavement of the Aguada Oriental originally had an extension of 77 x 95 m, and thus a surface area of 7,315 m^2 (see Figure 6.73).

During the documentation of this pavement, it also became apparent that the individual stone slabs had been carefully dressed in order to form a firm compound with a smooth surface. As Figure 6.74 indicates, the upper sides of the respective stone slabs had been carved more carefully than the bottom sides. In consideration of the whole pavement, it was also revealed that the stone slabs from different trenches featured almost identical thicknesses varying between 6 and 9 cm in all cases (see Figure 6.75). In the author's opinion, this observation indicates that they were produced specifically for this purpose. The surface of this pavement would have been comfortable to walk on and can still be considered intact today. The stucco matrix could be documented in many locations on and between single stone slabs. In all of these locations, it has a surprising hardness and seems to be an important element for sealing the pavement (see Figure 6.76). In the author's opinion, it can be assumed that immediately after the pavement's completion, the bottom of the Aguada Oriental was covered by a stucco layer. This would have resulted in the basin having the appearance of a plastered plaza as opposed to a limestone pavement.

Figure 6.74: Uxul, Example for the design of an individual stone slab of the pavement in the Aguada Oriental (Photos: N. Seefeld).

Figure 6.75: Uxul, Cross section of stone slabs from different trenches of the Aguada Oriental (Photos: N. Seefeld).

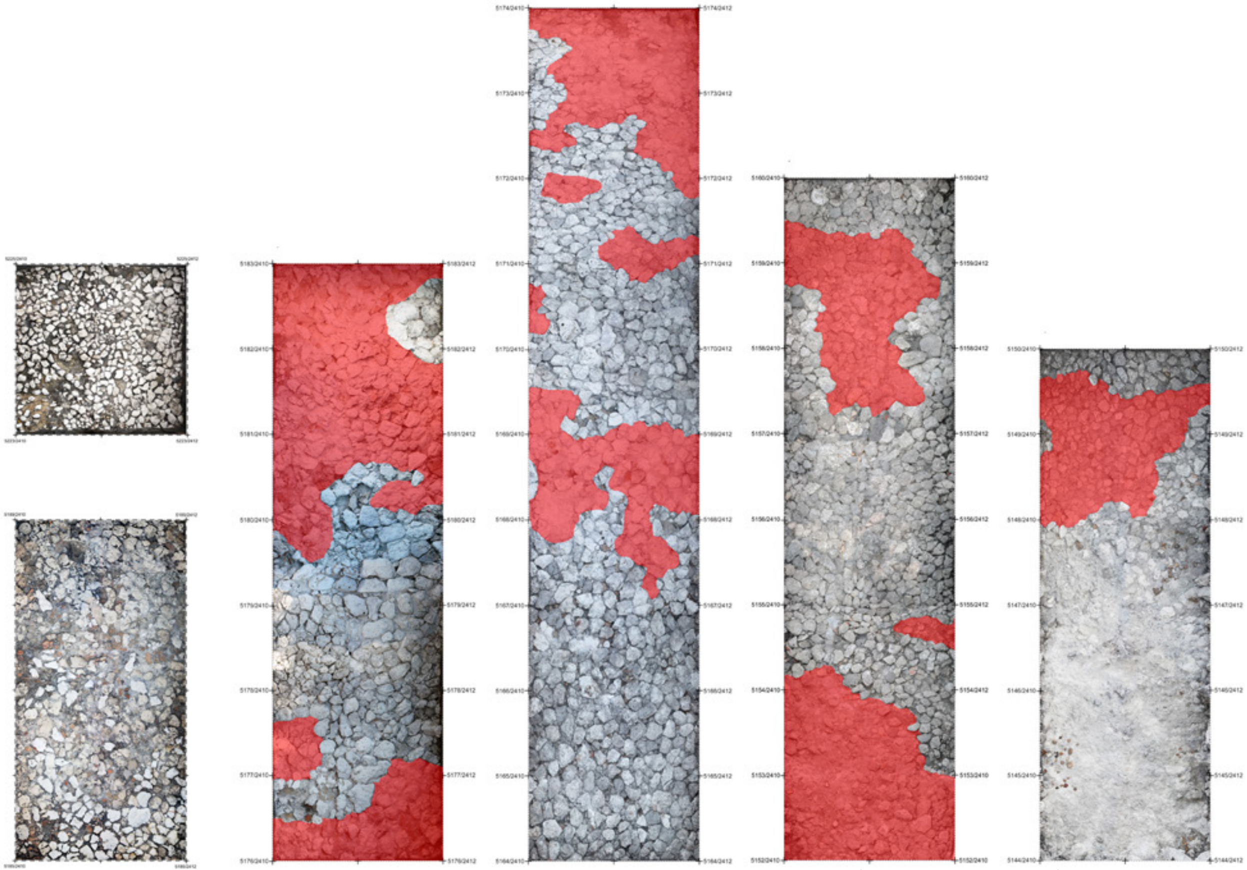


Figure 6.76: Uxul, Residues of stucco matrix upon the pavement of the Aguada Oriental (Graphics: N. Seefeld).

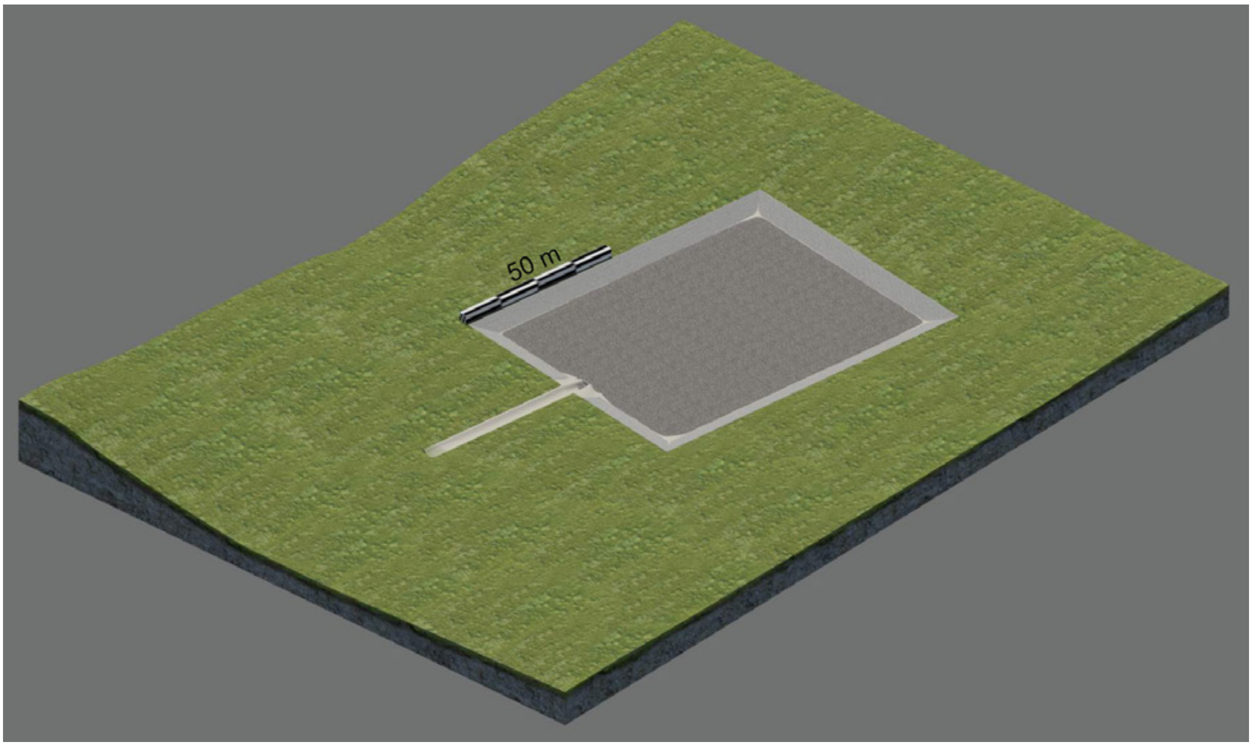


Figure 6.77: Uxul, Isometric view of the Aguada Oriental after its completion (Model: M. Lyons. Courtesy of Michael Lyons).

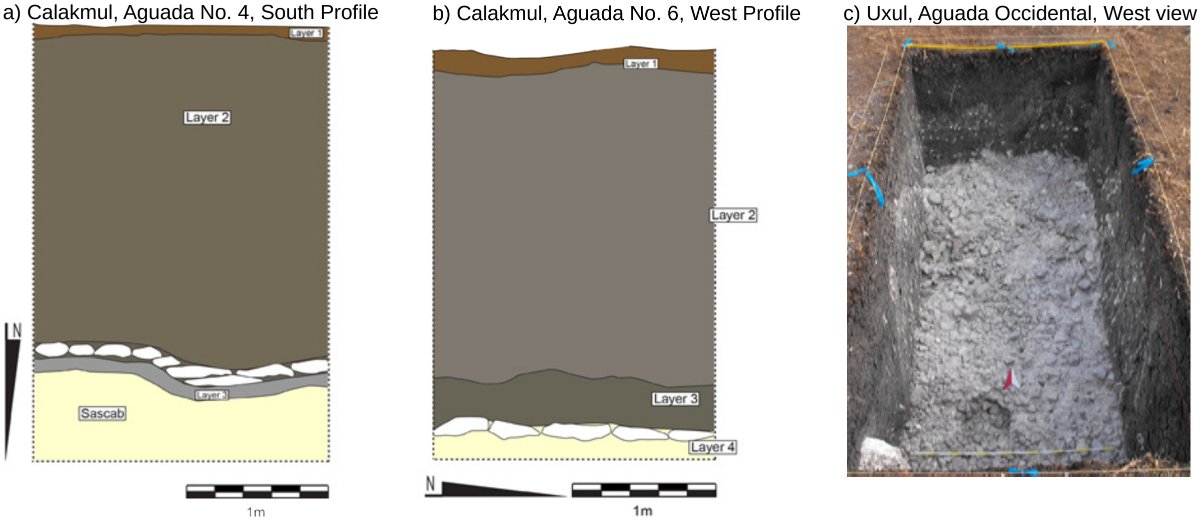
6.3.3 Comparative examples of the application of limestone pavements

As presented in Chapters 5.6.4 and 5.7, the application of pavements at the bottom of reservoirs has been documented in various sites of the Maya Lowlands. Similar examples to the pavements documented in the Aguada Occidental and the Aguada Oriental have been documented in six other Maya sites (see Figure 6.78).

Due to its geographic proximity, the limestone pavements documented at the bottom of Aguada No. 4 and Aguada No. 6 of Calakmul (see Figures 6.78a and 6.78b) can be considered as the closest parallel to the pavements documented in Uxul. Unfortunately, however, the documentation material published on these features is limited to profile drawings and did not include any photos. As Figures 6.78e and 6.78f illustrate, the composition, layout and context of the limestone pavements of the Palace Reservoir in Tikal (see Chapter 5.7.7.2.2), Reservoir A of Uaxactun (see Chapter 5.6.4.3.4) and the El Zotz Aguada (see Chapter 5.6.4.3.5) share many similarities with the pavements documented in Uxul. In contrast to the excavations in Uxul, the limestone pavements in other sites have generally been investigated with relatively small trenches.

An exception to this trend are the excavations in the "Royal Pool" and the Northern Reservoir of Cancuén (see Figures 6.78h and 6.78i), which were fortunately exposed in their entirety. From the nine documented examples of pavements in reservoirs, the two constructions of Cancuén can also be described as the most elaborate and best constructed pavements. The exceptionally high quality of these pavements becomes apparent in two basic details. Firstly, the individual stone slabs feature the largest dimensions of all known examples, and secondly, the different stone slabs show a remarkably smooth surface that creates the appearance of tiles.

Even though the limestone pavements of most other reservoirs have only been exposed to a rather limited extent, the author would like to note that the results from the Aguada Oriental of Uxul, where all essential constructional elements of the reservoir have been documented, can be considered a parallel to other reservoirs of the Maya Lowlands. Thanks to the initial research in the Aguada Oriental, there are now substantiated indications that the pre-Hispanic Maya had covered the entire level basin of their modified reservoirs with limestone pavements. Consequently, the documentation of limestone pavements in test trenches can now be considered an indication that the entire floor of a particular reservoir had been modified with a pavement.

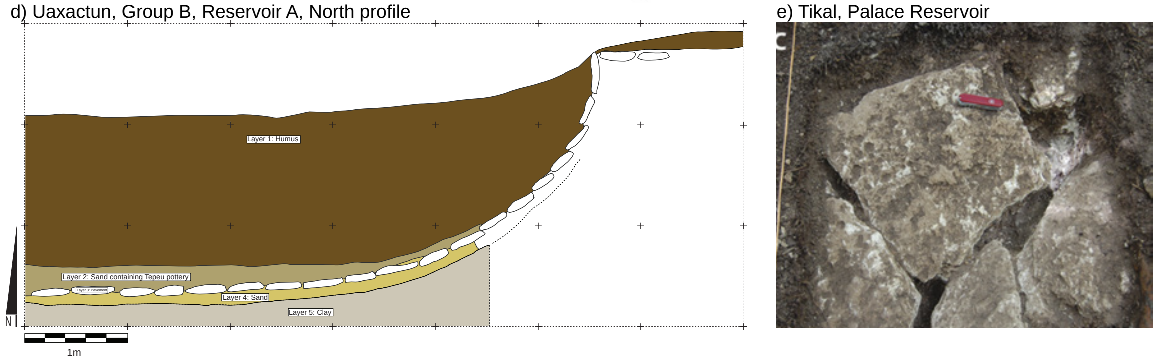

a) Calakmul, Aguada No. 4, South Profile

b) Calakmul, Aguada No. 6, West Profile

c) Uxul, Aguada Occidental, West view

d) Uaxactun, Group B, Reservoir A, North profile

e) Tikal, Palace Reservoir



f) Uxul, Aguada Oriental

g) El Zotz, El Zotz Aguada, East View

h) Cancuén, Southern Reservoir "Royal Pool"

i) Cancuén, Northern Reservoir

Figure 6.78: Overview of limestone pavements at the bottom of aguadas. (a) (modified from Domínguez Carrasco and Folan 1996: Figure 14); (b) (modified from Domínguez Carrasco and Folan 1996: Figure 15. Reproduced with kind permission of María del Rosario Domínguez Carrasco); (c) (Photo: N. Seefeld); (d) (modified from Smith 1950: Figure 99b. Reproduced with kind permission from the Carnegie Institution of Washington); (e) (source: Scarborough *et al.* 2012: Figure 4c. Reproduced with kind permission of Vernon Scarborough and PNAS); (f) (Photo: N. Seefeld); (g) (source: Beach *et al.* 2015a: Figure 8). Reproduced with kind permission of Timothy Beach and El Sevier; (h) (Photo: Courtesy of J. Szymanski); (i) (source: Alvarado Najarro 2013: Figure 8. Reproduced with kind permission of Silvia Alvarado Najarro).

6.3.4 Function of the influx canals to the Aguada Occidental and the Aguada Oriental

Even though they differ in size and complexity to a large extent, the influx canals to the Aguada Occidental and the Aguada Oriental pursue the same objective: the maximization of collected runoff water and the minimization of percolation. Therefore, both constructions are concrete examples of rainwater harvesting in this landscape. A closer examination of their location in the respective topography also indicates that the builders had evidently paid very close attention to the local environment because the two canals are perfectly adapted to the specific location.

The influx canal to the Aguada Occidental was located at the foot of a narrow corriental that already existed prior to the construction and drained large amounts of runoff. Consequently, the city planners decided to build a very formal and elaborate influx canal that could effectively drain runoff from the entire catchment area located between Groups A and B (see Figure 6.79). Throughout the construction of this canal, the natural flow of water was canalized, accelerated and directed towards the Aguada Occidental.

The influx canal to the Aguada Oriental, on the other hand, was located at the northern end of a relatively flat area that would have caught and directed comparatively small amounts of runoff into the aguada. Therefore, the city planners constructed a less elaborate influx canal that was apparently sufficient to drain the area's runoff (see Figure 6.79).

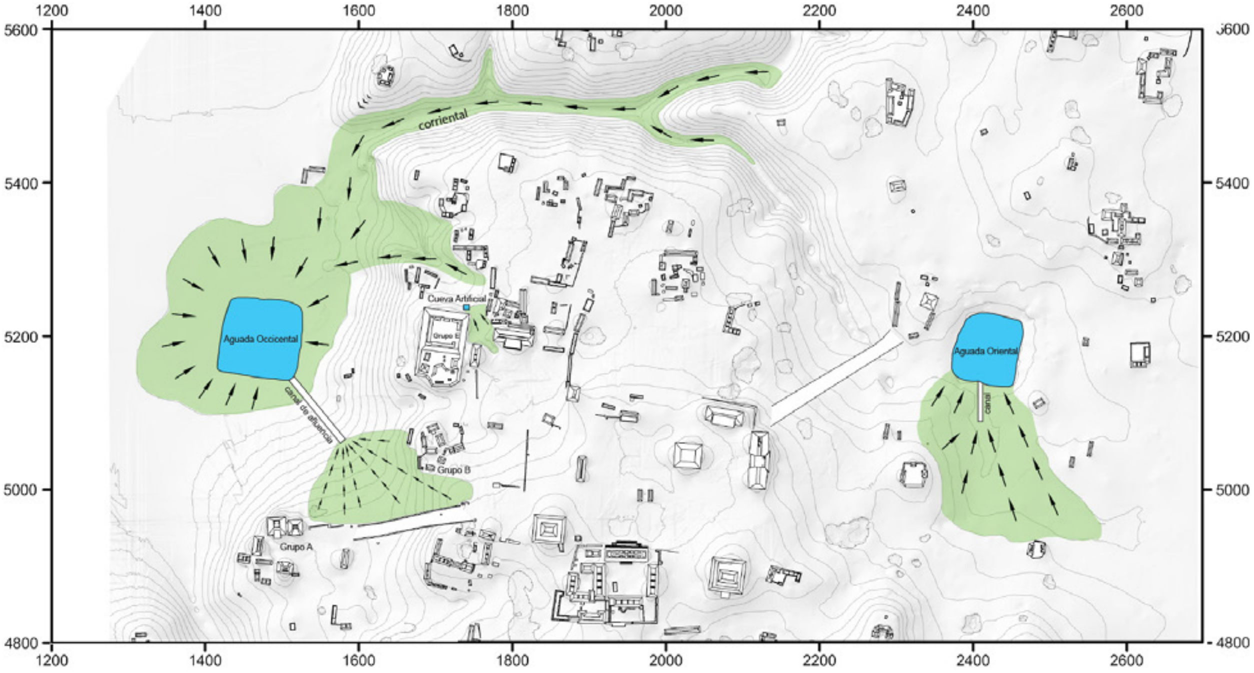


Figure 6.79: Uxul, Catchment areas of the Aguada Occidental and the Aguada Oriental (modified from Seefeld 2016: Figure 2). Base map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

In the author's opinion, the integration of the 50 cm high sidewalls into the construction of the Aguada Occidental's influx canal strongly indicates that the streamflow generated from the extensive catchment area must have been relatively strong. The fact that the stone walls of the canal were reinforced by rather elaborate supporting structures further substantiates the notion that the flow of water pushing against the sides of the construction was massive. The construction of the canal clarifies that the primary purpose of these elements was to generate mass in order to compensate for the pressure exerted on the sides by the flow of water (see Figure 6.80).

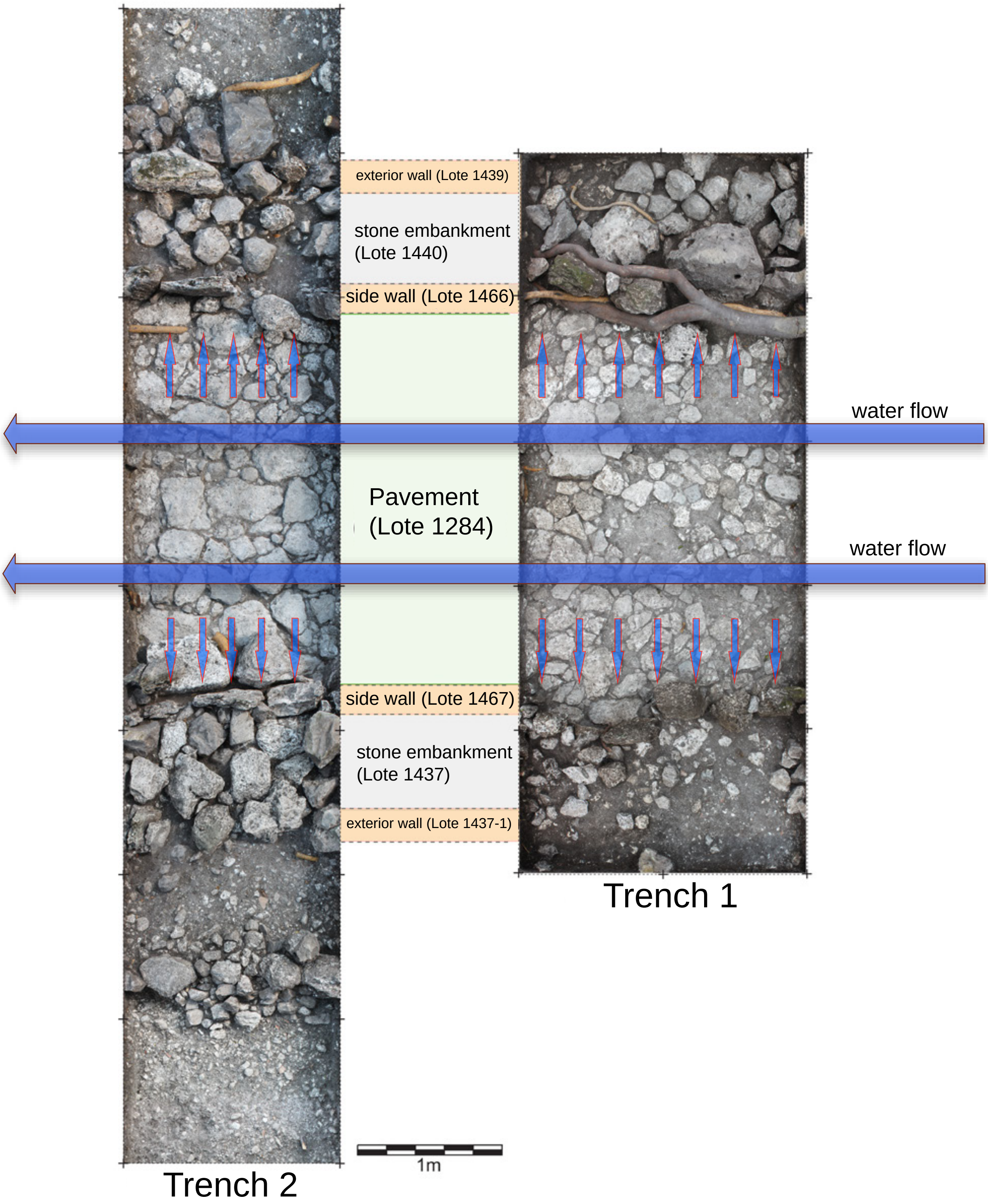
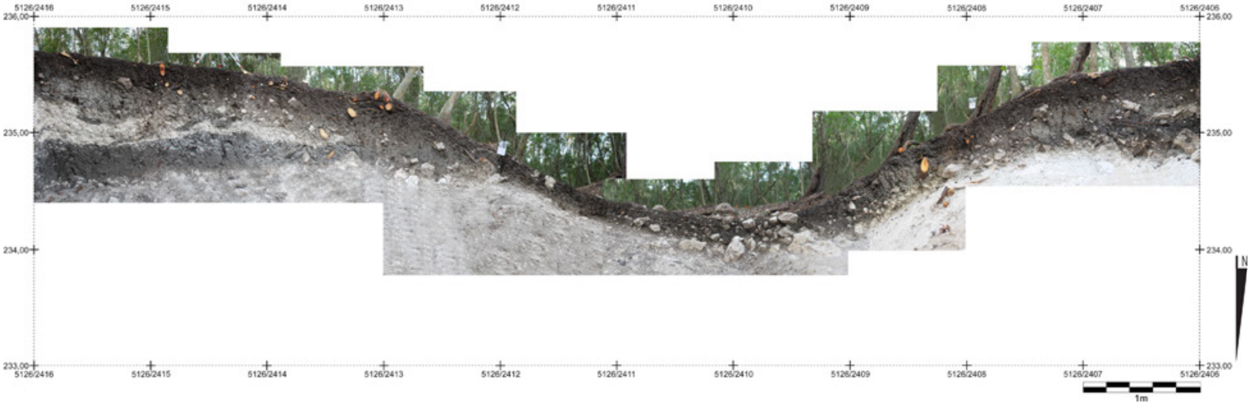


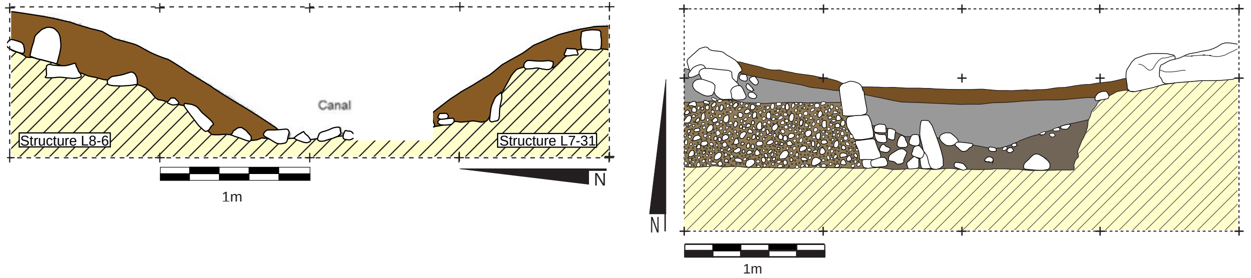
Figure 6.80: Visualization of the lateral water pressure in the influx canal to the Aguada Occidental (N. Seefeld).

Even though canal features in the Maya Lowlands were intensively investigated during the 1970s and 1980s, it is difficult to compare the two influx canals of Uxul with other published canal features. As already pointed out in Chapter 5.2, most scholars have focused on canal systems for agricultural purposes. Due to this tendency, there are few investigations on the technical design of canal systems integrated into hydraulic systems in urban contexts. From a technical perspective, the two influx canals of Uxul can be defined as drainage canals. Furthermore, they bear some similarities to the other canal systems documented in complex hydraulic systems of the Maya Lowlands.

The narrow influx canal to the Aguada Oriental (see Figure 6.81a) has a similar layout and composition to both the main canal of the northern drainage in Cancuén (Barrientos 2005; see Chapter 5.8.4.2 and Figure 6.81b), and the canal of the 3a drainage in the center of La Milpa (Scarborough *et al.* 1995: 108; see Chapter 5.7.9.1 and Figure 6.81c).

The closest analogy to the influx canal of the Aguada Occidental, however, is the drainage system documented in connection to the Calzada Blom in Yaxha (Hermes and Ramos 2004: 610; see Chapter 5.5.2 and Figure 5.82). Like the influx canal to the Aguada Occidental, the Calzada Blom was an elevated construction bordered by sidewalls that served to retain precipitation, impede its percolation and canalize it into a nearby reservoir.


a) Uxul, Aguada Oriental, Trench 6, South profile of southern influx canal

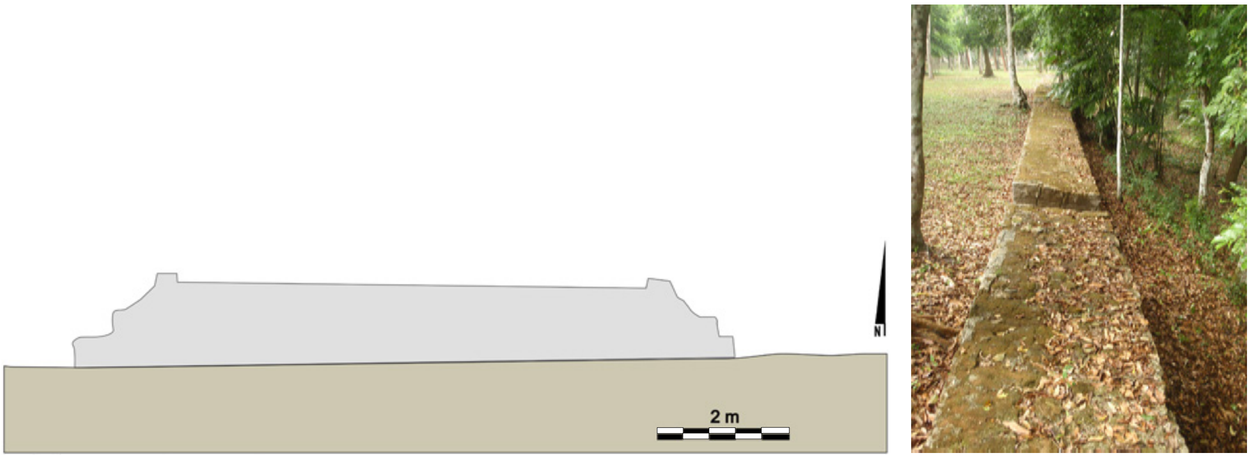

b) Cancuén, Northern drainage, Main canal, East profile

c) La Milpa, Drainage 3a canal, North profile

Figure 6.81: Technical analogies to the influx canal of the Aguada Oriental (a) (Photo and graphic: N. Seefeld); (b) (redrawn after Barrientos 2005: Figure 26. Reproduced with kind permission of Tomás Barrientos); (c) (redrawn after Scarborough *et al.* 1995: Figure 10. Reproduced with kind permission of Vernon Scarborough and Cambridge University Press).

a) Influx canal to the Aguada Occidental, Planum 3, Northwest view

b) Influx canal, Detail of side wall



c) Yaxha, Calzada Blom, North profile

d) Calzada Blom, Detail of side wall

Figure 6.82: Technical analogies to the influx canal of the Aguada Occidental. (a-b) (Photos: N. Seefeld); (c) (redrawn after Hermes and Ramos 2004: Figure 5. Reproduced with kind permission of Bernard Hermes); (d) (Photo: N. Seefeld).

6.3.5 Functionality of the filter wall at the bottom of Aguada Oriental

Due to its good state of preservation and its position within the reservoir, the function of the wall at the bottom of Trench 5 in the Aguada Oriental can be reconstructed quite well. As was already pointed out in Chapter 6.2.2.2, the filter wall can be defined as the most intriguing element of the Aguada Oriental, as it indicates that all components of the reservoir had to be planned prior to their construction. Furthermore, the filter wall combines several technical elements with functionalities that must be explained in greater detail. In general, the hydraulic features documented in Trench 5 can be subdivided into three different technological elements:

(1) A filter wall,

(2) A siltation tank, and

(3) A steeper inclined section of the southern influx canal.

6.3.5.1 Function of the filter wall

In technical terms, the filter wall documented at the bottom of Trench 5 bears several similarities to dam walls in streambeds, which have been documented in other areas of the Maya Lowlands. As Figure 6.74 illustrates, the filter wall of the Aguada Oriental has a similar layout to the filter wall of Blue Hole Camp (Healy 1983: 149; see Chapter 5.4.1.1) and the dam wall blocking a stream in the Río Copán Valley (Turner and Johnston 1979: 301; see Chapter 5.4.1.3).

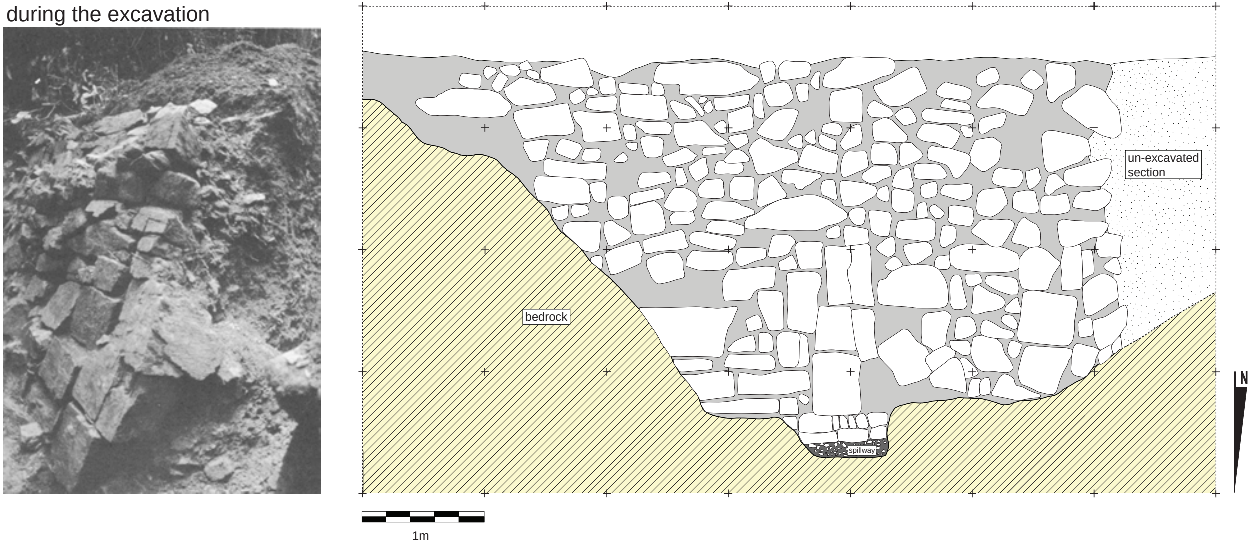
The dam wall of Blue Hole Camp stretches over a 10 m wide streambed, and just like the wall of the Aguada Oriental, the lowest rocks are tightly anchored in the bedrock (Healy 1983: 301; see Figure 6.83a). In the same manner, the base of the 4 m long, and 1.45 m high dam wall in the Copán Valley had been anchored into cavities carved into the bedrock (Turner and Johnston 1979: 301; see Figure 6.83b).

In technical terms, all of these filter walls represent flow obstacles that impounded inflowing water. The height of the impounded water caused additional pressure (Lüdemann 1995: 95). According to Lüdemann (1995: 96), stone constructions are always permeable to water given enough pressure. In the case of the filter wall of the Aguada Oriental, the water level supposedly rose up to a point where a fraction of the impounded water seeped through the stones (Lüdemann 1995: 95). Upon closer observation of the dam/filter walls shown in Figure 6.83 it appears that the pre-Hispanic Maya were aware of the fact that the highest pressure occurs at the base of a filter wall during the damming of water. Therefore, the water flowing through gaps in the wall has the highest speed at the base of the construction (Lüdemann 1995: 95). The compressive forces of water mostly affected the lowermost stone alignment of the filter wall (Lüdemann 1995: 95). Therefore, it is a basic principle of filter walls that the depth of the anchorage and the weight of the respective stones need to meet the requirements of the existing water flow (Lüdemann 1995: 97). If the base of the walls had not been properly anchored, the pre-Hispanic Maya would have risked the walls being washed away by the current, which could have potentially caused the erosion or collapse of the construction (Lüdemann 1995: 95). The filter walls shown in Figure 6.83 indicate that the pre-Hispanic Maya had a solid understanding of the basic principles of water pressure and therefore made sure that the filter walls that impounded water were firmly anchored into their supporting surface. Due to the geology of the Yucatán Peninsula, the pre-Hispanic Maya were generally able to anchor the lowermost stone alignment directly into the limestone bedrock (see Figures 6.83e and 6.83f). Since the builders of the Aguada Oriental were well aware that the highest pressure occurred at the base of the filter wall, they also made sure that the lowermost alignments featured larger dimensions than the remaining stones of the wall.

Since the water passing through this lowermost stone alignment would have had considerable speed, it can be stipulated that the filter wall would have been effective in detaining all dirt particles south of this barrier resulting in the actual reservoir located to the north having clean water. However, two important elements for the effectiveness of this filter wall would have been the pedestal on which it was erected and the siltation tank located south of it.

6.3.5.2 Function of the silting tank

Due to the high water pressure at the base of the filter wall in the Aguada Oriental, the wall's lowermost stone alignment would have been at risk due to the potential erosion of the anchorage. The builders of the Aguada Oriental had evidently recognized this potential danger and constructed the entire wall on a small pedestal of the bedrock, which they had left in place during the excavation of the reservoir basin. Thanks to this elevated position, the large blocks of the lowermost stone alignment would not have been directly exposed to the highest water pressure. In the author's opinion, the elevated position of this wall highly contributed to its good state of preservation and the relative lack of eroded material north of this barrier.



a) Blue Hole Camp,Dam wall during the excavation

b) Blue Hole Camp, South view

c) Copán, dam wall, top view

d) Copán, dam wall, front view

e) Uxul, filter wall, top view

f) Uxul, filter wall, south view

Figure 6.83: Technical analogies to the filter wall of the Aguada Oriental. (a) (source: Healy 1983: Figure 7); (b) (redrawn after Healy 1983: Figure 5). Reproduced with kind permission of Paul F. Healy; (c) (source: Turner and Johnston 1979: Figure 4. Reproduced with kind permission of Billie Lee Turner and Cambridge University Press); (d) (source: Turner and Johnston 1979: Figure 3. Reproduced with kind permission of Billie Lee Turner and Cambridge University Press); (e-f) (Photos: N. Seefeld).

However, as already pointed out in Chapter 6.2.2.2, the elevated position of this wall also enabled the deposition of coarse material and debris washed in through the southern influx canal. Therefore, it seems like the small depression behind the filter wall may have served as a siltation tank. From a technological perspective, siltation tanks follow a similar approach to filter walls as they try to impede the intrusion of debris into a larger reservoir (Akpinar 2011: 32). While filter walls are usually positioned at the same level as the inflowing water, siltation tanks are located below the level of the inflowing water. The lower level of siltation tanks causes washed-in coarse material to deposit at its bottom (see Figures 6.84 and 6.85). Essentially, siltation tanks reduce the flow velocity due to a sudden rise in the water level that allows the deposition of heavier dirt particles. Apart from the Aguada Oriental of Uxul, siltation tanks have been reported in connection with the Aguada Los Loros in San Bartolo (see Chapter 5.6.4.3.7), the Temple Reservoir of Tikal (see Chapter 5.7.7.2.1) and the Kinal West drainage of Kinal (see Chapter 5.7.8).

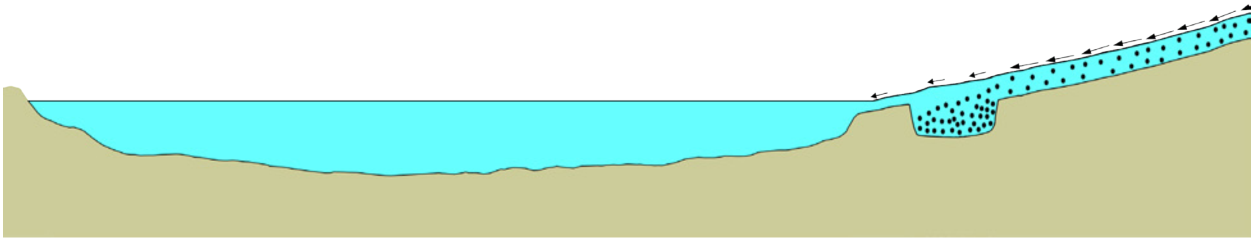


Figure 6.84: Technical approach of siltation tanks (Graphic: N. Seefeld).

Unfortunately, however, most of these described siltation tanks have only been displayed on maps, whereas the documentation material on the exact technical design has not been published. At the current state of research, the siltation tank of Kinal's west drainage and the siltation tank south of Tikal's Temple Reservoir are the only features that have undergone a focused scientific investigation. Both features were positioned at the end of a stream (a natural stream in Tikal and an artificial drainage in Kinal) and had been installed south of the actual reservoir in order to intercept coarse material or debris (Scarborough *et al.* 1994: 102; see Figure 6.86). Nevertheless, information regarding the way in which the siltation tank bases were modified and the elements used to fortify the transition into the actual reservoir basins are lacking.

In the case of Uxul's siltation tank, its technical layout and functionality are easier to determine because the different features of the Aguada Oriental have been extensively exposed. Essentially, the siltation tank of the Aguada Oriental does not necessarily constitute a separate feature as in the case of the siltation tanks of Tikal and Kinal, but is instead formed through the small depression at the northern end of the influx canal. In this case, the element forming the siltation tank is the pedestal built into the bedrock, which created a small tub with an extension of approximately 1 x 1 m (see Figures 6.85 and 6.87). Due to this layout, the features documented in Trench 5 consisted of an influx canal, a siltation tank and a filter wall whose combined effects would have considerably improved the quality of the water stored in the reservoir (see Figure 6.85).

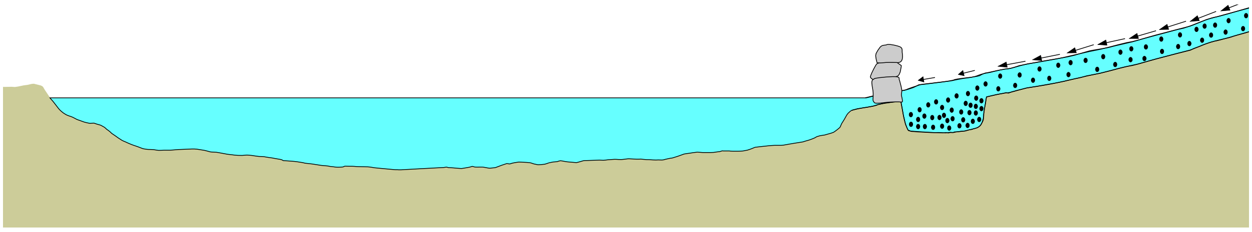
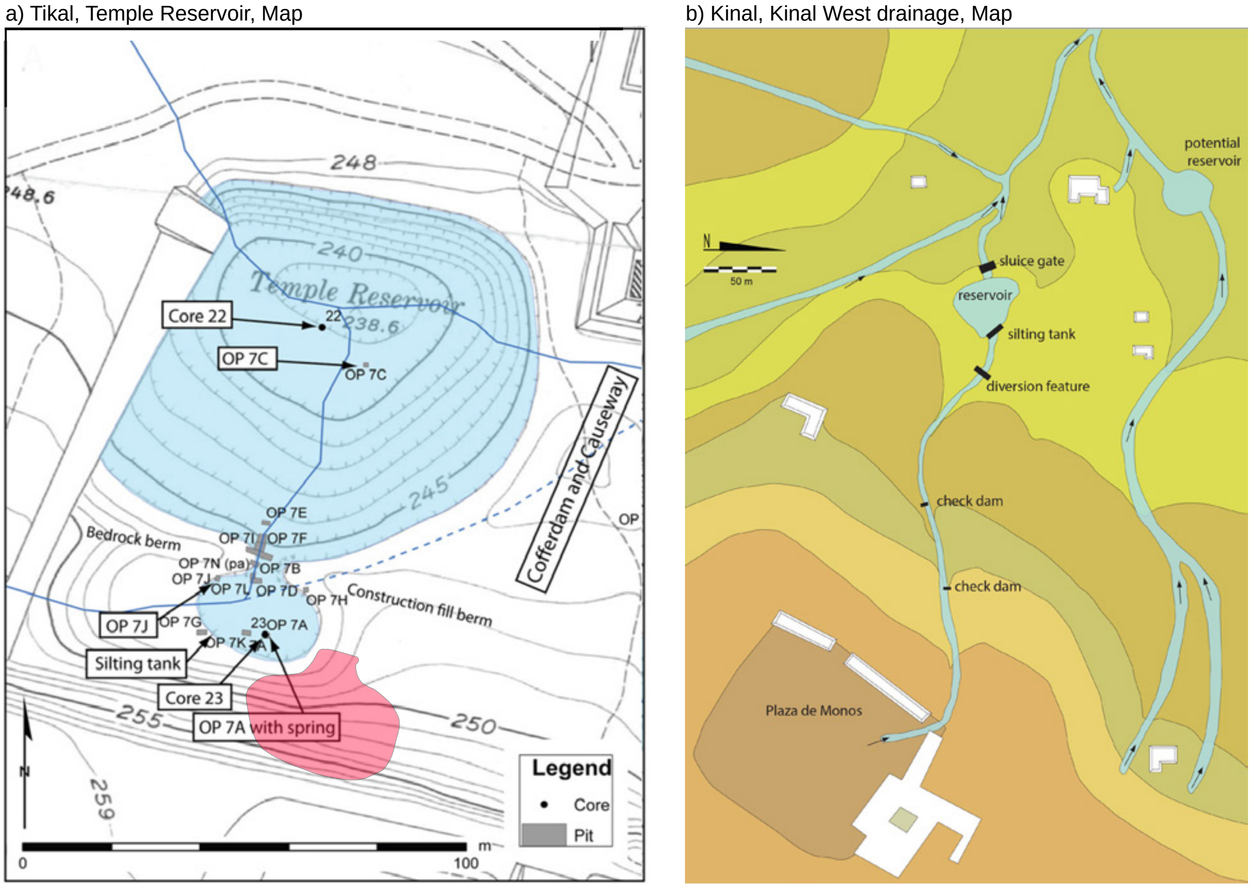
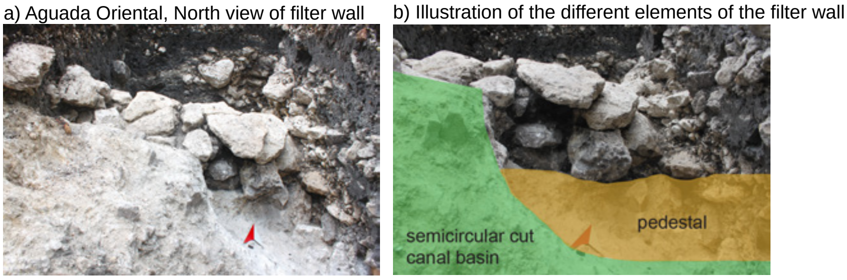


Figure 6.85: Uxul, Interaction of filter element in the Aguada Oriental (Graphic: N. Seefeld).

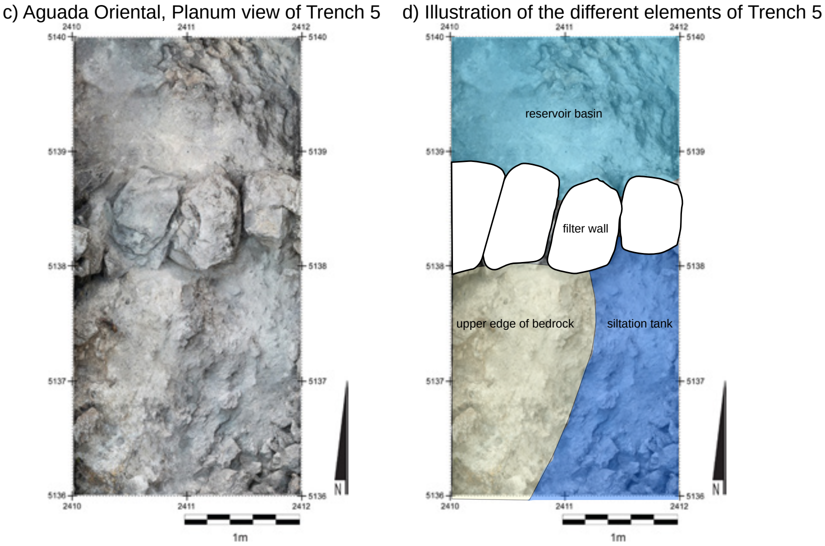

a) Tikal, Temple Reservoir, Map

b) Kinal, Kinal West drainage, Map

Figure 6.86: Overview of documented siltation tanks in the Maya Lowlands. (a) (source: Scarborough *et al.* 2012: Figure S3a. Reproduced with kind permission of Vernon Scarborough and PNAS. Base Map: Courtesy of the Penn Museum); (b) (modified from Scarborough *et al.* 1994: Figure 3). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.


a) Aguada Oriental, North view of filter wall

b) Illustration of the different elements of the filter wall


c) Aguada Oriental, Planum view of Trench 5

d) Illustration of the different elements of Trench 5

Figure 6.87: Uxul, Functionality of the siltation tank in the Aguada Oriental (Photos and graphics: N. Seefeld).

6.3.5.3 Function of the sloped end section of the influx canal

In addition to the two previously discussed filter elements, a closer examination of their location indicates that the final section of the influx canal had apparently featured a steeper inclination that would have increased the speed of inflowing water. While the southern portion of the canal apparently had a very mild slope in the catchment area, the builders of the Aguada Oriental had deliberately increased its inclination at the southern border of the reservoir (see Figure 6.88). In the author's opinion, this acceleration of the water at the end of the canal was an intended effect in order to increase the effectiveness of the two filter elements at the northern end of the influx canal.

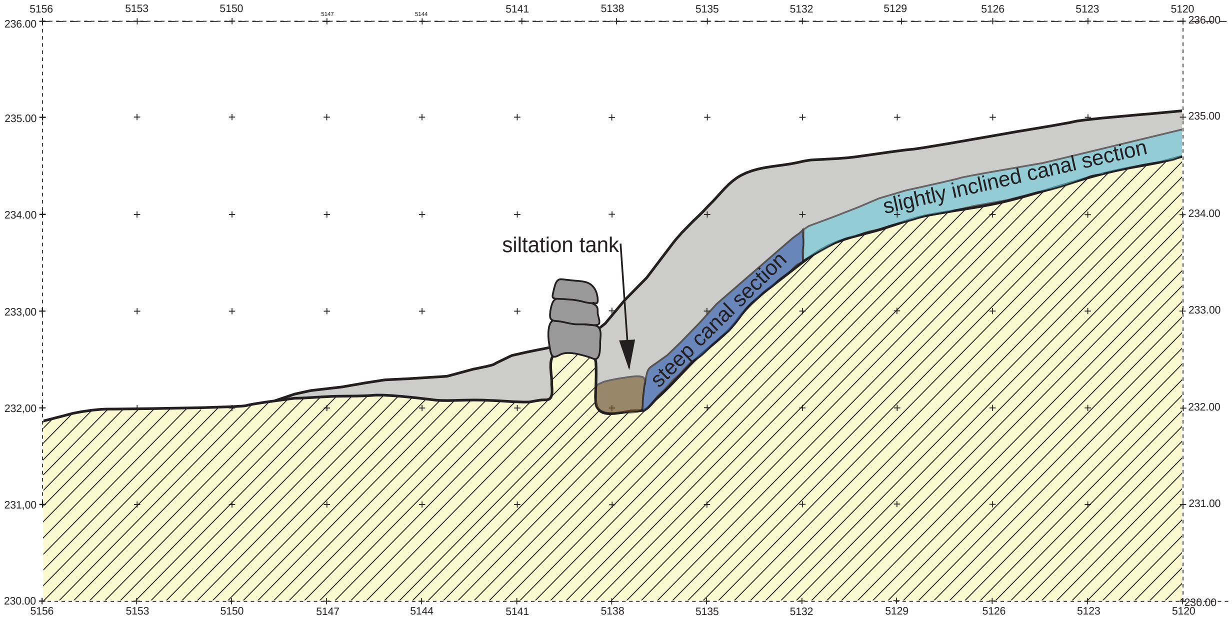


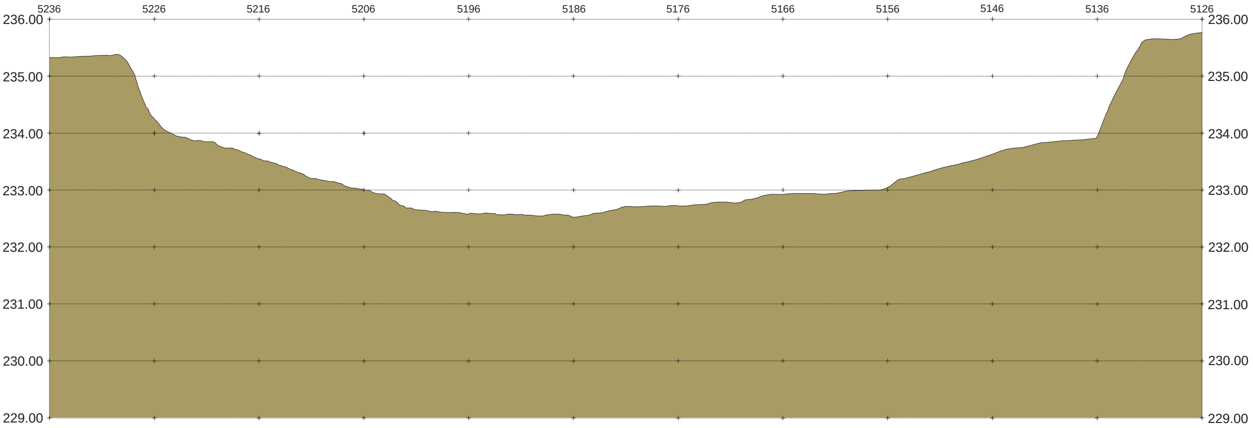
Figure 6.88: Uxul, Interaction of the influx canal and the filter elements of the Aguada Oriental (Graphic: N. Seefeld).

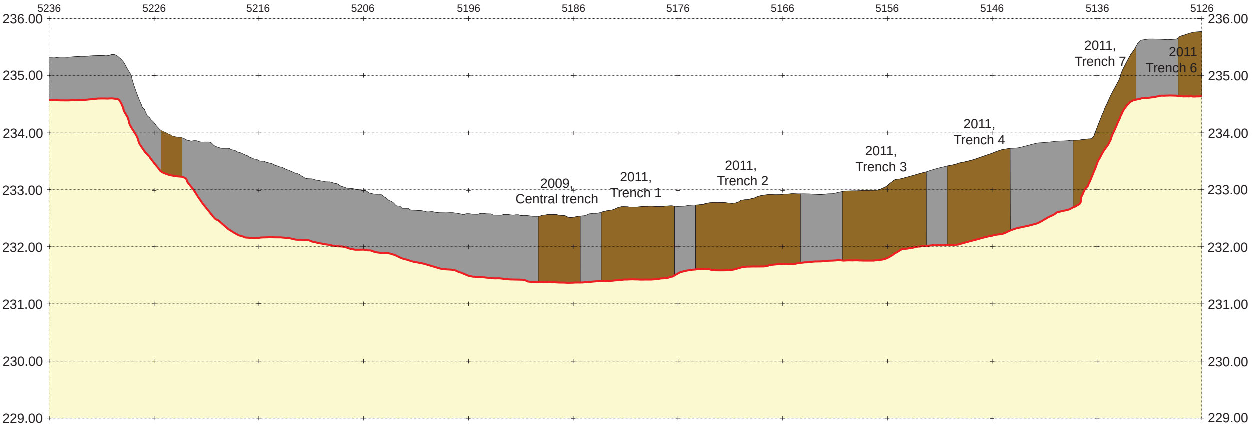
Due to the sophisticated layout and interaction of these elements, it is apparent that the designers of the Aguada Oriental were well aware of the risks of erosion of the filter wall and had therefore developed an elegant solution to protect it. In the author's opinion, the constructive element of the filter wall is not only the most intriguing technical element of the Aguada Oriental but also the clearest indicator that the persons responsible for the planning of this construction had advanced experience in the construction of such installations. This becomes apparent in the fact that the natural bedrock can only be modified in a subtractive manner. In order for the "filter wall" to be able to stand on the pedestal while being traversed by high-speed water, every last detail of the construction had to be planned so that all inclinations and height differences were coordinated. Furthermore, the filter wall vividly displays the fact that the builders of the reservoir had removed substantial amounts of the natural bedrock material.

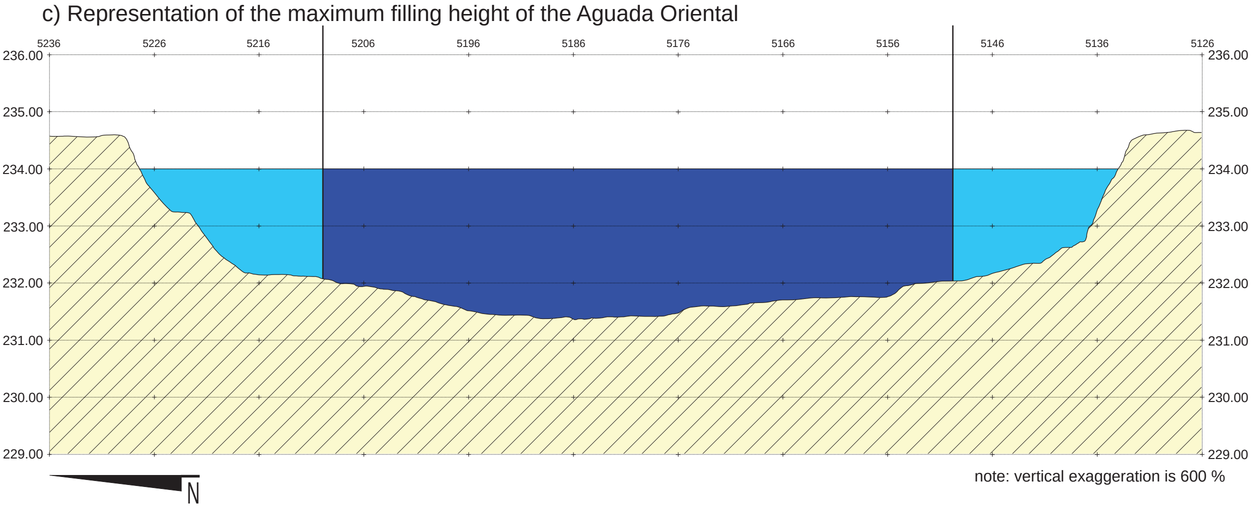
6.3.6 Catchment capacity of Uxul's hydraulic features

As the presented hydraulic structures clearly indicate, the pre-Hispanic inhabitants of Uxul had evidently experienced drastic water scarcities during the dry seasons, which forced them to develop a sophisticated hydraulic system in order to satisfy the needs of a growing population (Seefeld 2013: 76). In this process, the harvesting of rainwater was the most essential strategy, which the inhabitants were skillfully practicing on the local landscape. The fact that the available water sources had apparently been able to supply a population of almost 5,000 inhabitants during the Late Classic (see Grube *et al.* 2012: 20) raises two questions. (1) To what degree did the landscape modifications increase the amount of available water, and (2) how much water were the two central reservoirs able to store? (Seefeld 2013: 76).

Relating to these questions, the investigations of the Aguada Oriental have allowed for a credible calculation of its total capacity (Seefeld 2013: 76). To this end, the topographic survey data were used in order to extend the line of the excavated trenches towards the north and the south. By extracting the height values of the total station dataset, an exact east profile of the Aguada Oriental could be developed (see Figure 6.89a). Based on all of the excavated trenches, which compose 40% of the reservoir's total width, the profile of the entire pavement was reconstructed (Seefeld 2013: 76; see Figure 6.89b).


a) Illustration of the contemporary terrain profile within the Aguada Oriental


b) Accentuation of the exposed profiles within the Aguada Oriental


c) Representation of the maximum filling height of the Aguada Oriental

note: vertical exaggeration is 600 %

Figure 6.89: Uxul, Procedures during the calculation of the catchment capacity of Aguada Oriental (Drawing: N. Seefeld, based on measurements taken by N. Seefeld and S. Bayer).

Subsequently, the course of this pavement was used in order to determine the possible water level. The resulting graphic shows that retaining a water level of 2 m would have been technically possible (see Figure 6.89c). In order to avoid uncertainties in the calculation of the slope zones, these areas were entirely omitted for the calculation of the storage capacity (Seefeld 2013: 76). By the omission of these areas, the north-south distance was limited to 76 m (see Figure 6.89c). Subsequently, this distance was multiplied by the previously determined east-west extensions of the pavement of 77 m. At a water level of 2 m, the total storage capacity of the Aguada Oriental would have been at least 11,704 m^3 (Seefeld 2013: 76).

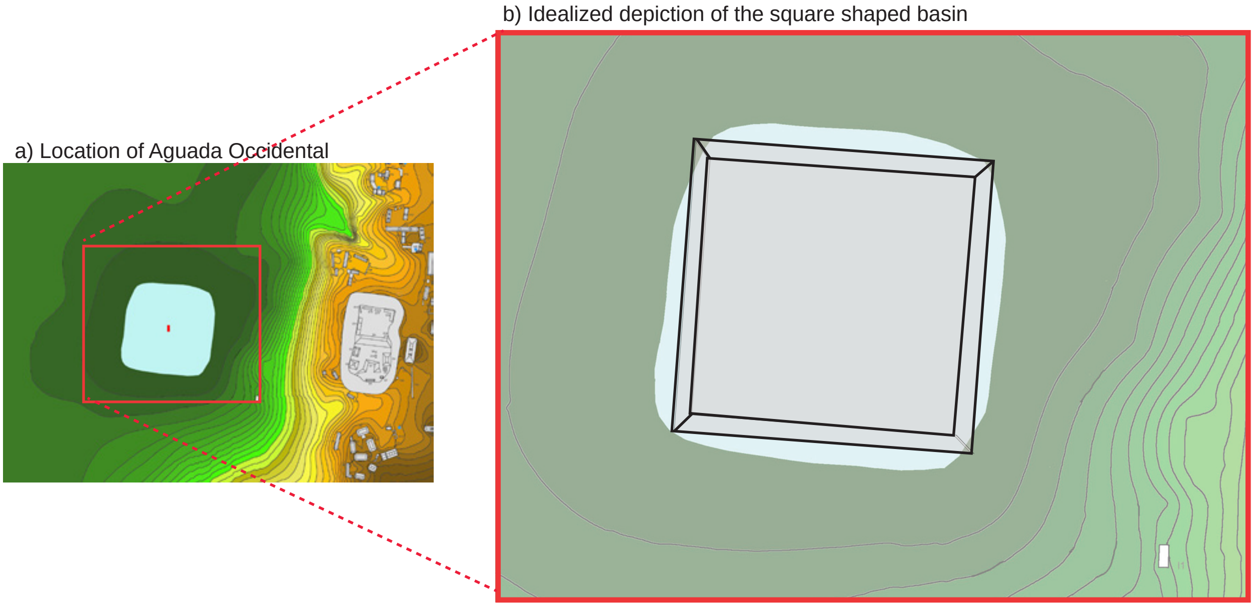
Due to its frequently inundated state, the Aguada Occidental could only be investigated with a single trench in 2010. Although the available data on this reservoir is not as extensive as it is in the case of the Aguada Oriental, its slightly larger surface area, the greater depth of its storage basin, and its connection with several sources of runoff indicates that its storage capacity was even greater. As already stated, the layout of the reservoir and the comparison to the Aguada Oriental suggests that the pavement originally had an extension of 80 x 80 m. By taking a conservative filling height of 2 m, and leaving out the sloped areas, it can be calculated that the Aguada Occidental was able to store at least 12,800 m^3 of water. Based on these results, it seems reasonable to estimate that these two artificial reservoirs of Uxul had a combined total capacity of a least 24,400 m^3. However, it should be stressed that this figure is only meant to give an approximation as to the maximum amount of water that could have been stored. It is impossible to determine if the precipitation would have ever been sufficient to fill the reservoirs to their maximum capacities, how effective the base modifications were at impeding water seepage during usage, and how much water would have evaporated.

6.4 Building history of Uxul's hydraulic system

In order to conclude this chapter on the archaeological investigation of Uxul's hydraulic system, the upcoming section provides a general overview of the construction history of Uxul's hydraulic system. In this context, it needs to be stressed that the chronology of hydraulic features is generally difficult to determine based on recovered material (see Chapter 7.3). Nevertheless, the available information should be used in order to retrace the development of the hydraulic system and identify the potential interrelationship with the expansion of the settlement. At the current state of research, it appears that the earliest constructions of Uxul began near the Aguada Occidental during the Late Middle or Late Preclassic Period (Grube *et al.* 2012: 44). This outcome can be attributed to the fact that the earliest settlers were necessarily dependent on a natural source of water for the foundation and installation of a permanent settlement.

6.4.1 Aguada Occidental

As already pointed out in Chapter 6.2.3, the immediate topographic surroundings and the proximity to an inner bajo habitat indicate that the Aguada Occidental represents a natural aguada. Furthermore, the rectangular shape and the base modifications suggest that the pre-Hispanic inhabitants of Uxul had modified this natural aguada according to their preferences. Even though the Aguada Occidental currently has an extension of 100 x 100 m, it is impossible to determine the exact size of the natural aguada that existed before the cultural modifications. The available excavation data suggest that during the first half of the Late Classic Period, Uxul's inhabitants artificially increased the aguada's capacity because the natural surface depression no longer provided sufficient water supply for an increasing population. To accomplish this, the builders first removed the aguada's natural, alluvial sediment until they reached the height of the natural sascab (see Figure 6.90c). In this process, a 3 m deep, rectangular basin with an artificially flattened floor and uniformly sloped embankments was excavated (see Figure 6.90).



a) Location of Aguada Occidental

b) Idealized depiction of the square shaped basin

c) Aguada Occidental, central trench, East Profile

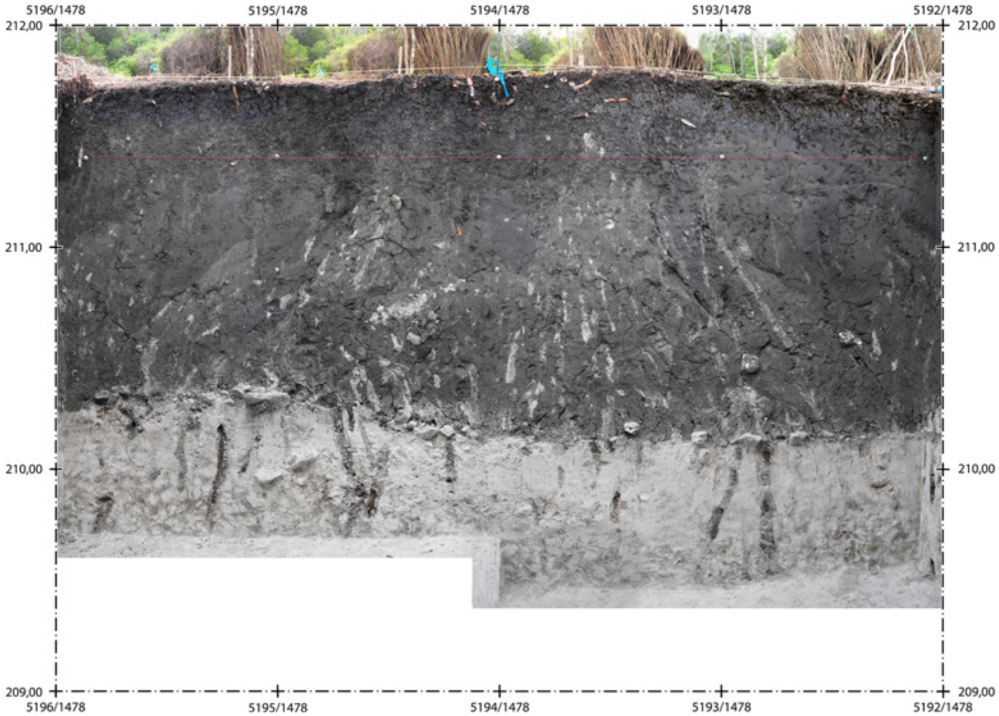


Figure 6.90: Uxul, Formation of the basin for the Aguada Occidental (Photos and Graphics: N. Seefeld).

As the excavation in the Aguada Occidental revealed, the bedrock material was not made up of limestone, but of a hard sascab layer. Due to the relatively soft consistency of the material recovered during the excavation of the basin and the absence of visible architecture in the immediate vicinity, it does not appear as if the aguada had been used as a stone quarry. Consequently, the creation of the basin can be identified as the primary purpose of the excavation process.

After the builders had completely carved out the basin of the reservoir, they assembled a pavement of limestone slabs (see Figure 6.91). Even though the stones used for this construction have homogenous dimensions, they lack clear processing marks. Moreover, this pavement, which was documented at a depth of 170 cm, exhibits numerous gaps (Seefeld 2013a: 65). The function of this base modification was apparently aimed at the prevention of water seepage and the potential storage of greater quantities of water for the critical dry seasons.

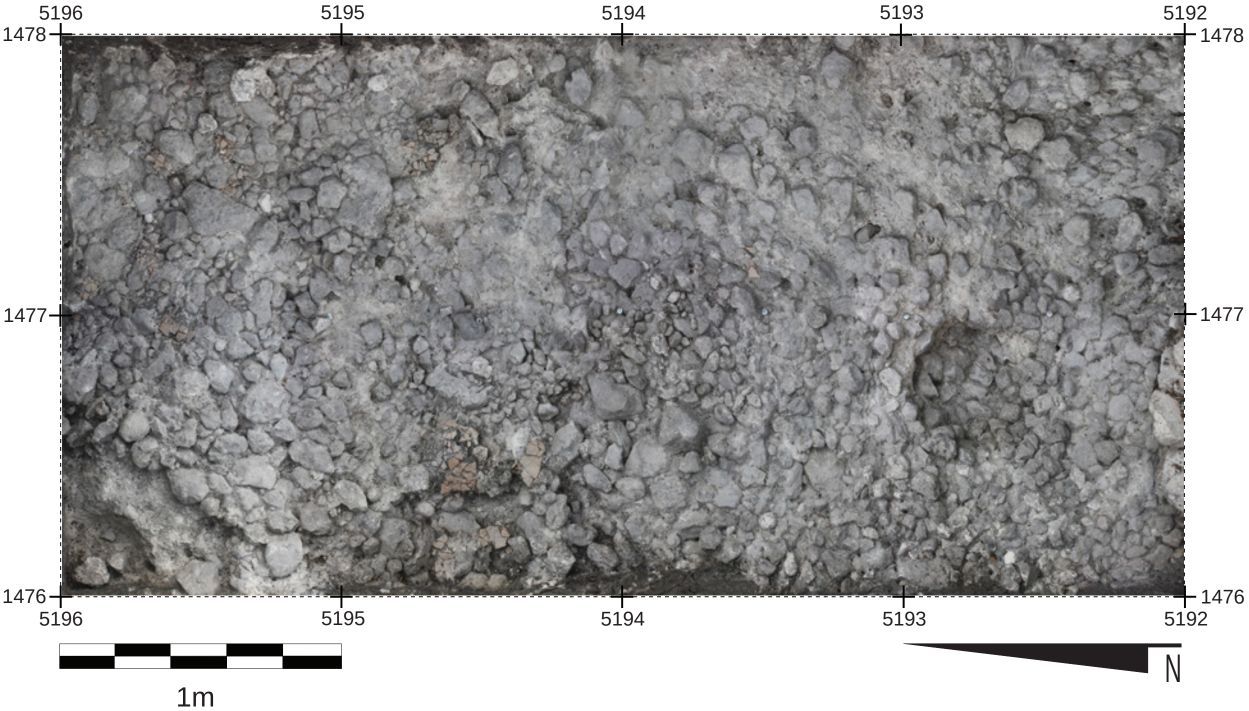


Figure 6.91: Uxul, Application of the limestone pavement at the bottom of the Aguada Occidental (Photo: N. Seefeld).

6.4.2 Feeding canal to the Aguada Occidental

During the second half of the Late Classic Period, when the modification of the Aguada Occidental no longer sufficed to store water for the entire dry season, Uxul's inhabitants chose to reduce the seepage of precipitation by connecting the catchment area between Groups A and B and the reservoir's southeastern corner via a canal (see Figure 6.92).

The canal's central element consisted of a highly compact 2.80 m wide pavement of limestone slabs, which feature a uniform height of 8 cm and were processed specifically for this purpose. On both sides, the pavement was subsequently delimited by two vertical, 50 cm high walls of stone flags (see Figure 6.85a and 6.85c). These vertical walls were enclosed by 80 cm wide and 40 cm high embankments of stones on both sides in order to laterally reinforce them (see Figure 6.94c). Finally, these embankments were delimited on both sides by low stone walls (see Figure 6.94c). Near Trenches 1 and 2, the canal had a relatively mild inclination of 1.49° dropping just 13 cm over a distance of 5 m. Over the entire distance of the exposed canal (32 m), there is a height difference of 1.92 m (214.02 m above sea level in the southeast and 212.10 m above sea level in the northwest) leading to an average inclination of 3.43°. The high quality pavement in conjunction with the lateral walls accelerated the rate of flow and thereby effectively impeded the seepage of water.

Because of this canal, it became possible to extend the reservoir's catchment area and increase the amount of stored water. Owing to the construction of a logging road built in the 1980s, the canal's origin in the elevated terrain between Groups A and B has been destroyed. Currently, the presence of the canal can be detected over a length of 50 m (see Figure 6.93). In the author's opinion, the observations made during the archaeological investigation of this complex canal construction proves that the pre-Hispanic Maya inhabitants of the site had a profound understanding of the drainages in the natural landscape, which they used in order to increase the catchment area and avoid the percolation of precious water.

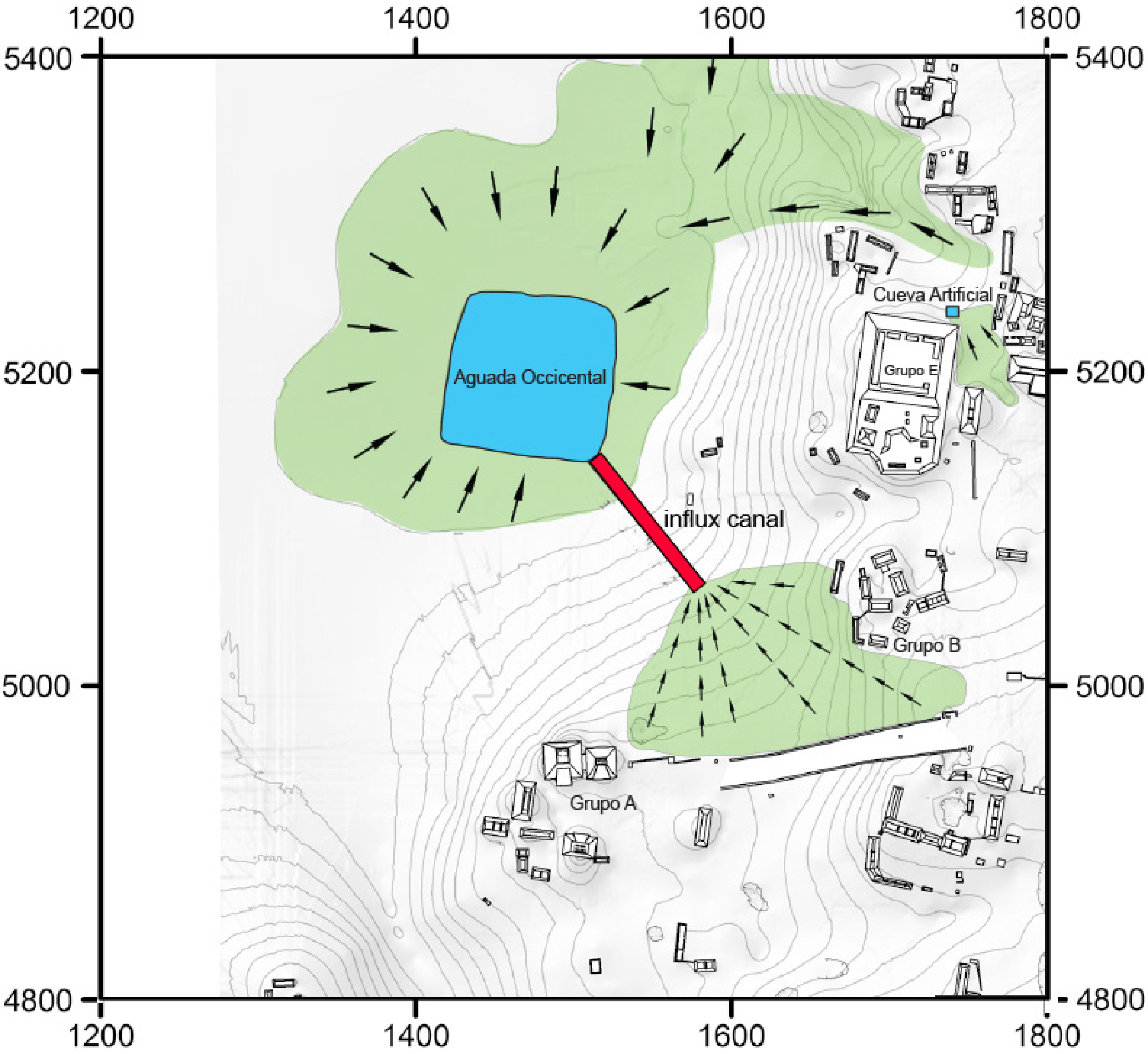


Figure 6.92: Map showing the influx canal to the Aguada Occidental and its integration into the catchment area (modified from Seefeld 2016: Figure 2). Base map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

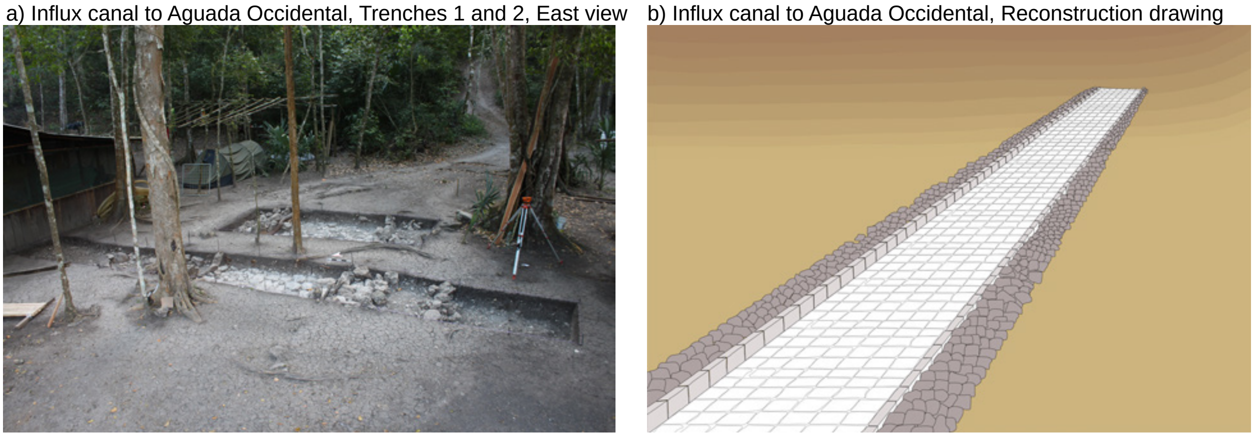

a) Influx canal to Aguada Occidental, Trenches 1 and 2, East view
b) Influx canal to Aguada Occidental, Reconstruction drawing

Figure 6.93: Uxul, Influx canal to Aguada Occidental. (a) (Photo: N. Seefeld); (b) (Drawing: N. Seefeld).

As already mentioned in Chapter 6.2.4, the investigations showed that the sophisticated canal construction evidently had a precursor consisting of a simpler construction (see Figure 6.94). Originally, the landscape to the southeast of the Aguada Occidental was marked by level layers of occupation (Construction Phase 1, see Figure 6.95a). In the next step, the inhabitants of Uxul excavated a semi circular canal into the soil (Construction Phase 2, see Figure 6.95b). This canal passed below the occupation layer of the surrounding landscape, had a width of 2 m and a depth of approximately 1.80 m (see Figure 6.95b). Ultimately, Uxul's inhabitants filled this earlier version of the influx canal and constructed a more complex canal with a stone pavement (Construction Phase 3, see Figure 6.95c). In the author's opinion, the deliberate backfilling of the earlier construction and the construction of a more elevated canal indicates that the builders tried to increase the inclination of the canal. Through this increased inclination, the water coming from the catchment areas in the southeast would flow with a higher velocity and thus effectively reduce percolation.

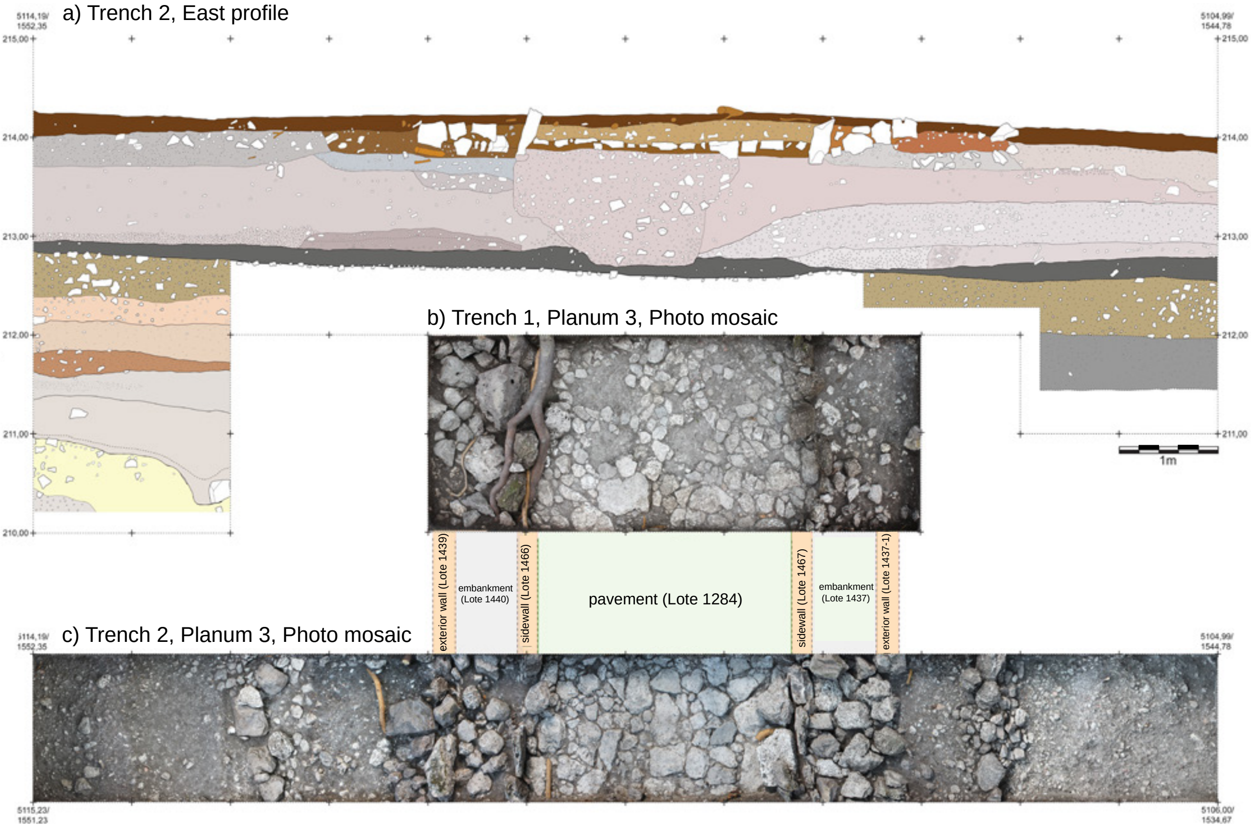
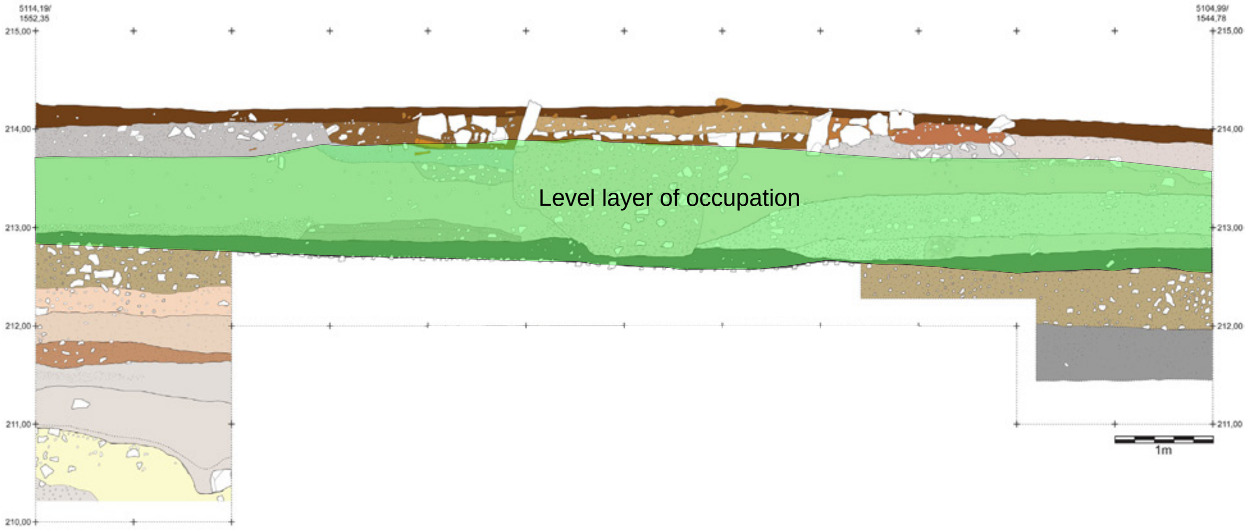
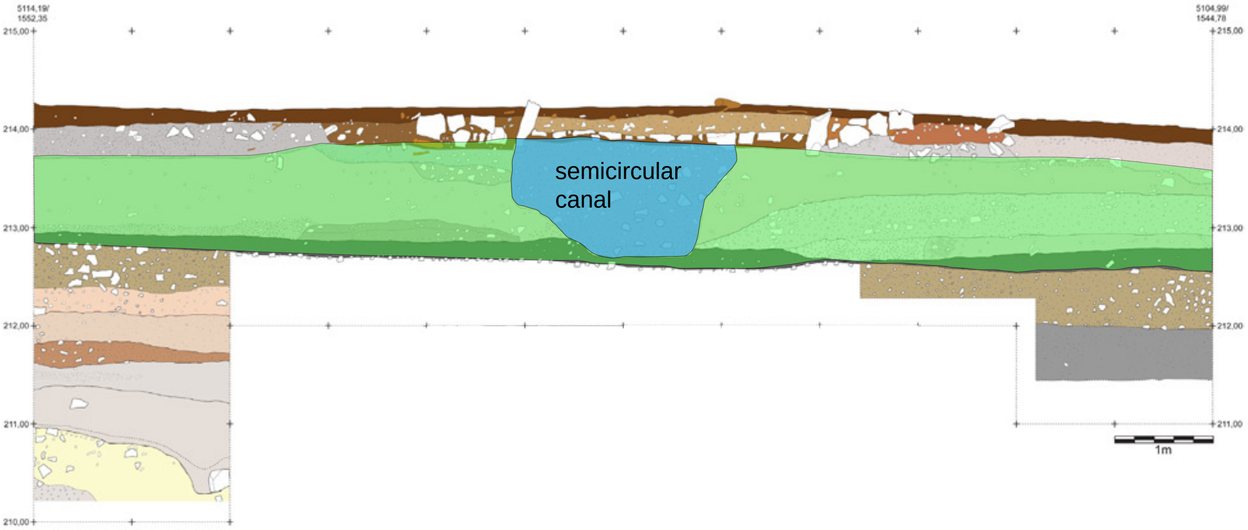


Figure 6.94: Uxul, Structural composition of the influx canal to the Aguada Occidental (Photos and Graphics: N. Seefeld).

a) Influx canal to the Aguada Occidental, Construction phase 1



b) Influx canal to the Aguada Occidental, Construction phase 2



c) Influx canal to the Aguada Occidental, Construction phase 3

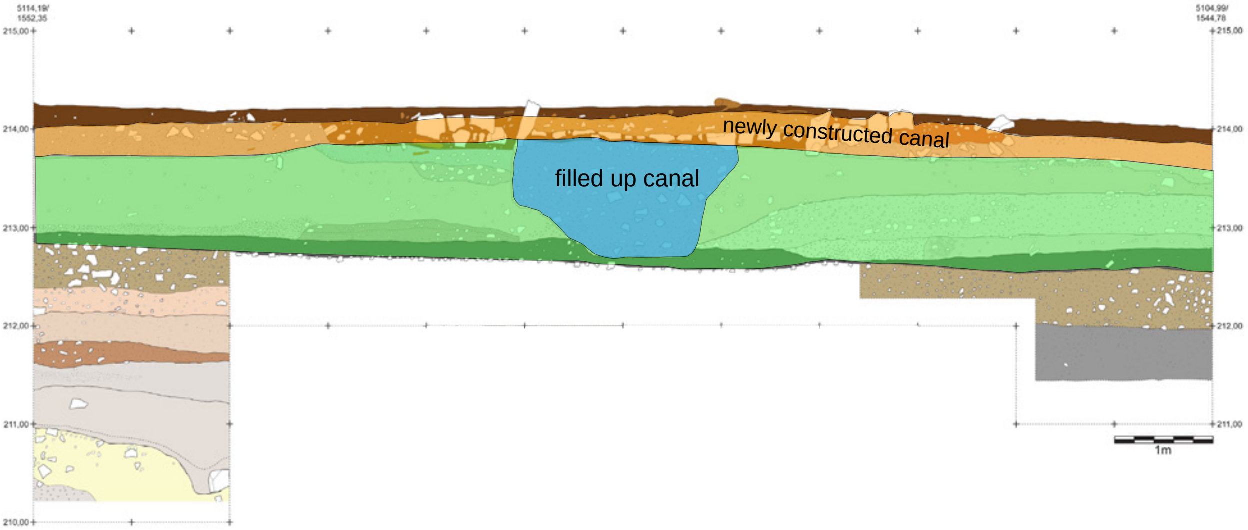
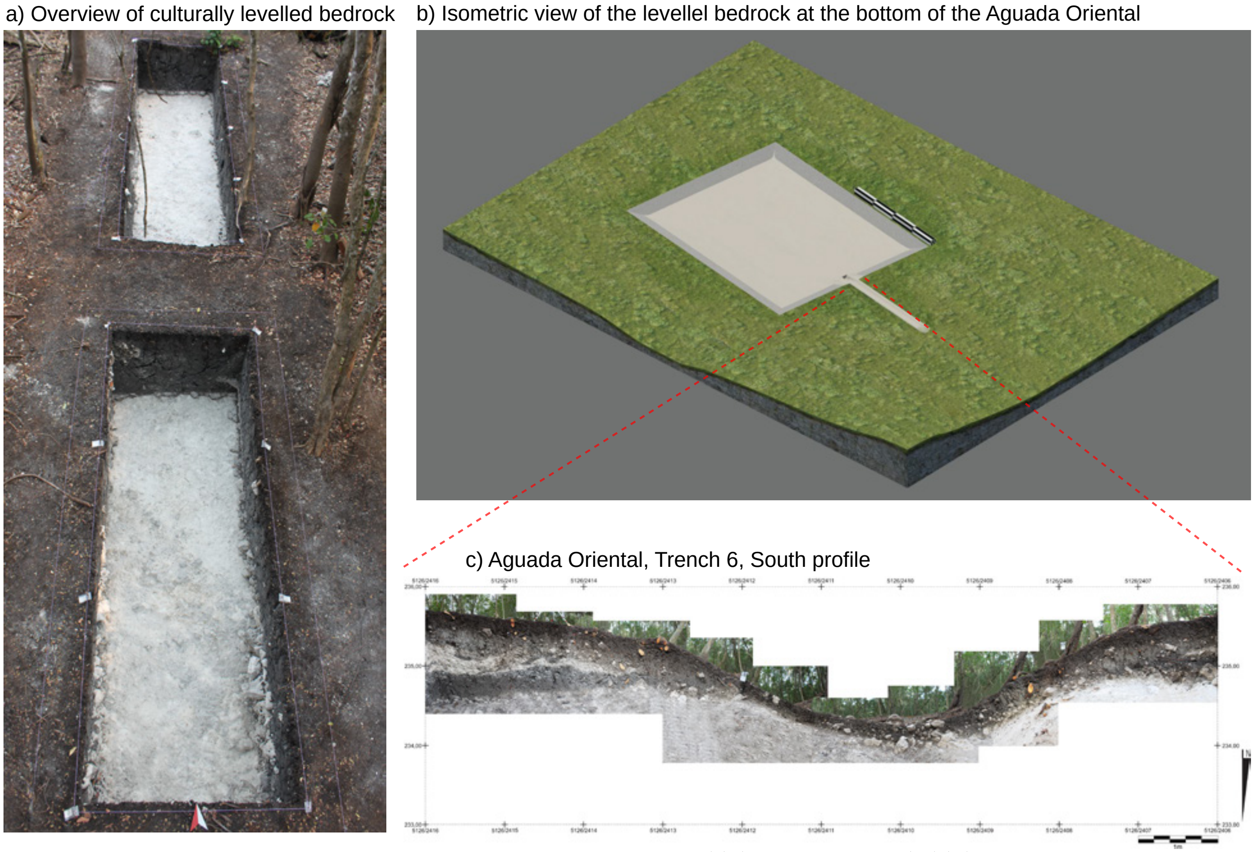


Figure 6.95: Uxul, Construction phases of the influx canal to the Aguada Occidental (Photos and Graphics: N. Seefeld).

6.4.3 Aguada Oriental

During the second phase of the Late Classic Period, when the modification of the Aguada Occidental and its catchment area no longer sufficed to provide the growing population of Uxul with the required water resources, the city planners were forced to construct a new reservoir, the Aguada Oriental. For the construction of this reservoir, the city planners selected a flat hilltop area to the east of the site core. As mentioned in Chapter 6.2.2, the excavations in the Aguada Oriental revealed that this reservoir does not represent a modification of a previously existing depression (Seefeld 2013a: 65). Instead, this upland area was intentionally selected for the construction of a completely new reservoir, a task that required enormous logistic expenses to excavate its entire volume (Seefeld 2013: 65). To this end, the city planners decided to create a water storage basin in the previously level landscape. The dating of the ceramic material from the Aguada Oriental indicated that this construction process took place during the second half of the Late Classic Period (Sara Dzul, personal communication 2012).

In the first construction phase, a rectangular basin with a depth of 2.5 m was cut into the bedrock, while the 3 m wide embankments were sloped at the same angle of approximately 23° on all four sides. The effects of this construction phase can still be observed in each of the nine trenches excavated in this reservoir (Seefeld 2013: 68; see Figure 6.96a). During this process, the 15 m long and 4 m wide, semicircular canal basin positioned exactly in the middle of the southern embankment was also cut into the bedrock (see Figure 6.96). At the north end of this sloping canal, a 40 cm high and 4 m wide pedestal of bedrock was left standing, while the rest of reservoir was carved out (Seefeld 2013a: 68). Upon this pedestal, huge, but carefully cut limestone rocks were assembled into a four-rowed, 1.20 m high wall that blocked the canal's northern end (see Figure 6.97). The lowest stone alignment was anchored into cavities in the bedrock pedestal, which had been cut especially for these blocks.


a) Overview of culturally levelled bedrock

b) Isometric view of the levellel bedrock at the bottom of the Aguada Oriental

c) Aguada Oriental, Trench 6, South profile

Figure 6.96: Uxul, Aguada Oriental, Modification of the natural bedrock (a) (Photo: N. Seefeld); (b) (Model: M. Lyons. Courtesy of Michael Lyons); (c) (Graphic: N. Seefeld).

Furthermore, the basin's floor area was leveled so carefully that the bedrock surface only exhibits a minute height difference between the center of the construction and the lower edge of the reservoir's embankment (see Figure 6.96a). This height difference, a distance of 45 m, is only 65 cm (231.40 m a.s.l. above sea level in the center and 232.05 m above sea level at the lower end of the embankment).

a) Isometric view of the filter wall at the northern end of the influx canal

b) Aguada Oriental, Filter wall, north view

c) Aguada Oriental, Filter wall, north view

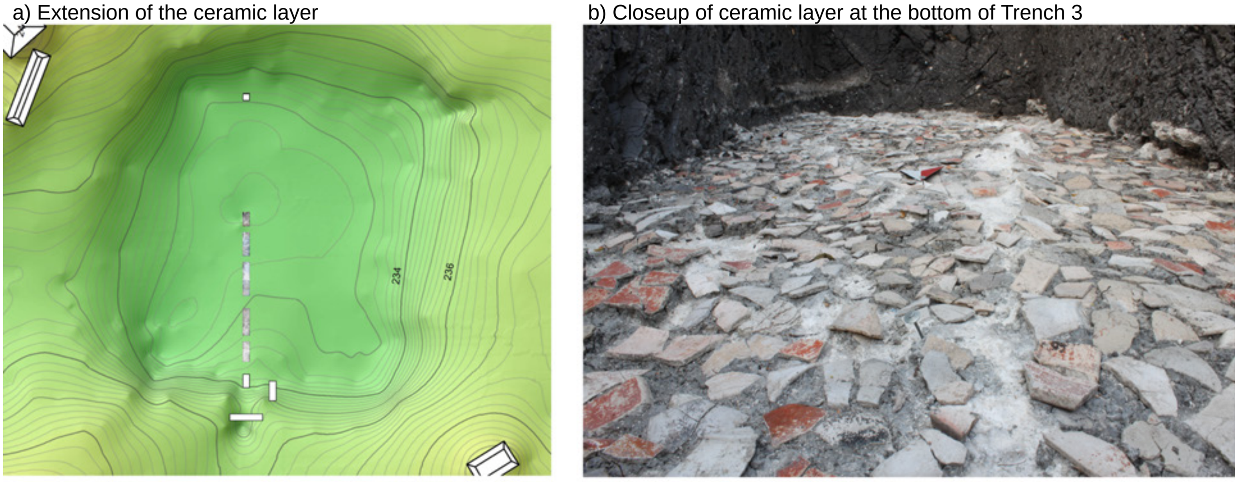
d) Isometric view of the filter wall at the northern end of the influx canal

e) Aguada Oriental, Filter wall, South view

f) Aguada Oriental, Filter wall, South view

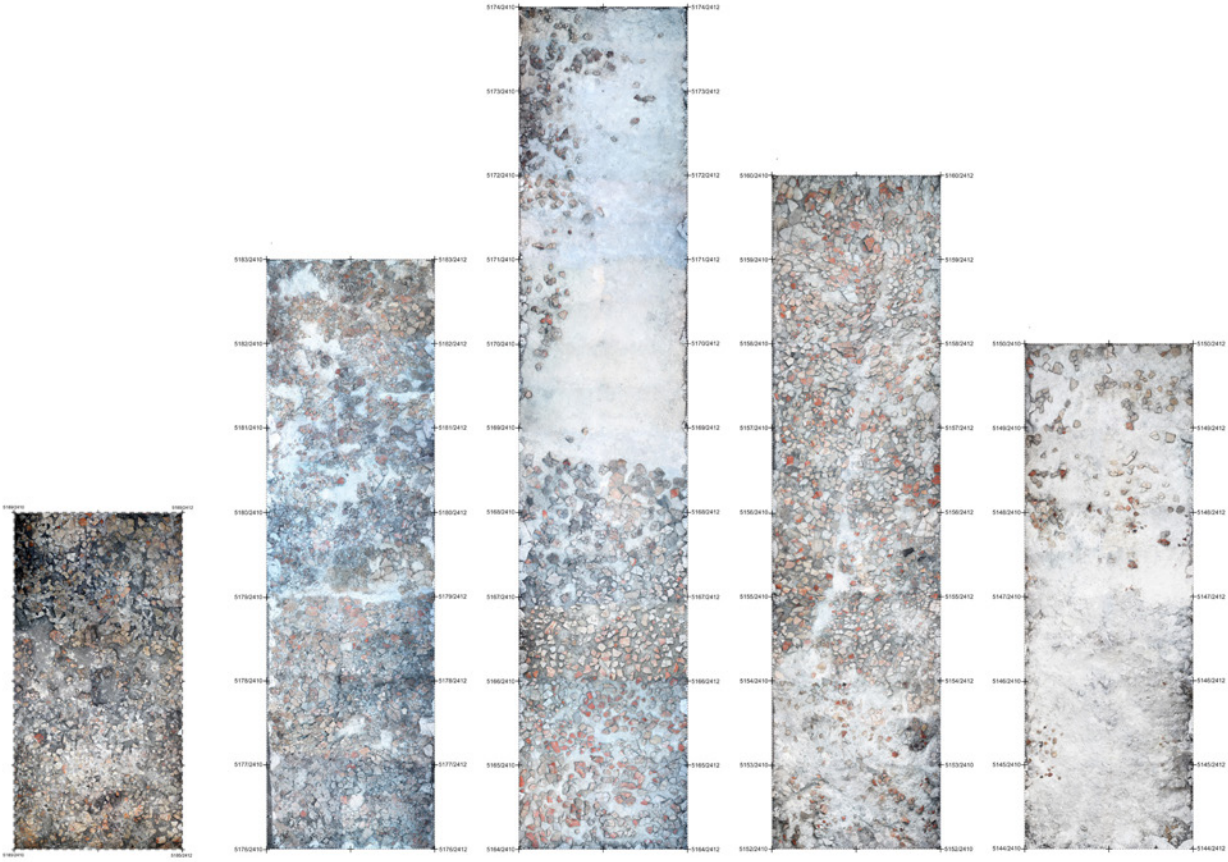
Figure 6.97: Uxul, Composition of the filter wall at the bottom of the Aguada Oriental. (a) (Model: M. Lyons. Courtesy of Michael Lyons); (b-c) (Photos: N. Seefeld); (d) (Models: M. Lyons. Courtesy of Michael Lyons); (e-f) (Photos and graphics: N. Seefeld).

In the following step, several thousand partially damaged plates and shallow bowls were carefully placed on this finely leveled bedrock surface so as to create a preferably tight bond (Seefeld 2013a: 68; see Figure 6.98). Due to their sheer numbers, these discarded plates and bowls had obviously been collected over a long period and stored for this specific purpose. The builders of this construction had evidently selected ceramic vessels with specific attributes, since only fragments with mild curvature were documented on the reservoir base. Apparently, the reservoir's engineer had purposefully assembled these specific fragments in order to assemble them into a ceramic layer with a surface as level as possible (Seefeld 2013a: 68). A close examination of this exposed feature shows that many sherds had been broken in exactly the location where they were documented. The archaeological documentation process showed that each sherd had deliberately been placed on the artificially leveled bedrock surface and that the individual sherds did not superimpose each other (Seefeld 2013a: 68; see Figure 6.98).


a) Extension of the ceramic layer

b) Closeup of ceramic layer at the bottom of Trench 3

c) Overview of documented ceramic layers


Central Trench of 2009

Trench 1 of 2011

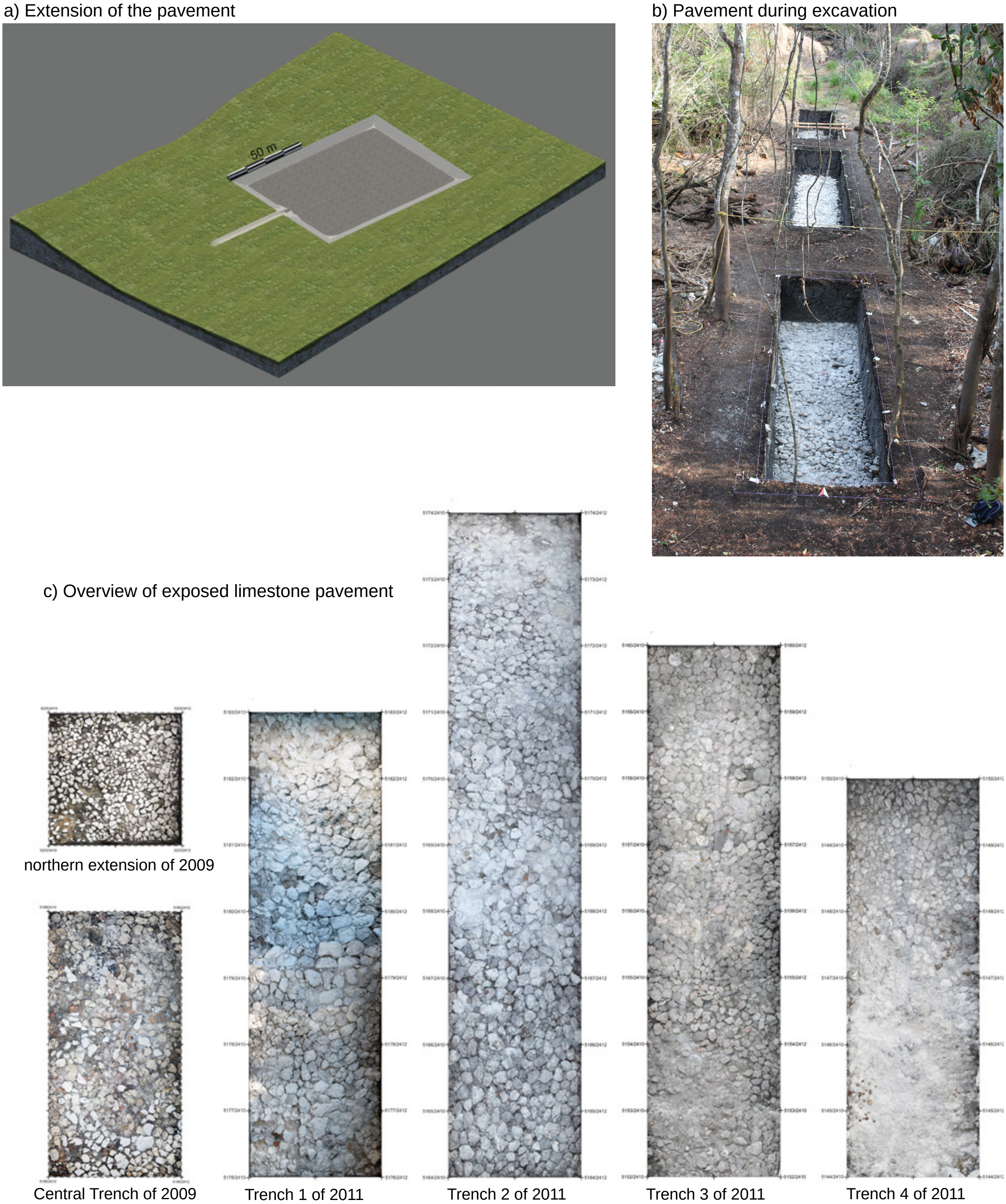
Trench 2 of 2011

Trench 3 of 2011

Trench 4 of 2011

Figure 6.98: Uxul, Layer of ceramic sherds at the bottom of the Aguada Oriental. (a) (Map: Courtesy of B. Volta. Reproduced with kind permission of Benjamino Volta); (b) (Photo: N. Seefeld); (c) (Photos and graphics: N. Seefeld).

During the next step, a pavement of flat limestone slabs was placed upon this ceramic layer (see Figure 6.99). These limestone slabs, which were presumably produced during the excavation of the bedrock, were cut to a uniform height of 6-9 cm and feature dimensions of 10 x 8 cm up to 40 x 28 cm (Seefeld 2013a: 68). In order to create a solid surface, they were carefully assembled into a very homogenous pavement. Remains of this pavement were documented in all of the excavated trenches. Excavations revealed that the pavement of the aguada's base begins precisely at the transition from the slope to the even base surface of the reservoir (see Figure 6.99). Furthermore, the builders had produced stone slabs with homogenous dimensions and form and assembled them into a pavement with very few gaps. A more


a) Extension of the pavement

b) Pavement during excavation

c) Overview of exposed limestone pavement

Figure 6.99: Uxul, Construction of limestone pavement at the bottom of the Aguada Oriental. (a) (Model: M. Lyons. Courtesy of Michael Lyons); (b-c) (Photos and graphics: N. Seefeld).

detailed examination of these archaeologically documented surfaces also shows that all gaps between the individual stone slabs had been filled with a startlingly solid stucco matrix (see Figure 6.99c). Due to this well-executed construction process, the finished surface effectively minimized water seepage and was able to remain largely intact until its documentation (Seefeld 2013a: 68).

Because of its position within the reservoir, the wall feature documented in Trench 5 could easily be identified as a filter wall. This filter wall served to purify the collected rainwater that would have flowed in from the southern catchment area via the southern influx channel ensuring that the reservoir's water to the north of this barrier was clean. The wall's elevated position supposedly facilitated the deposition of crude material. If these particles would have been removed on a regular basis, this construction element clearly would have improved the reservoir's overall cleanliness (Seefeld 2013a: 68).

The fact that the entire construction of the Aguada Oriental was formally connected to the settlement's center through the Denison Sacbe points to the desire to integrate it into the urban architecture. As the map and the low density of visible architectonic structures indicate, the major reason for the construction of the Denison Sacbe was apparently the desire to connect the aguada with the site core of Uxul (see Figure 6.100). Due to this settlement allocation, it seems reasonable to presume that this sacbe was built after the reservoir's completion. As already mentioned, the bedrock material in the area of the Aguada Oriental was made up of a very hard limestone which would have been suitable for the creation of building blocks for construction. In contrast to the Aguada Occidental, where the bedrock material was a hard sascab layer, it seems at least possible that the location of the Aguada Oriental had originally been used as a stone quarry. In this scenario, the Denison Sacbe might have also been used as a transport route through which the newly extracted building material could have been transported to the site core.

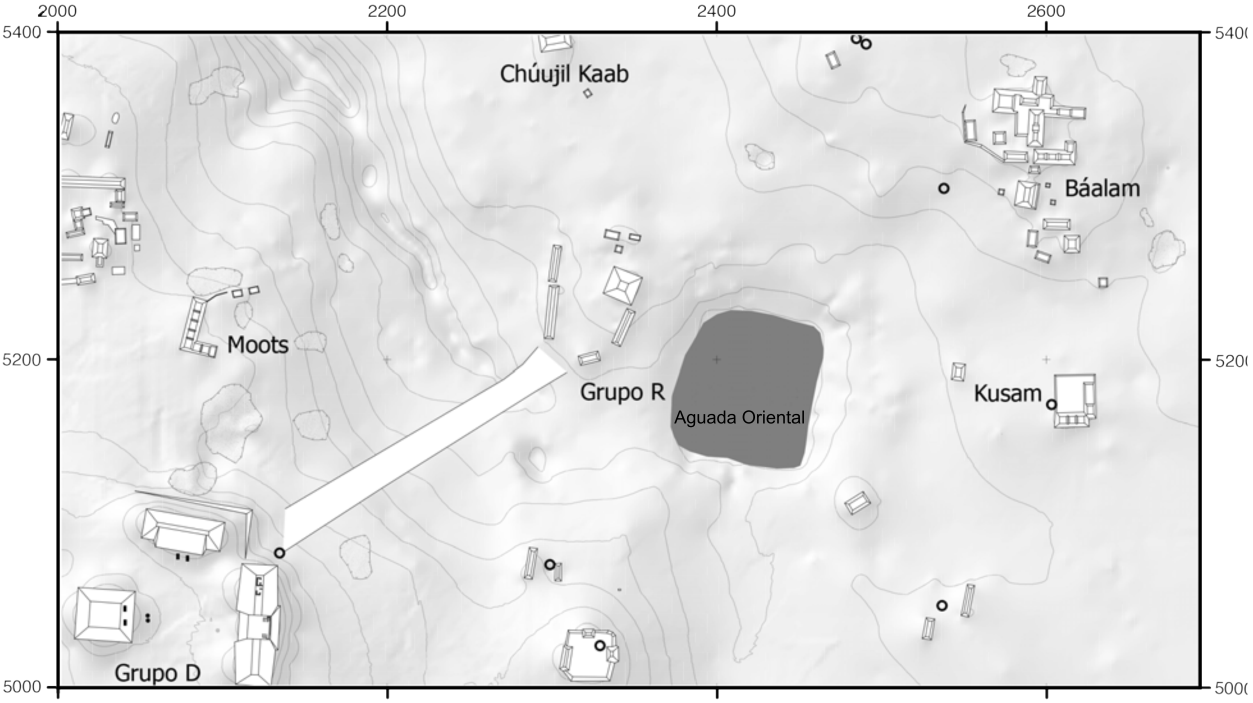


Figure 6.100: Uxul, Map of the Denison sacbe and its connection to the Aguada Oriental (modified from Seefeld 2016: Figure 2). Base map was produced by Iken Paap and Benjamino Volta for the Uxul Archaeological Project and originally published by Volta (2013: Figure 1). Reproduced with kind permission of Iken Paap and Benjamino Volta.

At the same time these larger hydraulic features were being constructed, the pre-Hispanic inhabitants of Uxul also built several small reservoirs near to their residential areas on the hilltops. Even though we are still lacking detailed information on the function and chronology of the more than 110 chultunes of Uxul, which might have partially been used as water storage features, the analysis of the ceramic material recovered during the excavation of the artificial cave of Group Q indicates that the construction of small-scale water reservoirs began early in Uxul's history. The ceramics recovered from the fill material (Lote 3374) under the stucco floor (Lote 3372) of Platform 1 of the artificial cave indicate that this small reservoir was already built during the Early Classic Period. This result is based on the fact that 95% of the fill material dates to the Early Classic and 5% to the Late Preclassic Period (Sara Dzul, personal communication 2015; see Figure 6.101). These results clearly indicate that Uxul's inhabitants had already started to construct small reservoirs near their residential areas during the Early Classic, a point when the demographic pressure was still not as severe as in the Late Classic Period.

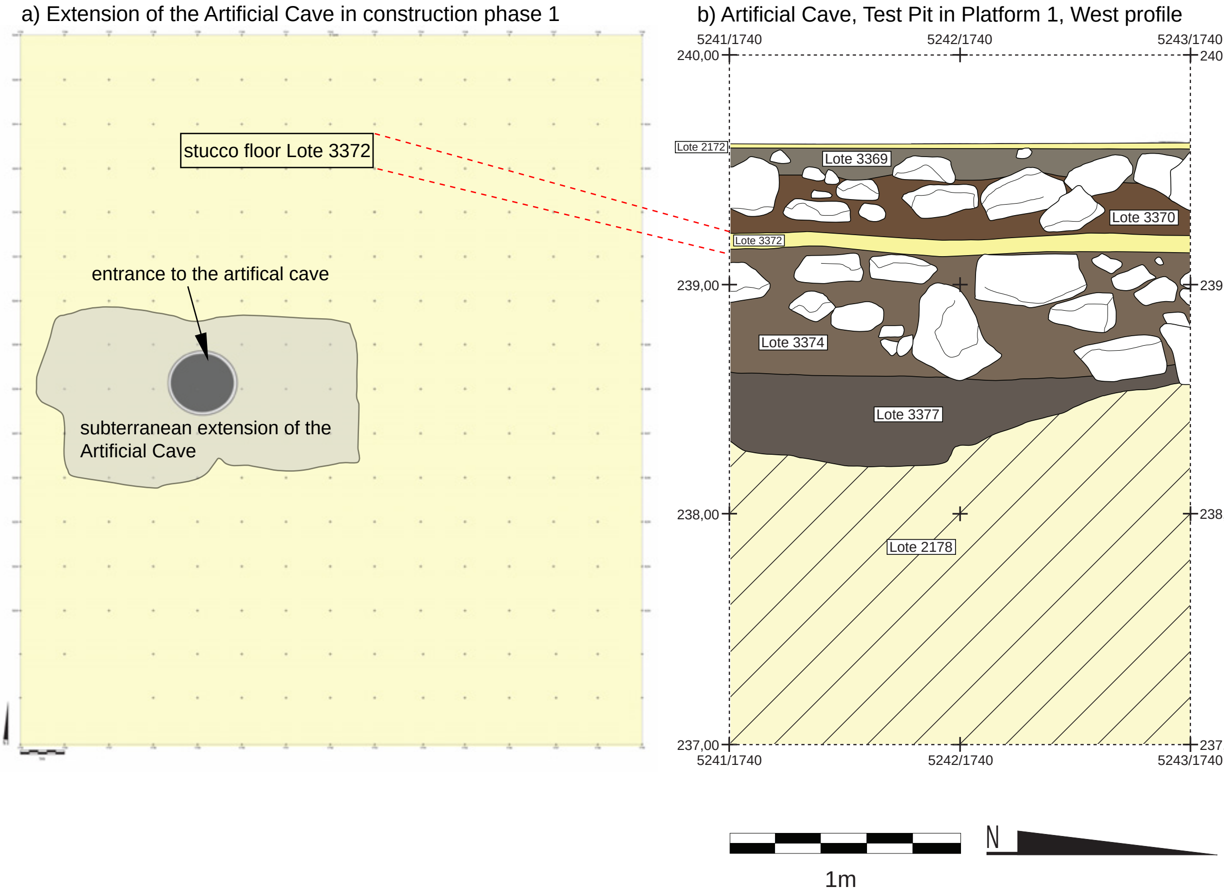


Figure 6.101: Uxul, Chronology of construction phase 1 of the artificial cave of Group Q (Graphic: N. Seefeld).

As a general statement, these results indicate that Uxul's inhabitants had constructed minor and major hydraulic features throughout the majority of the site's occupation. Interestingly, the distribution of the known hydraulic features indicates that the population had constructed privately controlled storage features at the same time the city planners devised large building programs for the construction of larger public reservoirs.

With the beginning of the Terminal Classic Period however, Uxul's pre-Hispanic inhabitants rapidly abandoned the site. While this abandonment process is mostly reflected in the absence of new building activity and the relatively small number of Terminal Classic ceramics (Grube *et al.* 2012: 20), the consequences of this abandonment process also seem to be reflected in the development of the hydraulic system, which disintegrated and seems to have even been deliberately destroyed during this period.

In the author's opinion, this disintegration process is reflected in the *buk'te'* feature documented at the bottom of the Aguada Occidental (see Figure 6.102). After excavating a cross section through the center of this feature, it became evident that this depression had been excavated after the initial construction of the pavement (see Figure 6.102). While the pavement obviously rests on a thick sascab layer, this depression was deliberately dug down to a depth of 60 cm until it hit the bedrock. The only explanation for this operation is the desire to extract small quantities of water on a short-term basis through the creation of a small well. Since the excavation of the documented *buk'te'* involved the partial destruction of the previously intact pavement, this operation in all likelihood took place during the Terminal Classic when the site was already partially abandoned and the upkeep of public architecture was no longer maintained. After this detailed description of the functionality and the development of Uxul's hydraulic system, the next chapter will highlight some of the main technological and geographical patterns of the hydraulic features presented in Chapters 5 and 6.

Figure 6.102: Uxul, Aguada Occidental, South view of *buk'te'* feature (Photo: N. Seefeld).

7 Functional and spatial patterns of hydraulic features in the Maya Lowlands

In light of the published examples of hydraulic features, it seems justified to state that the pre-Hispanic Maya were in fact ingenious in the modification of their natural landscape (Delgado Kú *et al.* 2012: 71). In consideration of all published hydraulic features, it is the author's opinion that two central conclusions can be made:

(1) Each hydraulic feature was always highly adapted to the very specific conditions of the particular local landscape, and

(2) The pre-Hispanic Maya had highly developed experience in the construction of hydraulic features.

For the theoretical framework of this dissertation, it is important to analyze how the pre-Hispanic Maya were able to adapt their hydraulic systems in such specific ways and how they developed and disseminated the knowledge about the construction of hydraulic features. The first process, the adaptation to the specific topographic conditions of a particular settlement landscape, cannot be understood with archaeological methods.

However, it can be assumed that, like every human group, the pre-Hispanic Maya had to acquire accurate knowledge of the local landscape, including its natural sources of water and the direction of natural surface drainage. In a later step, this careful examination of the local landscape would have enabled the local population to select attractive locations for residential areas, potential natural bodies of water for cultural modification and for the potential location of fault springs, which they later excavated in order to create artificial wells (see Chapter 5.6.3; Johnston 2004: 286). A general observable pattern in many hydraulic systems is that the local pre-Hispanic populations had to strategically plan the building complexes and plazas in such a way that the artificial watersheds would properly interact with the reservoirs (Brewer 2007: 34). This shows that the designers of building programs had a very distinct awareness for the special prerequisites of creating such an artificial watershed.

The second conclusion regarding the existence of highly developed experience in the construction of hydraulic features is deduced from observations of the published hydraulic features and may be explained with archaeological methods. In accomplishing this, this chapter will analyze the chronology and spatial distribution of particular types and particular technological elements of hydraulic features.

In the author's view, the spatial distribution of particular types or technological elements of hydraulic features provides a first impression of specific regional trends that indicate the routes on which certain forms of technological knowledge were distributed among the different regions of the Maya Lowlands. The chronology of hydraulic features, on the other hand, might indicate the section of the Maya Lowlands in which the first constructions of hydraulic features took place and if certain types of hydraulic features appeared earlier than others. In order to begin an initial systematization of the hydraulic features presented in Chapters 5 and 6, the analysis will first focus on the spatial distribution of different types of hydraulic features.

7.1 Spatial distribution of the different types of hydraulic features

As the specific hydraulic systems had to be adjusted accordingly to the local landscape, the geographic distribution of these different categories of hydraulic features corresponds with the distribution of the different ecological zones:

While the principal aim in regions without rivers was water detention, the principal aim for sites on flood plains was to divert water away from the settlement surfaces (Akpinar 2011: 19; Crandall 2009). As Figure 7.1 indicates, the spatial distribution of hydraulic systems that focused on the discharge of water are all located in the regions with the highest precipitation rates and permanent rivers.

Furthermore, Figure 7.1 also shows that all published canal features for agricultural purposes are concentrated on outer bajos and permanent streams. Despite numerous studies (Dahlin 1979; Puleston 1978) not as single irrigation or drainage canal has been documented inside an inner bajo. The highest concentration of canal features for agricultural purposes is located in the outer bajos of Belize and southern Quintana Roo. An additional cluster of raised and elevated fields can be observed along the floodplains of the Río Candelaria in southern Campeche.

As in most other regions of the world, the terrace systems of the Maya Lowlands are concentrated in hilly terrain with moderate slope gradients (see Figure 7.1). Due to this circumstance, the known terrace systems are confined to the Central and Southern Maya Lowlands (Dunning and Beach 1994). At the current state of research, the Vaca Plateau, the Maya Mountains, the Río Bravo region, the upper Belize river valley, the Petexbatun area and the Río Bec region have been identified as the main areas for agricultural terraces (Beach *et al.* 2002, 2008, 2015a: 20).

Due to a very limited scientific interest in dam features, only seven published constructions exist (see Figure 7.1). As shown in Chapter 5.4, their general spatial distribution does not allow for an interpretation as to which locations the pre-Hispanic Maya preferred for the construction of dam features.

In the case of drainage features, their purpose, the protection of residential areas or architectonical structures from inundations, makes it clear that they were located almost exclusively in urban contexts. Nevertheless, they did apparently fulfill slightly different functions according to their geographic location. In sites with an abundant water supply, these drainage features only served for water discharge. In sites with seasonally varying water supply however, drainage features deflected the excess runoff from the rainy season around the residential areas and directed them to reservoirs (see Figure 7.1).

As already pointed out in Chapter 5.6, reservoirs are prevalent in all regions of the Maya Lowlands. Even though the areas with the most limited access to sources of water feature the most monumental reservoirs, artificial or culturally modified water sources may also be located in regions with abundant water supply (see Figure 7.1). Generally, reservoirs exist in an enormously broad spectrum of form and size. Additionally, in many sites, several water sources of different dimensions were used in order to reduce risks. Thus, many hydraulic systems show a coexistence of monumental and more modestly sized hydraulic features in a single site. An example of such a deliberate risk diversification can be observed in the site of Dzibilchaltun, where local inhabitants constructed more than 100 artificial wells despite the fact that the settlement featured a cenote that supplied plentiful water (Maldonado *et al.* 2012: 50). Furthermore, several elements of the hydraulic systems presented in Chapters 5 and 6 indicate that labor investments for the construction of new reservoirs surpassed the level of mere necessity in many cases. Thus, the small bathtub-like reservoirs in Structure 1 of Ek' Balam (see Chapter 5.7.1), the small and private "pools" near the palace compound of Cancuén (see Chapter 5.8.4), the construction of artificial reservoirs in the water-rich site of Yaxha (see Chapter 5.5.2), the construction of wells in the water-rich site of Quirigua (see Chapter 5.6.3), and the construction of the artificial cave in Uxul (see Chapter 6.2.5) indicate that the pre-Hispanic Maya also constructed some of these hydraulic features in order to create more convenient living conditions. In consideration of this, it is surprising that hydraulic features that were unequivocally associated with elite residences were only located in Cancuén and Ek' Balam. In the remaining cases, all hydraulic features that were clearly built to create more convenient living conditions were publicly accessible and could thus be used for the collective good.

While the general spatial distribution of the different types of hydraulic features were already partially discussed in Chapter 5, some of the more specialized technological elements of hydraulic features have not yet been highlighted in detail. Therefore, the following section will identify the general functionality and spatial distribution of these elements.

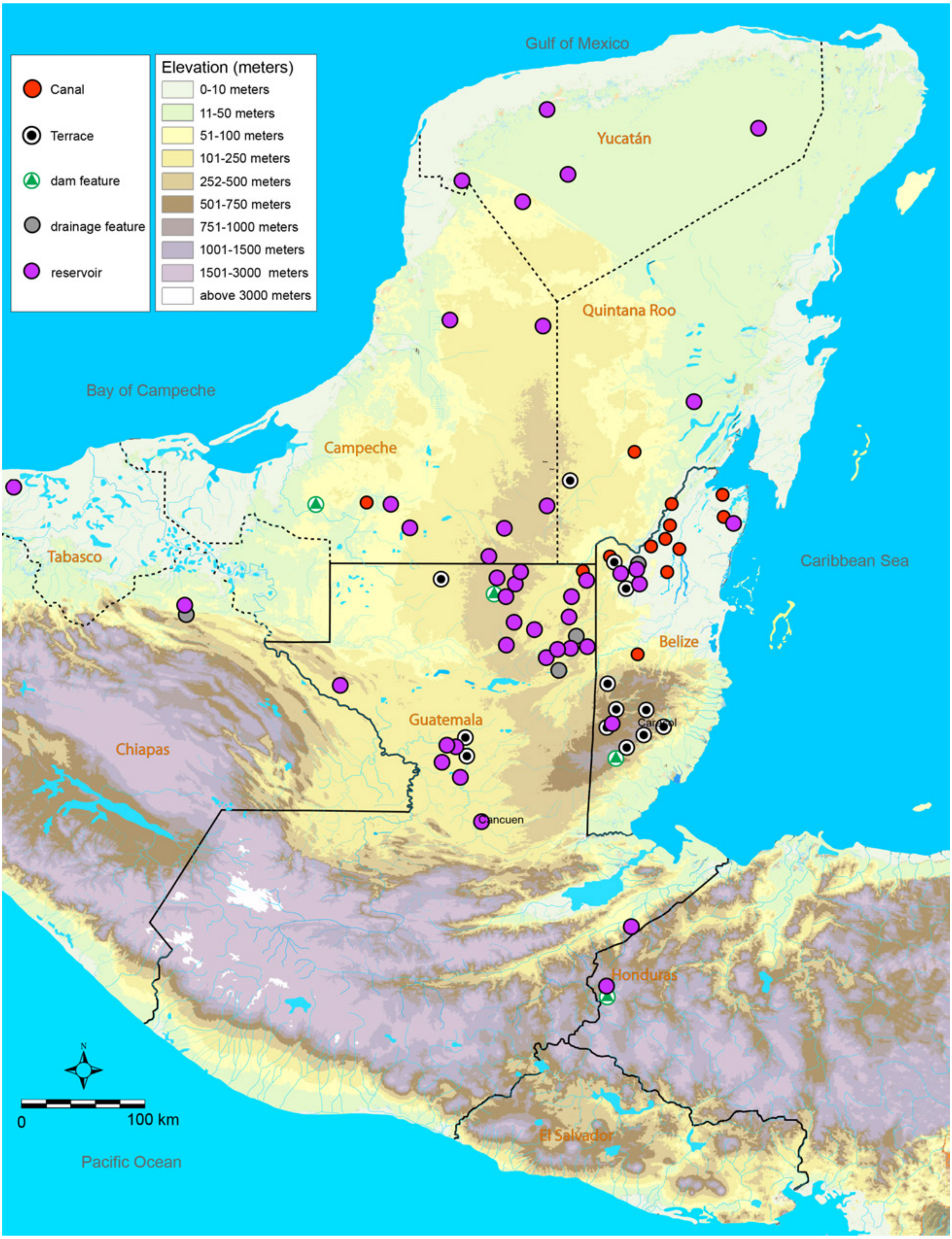


Figure 7.1: Spatial distribution of the different types of hydraulic features in the Maya Lowlands (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

7.2 Spatial distribution of particular technological elements of hydraulic features

As highlighted in Chapters 5 and 6, some technological elements of hydraulic features can only be observed in particular constructions and not in others. Of the various categories of hydraulic features, reservoirs generally exhibit the greatest variation and inclusion of specific technological elements. In succession, this chapter will highlight the general design and spatial distribution of the following three technological elements:

(1) Modification of reservoir floors (with limestone pavements, plaster linings, clay linings and ceramic elements),

(2) Filter elements, and

(3) Berms/water inlet and outlet devices.

7.2.1 Modification of reservoir floors

Akpinar-Ferrand and Dunning (2011: 115) reviewed the published aguadas in the Maya Lowlands and concluded that "regardless of the location or type, the majority of the studied aguadas displayed signs of Maya engineering, and evidence of nearby ancient Maya settlement and agriculture". In order to analyze the validity of this statement, the following section will highlight the spatial distribution and the general frequency of these floor modifications. The first examination will focus on the prevalence and spatial distribution of plaster linings and clay linings.

7.2.1.1 Plaster linings and clay linings

Akpinar-Ferrand and Dunning (2011: 115) claimed that labor-intensive modifications using plaster linings would have been confined to aguadas in "some city centers", whereas those using clay linings would have been more typical of aguadas on the urban fringe. Along these lines, the author would like to add that the sum of published aguadas does not reflect a strict separation of the two modification techniques on the basis of location. Instead, the current state of research indicates that the most monumental and elaborate hydraulic features were not located in urban areas, but in residential areas (see Chapter 8.7 and Table 9). Furthermore, the highly varying quality of documentation material does not currently facilitate verification as to which reservoirs actually had these modification elements. In fact, the sum of the published aguadas presented in Chapter 5 and 6 indicate that a plaster or clay lining could only be documented in 17 cases:

1. Xultun, Aguada Los Tambos (plaster lining, see Chapter 5.6.4.3.7).

2. San Bartolo, Aguada San Bartolo[180] (plaster lining, see Chapter 5.6.4.3.7).

3. Dos Hombres, Agua Lluvia Group, Reservoir 1 (plaster lining; see Chapter 5.6.4.3.8.5).

4. Nakbe, Aguada Zacatal (plaster lining; see Chapter 5.6.4.3.2).

5. Xcoch, Aguada La Gondola (clay lining, see Chapter 5.7.3).

6. El Zotz, El Zotz Aguada (plaster lining; see Chapter 5.6.4.3.5).

7. Tikal, Temple Reservoir (clay lining; see Chapter 5.7.7.2.1)

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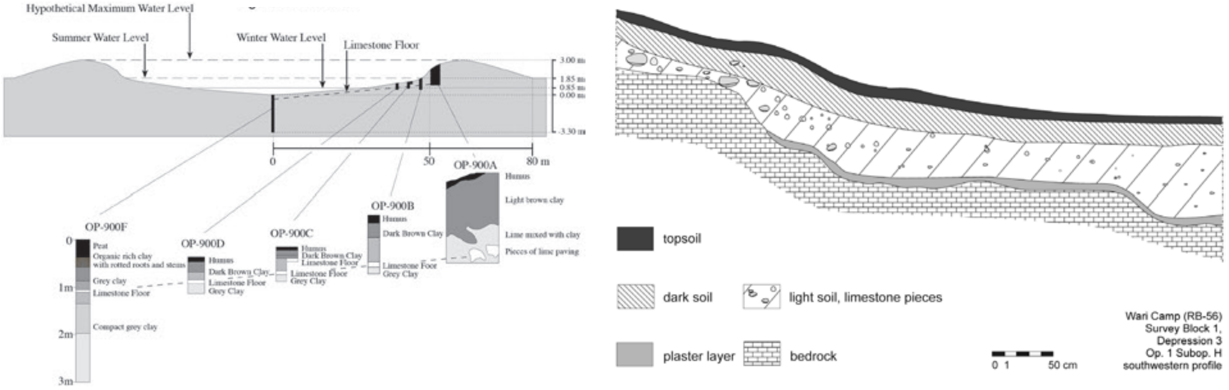
[180] Unfortunately, no graphic material of this constructional element has been published so far.

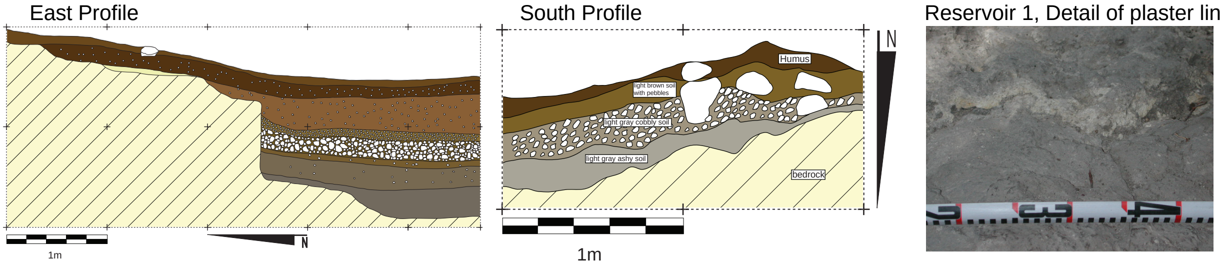
8. La Milpa, Medicinal Trail depression (clay lining; see Chapter 5.6.4.3.8.1.1).

9. La Milpa, Wari Camp, Survey Block 1, Depression 3 (plaster lining; see Chapter 5.6.1).

10. La Milpa, Wari Camp Center, Depression 1 (plaster lining; see Chapter 5.6.1).

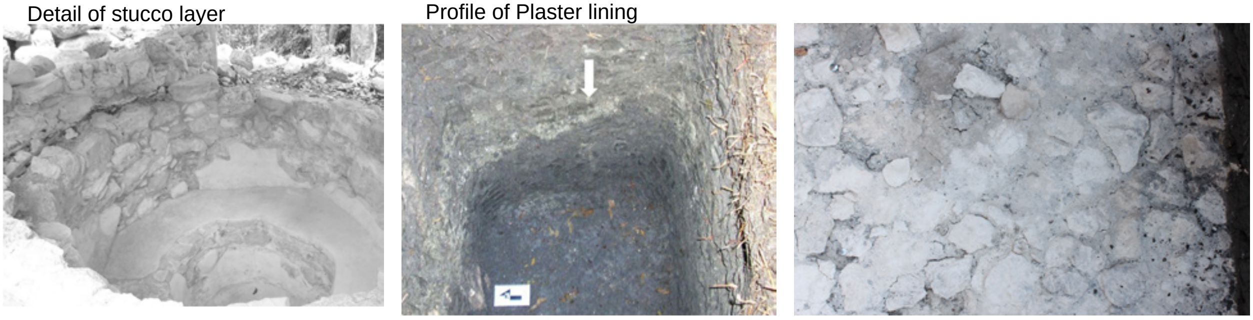

a) Nakbe, Aguada Zacatal, Schematic Profile

b) La Milpa, Wari Camp, Depression 3, Profile


c) La Milpa, La Milpa East, Depression 9, East Profile

d) La Milpa Medicinal Trail Depression, South Profile

e) Dos Hombres, Agua Lluvia Group, Reservoir 1, Detail of plaster lining


f) Ek' Balam, Structure 1, Reservoir D-12, Detail of stucco layer

g) Xultun, Aguada Los Tambos, Profile of Plaster lining

h) Uxul, Aguada Oriental, Detail of Stucco matrix


i) Uxul, Aguada occidental, Detail of Stucco matrix

j) Uxul, Artificial Cave, Stucco floor

k) El Zotz, El Zotz Aguada, West Profile

Figure 7.2: Overview of published reservoirs with a plaster and/or clay lining. (a) (source: Wahl *et al.* 2007: Figure 3; Reproduced with kind permission of David Wahl and Cambridge University Press); (b) (source: Weiss-Krejci 2013: Figure 3); (c) (Courtesy of Estella Weiss-Krejci); (d) (modified from Brewer 2007: Figure 5.2. Reproduced with kind permission of Jeffrey Brewer); (e) (source: Trachman 2007: Figure 5.12. Reproduced with kind permission of Clarissa Trachman); (f) (source: Castillo Borges and Vargas de la Peña 2009: Photo 9. Reproduced with kind permission of Victor Castillo Borges and Leticia Vargas de la Peña); (g) (source: Akpinar-Ferrand *et al.* 2012: Figure 5. Reproduced with kind permission of Cambridge University Press); (h-j) (Photos: N. Seefeld); (k) (source: Beach *et al.* 2015a: Figure 12.4.Reproduced with kind permission of Timothy Beach and Cambridge University Press).

11. La Milpa, La Milpa East, Depression A (plaster lining, see Chapter 5.6.5.4.8.2).

12. La Milpa, East Transect, Depression G (plaster lining, see Chapter 5.6.1).

13. La Milpa, Aguada Lagunita Elusiva (plaster lining, see Chapter 5.6.4.3.8.4).

14. Ek' Balam, Stepped Reservoir D 12 (plaster lining; see Chapter 5.7.1).

15. Uxul, Aguada Oriental (plaster lining; see Chapter 6.2.2).

16. Uxul, Aguada Occidental (plaster lining; see Chapter 6.2.3).

17. Uxul, Cueva Artificial (plaster lining; see Chapter 6.2.5).

Of these 17 cases, only 11 features were documented with accompanying graphic material (see Figure 7.2).

7.2.1.2 Limestone pavements

As presented in Chapters 5.6 and 5.7, the published examples of limestone pavements show a remarkable homogeneity in their design. An interesting side effect of base modifications seems to have been the enhanced water quality (see Chapter 5.6.4.1). While this might have been an unintended effect, Akpinar (2011: 32) argued that the dissolving plaster lining in artificial reservoirs might have also reduced waterborne diseases. Furthermore, Akpinar (2011: 32) also claimed that limestone pavements would have been a common modification technique in the Maya Lowlands (Ancona 1978; Domínguez and Folan 1996; Matheny *et al.* 1980). In this respect however, the author would like to point out that actual proof of such modifications are quite rare. At the current state of research, limestone pavements could only be documented in ten reservoirs (see Figure 7.3):

1) The Aguada No. 4 of Calakmul (see Chapter 5.7.5),

2) The Aguada No. 6 of Calakmul (see Chapter 5.7.5),

3) The Aguada Oriental of Uxul (see Chapter 6.2.2),

4) The Aguada Occidental of Uxul (see Chapter 6.2.3),

5) Nakbe, Aguada Zacatal (see Chapter 5.6.4.3.2),

6) Uaxactun, Group B, Reservoir A (see Chapter 5.6.4.3.4),

7) El Zotz, Aguada El Zotz (see Chapter 5.6.4.3.5),

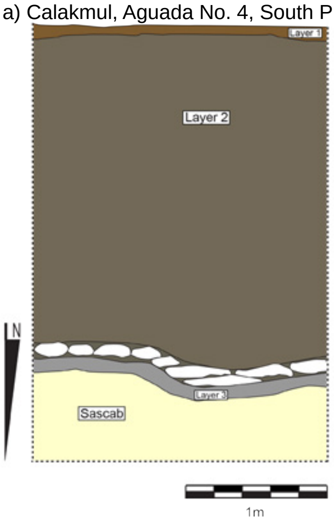
8) The Palace Reservoir of Tikal (see Chapter 5.7.7.2.2),

9) The southern reservoirs ("Royal Pool") of Cancuén (see Chapter 5.8.4.1), and

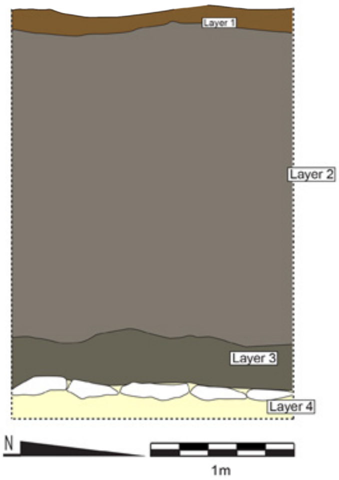
10) The northern Reservoir of Cancuén (see Chapter 5.8.4.2).

Of these ten reservoirs, nine examples have been published with the accompanying graphic documentation material (see Figure 7.3). While these more labor-intensive modifications might be associated with Late Classic population pressure, it is surprising to see that the recently discovered limestone pavement at the bottom of the Aguada El Zotz obviously dates to the Early Classic. Due to such a small typology, it is impossible to speculate as to the origin and degree of dispersion of this modification technique.

a) Calakmul, Aguada No. 4, South Profile

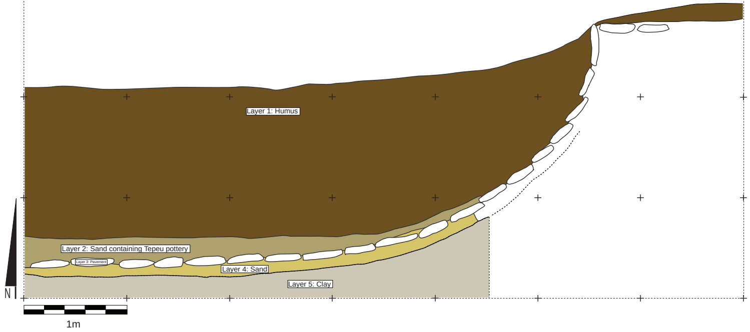


b) Calakmul, Aguada No. 6, West Profile



c) Uxul, Aguada Occidental, West view

d) Uaxactun, Group B, Reservoir A, North profile



e) Tikal, Palace Reservoir

f) Uxul, Aguada Oriental

g) El Zotz, El Zotz Aguada, East View

h) Cancuén, Southern Reservoir "Royal Pool"

i) Cancuén, Northern Reservoir

Figure 7.3: Overview of limestone pavements at the bottom of aguadas. (a) (modified from Domínguez Carrasco and Folan 1996: Figure 14); (b) (modified from Domínguez Carrasco and Folan 1996: Figure 15. Reproduced with kind permission of María del Rosario Domínguez Carrasco); (c) (Photo: N. Seefeld); (d) (modified from Smith 1950: Figure 99b. Reproduced with kind permission from the Carnegie Institution of Washington); (e) (source: Scarborough *et al.* 2012: Figure 4c. Reproduced with kind permission of Vernon Scarborough and PNAS); (f) (Photo: N. Seefeld); (g) (source: Beach *et al.* 2015a: Figure 8). Reproduced with kind permission of Timothy Beach and Elsevier; (h) (Photo: Courtesy of J. Szymanski); (i) (source: Alvarado Najarro 2013: Figure 8. Reproduced with kind permission of Silvia Alvarado Najarro).

7.2.1.3 Ceramic Elements

The usage of ceramic elements is so rare that it has not come under any focused research yet. However, as mentioned in the framework of Chapters 5 and 6, there are eight cases in which the pre-Hispanic Maya had not only used worked stones, plaster and modified bedrock for the construction of their hydraulic features, but also ceramic elements. These eight features are:

1) A ceramic layer underneath the limestone pavement of the El Zotz Aguada[181] (see Chapter 5.6.4.3.5),

2) A ceramic layer underneath a stucco floor in the small Reservoir D 1-8, incorporated into Structure 1 of Ek' Balam (see Chapter 5.7.1),

3) A ceramic layer underneath a stucco floor in the small Reservoir D 2-13, incorporated into Structure 1 of Ek' Balam (see Chapter 5.7.1),

4) A ceramic layer underneath a stucco floor in the small Reservoir D 2-16, incorporated into Structure 1 of Ek' Balam (see Chapter 5.7.1),

5) A ceramic layer underneath a stucco floor in the small Reservoir D 3-17, incorporated into Structure 1 of Ek' Balam (see Chapter 5.7.1),

6) A ceramic layer underneath the limestone pavement of the Aguada Oriental of Uxul (see Chapter 6.2.2),

7) Well shafts with a coating of composite ceramic elements in Quirigua (see Chapter 5.6.3), and

8) A drainage canal ("tube") composed of several ceramic elements in Joy' Chan (see Chapter 5.8.1).

The layout of these features indicates that the pre-Hispanic Maya had employed ceramic material in order to enhance the functionality of hydraulic features. According to the author's opinion, these eight examples can be classified into two different categories:

1) The utilization of ceramic sherds as a leveling element between the subsurface and a sealing layer, and

2) The utilization of ceramic tubes for the creation of watertight lining, or water pipes

Due to the small number of documented cases, none of these uses of ceramic elements have been previously described in the archaeological literature. Therefore, the following overview will illustrate the general functionality and varieties of these different applications.

(a) Usage of ceramic sherds as leveling elements between the subsurface and a sealing layer

The usage of ceramic sherds as leveling elements could be observed in four different reservoirs integrated into Structure 1 of Ek' Balam (see Figure 7.4a) and at the bottom of the Aguada Oriental of Uxul (see Figure 7.4b). In both sites, the individual ceramic sherds had been deposited in a highly dense arrangement resembling a mosaic. Furthermore, it could be observed that none of the individual sherds superimposed another, but instead, only a single layer of sherds was sandwiched between the subsurface and the sealing layer. In the case of Reservoir D-8 of Ek' Balam, the ceramic layer had been deposited on a stone

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[181] Although Beach *et al.* (2015a) described the existence of a ceramic layer at the bottom of the El Zotz Aguada, and compared it to the ceramic layer of the Aguada Oriental of Uxul, they regrettably did not provide any graphic documentation material of this feature.

pavement and sealed with a stucco layer. In the case of the Aguada Oriental however, the modification was complemented by an additional element: The fundamental subsoil of the construction consisted of the artificially leveled surface of the bedrock upon which the pre-Hispanic Maya deposited the ceramic layer. Upon the ceramic layer, the builders applied a pavement of flat limestone slabs. Ultimately, the seams between the individual slabs were sealed with a hard stucco matrix. In both cases, the positioning of the ceramic layer clearly indicates that it had served as a leveling element.

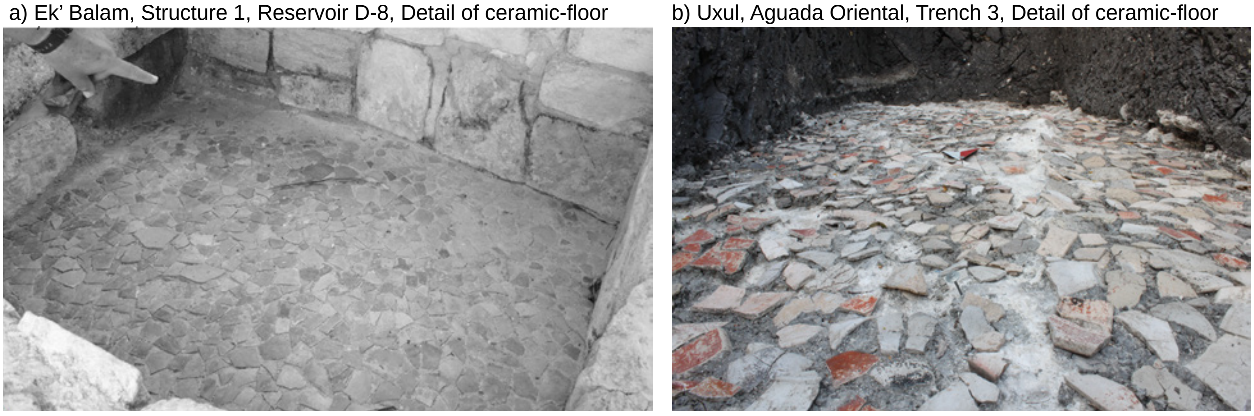
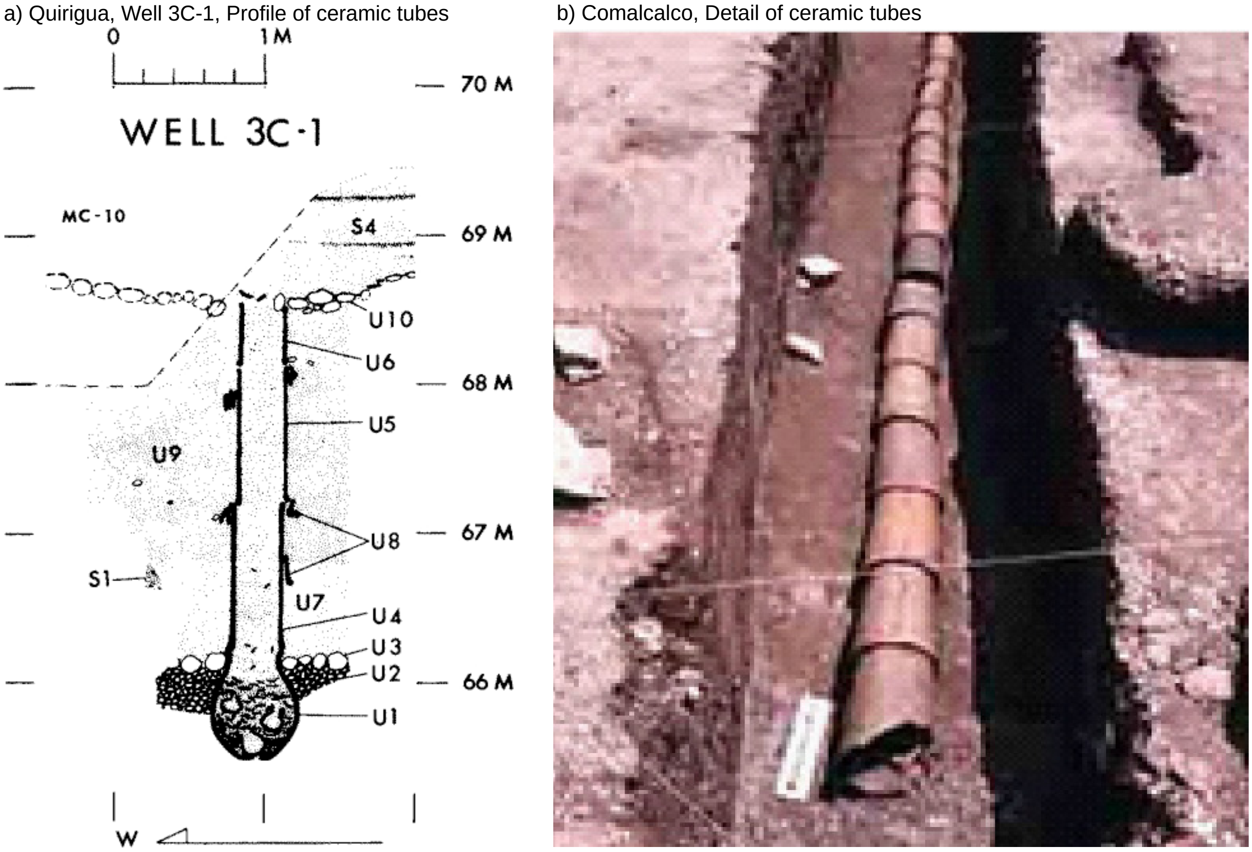


Figure 7.4: Overview of ceramic layers on the bottom of water reservoirs. (a) (source: Castillo Borges and Vargas de la Pena 2009: Photo 3); (b) (Photo: N. Seefeld). Reproduced with kind permission of Victor Castillo Borges and Leticia Vargas de la Pena.

(2) Usage of ceramic tubes

Even though the two documented ceramic tube features are based on the same technical approach, they pursue different goals. While the ceramic tubes in the wells of Quirigua serve as another form of sealing element for a "small reservoir" or well (see Figure 7.5a), the ceramic tubes of Comalcalco (see Figure 7.5b) form a drainage pipe. Thus, both features represent the only examples of their respective class. In the author's opinion, the evolution of these elements proves that the pre-Hispanic Maya had developed an impressive engineering knowledge and found effective solutions to construct watertight tube connections. According to Ashmore (1984: 151), potters had developed the individual ceramic elements of Quirigua specifically for this purpose. Curiously, even most Maya scholars still seem to be unaware of the fact that the pre-Hispanic Maya had developed this level of technical knowledge. Considering the general lack of research, the author would like to argue that more focused investigations would doubtlessly result in a more widespread documentation of ceramic water pipes in pre-Hispanic Maya sites.


a) Quirigua, Well 3C-1, Profile of ceramic tubes

b) Comalcalco, Detail of ceramic tubes

Figure 7.5: Overview of ceramic tubes in wells and drainage canals. (a) (modified from Ashmore 1984: Figure 2; Reproduced with kind permission of Wendy Ashmore and Cambridge University Press); (b) (source: Armijo Torres *et al.* 2012: Figure 6. Reproduced with kind permission of Ricardo Armijo Torres).

In conclusion, the detailed description of the published evidence of floor modifications has shown that Akpinar-Ferrand's and Dunning's (2011: 115) evaluation of the prevalence of floor modifications has been overly optimistic. Even though the development over recent years and the current state of research enable a far better evaluation than possible in previous decades, the author would like to state that the interpretations of many authors do not match up with the published documentation material and that the actual proof of such modifications are still relatively limited.

7.2.2 Filter elements

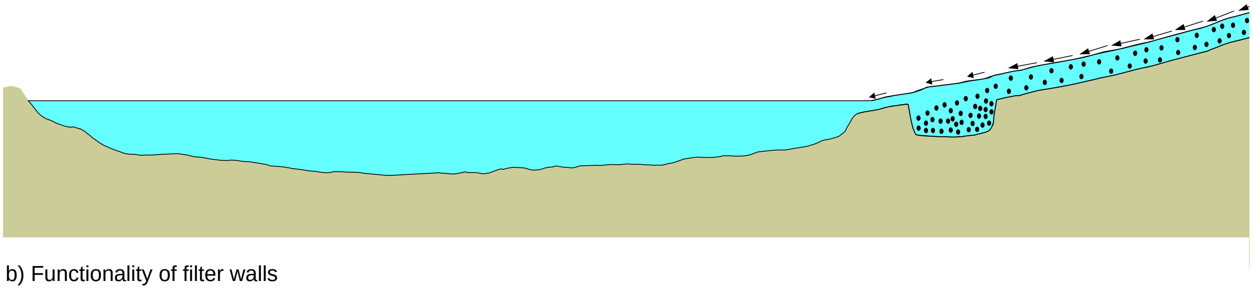
As Beach *et al.* (2015a: 14) correctly noted, urban infrastructure of water management did not only attempt to store water for the dry seasons and protect residential areas from excess water. In fact, many elements of hydraulic systems were also intended to improve the quality of the stored water (Scarborough *et al.* 2012: 12412). In the natural landscape of the Maya Lowlands, anthropogenic and zoogenic excreta as well as cultural waste would have been the most persistent concerns for the quality of water in the culturally modified watersheds (Luzzadder-Beach 2001: 494). Therefore, some scholars assumed that these factors would have required boiling the water, combining it with carbohydrates or fermenting it in order to make it potable (Dahlin and Litzinger 1986: 730; Scarborough *et al.* 2012: 12412). While these measures are hard to detect with archaeological methods, the construction measures for improving the quality of the stored water are easier to attest. In order to control the hazardous effect of these external factors and to improve the general quality of the stored water, the pre-Hispanic Maya had developed two central techniques: Siltation tanks and filter walls (a), and sand filters (b).

(a) Siltation tanks and filter walls

From a technical point of view, siltation tanks and filter walls follow the same technical approach. They impeded the intrusion of debris and filtered inflowing water (Akpinar 2011: 32; Matheny *et al.* 1980; Scarborough *et al.* 1994). According to some scholars (e.g. Scarborough *et al.* 2012: 12412), silting tanks and filter walls would have been able to control organic and inorganic pollutants.

In the author's opinion, the only difference between these two technical elements is their relation to the respective reservoir. While siltation tanks are located below the level of inflowing water, filter walls are usually positioned at the same level as the inflowing water. Due to their lower elevation, siltation tanks enable the deposition of coarse material that is washed in with the inflowing water at the bottom (see Figure 7.6a). Filter walls however, create a direct barrier for the inflowing water and prevent coarse material from passing through them (see Figure 7.6b). From a technical perspective, the key effect of both approaches is the reduction of flow velocity. Siltation tanks reduce the flow velocity due to a sudden increase of water depth that allows the deposition of heavier dirt particles. Filter walls on the other hand cause a sudden reduction of flow velocity causing heavier dirt particles to deposit at their base. As already pointed out in Chapters 5 and 6, the accumulation of dirt particles required the constant maintenance of these features in order to guarantee appropriate function.

a) Functionality of siltation tanks



b) Functionality of filter walls

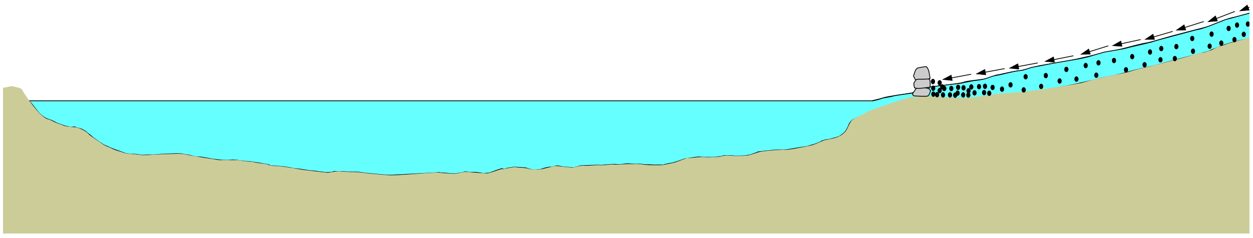


Figure 7.6: Schematic representation on the technical approach of siltation tanks and filter walls (Graphic: N. Seefeld).

At the current state of research, only six examples of siltation tanks and/or filter walls have been documented in the Maya Lowlands (see Figure 7.7).

1) San Bartolo, Aguada Loros (siltation tank, filter element) (see Chapter 5.6.4.3.7),

2) Tikal, Temple Reservoir (coffer dam and silting tank) (see Chapter 5.7.7.2.1),

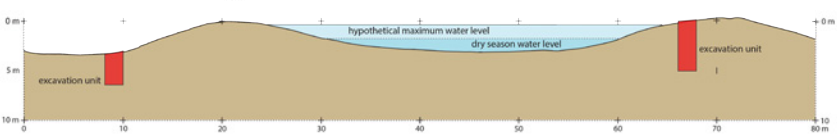
3) Tikal, Palace Reservoir (Palace dam filter wall) (see Chapter 5.7.7.2.2),

4) Uxul, Aguada Oriental (siltation tank and filter wall) (see Chapter 6.2.2),

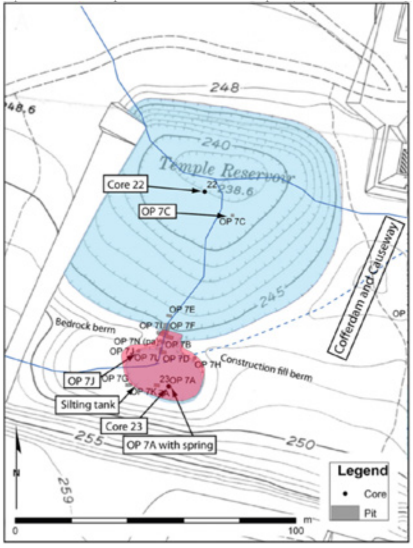
5) Naachtun, Artificial Reservoir (cobble-wall filter element) (see Chapter 5.6.4.3.3), and

6) Kinal, Kinal West drainage (silting tank, Suboperations H, I, J, K, L) (see Chapter 5.7.8).

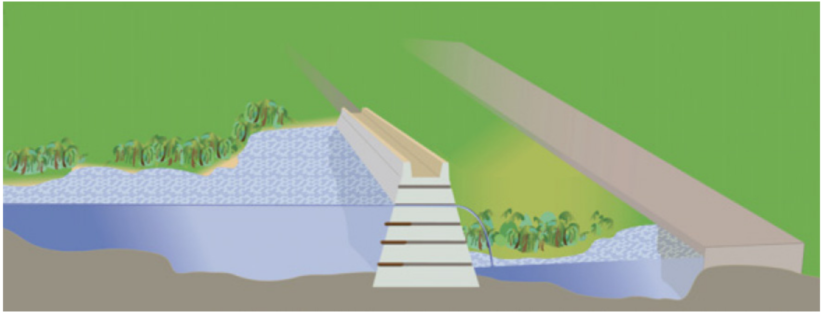
a) San Bartolo, Aguada Los Loros



b) Tikal, Temple Reservoir, Map

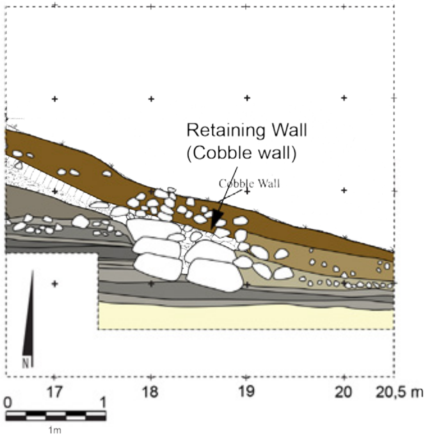


c) Tikal, Palace Dam, Reconstruction of filtering-function



d) Uxul, Aguada Oriental, Filter Wall, East view

e) Naachtun, Modified Reservoir, Subop. A, North Profile



f) Kinal West drainage, Location of silting tank

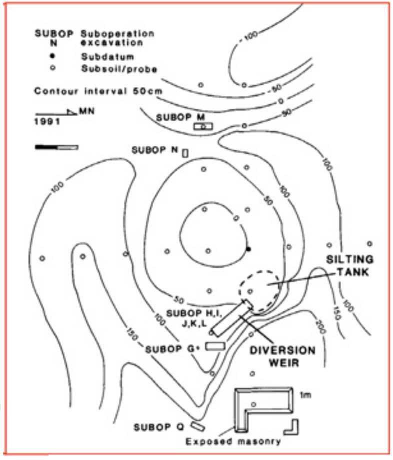


Figure 7.7: Overview of published siltation tanks and filter walls in the Maya Lowlands. (a) (modified from Akpinar-Ferrand *et al.* 2012: Figure 3. Reproduced with kind permission of Cambridge University Press); (b) (source: Scarborough *et al.* 2012: Figure S3a. Base map: Courtesy of the Penn Museum. Reproduced with kind permission of Vernon Scarborough and PNAS); (c) (source: Scarborough *et al.* 2012: Figure 4a. Reproduced with kind permission of Vernon Scarborough and PNAS); (d) (Photo: N. Seefeld); (e) (modified from Parry 2007: Figure 4.7. Reproduced with kind permission of Roberta G. Parry); (f) (source: Scarborough *et al.* 1994: Figure 6. Reproduced with kind permission of Vernon Scarborough and Cambridge University Press).

As Figure 7.7 indicates, siltation tanks are currently mostly represented in maps and have not been the subject of thorough archaeological investigations. A sound approach for future research projects would be an explanation of their technical structure and the implementation of necessary measures taken to prevent erosion. In the group of published filtering devices, the filter wall at the southern end of the Aguada Oriental of Uxul occupies a special position, as it technically represents a combination of a siltation tank and a filter wall (see Chapter 6.3.5).

(b) Sand filters

Similar to filtration tanks, sand filters were employed in order to filter inflowing water. Some scholars argued that sand filters would have controlled organic and inorganic pollutants (Scarborough *et al.* 2012: 12412). According to Akpinar (2011: 32), the documentation of coarse-textured sediments next to aguadas would be explicit evidence for the existence of these features. However, the author would like to note that the "observations" of such sand filters are first of all scarce, and second of all, the published documentation material is frequently so ambiguous that it is hard to know for sure if these features actually existed in the particular cases. At the current state of research, the only published feature of a potential sand filter was documented in the Corriental Reservoir of Tikal (Tankersley *et al.* 2011; see Chapter 5.7.7.2.3). In order to conclude this section on the spatial distribution of particular technological elements, the subsequent chapter will address the functionality and spatial distribution of berms, inflow gates and outflow gates.

7.2.3 Berms and water inlet/outlet devices

Technologically speaking, berms were usually used for controlled water inlet and outlet (Akpinar 2011: 32). Beach *et al.* (2008: 320) argued that berms also might have been used for drainage modifications and agricultural purposes, while Chmilar (2005) speculated that they also could have decelerated the water flowing into the aguadas and thus diminished the extent of contamination. At the current state of research, berms and inlet/outlet devices could be documented in 17 different cases (see Figure 7.8). These features are:

1. San Bartolo, Aguada Tintal (berm) (see Chapter 5.6.4.3.7),

2. San Bartolo, Aguada Los Loros (berm + inlet and outlet device) (see Chapter 5.6.4.3.7),

3. San Bartolo, Aguada Chintiko (berm) (see Chapter 5.6.4.3.7),

4. Xultun, Aguada Delirio (berm) (see Chapter 5.6.4.3.7),

5. Xultun, Aguada Los Tambos (berm) (see Chapter 5.6.4.3.7),

6. Nakbe, Aguada Zacatal (berm + inlet and outlet device (see Chapter 5.6.4.3.2),

7. Xcoch, Eastern Aguada (berm) (see Chapter 5.7.3),

8. Xcoch, Aguada La Gondola (berm) (see Chapter 5.7.3),

9. Xcoch, Aguada South 1 (berm) (see Chapter 5.7.3),

10. El Zotz, El Zotz Aguada (berm) (see Chapter 5.6.4.3.5),

11. Tikal, Temple Reservoir (berm and spillway) (see Chapter 5.7.7.2.2),

12. Tikal, Palace dam (sluice gate) (see Chapter 5.7.7.2.2),

13. Tikal, Corriental Reservoir (berm + inlet gate + outlet gate) (see Chapter 5.7.7.2.3),

14. Kinal, Kinal West Drainage, Reservoir (berm + spillway) (see Chapter 5.7.8),

15. La Milpa, Drainage 2, Reservoir C (berm) (see Chapter 5.7.9.1),

16. Aguada Lagunita Elusiva (berm) (see Chapter 5.6.4.3.8.3), and

17. Aguada 1 in Cival K'ante Ha' (berm) (see Chapter 5.6.4.3.8.4).

In the author's opinion however, a central, and yet unresolved issue is the exact functionality of water inlet and outlet devices in water storage features and the procedures during usage. As Wahl *et al.* (2007: 220) pointed out, there is no exact explanation for the technical implementation of irrigation. In Scarborough's (1991: 126) opinion, the controlled release of elevated reservoirs during the dry season would have solved both the problem of drinking water supply and that of agriculture. As has been shown in many hydraulic features presented in Chapters 5 and 6, the canalization of water *into* a reservoir had been successfully realized in a number of cases. At the current state of research however, it is still unresolved as to how the "controlled release" of reservoir water might have been realized.

To clear up this rather difficult issue, Fialko (1999: 686) and Scarborough *et al.* (1994: 102) referred to the "sluice gates" they claim to have observed in Tikal, Kinal and La Milpa. Scarborough *et al.* (1994: 102) described one of these sluice gates in Kinal (Suboperation M) as a V-shaped drain or spillway that reached down to the reservoir's floor thereby enabling the reservoir to be completely drained. Currently, these remarks still raise the question as to how exactly a 2 m deep reservoir that featured an "opening reaching down to the bottom" could have been filled up during the rainy season. At the onset of the rainy season, such a reservoir only could have been filled up to the opening's lowermost point, since the water would have simply flowed out at higher water levels. Consequently, a reservoir with such a permanent opening would not have been able to store any water at all, would have been empty both during the rainy season and the dry season, and accordingly would not have provided possibilities for irrigation. According to the author's understanding, this difficulty only could have been solved in two ways:

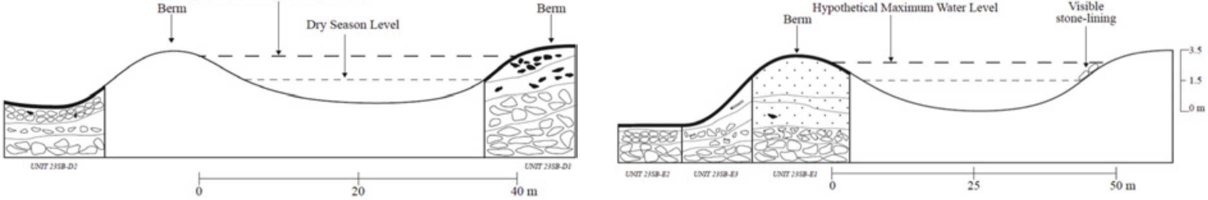
Practically speaking, the pre-Hispanic Maya only could have blocked these openings with a "plug" or some other device. However, apart from the mentioned openings, Scarborough *et al.* (1994) and Fialko (1999) did not report any wooden or stone construction that would have been necessary if it were a true sluice construction. Therefore, in the author's opinion, there is no explanation as to how the pre-Hispanic Maya designed a leak-proof closing mechanism that could withstand a considerable hydraulic thrust and impound water during the rainy season. In the case of Kinal and the Aguada Zacatal, the dams that enclosed the reservoirs could have been torn down in order to release the stored water for irrigation purposes. However, the resulting holes would have to be plugged afterwards. During the next rainy season when water levels would rise, these repaired locations would have doubtlessly represented weak spots. Therefore, the author considers it unlikely that reservoirs with such ever-recurring "weak spots" could have been filled with water to a level of 1 or 2 m.

In this context, the relatively distinct molding of the opening in the surrounding berm of the Aguada Zacatal is by all means mysterious. In the rainy season, such a deep and wide opening would have released the reservoir's content into the less-elevated terrain during a period when this landscape would have already been exposed to an excess of water. Consequently, future research should try to resolve the technical feasibility of water-outlet features of reservoirs in the Maya Lowlands. In hydraulic systems such as those in Calakmul, spillways draining excess water into additional reservoir constructions might have made sense.

In the author's opinion, the presented reservoir systems were primarily used as "closed" water tanks, since the controlled release would have only been possible via shallow openings. Smaller openings however, would not have been able to release the reservoir's entire contents. In this manner, the Maya would have been forced to extract the majority of the stored water by means of buckets or scoops. For agricultural uses, they would have been forced to transport the collected water to the acreages with large storage vessels. To conclude this functional analysis of hydraulic features in the Maya Lowlands, the upcoming chapter will point out the characteristic issues in the chronology of hydraulic features.

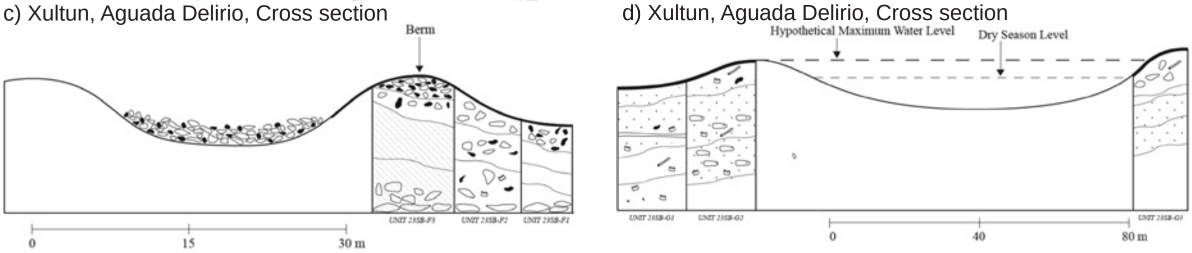
a) San Bartolo, Aguada Los Loros, Cross section

b) San Bartolo, Aguada Chintiko, Cross section



c) Xultun, Aguada Delirio, Cross section

d) Xultun, Aguada Delirio, Cross section



e) Tikal, Temple Reservoir, Map

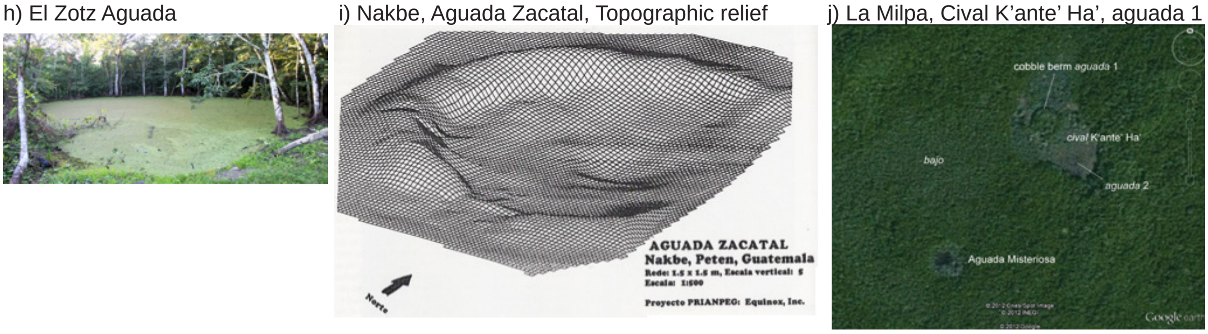
f) Tikal, Palace reservoir, sluice gate

g) Tikal, Corriental reservoir, Map

h) El Zotz Aguada

i) Nakbe, Aguada Zacatal, Topographic relief

j) La Milpa, Cival K'ante' Ha', aguada 1



k) Xcoch, Aguada South 1, Map

l) Xcoch, East Aguada, Map

m) Xcoch, Aguada Gondola, East Profile

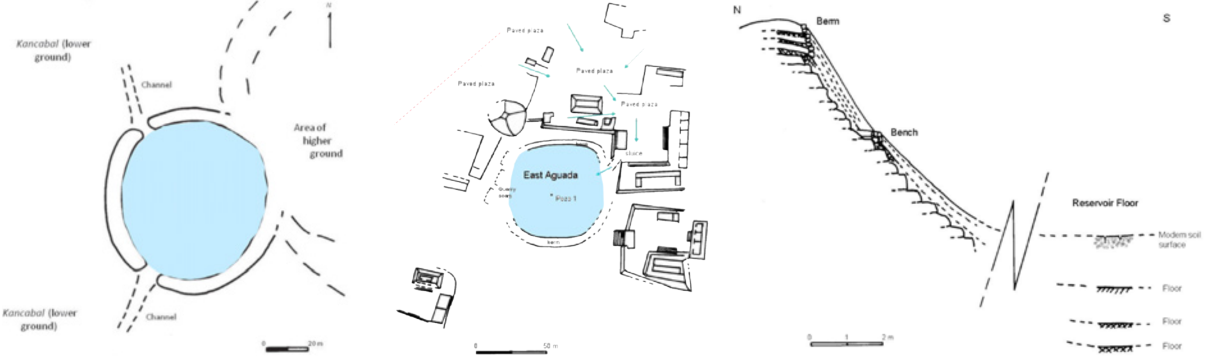


Figure 7.8: Overview of berms and inlet/outlet features in the Maya Lowlands. (a-d) (source: Akpinar-Ferrand *et al.* 2012: Figure 3. Reproduced with kind permission of Cambridge University Press); (e) (source: Scarborough *et al.* 2012: Figure S3. Base Map: Courtesy of the Penn Museum. Reproduced with kind permission of Vernon Scarborough and PNAS); (f) (source: Scarborough *et al.* 2012: Figure S6a. Reproduced with kind permission of Vernon Scarborough and PNAS; (g) (modified from Dunning *et al.* 2013: Figure 2. Reproduced with kind permission of Nicholas P. Dunning; (h) (Photo: N. Seefeld); (i) (source: Hansen *et al.* 2002: Figure 14. Reproduced with kind permission of Richard Hansen); (j) (source: Weiss-Krejci 2013: Figure 7. Reproduced with kind permission of Estella Weiss-Krejci); (k) (Courtesy of Nicholas Dunning. Reproduced with kind permission of Nicholas Dunning); (l) (modified from Dunning *et al.* 2014: Figure 4.5); (m) (source: Dunning *et al.* 2014: Figure 4.6). Reproduced with kind permission of Nicholas P. Dunning.

7.3 Chronology of hydraulic features

Overall, hydraulic features are always hard to date, as they generally contain limited amounts of ceramics or other datable material (Crandall 2009: 7; Seefeld 2008: 108). In most cases, the findings are too heavily eroded in order to be diagnostic as well (Pyburn 2003: 127). This issue is further exacerbated due to the absence of sealed contexts (Pope and Dahlin 1989: 101; Turner 1983: 96). Because of this lack of diagnostic ceramics, many scholars are forced to refer to the nearest datable or dated residential structure (Kunen 2001: 340; Seefeld 2008: 108). Throughout the history of research, most scholars assumed that there would have been a connection between the settlement and the adjacent hydraulic features (Seefeld 2008: 108; Treacy and Denevan 1994: 104; Turner 1983a: 96). The question as to whether or not such "connections" were actually present was entirely subject to the (mostly subjectively shaped) assessment of the respective scholar (Seefeld 2008: 108).

In the specific case of canal features, datings are inherently imprecise due to the necessary, ever-recurring maintenance procedures that were regularly carried out in pre-Hispanic times (Jacobs 1995: 186). Furthermore, many fields were steadily aggraded by active deposition throughout different periods (Beach *et al.* 2015a: 14). In most cases, the creation of canals resulted in the deposition of older strata on top of younger strata (see Figure 7.9). This process can lead to distortions in the chronology. Consequently, the samples or diagnostic findings from the deepest, culturally disturbed sediments can only provide a minimum age for the construction of canals, since the earliest disturbed sediments might have been extracted during one of the maintenance procedures (Jacob 1995b: 186; Seefeld 2008: 108; Stein 1990: 324).

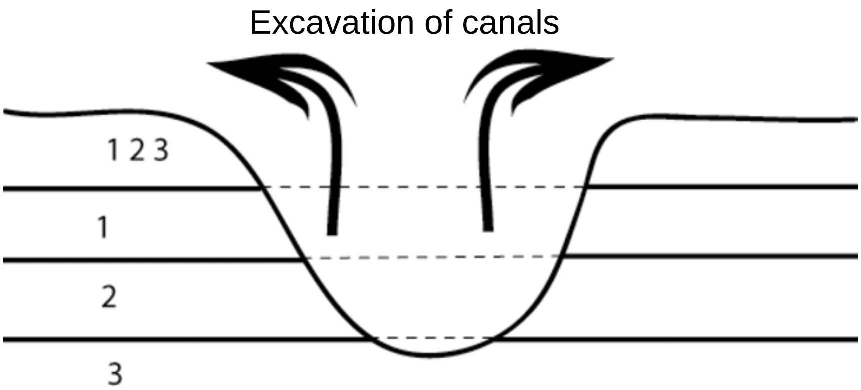


Figure 7.9: Mixing of strata during the construction of canals (source: Baker 2003: Figure 7-1. Reproduced with kind permission of Jeffrey Baker).

According to Kunen (2001: 326), investigations of terraces did not yield results displaying any chronological depth of these features. Due to these inherent problems, most authors generally assume that the construction of terrace systems was a Late Classic phenomenon (Seefeld 2008: 108). These issues are only mentioned in this respect because they caused considerable ambiguities in the scientific discussion on the chronology of hydraulic features. At the same time however, questions regarding the precise formation date of individual features and the general development patterns that can be deduced by these, might be an essential basis for theories on the historical development of hydraulic features (Seefeld 2008: 109; see Chapters 8.3 and 8.8).

7.4 Concluding remarks on the technological approaches to water management in the Maya Lowlands

If we recall the wide range of technological approaches and adaptation strategies employed to secure a constant water supply, it quickly becomes apparent that the pre-Hispanic Maya had to use as many sloping plazas, drainages, reservoirs and possibly even roof gutters as possible in order to collect sufficient amounts of water (Silverstein *et al.* 2009: 49). At the moment, it is impossible to estimate the number of architectonic structures that employed roof-gutters, and since most archaeological projects do not include the issue of water management in their agenda, it is very probable that they have been overlooked on many occasions.

As Silverstein *et al.* (2009: 49) justifiably remarked, the amount of collected water probably exceeded the immediate domestic demand because a considerable portion would have been required for construction, washing and pot-irrigation. Consequently, the author would like to highlight that, in many instances, it is impossible and even unnecessary to determine if a specific water source was used for domestic or agricultural purposes. This is because the pre-Hispanic inhabitants presumably had to react dynamically to the ever-changing precipitation rates and were therefore unable to assign each water source a unique function.

In order to conclude this chapter, the author would like to note that the prevalent focus on the collapse of Classic Maya civilization has unfortunately overshadowed the fact that the pre-Hispanic Maya had been a very successful culture highly adapted to the natural landscape in a most sustainable way. As with several other examples, this becomes obvious in the hydraulic system of Tikal. Here, the trivial amount of infilled sediment in the bajo margins suggests that the steep slopes of Tikal's landscape must have been covered with vegetation that served to anchor the soils and slow erosion (Scarborough *et al.* 2012: 12413). After this extensive overview on the technological approaches to water management, the upcoming section of this book will analyze the development and sociopolitical relevance of water management in Classic Maya society.

8 Development and sociopolitical relevance of water management in Classic Maya society

As briefly described in Chapter 3, the discussion on the hydraulic features of the pre-Hispanic Maya has focused on their development and functionality. However, an equal amount of scholarly attention has also been placed on the impacts of water management on the social and political structure of pre-Hispanic Maya society (Seefeld 2013: 61). The upcoming chapter both introduces and discusses the published theories on the development, function and social and political effects of water management in the Maya Lowlands. In accomplishing this, this chapter fulfills three tasks.

(1) The reconstruction of the historic development of water management strategies in the pre-Hispanic Maya society.

(2) The determination of the sociopolitical relevance of Uxul's hydraulic system based on the documented hydraulic features and the known history of the site. Ultimately, this knowledge will be used to define the social setting in which the hydraulic system developed.

(3) The reconstruction of the general sociopolitical relevance of water management in pre-Hispanic Maya society. This comparative approach will integrate the knowledge gained from the investigation of Uxul's hydraulic system into the general ideas about the sociopolitical relevance of water management and the general types of adaptation strategies in the Maya Lowlands.

In order for a comprehensive representation and discussion of the different theories to take place, this chapter will first introduce the fundamental concepts of water management (Chapter 8.1). After this more exhaustive overview, the attention shifts to specific models of agriculture and water management in the Maya Lowlands (Chapter 8.2). In succession, Chapter 8.3 will present the historical and technological development of hydraulic features in the Maya Lowlands. Chapter 8.4 will introduce the models on the social relevance of water management in the Maya Lowlands. Based on the theoretical information provided in the previous chapters, Chapter 8.5 will introduce a series of newly developed evaluation criteria for determining the social relevance of hydraulic features. Chapter 8.6 will interpret the social and political relevance of Uxul's hydraulic system. Building on this, Chapter 8.7 will apply these evaluation criteria to the hydraulic features presented in Chapters 5 and 6. Next, Chapter 8.8 will discuss the theories on the social and political relevance of water management in the Maya Lowlands. In conclusion, Chapter 8.9 will provide a summarizing evaluation of the social relevance of water management in pre-Hispanic Maya society.

8.1 Fundamental studies on water management

As both preindustrial and contemporary societies are heavily dependent on the resource of water, many scholars have defined the role of hydraulic features as the focal point of their research. Ortloff (2009: 2) stated that the archaeological investigation of hydraulic features enables more than just the comparison of technological knowledge between prehistoric societies. It also allows the origin of new innovations in water management to be identified, the diffusion of these technologies to be retraced and their effects on human culture to be analyzed (Ortloff 2009: 2). Due to the importance of this resource, the collection and control of water was given a relatively high status in the first models of state development (Childe 1956; Steward 1976). This becomes apparent in the fact that Childe (1956) and Steward (1955b) defined water management as a crucial element during the transition from the hunter-gatherer lifestyle to sedentism (Parry 2007: 22). During the 1950s, Childe's (1956) and Steward's (1955b) models became an alternative concept to the prevalent unilinear evolutionist theories of the decade (Parry 2007: 22).

The most influential theory in the study of hydraulic features in prehistoric societies was undoubtedly Wittfogel's (1957) concept of *hydraulic societies*. This concept was originally drafted in Karl Marx's theory of a hydraulic society (*Oriental* or *Asiatic*), which he began to develop in 1853 (Marx 1853; Marx and Engels 1957-1968 [13]: 9) and was later adopted by Wittfogel (1957: 61). According to Marx, three pre-capitalistic forms of society had preceded the civic society. The "Asiatic society" (1), the "ancient society" (2), and the "feudal society" (3) (Marx and Engels 1957-1968 [13]: 9). Marx's Asiatic mode of production was an economic concept that included "the object of labor, the means of labor and the organization of labor" (Bailey and Llobera 1979: 543; Parry 2007: 24). In Marx's (2011: 443) definition, the Asiatic mode of production here is formed by *"the unity of small scale agriculture and home industries, to which in India we should add the form of communities built upon a common ownership of land, which incidentally was the original form in China as well".*

Critics of Marx remarked that he had never clearly defined the ruling class and failed to include the "functional bureaucracy" along with the despotic ruler (Bailey and Llobera 1979, 1989; Krader 1981; Parry 2007: 25; Wittfogel 1957: 281). In order to counter these arguments, Wittfogel (1957) devised an extended theory of hydraulic societies in his main work "Oriental Despotism: A Comparative Study of Total Power". In this work, Wittfogel (1957) complemented Marx's model with cross-cultural historical references to sociopolitical and economic developments and focused on the examination of large hydraulic systems on a regional level (Parry 2007: 25; Scarborough 1991: 123). According to him, despotic bureaucracies were the consequence of large-scale irrigation systems in arid or semi-arid regions, which had to be supplied with water from far-off sources via canals (see also Seefeld 2008: 21). These irrigation attempts led to the centralization of resource control and triggered the uneven relation between managers and consumers, which subsequently resulted in a strictly defined social stratification (Scarborough 1991: 123).

While Wittfogel's (1957) model had originally been developed for Mesopotamia, China, Egypt and India, he had intentionally defined it in such a way that it could be used for the characterization of societal developments in most other parts of the world (Wittfogel 1957: 3; Parry 2007: 23). Most importantly, Wittfogel (1957: 3) sought to emphasize the governmental role in these societies and the "agromanagerial and agrobureaucratic character" of power in the governmental structure of hydraulic societies (Parry 2007: 23). In his opinion, hydraulic societies would have been despotic because they would have maintained "a bureaucratic managerial policy which would have kept the state supremely strong and the non-bureaucratic and private sector of society supremely weak" (Parry 2007: 23; Wittfogel 1957: 9). It is interesting to note that even in Wittfogel's view, the development of hydraulic societies are the result of sedentism and plant domestication (Parry 2007: 23). This notion exemplifies that most theories on water management were tightly connected to theories on agriculture and considered agriculture an essential prerequisite for water management.

According to Wittfogel (1957: 122), an increasing investment in water management had resulted in a greater potential for despotic state control (Parry 2007: 24). In Wittfogel's (1957) view, the hydraulic features necessary for these hydraulic states would have been erected by unpaid labor forces that were obliged to work for the state or noble landowners (Parry 2007: 24). Wittfogel (1957: 22) defined three necessary criteria for the basis of a *hydraulic economy*. According to his idea, agricultural production required labor-division that would have enabled intensified cultivation and would have triggered a large-scale cooperation (management) (Wittfogel 1957: 22). In this model, the government played a key role as a manager, which resulted in almost unlimited control over the land and the goods produced on it (Parry 2007: 27). According to Wittfogel (1957), Childe (1956) and Steward (1955b), irrigation culture triggered social complexity and the establishment of state-level society (Parry 2007: 279). Through this development, agricultural intensification would have produced surpluses of food and an eventual population growth that would have required the development of more sophisticated subsistence strategies (Parry 2007: 27). According to Wittfogel (1957), these developments would have required a controlling entity and the emergence of government (Parry 2007: 27). Ultimately however, the commoners were responsible for the expansion and maintenance of hydraulic systems (Parry 2007: 27). A central element of Wittfogel's (1957) *Oriental Despotism* was the classification of "loose" and "compact" hydraulic societies:

In *compact* hydraulic societies, the controlled territory is almost identical to the cultivated area, even though most "*compact*" hydraulic societies, such as Egypt, feature some non-hydraulic economic elements (Wittfogel 1957: 164; 1972: 71).

In *loose* hydraulic societies, planned hydraulic features cover only a portion of the cultivated land, while the majority is irrigated by small-scale irrigation structures and natural precipitation (Wittfogel 1972: 71).

After a brief educational journey to Mexico, Wittfogel (1972: 68) classified Mesoamerica as a *loose* hydraulic society. Furthermore, he observed that sources of water in Mesoamerica were distributed in a very heterogenous manner and concluded that the population density in the hydraulic areas of Mesoamerica must have been higher than in non-hydraulic areas (Wittfogel 1972: 675). Wittfogel also believed that hydraulic societies in Mesoamerica would have been able to mobilize larger workforces than non-hydraulic societies (Wittfogel 1972: 75). Hence, the political power had exerted centralized control over one or several "supra-localities" such as valleys, plains or larger regions (Wittfogel 1972: 75).

8.2 Models on agricultural production and water management in the Maya Lowlands

Drawing on these more general theories on agricultural production and water management, several scholars developed specific models for the Maya Lowlands. In this respect it should be noted that the author does not entirely support the strict technological distinction between hydraulic features and agricultural features because, as discussed in Chapter 5, most of these features could have been used for pot irrigation. Furthermore, both hydraulic and agricultural features are a direct expression of demographic pressure and served as subsistence strategies. The only hydraulic features that were definitely not used for agricultural purposes are drainage features in city centers and reservoirs integrated into residential structures (see Chapters 5.5.2, 5.5.3 and 5.7.1). Thus, in the author's opinion, the strict distinction between hydraulic and agricultural features does not benefit the discussion of theoretical models. Nevertheless, since numerous models and theories on the development of agriculture and water management have shaped the course of research history, it is essential to describe their basic concepts and their effect on the current state of research.

8.2.1 Models on the development and forms of agricultural production in the Maya Lowlands

Current dating estimations, which are still fairly imprecise, indicate that the first traces of human agricultural production in the Maya Lowlands appear around 3000 BC in sediment and paleosols of *Zea mays* and other disturbance pollen (Beach *et al.* 2009: 1712, 2015: 7; Jones 1994: 37; Pohl *et al.* 1996: 355). Ax Beach *et al.* (2009: 1712) noted, the first forms of extensive agriculture were introduced to all areas of the Maya Lowlands between 2000 and 1000 BC (Pohl *et al.* 1996: 358). As mentioned in Chapter 4, the expansion of extensive agriculture and the erosion of upland soils in the Maya Lowlands have been documented in numerous locations. The erosion processes date back to the beginning of the first millennium BC (Beach *et al.* 2009: 1712). According to Fedick *et al.* (2000: 134), the first settlers of the central Maya lowlands used traditional cultivation techniques that their ancestors had developed for the seasonal exploitation of wetlands or *cenotes* in the northern lowlands (Fedick 1998; Ford 1996; Parry 2007: 17).

During the Late Preclassic, the constant population growth led to demographic pressure, which forced the pre-Hispanic Maya to invent intensive cultivation methods to support the growing population, such as agricultural terraces (Beach *et al.* 2002; 2015: 7; Chmilar 2005: 7; Luzzadder Beach and Beach 2009; Scarborough 1993, 1994). Wetland agriculture had obviously commenced by the beginning of the first millennium BC[182] by means of drainage canals (Scarborough 1994: 186). The first elevated fields were

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[182] ^{14}C datings from the Río Hondo riverbed (Bloom *et al.* 1985: 28) indicate that the emergence of wetland modifications occurred between the early and middle Preclassic (around 1000 BC) (Pope and Dahlin 1989: 110). An isolated ^{14}C date (222 AD) from a field

then constructed in the subsequent centuries. As in the case of the terraces, the majority of the elevated and drained fields did not develop before the Late Preclassic (Pope and Dahlin 1989: 101; Turner and Harrison 1983b: 263).

Although there are increasing data on terrace construction and forms of wetland agriculture from the Preclassic (Beach *et al.* 2008), most scholars are still convinced that the widespread application of intensified agriculture started in the Classic Period (Beach *et al.* 2002; 2009: 1712). However, it should be pointed out that because precise dating is not generally possible, most scholars simply assume that the majority of agricultural features were constructed during the Late Classic Period as a reaction to increased demographic pressure (Dunning and Beach 1994: 51; Seefeld 2008: 112).

During the Terminal and Postclassic Period, many archaeological data indicate that populations declined dramatically (Guderjan 2004: 14; Guderjan *et al.* 2010; Valdez and Scarborough 2014: 259; Turner and Sabloff 2012: 13908). Beach *et al.* (2009: 1712, 2015a: 7) reasoned that the remaining Postclassic populations would have been smaller and less sedentary, dispersing along waterways in a lifestyle that caused a lower impact on the natural landscape. According to Puleston (1978), this pattern continued until European contact (Beach *et al.* 2009: 1713).

8.2.1.1 Theories on the agricultural potential of wetlands

After the animated discussion of the 1970s and early 1980s, the debate on the agricultural potential of wetlands had largely subsided by the mid 1980s. This situation gave way to a more encompassing and problem-oriented consideration of the topic. Since the beginning of the 21st century, the attention given to the wide diversity of micro-habitats (see Chapter 3) has led to the realization that wetland cultivation could not be practiced in all regions of the Maya Lowlands (Dunning and Beach 1994: 53). Thus, Dunning and Beach (1994: 61) reasoned that the extreme annual variations of water levels would have impeded wetland agriculture in the Petexbatun region. Instead, the local population would have based their intensified agricultural systems on pot-irrigation (Dunning and Beach 1997: 263). As interest in aguadas increased, some scholars also started to investigate the agricultural potential of these landscape features.

8.2.1.2 Agricultural potential of aguadas

Taking into account the *marceño*[183] cultivation technique practiced in the Mexican state of Tabasco, some authors claimed that the margins of bajos and aguadas could have been used for the cultivation of fast growing crops once the water tables began to drop at the onset of the dry seasons (Gliessman *et al.* 1983: 105; Orozco-Segovia and Gliessman 1979; Siemens 1982: 207; Turner and Harrison 1983b: 254). In Fialko's (1999: 688) opinion, this cultivation technique may have enabled two or three additional harvests, just as elevated fields would have done. Thus, the pre-Hispanic Maya could have first sown their crops at the onset of the rainy season along slopes and ridges in the form of a slash and burn cultivation (Culbert *et al.* 1991: 116; Fialko *et al.* 2005: 490). At the end of the rainy season, crops would have been sown once again and would have concentrated on the lower sections of bajos and aguadas (Fialko 1999: 688). In the middle of the dry season, the pre-Hispanic Maya may have also used shallow "bajo islands" and aguada habitats for sowing crops a third time (Fialko 1999: 688; Fialko *et al.* 2005: 490; Lou 1996: 688; Weller 2007: 32). In this respect however, it should be emphasized that the feasibility of such cultivation methods has not been verified in experimental projects. Furthermore, the high montmorillonite content of clays accumulating in aguadas (see Chapters 4.4, 6.2.2 and 6.2.3) and the resulting gilgai fissures surely would

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of the Candelaria floodplain indicates the utilization from the Late Preclassic into the Early Classic (Seefeld 2008: 112; Siemens and Puleston 1972: 234).

[183] The technique can be translated as „the March planting" (Orozco Segovia and Gliessman 1979: 3). It is usually practiced in flooded areas in the state of Tabasco that remain inundated for 3 to 8 months at a time.

have impeded the success rate of cultivation efforts. However, numerous scholars have documented pollen of *Zea mays* in sediment cores recovered from aguadas (Chmilar 2005: 3; Cowgill and Hutchinson 1966). Since *Zea mays* pollen cannot be dispersed over long distances, the notion that is was cultivated in the immediate proximity of aguadas in pre-Hispanic times is verifiable (Akpinar 2011: 17).

Even though direct evidence has not yet been recovered, Akpinar-Ferrand and Dunning (2011: 120) speculated that the pre-Hispanic Maya also might have used aguadas for breeding fish.[184] According to Akpinar-Ferrand and Dunning (2011: 120), the use of specific aguadas for this purpose would not be surprising given the naturally present fish species within them during the wet season (see Chapter 2.3). In order to support this theory, Akpinar-Ferrand and Dunning (2011: 120) refer to seasonal shallow depressions in the state of Yucatán where local farmers developed a rotational system that combined agriculture and aquaculture (Flores-Nava 1994).[185] While it is currently still being discussed as to which cultivation methods the Maya employed in pre-Hispanic times, another unsolved issue is the implementation of food supply of larger urban centers. In particular, the question is if these urban centers had produced their own food supplies, or if they had imported agricultural products from their respective hinterlands.

8.2.2 Theories on long distance transport and migratory agriculture

At the current state of research, most scholars believe that the majority of Maya centers had practiced agriculture in the immediate vicinity of or within their urban centers (e.g. Crandall 2009: 14). Other scholars however, developed the hypothesis that some of the less densely populated areas had produced tremendous agricultural surpluses that exceeded the local and even regional demand (Pyburn 2003: 127; Wilk 1984: 33). Following this idea, they claimed that the diversity of settlement patterns would have been an adaptation to the specific local topographies, local population densities and the market orientation. The market would have stimulated the development of central places, trade networks[186] and political frontiers since 1000 BC (Gunn *et al.* 2002: 81; Pyburn 2003: 127; Wilk 1985: 47, 53). Following Cooke's (1931) theory which implied that all inner bajos would have been perennial wetlands in Preclassic and Classic times (see Chapters 3 and 4), some authors claimed that the food supply of some urban centers had been facilitated by long-distance transports (Pyburn *et al.* 1998: 53; Puleston 1977a: 456; Siemens 1982: 216).

The foundation for the theory of long-distance transport of agricultural products was the calculation of the agricultural potential of elevated fields near Pulltrouser Swamp. In this process, Turner and Harrison (1983b: 253) observed that the extent of harvests would have far exceeded the local demand and concluded that the elevated fields had been installed for the production of agricultural surplus from the very beginning. In succession, other scholars concluded that the intensive cultivation systems of Blue Creek (Guderjan *et al.* 2003: 88), Cerros (Freidel and Scarborough 1982: 152) and Albion Island (Pyburn *et al.* 1998: 53) had also produced agricultural surpluses that were exported to pre-Hispanic urban centers.

In order to explain the feasibility of long-distance food transports, most scholars refer to the potential existence of water transportation systems because they would have been an essential prerequisite for the feasibility and profitability[187] of excess production (Cowgill 1993: 210; Pyburn *et al.* 1998: 53; Sluyter 1993: 197). Throughout the 1980s and 1990s, several scholars speculated that the surplus production

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[184] Arredondo *et al.* (1982) carried out an experimental project in which they placed 18 grams of tilapia fish in a seasonal shallow depression in central Mexico (0.8 gih/ m^2) resulting in 450 kg/ha after one year without additional feeding (Akpinar-Ferrand and Dunning 2011: 121).

[185] Flores-Nava (1994) pointed out that when the water recedes during the dry season, nutrient-concentrated sediments that fertilized by the fish excrements could have been harvested and applied to agricultural plots (Akpinar-Ferrand and Dunning 2011: 121). Although they highlight that many of these results still would have to be tested more thoroughly, they claim that a rotational usage of aguadas might have been a very good agricultural technique for the pre-Hispanic Maya.

[186] Later, Scarborough and Valdez (2003: 7) considered the widespread distribution of the Chicanel ceramic with strikingly homogenous forms as an indicator for such trading networks and interdependencies between different sites (Seefeld 2008: 117).

[187] Reina and Hill (1980: 78) emphasized that surplus productions would have been enabled by the development of conservation methods in the first place, since only these techniques would have enabled a storage and tribute-trade.

from the wetlands of Quintana Roo and Belize may have been transported into the Petén (McKillop 1996: 52; Siemens 1982: 216; Turner and Harrison 1983b: 252). In order to explain the practicability of water transport, scholars developed three potential routes (see Figure 8.1):

According to the first model, the Río Hondo (the northernmost river system along the Caribbean Coast), the Río Azul, the Río Holmul and a network of artificial and natural canals had been used for canoe-based trade between the coast and the Petén (Guderjan *et al.* 2003: 88; Thompson 1974: 301). According to Źrałka (2012: 178), the Holmul River was an important part of the far-reaching river network that connected Petén centers of northern Guatemala to Belizean sites and the Caribbean coast while providing a means of trade and transportation throughout the region.

According to the second model, canoes travelled upstream along the Belize River until reaching the Black Creek tributary, which they would have navigated along short canals or over land in order to reach the New River system (Pyburn 2003: 123). Siemens (1982: 217) suggested that a route along this river or one of the other complex water systems between the Río Hondo and the New River system might have led travelers to the eastern borders of the large bajos of the Petén (Thompson 1970: 129).

According to the third model, the Río Candelaria served as a communication route able to connect sites, such as Tikal and Calakmul to the coast by using the upper part of the Río San Pedro and the Río Caribe (Vargas 2012: 194-195).[188]

In order to explain the feasibility of their long-distance transport model, Pyburn (2003: 123) speculated that these water trade networks would have been used from the Late Preclassic until the 20th century AD[189] (Guderjan *et al.* 2003: 88). To verify the existence of these networks, some scholars referred to archaeologically documented features. Among these features are the potential remnants of large canals in the New River Lagoon (Siemens 1982: 216) and Chau Hiix (Pyburn 2003: 123) that were interpreted as water routes.[190] Furthermore, the discovery of "port mounds" and "dock features" in Ambergris Caye (Guderjan 1995; Guderjan and Garber 1995), Cerros (Robertson and Freidel 1984), Nojmul (Pring and Hammond 1975) and Blue Creek (Barrett and Guderjan 2006; Guderjan 1997) were considered indications of active trade along the rivers in pre-Hispanic times.

Whether or not these features can actually be considered indicators for the existence of a water transportation system is doubtlessly subject to the highly subjective judgment of the investigators (Seefeld 2008: 120). According to Turner and Harrison's (1983b: 252) estimation however, it is still debatable if such a canal system ever existed and/or if the engineering capacities of the Maya would have even been sufficient to connect the elevated Petén with the Caribbean Coast. In the author's opinion, the observation by Pyburn *et al.* (1998: 39) that many of the largest Maya centers were connected to the main transportation routes by means of tributaries cannot be retraced based on current knowledge.

In conclusion, it should be emphasized that there are currently no indications that the pre-Hispanic Maya had ever practiced migratory agriculture (Crandall 2009: 14). For the scientific issue of this book, this assessment contains a crucial significance: As agricultural products were most likely produced locally, it was important for most installations of intensified agriculture with hydraulic features to be constructed in proximity to large urban centers. In order to illustrate the interconnected relationship between demographic pressure, agriculture and water management, the upcoming chapter will introduce the models of water management specifically defined and developed for pre-Hispanic Maya civilization.

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[188] In order to support this theory, Vargas (2012: 194) claims that oral traditions of the K'ichée, Kakchikel and the Yucatecan Maya described the usage of the Candelaria river as a long distance transport route. Vargas (2012: 195) remarks that historical sources indicate that a journey from Itzamcanac to Xicalango had taken three days in kayak.

[189] According to Siemens' (1982: 214) statement, one of his middle-aged informants still remembered that the canals upon Albion Island would have been navigable with canoes.

[190] Pyburn (2003: 127) also remarked that these alleged canals had become abandoned after the collapse of the Classic Maya civilization, so that many of them would not yet have been detected by modern scholars.

Figure 8.1: Visual representation of hypothesized water trade routes (Map: N. Seefeld, modified from Witschey and Brown 2010).. Reproduced with kind permission of Walter Witschey.

8.3 Models of the historical development of water management in the Maya Lowlands

As already pointed out in Chapters 3 and 8.1, the issue of water supply in the Maya Lowlands was discussed rather late in the history of research and only after decades of discussions on the historical development of agriculture had taken place (see Chapter 3 and 8.2.1). Consequently, none of these models were developed before the 1990s. As they were mainly based on a very limited number of studied features, most of the earlier models on the historical development of water management were not based on the hydraulic features themselves. Instead, they tried to incorporate the emergence of water management into well-established concepts on the general historical and social processes of Classic Maya society. The resulting accordance with well-established concepts on the development of the Classic Maya society did not bring about any conceptual incompatibilities. Consequently, the earliest discussions on the historical development of water management were not as vividly debated as the historical development of agriculture in the Maya Lowlands (see Chapters 3 and 8.2.1). Therefore, most scholars envisioned a virtually identical course of development for water management.

In this process, Adams (1991) and Scarborough (1991, 1993) were the only scholars who tried to develop their own independent models of the historical development of water management in the Maya Lowlands. Most later scholars adapted Adam's (1991) and Scarborough's (1993) models without any modifications (Parry 2007: 21). To clearly distinguish between the different levels of interpretation, the upcoming presentation of the models of the historical development of water management does not take into account the sociopolitical relevance of water management. Since the models on the social relevance of water management represent a higher level of interpretation, they will be presented in Chapter 8.4.

8.3.1 Preclassic water management

According to Adams (1991: 62), the initial development of water management occurred in the Middle Preclassic Period (1000-400 BC) when the demographic pressure forced the inhabitants of the Maya Lowlands to search for alternatives to the extensive milpa system (Chmilar 2005: 8). This consideration illustrates that the development of water management in the Maya Lowlands was always interpreted as a consequence of intensified agriculture.

Dunning and Beach (2000: 196) argued that despite their relatively small population, the extensive agricultural techniques of the Preclassic Maya already would have caused massive environmental changes (see Chapter 4).[191] The desiccation of perennial water sources and the loss of productive highland soils (see Chapter 4) would have motivated the Preclassic population to search for natural water sources – a search that inevitably led them to the margins of inner and outer bajo landscapes (Chmilar 2005: 5; Dunning and Beach 2000: 196; Ford 2006: 297). According to many scholars, these bajos featured a higher concentration of water sources than the upland areas and enabled people to settle at greater distances from riverine locations (see Chapter 2.4) (Gunn *et al.* 2002; Parry 2007: 17, 29; Scarborough 1993). Apart from the availability of water, bajos would have also been attractive due to other resources such as fertile sediments for the fertilization of fields, clay for pottery, chert nodules, plentiful fauna, etc. (Adams *et al.* 1981: 1462; Chmilar 2005: 7; Dahlin 1984: 22; Folan *et al.* 1995a: 311; Hansen *et al.* 2002: 278; Harrison 1977: 491; Lou 1996: 92; Pope and Dahlin 1989: 102; Weller 2006: 31).

Furthermore, many scholars noted that the earliest settlers may have also favored bajo habitats because they were relatively difficult to access and thus would have provided natural defense (Hansen *et al.* 2002: 278; Puleston and Callender 1967; Silverstein *et al.* 2009: 47). In this respect, some authors (Dunning *et al.* 2002; Hansen *et al.* 2002) referred to the old hypothesis of Cooke (1931) (see Chapter 3 and 4). They noted that if the inner bajo landscapes of today had once been perennially inundated water features, they would have been even more attractive locations for the foundation of settlements (Parry 2007: 13,

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[191] Gill (2000) developed the scenario that the Maya would have already carried out large-scale landscape modifications by 1000 BC (Scarborough 1993b; Brewer 2007; see also Chapter 4).

170). As evidence for this hypothesis, they noted that the largest and most successful early Maya cities (e.g. Nakbe, El Mirador, Uaxactun, Tikal and Calakmul) had been founded in close proximity to bajo habitats and suggested that "agricultural features in most of these sites" would indicate "some sort of link between bajos and the Maya civilization" (Adams 1980; Bullard 1960: 365; Dahlin 1989: 102; Dunning *et al.* 2006: 88; Folan *et al.* 1995; Green 1973; Gunn *et al.* 2002a: 302; Hansen *et al.* 2002; Parry 2007: 13, 171).[192]

Most authors generally agree that the isolated distribution of natural aguadas and other sources of water in the landscape were major factors for the "scattered distribution of residential areas" in Maya centers (Brewer 2007: 42; Pope and Dahlin 1989: 102; Weller 2006: 32). According to this idea, the earliest settlers preferred to settle close to bajo margins that featured a higher concentration of natural aguadas than the remaining landscape types (Lohse 2004; Lundell 1933; Maler 1908; Ricketson and Kidder 1930). While all scholars agree that the inner and outer bajo landscapes were popular locations for the foundation of the earliest settlements, different opinions exist on the importance of these habitats regarding the later course of Maya history.

Some scholars argued that archaeological sites could be documented on almost every single slight elevation[193] within bajo landscapes (so-called "bajo islands") that remained above the level of annual inundations (Culbert *et al.* 1997: 367). Grazioso Sierra *et al.* (2002: 206) argued that these smaller sites remained occupied from the Late Preclassic until the Late Classic and would have been connected to the larger centers.

However, other scholars argued that upland areas would have always been the preferred locations for the construction of residential areas (Tourtellot *et al.* 2003: 40). Since most extensive architectonic structures and elite residential areas were concentrated on central hilltops, Tourtellot *et al.* (2003: 42) even argued that bajo margins would have been populated by groups of lower social status. Pope and Dahlin (1989: 102) claimed that the proximity of early Maya settlements to bajo habitats would simply be a consequence of the frequency of bajo landscapes and argued that bajos never would have been attractive settlement areas.[194] Tourtellot *et al.* (2003: 42) even described bajos as "gaps or buffer zones in the visible occupation". Although some authors still refer to the importance of bajo landscapes as residential areas, the current state of research suggests that the pre-Hispanic Maya strongly favored the hilltop areas over the bajo landscape – a pattern the author has also observed on several occasions (Bronson 1966; Haviland 2003; Puleston 1973, 1983).

In the view of some authors, the newly arrived settlers would have soon carried out modifications of these bajo landscapes, a process that represented the first form of "water management" in the Maya Lowlands (Dahlin and Dahlin 1992; Dunning *et al.* 2002; Parry 2007: 169). Fedick *et al.* (2000) reasoned that these settlers had employed the established agricultural techniques of their ancestors (Fedick 1996; Parry 2007: 17). At the current state of research, the earliest absolute dates of hydraulic features are

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[192] The widespread distribution becomes obvious in the notion of Parry (2007: 13), who noted: *"Considering the conspicuous location of the number of Maya sites next to bajos, it is certain that these features held innumerable resources and played a central role in the development of Maya sociopolitical complexity".*

[193] Grazioso Sierra *et al.* (2002: 206) reported the identification of 27 settlements within the Bajo La Justa that ranged from small hamlets to sites with several architectonical groups to sites with monumental architecture. Grazioso Sierra *et al.* (2002: 206) interpreted the different size of these sites as an indicator for an organization structure or a hierarchization (Seefeld 2008: 114). Smaller platforms upon elevated fields were also reported, but not "documented" in the Bajo Morocoy (Gliessman *et al.* 1983: 106) and near Río Azul (Adams *et al.* 1981: 1459). On bajo islands in the Bajo El Laberinto (near Calakmul), Folan *et al.* (1995a: 313) documented a number of house platforms, which they interpreted as workshops for the processing of chert (Domínguez Carrasco 1992; Gunn *et al.* 2002a: 298). Moreover, Gunn *et al.* (2002a: 298) documented a number of stone-encompassed fields in the Bajo El Laberinto, which were interpreted as indicators for an agricultural usage of this wetland. Turner and Harrison (1983b: 262) also reported three sites at the margins of Pulltrouser Swamp. Scarborough and Valdez (2003: 11) described that "carefully constructed house platforms and well built structures" were found on bajo islands within the Far West Bajo. Within an inner bajo near Kinal, Culbert *et al.* (1991: 123) also documented several low platforms erected upon small, and apparently natural elevations. In Guijarral, Kunen and Hughbanks (2003: 98) documented a small site within a bajo that featured residues of fieldwalls, terraces and reservoirs.

[194] In order to support his argument, Tourtellot *et al.* (2003: 42) referred to the results of settlement studies showing that the settlement densities dropped considerably near bajos. During an intersite transect between Yaxha and Nakum, Lou (1996: 42) observed that all residential structures were concentrated in upland areas.

for the drainage canals and elevated fields in northern Belize (1995). Among these canal systems, the elevated fields of Albion Island (see Chapter 5.2.4.8; Bloom *et al.* 1985; Pohl 1990) and Colha (dated to 800 BC; see Chapter 5.2.4.9) represent the earliest examples (Brewer 2007: 29; Chmilar 2005: 7). The next most recent hydraulic features were located in Cuello (dated to 600 BC [Middle Preclassic]; see Chapter 5.2.4; Chmilar 2007: 7; Hammond 2009).[195]

Despite the discussion on the relevance of bajo landscapes for the development of early Maya settlements, most scholars believe that the earliest settlers deliberately modified inner bajos. Turner (1978) reasoned that these modifications were the direct results of the agricultural innovations of drained and raised fields in the outer bajos (Harrison 1973, 1977; Parry 2007: 169). According to this theory, the development of water management techniques in bajo landscapes was a two-step process:

In the first step of bajo modifications, settlers would have tried to collect and divert rainwater from the surrounding areas into the natural aguadas at the margins of inner bajos (Chmilar 2005: 7; Harrison 1977, 1993; Parry 2007: 29).

In the second step, the demographic stress would have motivated the settlers to increase the storage capacity of these aguadas. This would have been accomplished by sealing the bottoms with impermeable clay layers and through the construction of earthen dams, which would have enabled more of the inflowing runoff to collect (Adams 1980, 1991; Folan *et al.* 1995; Parry 2007: 30; Pope and Dahlin 1989: 102; Scarborough 1993; Scarborough and Gallopin 1991; Scarborough *et al.* 1994, 1995; Wahl *et al.* 2007).

Although most scholars agree on this general development of modification techniques, different opinions exist as to when the first artificial modifications of aguadas occurred. While Turner and Harrison (1989b: 254) speculated that the first construction of sealing layers occurred at the end of the 7th century BC, Weiss-Krejci *et al.* (n.d.) argued that these modifications would have taken place at the transition from the Late Preclassic to the Early Classic as a reaction to the drought period of the time (Puleston and Puleston 1971: 335). At the current state of research, most scholars agree that the Maya had developed all essential water management techniques (canals, dams, terraces, modified aguadas/artificial reservoirs) by the Late Preclassic Period (400 B.C - AD 250) (Parry 2007: 29 172). Scarborough *et al.* (1995: 99) reasoned that these hydraulic features had expanded the subsistence potential of the inhabitants in the Lowlands and caused the formation of extensive economic networks. Furthermore, Scarborough (1993: 29, 1994: 26) argued that the hydraulic features of the Late Preclassic were still confined to the bajo margins and had been directly linked to agriculture. The most essential element of these adaptation strategies would have been canals (Parry 2007: 29). In this situation, the relatively isolated natural aguadas and modified aguadas would have been nodes for households and small communities (Scarborough 1996).

In order to characterize the water management practices during the Late Preclassic Period, Scarborough (1993: 40, 1998: 149) developed the concept of "concave watersheds". These would have had the goal of maximizing the accumulation and storage of water in natural landscape features. Scarborough (1994: 188) reasoned that concave watersheds would have included four functional components: Central reservoirs or canals (1), drainage canals in the site centers that transported runoff (2), causeways (3) and cultivation areas at the bajo margins (4) (see Figure 8.2; Chmilar 2005: 7).

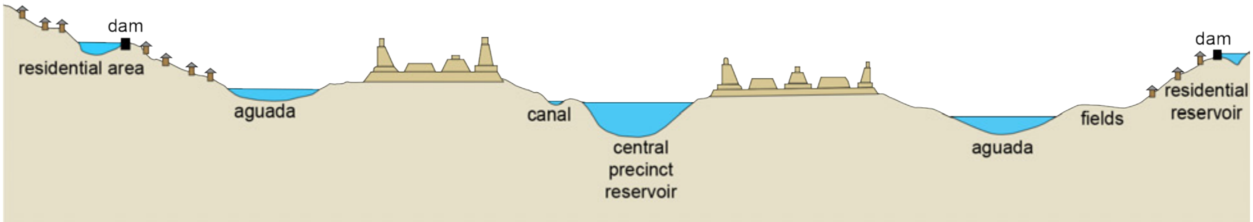

Figure 8.2: Schematic representation of a concave watershed (redrawn after Scarborough 1998, Figure 2). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.

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[195] Apart from the described canal systems, the site also developed the first known cistern of the Maya Lowlands (Chmilar 2007: 8; Scarborough 1993).

In Scarborough's (1994: 188) view, the Maya built their settlements at the margins of the inner bajos or natural aguadas in order to collect the surface runoff flowing towards them. With this system, it would have been possible to store water over longer periods, possibly even through the entire dry season. Despite the basic operation of this concave watershed, Scarborough (1998: 13) defined this Late Preclassic strategy as a "passive form of water management", which only would have modified the lower sections of hillslopes for the collection and diversion of water. Due to these limitations, it would have been inadequate for the expansion of urban centers. Furthermore, Scarborough *et al.* (1995: 100) suggested that the landscapes of Cerros (see Chapter 5.2.4.3) and El Mirador (see Chapter 5.7.6) could be considered examples of concave watersheds. The site of Cerros was positioned at the terrain's lowest elevation so that runoff from the surrounding slopes would have naturally been diverted into the center (Chmilar 2005: 8).

At the current state of research, it appears that the initial development of hydraulic systems in urban settings took place in the Mirador Basin, which evolved into the most powerful and densely occupied area of the Maya Lowlands during the Preclassic Period (Hansen *et al.* 2002; Parry 2007: 29, 169). Here, the (alleged) earliest known artificial reservoir was located in Nakbe (Chmilar 2005: 8; Scarborough 1993). Furthermore, many scholars speculated that the stone quarries of the Mirador Basin were transformed into artificial reservoirs (Chmilar 2005: 9; Scarborough 1993).[196] Matheny (1982) also speculated that the four causeways emanating from El Mirador were used for agricultural purposes (Chmilar 2005: 9; Scarborough 1993).[197]

Outside of the Mirador Basin, other Late Preclassic hydraulic features were constructed in Edzná (see Chapter 5.741) and Cerros (see Chapter 5.2.4.3) (Chmilar 2005: 7). El Mirador however, experienced a grave cultural and political decline[198] by the end of the Late Preclassic Period, which was soon followed by most other cities of the Mirador Basin (Parry 2007: 170). Recent discoveries (see Scarborough *et al.* 2012; Scarborough and Grazioso Sierra 2015) indicate that the earliest hydraulic features of Tikal were also built during the Late Preclassic (see Chapter 5.7.7.2).[199] Scarborough *et al.* (2012: 12512) reasoned that the pronounced drought conditions of that period (see Chapter 4) acted as a major catalyst for the construction of Tikal's hydraulic system. Furthermore, the labor investment in hydraulic features would have essentially ensured the survival of Tikal and other cities, while many Preclassic cities with insufficient hydraulic systems (such as many cities of the Mirador Basin) would have been abandoned (Dunning *et al.* 2012: 3654; Scarborough *et al.* (2012: 12412). Despite the frequent claims that water management features in the Maya Lowlands emerged as a result of climate change, most scholars believe that the increasing labor investments in hydraulic features during the Late Preclassic were primarily the result of demographic pressure, a stress that would have also brought about the construction of agricultural terraces (Beach *et al.* 2015: 20; Dunning and Beach 2000: 196).[200]

By the Early Classic however, the accumulated effects of demographic stress and a heavily deforested landscape (see Chapter 4) had apparently exceeded the capacity of the existing hydraulic systems (Chmilar 2005: 9; Dunning and Beach 2000: 195; Parry 2007: 30; Scarborough 1994: 188). As a result, the inhabitants of the Central Lowlands were forced to develop new adaptation strategies, a course of innovations that formed the more sophisticated hydraulic systems of the Classic Period (Chmilar 2005: 9; Dunning and Beach 2000: 195; Scarborough 1993: 40).

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[196] Based on the calculated construction fill of 1,750,000 m^3 that were necessary for the construction of El Mirador's monumental structures, Scarborough (1993) estimated that "several reservoirs with large capacities" would have evolved.

[197] Unfortunately, Chmilar (2005: 9) does not provide a more detailed description on the agricultural purpose of these causeways.

[198] This process was documented in the archaeological record in the form of abrupt terminations and accumulated cultural material (Parry 2007: 170).

[199] Earlier propositions by Fialko (1999: 685), who claimed that the hydraulic system had already evolved the Middle Preclassic (around 600 BC), could not be confirmed in the recent investigations.

[200] Current research indicates that the first Preclassic terraces were built near San Bartolo (Beach *et al.* 2009) and Minanha (Macrae and Iannone 2011).

8.3.2 Classic Period water management

Regarding the Classic Period, several scholars calculated a population density of up to 3,800 people per km^2 in urban centers and 800 to 2,100 people per km^2 in the rural hinterlands (Gidwitz 2002: 28; Rice 1991: 12). Scarborough (1993: 40) reasoned that these circumstances forced the Maya to change their adaptation strategies in order to modify the entire local watershed. To systematize these new adaptation strategies of the Classic Period, Scarborough defined the term "convex watershed":[201]

To create a convex watershed, the Late Classic Maya would have moved their city centers to the highpoints of natural hillocks and ridges (Scarborough 1994: 189). In order to modify the entire landscape, they would have constructed artificial reservoirs on the hilltops and agricultural terraces along slopes. Essentially, the convex watersheds would have focused on the creation of artificial rainwater catchment systems. These would have consisted of slanted plaza floors and drainage systems that caught and directed rainfall into artificial reservoirs (Parry 2007: 17, 30; Scarborough 1998: 20; see Figure 8.3). Brewer (2007: 34) claimed that "the hydraulic innovations of the Classic Period enabled the Maya to build cities on higher ground".

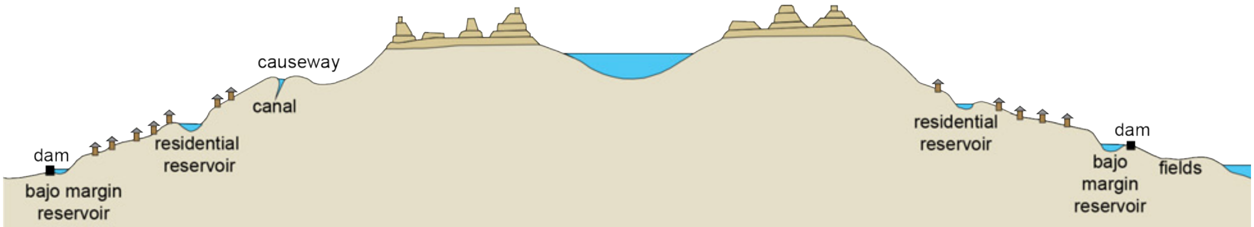

Figure 8.3: Schematic representation of a convex watershed (redrawn after Scarborough 1998: Figure 2). Reproduced with kind permission of Vernon Scarborough and Cambridge University Press.

Scarborough (1993) reasoned that the Preclassic hydraulic system of Edzná (see Chapter 5.7.4) was a precursor to the new landscape modifications of the Late Classic Period because the builders had deliberately positioned the artificial reservoirs at higher elevations than the connected canals. This layout would have enabled the diversion of water away from the immediate city center (Akpinar 2011: 23; see Figure 8.3). Moreover, they would have facilitated the storage of greater quantities of water and, consequently, could have supplied larger populations (Chmilar 2005: 10). Lucero (2002: 818) would later add to this concept of convex watersheds by claiming that the excavated fill resulting from the construction of artificial reservoirs could have been used to construct ceremonial or civic architecture (Parry 2007: 17, 30; Scarborough 1998: 139).

In Scarborough's (1995: 116) opinion, the engineers of the Late Classic did not pursue (Old World) concepts of horizontal grids and radial city planning principles (Kostof 1991). Instead, the planning of Maya cities was guided by the "principle of verticality". This "vertical city planning" would have resulted in gravity-based water manipulation systems intended to enable intensified agricultural production and would have transformed the passive concave watersheds of the Preclassic Period into the more "active" convex watersheds of the Classic Period (Scarborough *et al.* 1995: 116). According to Scarborough *et al.* (1995: 116), the possibilities for such vertical city planning heavily influenced the selection of locations during the foundation of new settlements. Ultimately, this process would have also increased the preference for hilltop locations. In order to explain the strategies employed during the transformation of the natural landscape into convex watersheds, Scarborough (1998: 139) used the hydraulic system of Tikal as an example (see Chapter 5.7.7; Scarborough and Gallopin 1991). After its publication in the early 1990s, Scarborough's (1994) concept of convex watersheds was accepted by many scholars who claimed that the hydraulic systems of La Milpa (see Chapter 5.7.9), Kinal (see Chapter 5.7.8) and Naachtun (see Chapter 5.6.4.3.3) had been built with the same strategies (Chmilar 2005: 10; Parry 2007: 174, 192).

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[201] Another more topographic metaphor for this term was the concept of the "water mountain" Scarborough and Valdez 2003: 10).

Although almost all scholars, including the author, nowadays agree on the fact that upland regions were the most popular settlement areas within the Maya lowlands, not all scholars share Scarborough's (1995) idea that this choice would have been guided by the "principle of verticality" (Healy *et al.* 2007: 35; Lou 1996: 39; Tourtellot *et al.* 2003: 42). In fact, it seems more likely that the preference of upland areas was led by the desire to be protected from the torrential downpours of the rainy season (Lou 1996: 41).

While most scholars were interested in the historical development of hydraulic features in urban settings and the immediate water supply of their inhabitants, Beach *et al.* (2015a: 20) have rightfully turned the attention towards the issue of food supply once again. In their view, the general population growth and the associated need for agricultural products resulted in the increased construction of terrace systems during the Late Classic Period (Beach *et al.* 2015a: 20; Holley *et al.* 2000).

The theories on the decline of hydraulic systems are mostly inspired by the established concepts regarding the collapse of Classic Maya civilization. Among other factors, the environmental degradation has frequently been identified as one of the primary factors for the abandonment of Maya centers in the Central and Southern Lowlands (see Chapters 3 and 4; Abrams and Rue 1988; Culbert and Rice 1990; Curtis *et al.* 1996; Parry 2007: 18; Rice *et al.* 1985; Wiseman 1985). Following these established ideas, most scholars believe that the continuous sedimentation of lowland depressions and erosion of upland areas ultimately affected the artificial reservoirs in hilltop locations (Beach and Dunning 1997; Parry 2007: 32). Moreover, some scholars remarked that the extended droughts during the end of the Late Classic and the Terminal Classic would have exacerbated the environmental stress caused by the anthropogenic landscape transformation (Binford *et al.* 1987; Curtis *et al.* 1996; Deevey *et al.* 1979; Parry 2007: 32). The resulting water scarcity would have ultimately overstrained the existing hydraulic features.

At the current state of research, most scholars believe that the political stability of sites in the Central Lowlands would have diminished considerably by the close of the Late Classic Period (Parry 2007: 32). Some scholars reasoned that the inhabitants largely abandoned the Central Lowlands and moved towards the Northern Lowlands (McAnany 2004: 161). However, it is important to highlight that some of the pre-Hispanic hydraulic features, such as the well features in and around Dzibilchaltun, had apparently been used in Postclassic times and even after the conquista (Maldonado *et al.* 2012: 56).

As the previously presented theories indicate, most models on the historical development of hydraulic features are not based on documented examples but adapt to the general and established concepts of the pre-Hispanic Maya civilization. In addition, the lack of certainty that exists in the dating of many hydraulic features (see Chapter 7.3) limits the validity of all further interpretative steps that try to reconstruct the social relevance of water management (see Chapter 8.4). In view of this situation, it is surprising that the only model developed specifically for the characterization of the historical development of water management in pre-Hispanic Maya society is Scarborough's (1994) model of concave and convex watersheds. In the author's opinion however, the applicability of these models is very limited since they are based on the observations of only a handful of sites (Seefeld 2008: 116). Furthermore, more recent discoveries showed that several "convex watersheds" (e.g. Calakmul and Tikal), which were interpreted as phenomena of the Classic period, were already developed during the Preclassic Period (Domínguez Carrasco and Folan 1996: 177; Scarborough *et al.* 2012). Silverstein *et al.* (2009: 49) also criticized that Scarborough's (1994) model of convex watersheds failed to integrate the whole environment and, instead, entirely focused on city centers. In their view, an adaptation model of pre-Hispanic Maya water management practices should try to incorporate the "full range of usable environs" including the hinterland (Hammond 1978; Silverstein *et al.* 2009: 49). Despite the lacking empirical base for Scarborough's concept of convex vs. concave watersheds, it has been cited and mentioned in many publication on Maya water management (e.g. Akpinar 2011; Brewer 2007; Chmilar 2005; Lucero 2002; Parry 2007).

In concluding, it is important to stress the point that the current state of research regarding the functionality and distribution of hydraulic features, as well as the limited number of thoroughly investigated hydraulic features, highly limit the validity of the aforementioned models and theories. For a more problem-oriented discussion and evaluation, it may be useful to present the existing models as preliminary concepts and maintain a certain openness towards alternative or new interpretative approaches.

8.4 Models on the sociopolitical relevance of water management in the Maya Lowlands

As emphasized at the beginning of this chapter, it is important to separate the discussion of the historical development of water management from the discussion of the social relevance of water management because they represent two different approaches for interpretation. Many Mayanists believe that hydraulic features, just like all other architectonical features, do not only enable inferences as to their functional value, but also their socioeconomic importance for households and communities (Crandall 2009: 10). While the models on the historical development of water management in the Maya Lowlands were a rather late development in the research history, the social effects and the sociopolitical relevance of water management were analyzed and discussed earlier and more intensively. Due to the wide range of different theories, the upcoming chapter is divided into three sections that reflect the different levels in which water management affects individual persons, smaller social units or entire societies: Chapter 8.4.1 highlights the potential issues of water distribution for each individual, Chapter 8.4.2 focuses on logistic aspects and Chapter 8.4.3 presents the published theories on water management's social and political effects on pre-Hispanic Maya society as a whole.

8.4.1 Social aspects of water management

In a practical sense, water management touches on four main social aspects:

1) Distribution of water resources,

2) Planning of hydraulic features,

3) Construction of hydraulic features, and

4) Maintenance of hydraulic features.

As noted in Chapter 5.1, each of these aspects implies the collaboration and agreement of different individuals or social groups. Since these four aspects are necessary for the management of all hydraulic features, from the smallest reservoir or irrigation canal to monumental artificial reservoirs, the social tasks or social aspects of water management always remain consistent. The only difference lies in the number of people and the extent of collaboration necessary for the realization of each task.

8.4.1.1 Theories on the organization of water distribution

Scarborough (1991: 121) suggested that the organization of water distribution in all hydraulic systems is essentially determined by the size of the area (1), the amount of available water (2) and the traditional social norms and forms of distribution (3). In all human societies, each individual consumer tries to receive the best possible access to the natural or artificial water source (Scarborough 1991: 121). Therefore, the distribution of water supply was the main source of conflict in hydraulic systems of all sizes (Chambers 1980; Scarborough 1991: 115). Often, the distribution of water did not operate as well as it could have due to consumers at the head of a hydraulic system (i.e. river or irrigation system) always taking more than originally agreed upon and thereby provoking conflicts (Scarborough 1991: 115).[202] During long drought periods, consumers at the end of a system almost never received any water. Furthermore, the unannounced construction of additional elements such as canals could have a strong impact on the entire group (Vandermeer 1971). The potential consequences could range from regional changes in water levels to a change of soils due to altering rates of runoff (Scarborough 1991: 116). Consequently, the construction and maintenance of hydraulic systems would have implied both short-term and long-term investments for all social groups (Hunt and Hunt 1976; Scarborough 1991):

Short term labor investments included routine tasks such as the distribution of water, the resolution of intragroup conflicts, and the maintenance of functional features, which would have needed to be carried out consistently throughout the year. According to Scarborough (1991: 116), the maintenance of a hydraulic system was predetermined by the particular tradition of the society and sanctioned by the governmental form.

Long-term labor investments such as larger constructions projects, occurred less often, but required longer planning phases and greater investments of labor.

In order to explain and reconstruct the social processes of the Classic Maya society, Scarborough (1993) adapted Lansing's (1993) accretive development model,[203] which implied that watersheds were manipulated by means of incremental adaptations over time (see Chapter 8.2.2; Parry 2007: 28). In Scarborough's (1998) view, the scarcity of water in the Maya Lowlands made it easy to convert water resources into a powerful tool for control (Brewer 2007: 25). In order to support this hypothesis, Scarborough (1991: 120) referred to ethnographic studies that showed that the allocation of water may be a cause for both social conflicts and collaborations. As is apparent in the aforementioned theories, the current models on the organization of water distribution in pre-Hispanic Maya society are either adapted from other world regions, or from ethnographic studies. Since our evaluation and reconstruction of water management in the pre-Hispanic Maya society are based on archaeological and palaeoecological data, the determination of these intricate social processes is obviously very limited.

8.4.2 Logistic aspects of water management

The logistic aspects of water management in pre-Hispanic Maya society included the planning of constructions, the mobilization of workforce, the supervision of the construction, and the maintenance of hydraulic features. Since the vast majority of scholars have focused on monumental hydraulic features in urban settings, they inevitably arrived at the conclusion that these constructions could only be built with central planning and supervision. Moreover, the size, complexity and adaptation to the local environment raised the question as to how the construction process of these features had taken place. As Beach *et al.* (2015a: 16) correctly noted, adding up the total sediment moved for artificial reservoir constructions would also need to account for the dams, berms, surrounding floors, sediment removal and buildup, diversions and dredged materials over time.

Scarborough (1991: 118) argued that the hydraulic systems documented in the Maya Lowlands are the result of a slow growth process in which the organization of the community and the technology adapted to the growing population. The great extent of adaptations to local topographic conditions apparent in many hydraulic systems of the Maya Lowlands (see Chapters 5 and 6) indicates that the designers of these constructions had observed the characteristics of the natural landscape very carefully. In the author's opinion, this intricate adaptation also suggests that the designers had a certain amount of local

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[202] In some cases, such as India and Sri Lanka (Chambers 1980; Leach 1959) and the Philippines (Coward 1979), this conflict led to a solution where the acreages of each consumer were situated in equal parts at the head and at the end of a river or irrigation system (Scarborough 1991: 121).

[203] Originally, Lansing (1987, 1991) had designed the model of accretive development in order to explain the modern landscape modifications of Balinese rice farming villages (Lansing and Kremer 1993: 112).

knowledge gained either as local residents or through the local population. Unfortunately, the planning process of hydraulic features has received no interest from other scholars in the past.

However, some scholars have recognized the importance of mobilizing workforces. Thus, Lucero (2002: 815) argued that the success of Maya rulers in providing sufficient amounts of (decontaminated) water throughout the entire year would have been dependent on their ability to mobilize and organize workers for the construction and maintenance of hydraulic systems (Parry 2007: 199). McAnany (2004: 155) even speculated that some peasants would have paid their rulers with their own labor (Parry 2007: 199). Because it is difficult to trace the construction process and maintenance of hydraulic features, theories on these undertakings are also scarce.[204] Instead, most scholars have focused on the social and political effects of these constructions.

8.4.3 Theories on the social and political effects of water management on pre-Hispanic Maya society

As the models presented in Chapter 8.2.2 have shown, water management systems are interpreted as "reflections of the political, religious and social influences, which were necessary for the constructions and maintenance of such control mechanisms" (Crandall 2009: 16). In these models, monumental architecture and the built environment, including its hydraulic systems, are considered a possible method for defining the hierarchy of social and political processes (Crandall 2009: 38).[205] As most scholars used the size of hydraulic features as their central basis for evaluation of the social and political effects of water management, the interpretation of specific constructions led to varying conclusions as to their relevance in the respective site. For example, Matheny *et al.* (1983: 76) claimed that the dimensions of Edzná's hydraulic system would indicate enormous labor inputs that would have far exceeded the possibilities of family groups. Therefore, Matheny *et al.* (1983: 76) argued that the documented system would have been the result of a public construction requiring very careful planning. This planning, the construction of the actual canals and reservoirs,[206] as well as the production of tools and the procurement and distribution of food supplies, would have required supervision by a powerful political organization (Matheny *et al.* 1983: 76). Similar to the results indicated by the presented evaluation criteria (see Table 9), Matheny *et al.* (1983: 76) suggested that the numerous small aguadas of the residential areas would have been the result of labor input by family groups. Thus, Matheny *et al.* (1983: 76) already took into account the coexistence of centrally organized and privately organized water sources in the same settlement.

While the early investigations in Edzná exemplified a fairly encompassing interpretation of water management, scholars in subsequent decades generally had a tendency to differentiate theories of water management based on a strict dichotomy between centralized and household based organizations of ownership of hydraulic features (Kunen 2001: 325). Thus, the "culturally modified watersheds" of Tikal, La Milpa and Kinal were interpreted as a result of centrally organized water management (Scarborough *et al.* 1994: 98, 104, 1995: 116). In these sites, the small scale hydraulic features were not initially taken into account. The only differentiation between these interpretations was the fact that the comparatively limited size of Kinal's hydraulic system was considered an indicator for "less centralized control than in Tikal" (Scarborough *et al.* 1994: 101).

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[204] As already pointed out in Chapter 5.6.4.1, some scholars reasoned that many of the artificial reservoirs of the Maya Lowlands had originally represented stone quarries ("quarry aguadas"), which would have been modified into reservoirs later on (Akpinar-Ferrand *et al.* 2012: 85; Beach *et al.* 2008; Bullard 1960; Hester and Shafer 1984; Weiss-Krejci and Sabbas 2002).

[205] The theory, that the size of specific structures can serve as indicators for prehistoric power relations becomes most obvious in the following citation:"*...there is a direct relationship between a monument's design and its communicative potential, and thus its availability to serve as a marker of social cohesion*" (Moore 1996: 98).

[206] According to Matheny *et al.* (1983: 79 with Table 35), the canals, reservoirs and small aguadas of Edzná would have reached a total storage capacity of 225 million m^3. Based on an estimation by Erasmus (1965: 289) according to which one worker with primitive stone tools would have been able to move 4 cubic meters of soil each day, Matheny *et al.* (1983: 79) calculated a total amount of four million human working days for these constructions.

Apart from these more specific interpretations of hydraulic features in a particular site, many scholars also developed hypotheses on the social and political relevance of water management in the pre-Hispanic Maya society as a whole. Surprisingly, these ideas are focused almost entirely on the Classic Period and have arrived at very different conclusions as to the sociopolitical relevance of water management. On the one hand, the scholars who focused their investigations on monumental hydraulic systems concluded that water management would have had a strong centralizing effect and would have been a necessary precursor to urban development. On the other hand, the scholars who tried to determine the social relevance of water management based on hydraulic features of all sizes scales and landscape areas concluded that the water supply could have also been managed on a household level and would not have necessarily required centralized supervision.

These two different approaches can be described as “centralization theories” (1), and “decentralization theories” (2). In order to provide an overview of the current theories regarding the social and political effects over time, the main points of these two concepts are presented in detail in the following sections.

8.4.3.1 Centralization theories

According to centralization theories, the Classic Period was the peak in the technological development and design of hydraulic features (Adams 1980; Folan *et al.* 1995; Matheny 1976; Parry 2007: 172). Following this line of thought, some scholars even argued that the development of water management had been a necessary precursor to urban development in the Maya Lowlands (Dunning *et al.* 1999: 653; Gunn *et al.* 2002: 298; Matheny 1982: 163; Scarborough 1993b: 28, 61).

Following Wittfogel’s models (see Chapters 8.1.2 and 8.2.2), these scholars speculated that the installation of hydraulic systems had spurred the development of social stratification, which ultimately would have resulted in the manifestation of centralized and authoritarian governance during the Late Classic Period (Adams 1991: 632; Kunen 2006: 100; Palerm 1955; Puleston and Puleston 1971: 336). In the author’s opinion, these centralization theories base their argumentation on three different hypotheses:

1: The importance of water management in the emergence of social stratification and centralized power.

2: The importance of hydraulic features as an instrument of power for the rulers of Late Classic Maya centers.

3: The implication that centralized reservoirs had attracted inhabitants of hinterland areas.

8.4.3.1.1 Importance of water management for the emergence of social differentiation

According to Dunning *et al.* (2006: 96) and Scarborough (1983: 720; 1998), the development of social differentiation and centralized power took place in several stages (Seefeld 2013a: 62):

During the Early and Middle Preclassic Period (2000-300 BC) the central Maya Lowlands were still sparsely settled (Dunning *et al.* 1997: 93). From the Late Preclassic on however, the dry seasons had forced the Maya to construct modified aguadas at the margins of inner bajos (Parry 2007: 200; Scarborough and Gallopin 1991: 661; Scarborough *et al.* 1994: 104, 1995: 109, 1998: 137). According to Dunning *et al.* (2006: 96), this development was partially caused by the (hypothetical) loss of permanent water sources, which would have forced the Maya to use new water sources and develop water saving cultivation techniques.[207] Because the availability of water limits the location of permanent settlements, some authors argued that

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[207] For many scholars, this dependence indicates the existence of a socially centralized water control, which would in turn indicate a strictly centralized sociopolitical system (Dunning *et al.* 1997: 93; Scarborough 1998).

the storage and management of water had enabled the foundation of permanent settlements in the Maya Lowlands in the first place (Brewer 2007: 1, 23; Chmilar 2005: 6; Scarborough and Gallopin 1991: 658).

According to this belief, reservoirs would have evolved during the transition period between the Late Preclassic and the Early Classic and would have eventually constituted "integral parts of the urban landscape" in which such artificial water sources would have represented "foci of urbanization" (Dunning *et al.* 2006: 92-96; Seefeld 2013a: 62). In this process, the construction and maintenance of hydraulic systems would have caused an "unnatural" concentration of water resources (Scarborough and Gallopin 1991: 661). Garrison and Dunning (2009: 540) claimed that the droughts and anthropogenic hydrologic changes at the transition from the Late Preclassic to the Early Classic had caused several social disruptions and instabilities (see Chapter 4). These social processes would have triggered increased investments in hydraulic infrastructure and an increase in the protection of agriculturally productive land (Garrison and Dunning 2009: 540; Lucero 2003, 2006). Other authors reasoned that the quality of the site's hydraulic infrastructure would have been a decisive factor for the survival of settlements in this transitional period (see Chapter 4). According to this line of thought, investments in agricultural and hydraulic features would have been the driving force of social differentiation (Lentz *et al.* 2015b: 290). As Ford (1996) noted, the (artificial) concentration of resources in a small area was the decisive factor for central authorities to gain a foothold (Chmilar 2005: 4). In a recent publication on the hydraulic system of Tikal, Lentz *et al.* (2015b: 290) developed a more detailed scenario of this process.

In the view of Lentz *et al.* (2015b: 290), the earliest families or lineages settling in Tikal during the Middle Preclassic claimed the most fertile agricultural land and the most productive forest tracts.[208] Over time, these "founding families" would have gained wealth based on their agriculturally productive landholdings and unobstructed access to scarce water sources. Most scholars believe that these two essential resources[209] would have enabled these founding families to become the ruling elite of Classic times (Brewer 2007: 25; Dunning *et al.* 2006: 96; Lentz *et al.* 2015a: 290; Scarborough 1983a: 720, 1998). Ultimately, this development would have caused the gradual emergence of centralized control over water resources by local elites, and a centralization and stratification of land ownership (Sanders *et al.* 1979; Seefeld 2013a: 62; Scarborough 1983a: 720, 1991: 135).

Other scholars claimed that since population growth was highly dependent on the effectiveness of the hydraulic infrastructure, water management features such as elevated fields and artificial reservoirs had appeared prior to monumental architecture (Brewer 2007: 29; Matheny 1982: 163; Scarborough 1993b: 28, 61). In this respect, Chase and Chase (1998: 73) suggested that social stratification would have also caused the development of agricultural terraces and the frequently observed tendency of clustered residential areas. In the same way, the maximum production limit of terraces would have dictated the number of people able to depend on them (Netting 1993: 161). In this process, the population expansion of the Early and Late Classic periods would have resulted in only the most undesirable patches of land, such as bajos, being settled by new families (Lentz *et al.* 2015b: 291). Simultaneously, the elites concentrated their control over water sources that would have developed into more sophisticated constructions during the Late Classic Period (Parry 2007: 30; Scarborough 1993: 44). Following these ideas, most scholars agreed that the centralization of water sources by elites would have reached its peak during the Late Classic (Ford 1996; Parry 2007: 31; Scarborough 1993: 44; 1998: 143).

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[208] This model follows the theories of Donkin (1979: 132) and Fedick (1994: 124), who claimed that investments into landscape modifications could be assessed as attempts for the protection of land rights and a (relatively) permanent linking to a specific location (Seefeld 2008: 125). Thus, a continual residence at a specific locality had cemented claims on the essential resources and would have consolidated hereditary rights over several generations (Kunen 2001: 342). Some scholars argued that this process of social stratification would become visible in the construction of field-demarcation walls during the Late Classic (Dunning and Beach 1994: 61, 1997: 263; Dunning *et al.* 1997: 659; Seefeld 2008: 125).

[209] Houston *et al.* (2010) also identified wetland fields as potential factors in this process and argued that the sharp increase of raised fields during the Late Classic would „underscore the relationship between water resources and hydraulic Maya society" (Beach *et al.* 2015a: 7).

Throughout the course of this discussion, other scholars speculated that the construction of the largest hydraulic features would have required central supervision and the existence of an organized labor force. Ultimately, these logistic requirements would have triggered the development of a hierarchical society and the consolidation of political power[210] (Adams 1991; Folan *et al.* 1995; Dunning *et al.* 2006: 96; Ford 1996: 300; Parry 2007: 30).

8.4.3.1.2 Importance of hydraulic features as instruments of power

Essentially, the argumentation of the second hypothesis of the centralization theories is based on the fundamental hypothesis that water management had triggered the social differentiation and centralization of power in Classic Maya society. Building on this, some scholars claimed that members of the elite or rulers of settlements had intentionally used water management as a "political resource" or "political control mechanism" (Brewer 2007: 26) in order to have an effective form of control over resources and the productivity of peasant labor (Ford 1996: 300; Lucero 1999, 2002; Parry 2007: 35). Thus, many scholars argued that the control of water and its sources might have been "one of the major fundaments on which the power of Maya rulers was based" (Źrałka and Koszkul 2015: 414) and would have enabled control over many social strata (Alvarado Najarro 2013; Fash 2005, 2010; Lucero 2002, 2006; Scarborough 1998). In this process, the elites would have deliberately constructed artificial reservoirs in the center of Classic Period communities and used them as a major control mechanism during the critical absence of drinking water in the dry seasons (Brewer 2007: 25, 27; Ford 1996).

In order to support this hypothesis, Ford (1996) and Lucero (1999, 2002) argued that the access to artificial reservoirs in city centers could have been easily monitored and restricted by the elites. This control would have both solidified ties among members of the elites and served to integrate the respective groups of commoners (Brewer 2007: 27; Ford 1996; Lucero 1999, 2002: 818). Furthermore, Parry (2007: 200) claimed that elites would have controlled labor forces during the dry seasons, a factor that would have given them power over the productivity of the population and the "associated social relations of production" (Ford 1996; Scarborough 1998: 149). Ultimately, the control over these most critical regional water resources would have enabled the elite leaders to exert power over local communities or entire regions (Ford 1996; Parry 2007: 200).

8.4.3.1.3 Immigration of hinterland population due to urban hydraulic systems

As an extension of these theories on the social and political effects of water management, some scholars even claimed that the development of hydraulic systems would have influenced the entirety of settlement dynamics of the Maya Lowlands. According to this theory, centralized reservoirs attracted inhabitants of hinterland areas that had previously cultivated small plots of land, or practiced horticulture and arboriculture (Parry 2007: 200).

Fundamentally, this theory is also based on the integral hypotheses that water management had facilitated the emergence of social differentiation and that elites had subsequently used hydraulic features as instruments of power. In order to explain the (alleged) process of an increase in the concentration of populations after the Late Preclassic, some scholars (e.g. Ford 1996; Lucero 1999; Parry 2007: 200)

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[210] In this respect, Scarborough (1991: 106) argued that hydraulic structures, as opposed to the usual public architecture, had required more intensive planning and maintenance, and would therefore constitute a more suitable indicator for the power of elites (Kaplan 1963: 404; Pyburn 2003: 28). Following Scarborough's (1991) argumentation, Pyburn (2003: 127) claimed that the generally poor state of preservation of hydraulic features could be attributed to the fact that the small population groups inhabiting the Central Maya Lowlands after the collapse had been unable to assemble sufficient labor in order to maintain them (Scarborough 1994: 198; Turner and Harrison 1983: 248).

speculated that the rural population would have been driven towards the urban centers due to the obligation to pay tribute in the form of their own workforce,[211] and the appeal of commodities like public water sources, markets, and social events (McAnany 2005: 151; Scarborough 1998). Thus, Ford (1996) and Lucero (1999) argued that they had documented "noticeable patterns"[212] that indicate a nucleation of hinterland populations around urban water sources during the Early Classic.

Expanding on these theories, Parry (2007: 31) argued that urban water sources were "probably" kept well-supplied and maintained. Consequently, they provided a reliable infrastructure for the economic, agricultural and daily consumption needs of the commoner population (Parry 2007: 31). Ultimately, the reliability of the urban infrastructure was the main reason for rural populations to migrate towards city centers – particularly in times of seasonal drought (Parry 2007: 31). According to Parry (2007: 200), this migration process would have been a decisive factor for the centralization of power in pre-Hispanic Maya society (Ford 1996, Lucero 1999, 2002).

The idea that a successful water supply would have required centralized management would later be questioned by several authors (e.g. Mitchell 1973: 532). Following the ideas of Weiss-Krejci and Sabbas (2002: 354), the theories of these scholars have been summarized as "decentralization theories" and shall be presented in the following section.

8.4.3.2 Decentralization theories

A central point of criticism on the centralization theories is the requisite universality. Kunen (2006: 100) argued that several models should be applied to determine the extent of resource control and resource management as opposed to just one. Even Scarborough (1991: 124) recognized some of these problems and therefore limited the applicability of centralization theories to urban environments (Seefeld 2008: 123). He acknowledged that isolated and autonomous villages at greater distance from large centers would have also been able to plan and execute the construction of reservoirs without some type of centralized organization (Scarborough 1991: 131). The validity of this theory was later demonstrated by Johnston (2004a), who identified several natural and artificial water sources in hinterland areas.

Weiss-Krejci and Sabbas (2002: 343) argued that "hypotheses of centralized water management in the Central Maya Lowlands should be critically reviewed". In their view, the pre-Hispanic Maya had not necessarily required large construction projects carried out under centralized control. This is because the multitude of natural and artificial water sources, such as modified aguadas, natural aguadas, small depressions or chultunes could have ensured a sufficient water supply for the entire population throughout the year (Weiss-Krejci and Sabbas 2002: 343). They are convinced that households ensured water storage for themselves during the dry seasons when water would have become scarce (Weiss-Krejci and Sabbas 2002: 353). Therefore, they argued that the entire landscape should be investigated for alternative or decentralized water sources before consulting centralized water management models (Weiss-Krejci and Sabbas 2002: 354). As examples for such potential water storage facilities, Weiss-Krejci and Sabbas (2002: 343) referred to the investigation of the numerous small depressions in the Río Bravo region (see Chapters 5.6.1 and 5.6.4.3.8). In their opinion, household communities may have used several forms of small-scale storage, such as jars, small depressions, wells, and chultunes, to secure sufficient water during the dry seasons (Weiss-Krejci and Sabbas 2002: 353).

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[211] Lucero (1999: 35) defined political power as "the ability to impose tribute demands on citizens".

[212] In this respect, it should be noted that Ford (1996) and Lucero (1999) do not provide any data that would support such a "pattern of migration towards urban centers during the Early Classic".

8.4.3.3 Differentiated theories

Between these two positions, some scholars have tried to develop more differentiated scenarios on the social and political relevance of water management in pre-Hispanic Maya society. As noted in Chapter 3, this trend is the result of taking the specific conditions in different regions of the Maya Lowlands into consideration, which only began in the first decade of the 21st century.

As a result, Lucero (2002: 815) argued that agricultural techniques, such as house gardens, raised fields, dams, canals and terraces were not under governmental control (Parry 2007: 31). Furthermore, Scarborough (1991: 139) admitted that larger, publicly erected hydraulic features would have been more visible than small constructions carried out by household groups. The apparent imbalance between investigations of monumental and "modest" hydraulic features could thus be explained with the differing visibility and accessibility. Although Scarborough (1991: 139) did not deny the existence of centralized water management, he also concluded that monumental hydraulic features had been published far more frequently than their modest counterparts, and that due to this imbalance, "the role of public regulation" had been overemphasized in many publications.

After this overview on the published theories on the sociopolitical relevance of water management in the Maya Lowlands, the upcoming chapters will attempt to evaluate their validity based on the hydraulic features presented in Chapter 5 and 6. In the author's opinion, the structural composition and spatial distribution of the previously published features allow for several conclusions to be made regarding the societal structure (the "social setting") in which the documented hydraulic features were created. A central prerequisite for both the evaluation of the social relevance of hydraulic features in a particular site and the objective comparison of different hydraulic systems is the application of identical evaluation criteria.

8.5 Evaluation criteria for determining the social relevance of hydraulic features

In most previous publications, scholars have interpreted the social and political relevance of a particular hydraulic feature based on the chronology (1), location (2), and size (3) (Crandall 2009: 199; Kunen 2001: 340). However, due to the uncertain dating of many hydraulic features, and the fragmentary knowledge on the historical development of "hydraulic technology" in the Maya Lowlands, it is problematic to use chronology for the interpretation of hydraulic features. In order to determine the practicality and validity of the theories presented in Chapter 8.4 and to evaluate the possible organizational structure and social consequences of water management and intensified agriculture, the author developed a set of evaluation criteria with three categories:

(1) Size, execution quality and/or complexity,

(2) Extent of interaction between individual elements, and

(3) Geographic location.

Figure 8.4 shows an overview of these three categories and the qualitative statements, which can be deduced from them.

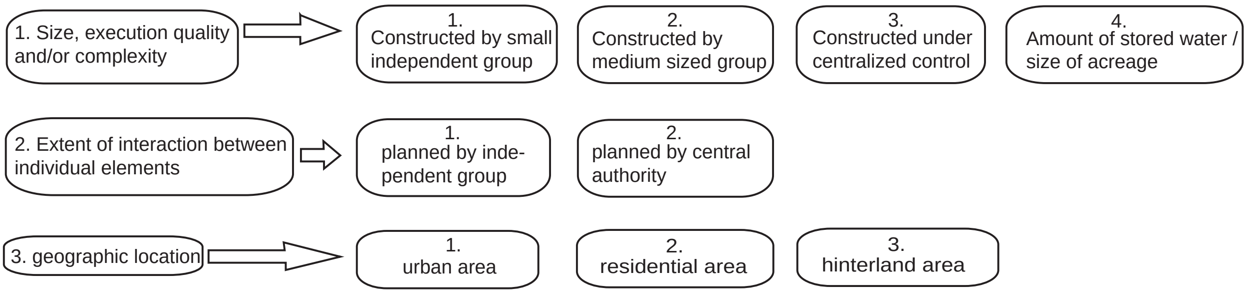


Figure 8.4: Diagram of evaluation criteria (Graphic: N. Seefeld).

1. Size, execution quality and/or complexity

In order to effectively compare the different hydraulic features or hydraulic systems, the author chose to combine the factors of size, execution quality and/or complexity into a single category. These three factors can all be identified as a direct reflection of the invested labor input and the relevance of a hydraulic feature for the respective population (Seefeld 2013a: 61). Thus, the author chose to use these factors to sort the different hydraulic features into three different categories (see Figure 8.4).

(1) Hydraulic features built by small, independent groups,

(2) Hydraulic features built by medium sized groups, and

(3) Hydraulic features built under centralized control.

In those cases where the investigating and/or publishing of a hydraulic feature also determined the storage capacity of a specific reservoir or the extent of land for intensified agriculture, this information was also included in the same dataset.

2. Extent of interaction between individual elements

In the author's opinion, the extent of interaction between different features of a hydraulic system reflects the amount of planning, engineering knowledge and interaction between different social groups. For the presented categorization, the extent of interaction was determined based on the number of features that formed a hydraulic system and interacted with each other. In order to account for the dynamic construction history of many hydraulic systems, the presented categorization still treats every single hydraulic feature as a single dataset. The extent of interaction is measured in a three-stage system:

(1) Standalone hydraulic features without an immediate connection to other hydraulic features.

(2) Hydraulic features with a connection to one other hydraulic feature, and

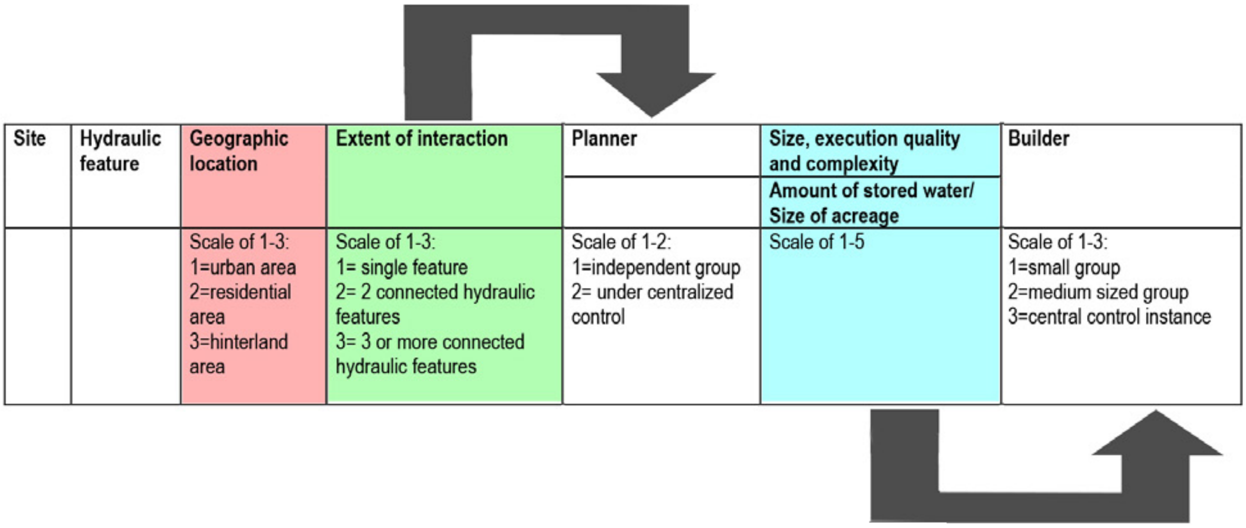
(3) Hydraulic features with an immediate connection to two or more hydraulic features.

In this relation, it is important to note that a conglomeration of several hydraulic features without any form of interconnection, such as clusters of drainage canals or wells were still defined as standalone hydraulic features. In those situations however, each hydraulic feature of the conglomeration was defined as a single dataset.

3. Geographic location

As presented in Chapter 8.4, many scholars argued that hydraulic features would have been confined to the urban areas of the Maya Lowlands. For an objective presentation of the number of studied features in the different landscape areas, and a more precise assessment of the relationship between hydraulic features and different settlement areas, the author decided to include the geographic location of hydraulic features in the presented categorization. For this purpose, this system distinguishes between three different categories: Urban areas (1), residential areas (2), and hinterland areas (3). Figure 8.5 provides an example of the exact process of categorization.

It should be noted that the geographic location, and the extent of interaction are clearly reflected in the location and the general character of a hydraulic feature. However, the determination of the "planner" is determined on the extent of interaction, while the "builder" is determined based on the size of the particular hydraulic feature. In this categorization, the factor regarding size was most difficult to determine. For a comparative analysis, the indication of metric values would not have been a fruitful approach as many publications are lacking exact size indications. Instead, the author chose to assess the "size" of a respective hydraulic feature based on a scale of 1 to 5 (see Figures 8.5 and 8.6).



Site	Hydraulic feature	Geographic location	Extent of interaction	Planner	Size, execution quality and complexity Amount of stored water/ Size of acreage	Builder
		Scale of 1-3: 1=urban area 2=residential area 3=hinterland area	Scale of 1-3: 1= single feature 2= 2 connected hydraulic features 3= 3 or more connected hydraulic features	Scale of 1-2: 1=independent group 2= under centralized control	Scale of 1-5	Scale of 1-3: 1=small group 2=medium sized group 3=central control instance

Figure 8.5: Exemplary illustration of the categorization process (Graphic: N. Seefeld).

In this system, the value of 1 designates a very small hydraulic feature while the value of 5 designates a monumental hydraulic feature. In order to enable a differentiated evaluation, the author decided to adopt the same functional classification as in Chapter 5. Thus, the "size" of a specific canal feature was determined in consideration of the entire scope of all other published canal features. All other hydraulic features were also determined in consideration of their general range of size. Thus, the categories of canals, terraces, drainage features, dam features and reservoirs were evaluated separately.

In the presented model, the size values were employed to identify the social group or builders that were responsible for the construction of a particular hydraulic feature. During the determination of these builders, the author included the assessment of the scholars that documented and/or published the respective hydraulic feature. For a general determination of the builder, the author used the following classification (see Figure 8.6):

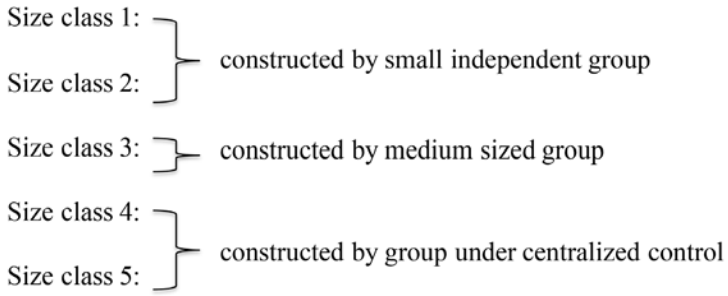


Figure 8.6: Size classes of hydraulic features.

For the determination of the social groups responsible for the planning of a particular hydraulic feature, the author referred to both the extent of interaction and the size class categories. In this process, the author used the basic assumption that the planning of hydraulic features composed of two or more individual elements would have exceeded the capacity of small individual groups. For this categorization, it was assumed that standalone hydraulic features could have been planned by small individual groups, while planning of more complex hydraulic systems would have required centralized control or supervision. Because the extent of planning of a hydraulic feature was not only determined by its complexity, but also by its sheer extent, the evaluation of the potential planner was complemented by the size class of the construction. In addition, the author also took into account the opinions of those scholars who had documented and/or published the specific hydraulic feature. In order to illustrate the exact application of these newly developed evaluation criteria, they are applied to the hydraulic system of Uxul in the following section.

8.6 Social setting of Uxul's hydraulic system

While the general functionality of Uxul's hydraulic system and its dynamic development over time were already described in Chapter 6, the current chapter will try to reconstruct the social setting in which these hydraulic features were created. Relating to the construction process of the hydraulic system, the sheer scale of landscape modifications necessarily raises the central question of the form of society or social setting, in which these features were planned and erected (Seefeld 2013a: 77). In the author's opinion, the archaeological investigation of Uxul's hydraulic system enabled six central conclusions to be made on the social setting it evolved in:

(1) The hydraulic features indicate that the local population of Uxul was in drastic need of reliable water sources during the Late Classic Period.

(2) The high quality of execution reflected in the documented constructions indicates that the population had advanced experience in the construction of hydraulic features, something indicative of a long history of learning to work on and with these features.

(3) The sophistication of the hydraulic system displays the necessity of centralized control.

(4) The apparent labor investment in public architecture indicates that the assurance of water supply was among the ruler's responsibilities.

(5) The coexistence of monumental public reservoirs and smaller reservoirs in residential areas indicate that individual families or lineages were able and allowed to create their own, private reservoirs.

(6) The local population of Uxul had developed a high dependency on the hydraulic infrastructure.

1. Evidence for drastic need of water sources during the Late Classic Period

It is the author's opinion that the construction of Uxul's hydraulic features indicates that the local population was in drastic need for reliable water sources during the Late Classic Period. The extent and severity of water scarcity during the dry season becomes apparent in each of the described hydraulic features. In this case, the apparent expenditure of work itself bears witness of the relevance of these features for the survivability of the settlement and, moreover, demonstrates that the climatic conditions during the Late Classic Period could not have been much more favorable. Among these features, the hurriedly excavated *buk'te* (see Figure 6.36), which was exposed at the bottom of Aguada Occidental, displays the gravity of this water scarcity most drastically. The desperate search for water obviously motivated the population to accept the partial destruction of an intact pavement in order to extract small quantities of water for the short term.

2. Evidence for a highly developed experience in the construction of hydraulic features

Due to the obvious adaptation of Uxul's hydraulic system to the local landscape and the intricate interrelation of its different components, it seems reasonable to state that the designers responsible for the planning of these hydraulic features were highly experienced in their construction. The level of development of Uxul's hydraulic system then raises the question as to the existence of potential precursors (see Figure 8.7). At the current state of research, these direct precursors cannot be identified, at least not in the regional vicinity of Uxul. Nevertheless, certain elements of the hydraulic systems could be documented in other Maya Lowlands sites (see Chapter 6.3 and 7).

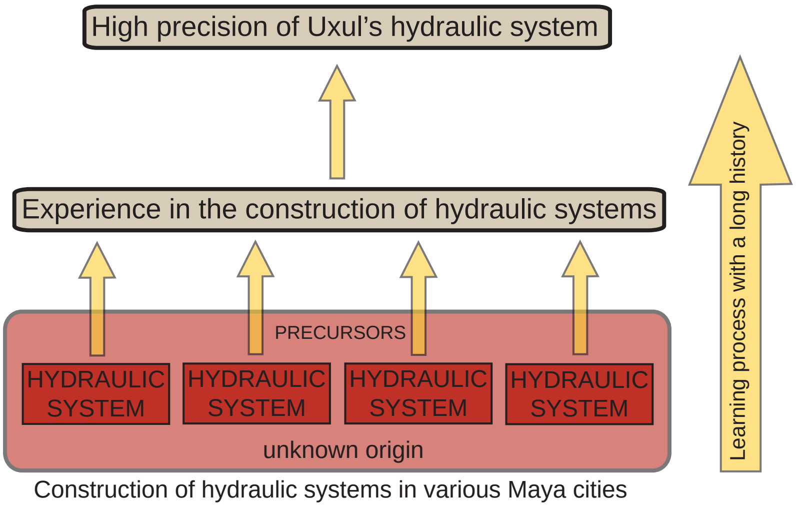


Figure 8.7: Developmental process of hydraulic systems (Graphic: N. Seefeld).

3. Necessity of centralized control for the planning, construction and maintenance of the hydraulic system

The most essential indicator for the necessity of centralized power for the design, realization and maintenance of the hydraulic system is once again the extent of the accomplished labor (Seefeld 2013a: 78). Although Uxul's inhabitants had also constructed a number of smaller hydraulic features, the author would like to argue that the three largest hydraulic features (Aguadas Occidental, the influx canal to the Aguada Occidental and the Aguada Oriental) could not have been planned, constructed and maintained by household communities or smallholder groups. The documented public building activities, especially the recruitment of labor, required central supervision and a higher hierarchical authority. Moreover, the layout of the three major hydraulic features shows that each individual constructional element, including its exact position, had to be planned in all details prior to the actual construction (Seefeld 2013a: 78). The finely tuned construction elements indicate that each hydraulic feature formed part of a building program that had been planned well in advance. In this process, the ruler needed to be resourceful enough to recruit vast numbers of laborers with different technical skills. In the author's opinion, this process would have required the availability of both specialists and unskilled workers for the planning, building process and regular maintenance and cleaning of the construction (Seefeld 2013a: 78). In this respect, the author would like to argue that the centralized supervision presumably enabled the emergence of specialists for such constructions and that it ultimately would have led to the advanced level of experience demonstrated in Chapter 6.

4. Safeguarding of the water supply was a responsibility of the ruler

Since the realization of these constructions was apparently directed and supervised by a central authority, it seems reasonable to argue that the safeguarding of the water supply was one of the ruler's responsibilities (Seefeld 2013a: 78). The mere fact that the strategy of rainwater harvesting was so skillfully applied to the local landscape indicates that the site's rulers were quite aware of the fatal risk of an ebbing water supply in this environment (Seefeld 2013a: 78). Therefore, they used a considerable portion of their disposable labor to ensure a constant water supply. The diligence ascribed to this task becomes apparent in every constructional element of the documented hydraulic system. Although each of the four described features was erected in a single construction phase, they cannot be attributed to a single ruler (Seefeld 2013a: 78). In fact, the development of this hydraulic system should be understood as a highly dynamic process. New water storage features were apparently constructed only when a demographic stress had overstrained previous constructions. Nevertheless, each ruler always had to consider the essential factor of water supply during the development of new building programs (Seefeld 2013a: 78).

The general form of the documented hydraulic system hints that an effective implementation of the rainwater harvesting strategy was pursued during the planning phase of a new building program. Previous results attest that the entire landscape in the immediate vicinity of the Aguada Occidental was modified for rainwater harvesting. In addition, the Denison *sacbe* was apparently constructed solely to connect the Aguada Oriental with the settlement's center. Therefore, it seems reasonable to presume that the goal of watershed maximization also played a role in the layout of the central hilltop. However, this proposition does not imply that rainwater harvesting would have been the central or decisive factor in the settlement planning of Uxul (Seefeld 2013a: 78).

5. Individual families were able and allowed to create their own, private reservoirs

As observed in many other sites of the Maya Lowlands, the investigation of Uxul's hydraulic system showed that its builders followed a multi-strategic approach (see also Weiss-Krejci and Sabbas 2002: 353). In contrast to the opinions expressed in the presentation of centralization theories, which implied that water sources would have been centralized and used as instruments of power (Brewer 2007: 27; Lentz *et al.* 2015b: 290; see Chapter 8.4.3.1), the location, layout and accessibility of Uxul's hydraulic features indicate that individual families or household groups had installed privately owned reservoirs. Furthermore, even the two monumental reservoirs (the Aguada Occidental and the Aguada Oriental) did not show any restricted accessibility. Therefore, the hypothesis of Ford (1996: 301) and Lucero (2002: 818), who claimed that the access to artificial reservoirs in city centers could have been "easily monitored and restricted by the elites" is certainly not recognizable in the hydraulic system of Uxul. Consequently, it is also difficult to explain the way in which Uxul's rulers would have used these features as instruments of power in order to exert control over different social strata (Scarborough 1998: 136; Źrałka and Koszkul 2015: 414).

6. The local population had developed a high dependency on the hydraulic system

Apart from the severe water scarcity, the necessity of central power for the execution of the construction and the liabilities of the ruler, the hydraulic system allows for further inferences on the society of Uxul during the Late Classic and Terminal Classic Periods (Seefeld 2013a: 78). In this context, the small well-like depression or *buk'te'* (see Figure 6.36) at the bottom of Aguada Occidental is of particular relevance, as it was hastily excavated in order to extract minute quantities of water on a short-term basis and thereby required the partial destruction of a previously intact pavement (Seefeld 2013a: 78). Considering the amount of recruited labor, it seems highly unlikely that the local elites who had supervised the construction were still exerting power when the destruction took place. The stratigraphic position of this *buk'te* indicates that it was excavated during the Terminal Classic, at a time when Uxul was already largely abandoned (Seefeld 2013a: 78).

Based on these observations, it seems reasonable to state that both a hierarchical society and the ruling of a central power were integral to the development and maintenance of such a sophisticated hydraulic system. Scattered inhabitants of the Terminal Classic were evidently not able to build additional artificial reservoirs and were lacking the social cohesion to protect the infrastructure that had originally enabled a consistent and florescent settlement of the Maya in this environment (Seefeld 2013a: 78). This correlation indicates that a form of interdependency between rulers and commoners might have prevailed in Uxul. In other words, this power relation could be described as a bilateral power relation, as opposed to a unilateral power relation (see Figure 8.8). Within such a relationship, a ruler had to satisfy the basic needs of his subordinates, which in turn enabled his privileged position. Despite these privileges, a ruler was not in possession of "total power" (Wittfogel 1957).

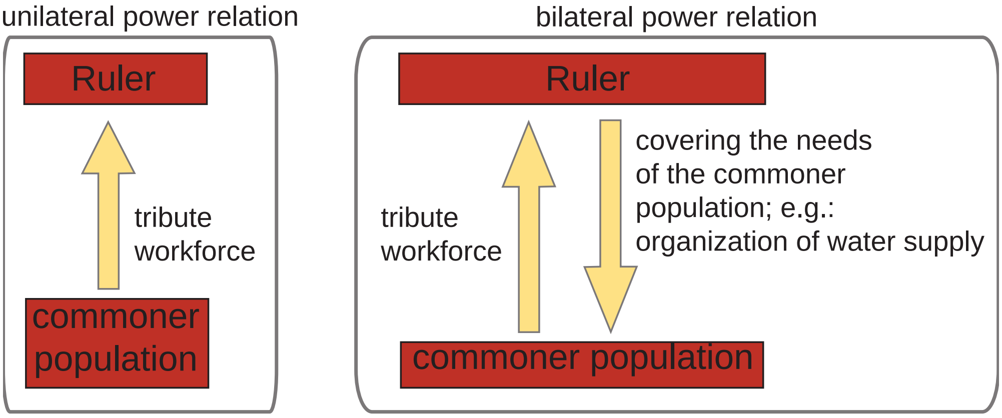


Figure 8.8: Schematic graphic representation of unilateral and bilateral power relations (Graphic: N. Seefeld).

In the same vein, the commoners were dependent on the authority of a centralized ruler, whose position enabled the design, enforcement and supervision of the construction of the vitally important infrastructure (Seefeld 2013a: 79). In this relation, the author would also like to postulate that a hierarchical society and the existence of a central authority were indispensable for the development and maintenance of a hydraulic system the size of Uxul (see Figure 8.9).

When the power of central authorities declined, the Terminal Classic population obviously no longer had the social cohesion to protect the infrastructure that had originally enabled their survival in this environment. The relationship of interdependency between rulers and commoners and the relevance of public infrastructure for the survival of the society might help to explain why the process of the collapse of the Classic Maya society evolved so rapidly. The neglected maintenance of existing infrastructure and the lack of new constructions could have caused a domino effect that accelerated and exacerbated the process of collapse (Seefeld 2013a: 79; see Figure 8.9).

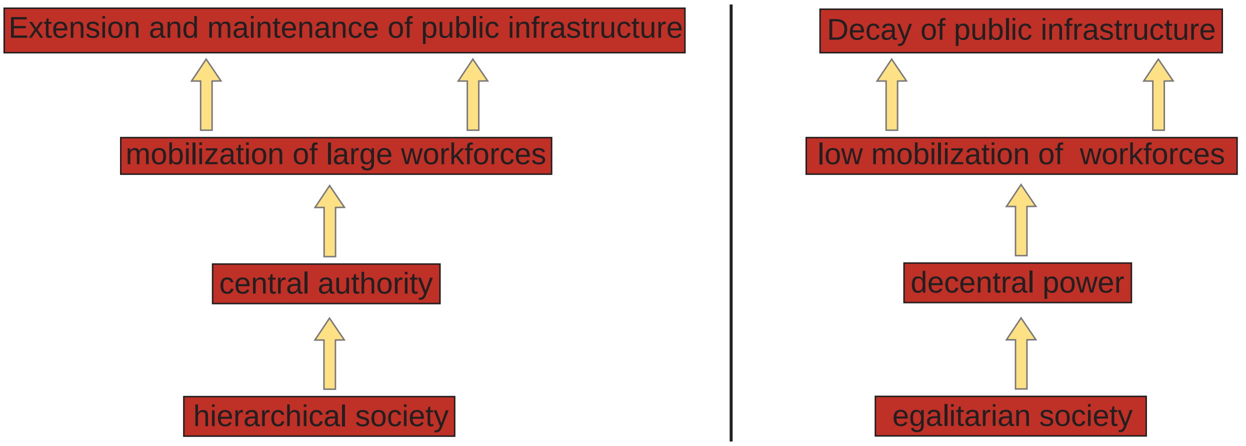


Figure 8.9: Mobilization of workforces in egalitarian and hierarchical societies (Graphic: N. Seefeld).

In order to conclude this section on the social setting of Uxul's hydraulic system, the author would like to illustrate the application of the evaluation criteria presented in Chapter 8.5 using the example of the different hydraulic features of Uxul. As Table 3 illustrates, the hydraulic features documented in Uxul can be subdivided into eight components: three canals, one dam feature, two small reservoirs and two larger reservoirs. The geographic location, extent of interaction, and size of those features vary considerably indicating that they were constructed by small independent groups, medium sized groups or under central control. Thus, the application of the newly developed evaluation criteria showed that there had been a coexistence of both public and private water management features. Furthermore, it became apparent that the two smaller water storage features (see datasets 5 and 6) were located in urban locations and were obviously integrated into architectonic groups.

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, execution quality and complexity Storage capacity/ Size of acreage	Builder 1= small group 2 =medium group 3= central control
1	Uxul	Influx canal to Aguad Oriental	2 (residential)	3 (complex)	2 (central)	4	3 (central)
2	Uxul	Influx canal to Artificial Cave	1 (urban)	2 (connected)	1 (individual)	1	1 (small)
3	Uxul	Influx canal to Aguada Occid.	2 (residential)	2 (connected)	2 (central)	5	3 (central)
4	Uxul	Filter wall of Aguada Oriental	2 (residential)	3 (complex)	1 (central)	2	3 (central)
5	Uxul	Group G, Well feature	1 (urban)	1 (single)	1 (independent)	1 m^3	1 (small group
6	Uxul	Group G, Artificial Cave	1 (urban)	2 (connected)	1 (independent)	2, 33 m^3	2 (medium)
7	Uxul	Aguada Oriental	2 (residential)	3 (complex)	2 (central)	5; 11,704 m^3	3 (central)
8	Uxul	Aguada Occidental	2 (residential)	2 (connected)	2 (central)	5; 10,000 m^3	3 (central)

Table 3: Tabular representation of the social setting of Uxul's hydraulic features.

8.7 Documented organizational structure of hydraulic features in the Maya Lowlands

In order to enable a more objective comparison of the social and political relevance of the hydraulic system of Uxul and those of other sites, the newly developed evaluation criteria were applied to the full range of hydraulic features in the Maya Lowlands. In the author's opinion, the hydraulic features presented in Chapters 5 and 6 represent the best foundation for a differentiated reconstruction of the social and political relevance of water management in pre-Hispanic Maya society. Therefore, these hydraulic features also enable inferences regarding the social and political system in which they were created.

For a differentiated analysis of their social and political relevance, the different hydraulic features were compared in their respective categories. Therefore, canal systems, terraces, dam features, drainage features and reservoirs are compared separately. Moreover, the analysis will attempt to identify patterns in the geographical distribution and technical layout of hydraulic features. For a more objective comparison and representation, the hydraulic features of Uxul will also be included in this list.

1. Canal systems

As pointed out in Chapter 7.3, due to the frequent excavation processes of canal features, potential distortions in the original stratification form. This results in the chronology of canal systems being a particular poor reference point for further investigations (Baker 2003; Seefeld 2008: 126). Instead, the investigation of their structural composition is far more informative since the Maya constructed canal systems quite differently from one case to the next (Jacob 1995b: 188; see Chapter 5.2).

Despite the relatively small number of studied canal systems, Table 4 already indicates that these systems widely ranged in size and complexity. The construction of canals ranged from the creation of small ditches (see data set 58) and the straightening of existing (natural) depressions to more sophisticated compounds that required larger movements of soil (Jacob 1995b: 188; Seefeld 2008: 126). Furthermore, the canal systems included in this study can be divided into agricultural canals (data sets 1-14) and canals that formed part of a hydraulic system (data sets 15-58).

As becomes apparent in Table 4, most of the drainage canals with agricultural purposes are smaller than the drainage canals of hydraulic systems. Furthermore, most agricultural canals (see data sets 1-14) are located in hinterland areas and thus do not have a close connection to any visible architecture. An important question of this study is who planned and constructed these features. In the author’s opinion, Table 4 enables a fairly comprehensive evaluation of this question.

While the location and composition of some of the agricultural canal systems suggest that they had been planned, built and managed by independent social groups, other agricultural canal systems had apparently been planned and constructed under centralized supervision. In most earlier publications, the determination of the “builder” of a particular canal system was mostly based on single field sites where the size of the cultivation area and the homogeneity of the fields were taken into account (Wilk 1985: 85). Moreover, scholars usually chose large, homogenously formed and uniformly aligned isolated features for their studies (Turner and Harrison 1983b: 259). Consequently, the majority of the “less organized” fields have not yet experienced a detailed study. Thus, the following tabular listing of agricultural canals shows a strong focus on the largest features. In order to determine the social setting of the published canal systems, the author defined the size and extent of interaction of a particular canal system as the basis for evaluation.

Based on Table 4, the author would like to argue that the features from datasets 4, 5, 7, 9, 10, 11, 12, and 13 had been built by individual groups. This interpretation coincides with the assessment of several scholars, who had claimed that many elevated fields of the Maya Lowlands would have been “far more rudimental than previously assumed” (Pohl *et al.* 1990: 241; Siemens 1982: 219; 221). Similarly, Denevan (1982: 186) argued that even labor intensive wetland modifications such as the maintenance of canals could have been carried out in egalitarian societies. Other scholars argued that even the largest conglomerations of drained and raised fields could be the result of a gradual construction process. In order to underline this issue, Siemens (1982: 220) emphasized that many important questions such as the required labor input, the extent of maintenance tasks and the agricultural potential of canal systems in the Maya Lowlands had still not been properly studied and answered (Seefeld 2008: 126). In order to systematize this discussion, Turner and Harrison (1983b: 259) argued that heterogeneous dimensions or allocations of fields might be considered an indicator that these systems had been constructed over longer periods and by lower annual labor investments of independent peasant groups. Indeed, the heterogeneous distribution of features such as the drainage canals of Colha (Jacob 1995b: 188) or other examples (see Table 4) indicate that these systems were either moderate modifications of previously existing (natural) landscape features, or were constructed without the coordination of a supervisor.

On the other hand, scholars interpreted canals with homogenous forms, sizes and alignments as centrally supervised constructions (Wilk 1985: 85). Thus, the canal systems of El Tigre, Bajo Morocoy, Blue Creek and Pulltrouser Swamp were defined as the "result of a public building program" (Siemens and Puleston 1972: 229) or "central master plan" (Turner and Harrison 1983b: 259). In relation to the wetland fields of Blue Creek, Guderjan *et al.* (2003: 88) even argued that the acreages were "part of the royal possession and cultivated by small subordinate families, who could have participated in a large scale export production". The canals documented in connection with the more complex hydraulic systems in urban contexts (see datasets 15-56) represent another aspect of interpretation. In the author's opinion, their location within highly interconnected hydraulic systems furthermore suggests that they had been planned under centralized supervision. However, as many investigations of hydraulic systems in urban settings concentrate their excavations on artificial reservoirs, most publications only describe the existence of these canals without providing any further information on their general dimensions, course or technical layout.

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity	Builder 1= small group 2 =medium group 3= central control
						Storage capacity/ Size of acreage	
1	El Tigre	Complex of drainage canals and raised fields.	1 (urban)	2 (connected)		4; acreage: 1,5-2 km^2	3 (central)
2	Bajo Morocoy	Complex of drainage canals and raised fields	3 (hinterland)	3 (complex)	2 (central)	5, acreage: 34,4 km^2	3 (central)
3	Cerros	Complex of drainage canals and raised fields	1 (urban)	2 (connected)	2 (central)	4	3 (central)
4	Río Azul, Bajo Pedernal	Drained fields	3 (hinterland)	1 (single)	1 (independent)	3	2 (medium)
5	Far West Bajo	Drainage canals	3 (hinterland)	1 (single)	1 (independent)	1	1 (small)
6	Blue Creek	Drainage canals	3 (hinterland)	1 (single)	1 (independent)	4; acreage: 6 km^2	3 (central)
7	Nojmul	Complex of drainage canals and raised fields	2 (residential)	2 (connected)	1 (independent)	3	2 (medium)
8	Pulltrouser Swamp	drained and raised fields	3 (hinterland)	3 (complex)	1 (independent)	4; acreage: 3.11 km^2	3 (central)
9	Albion Island	Complex of drainage canals and raised fields	2 (residential)	2 (connected)	1 (independent)	2; acreage: 0.003 km^2	1 (small)
10	Colha	Drainage canals	3 (hinterland)	1 (single)	1 (independent)	2	1 (small)
11	Lamanai	Drainage canals	2 (residential)	1 (single)	1 (independent)	2	1 (small)
12	Belize River Valley	Drainage canals	2 (residential)	2 (connected)	1 (independent)	2	1 (small)
13	Chan Cahal	drained and raised fields	2 (residential)	2 (connected)	1 (independent)	2	1 (small)
14	Chunchucmil	Raised fields	2 (residential)	2 (connected)	1 (independent)	2	1 (small)
15	Edzná	Canal (Structure 59)	1 (urban)	2 (connected)	2 (central)	4; Vol.: 1485 m^3; Length: 212 m	3 (central)
16	Edzná	Canal 9 (Structure 81)	1 (urban)	3 (complex)	2 (central)	5; Volume: 3923 m^3; Length: 325 m	3 (central)
17	Edzná	Canal 8 (Structure 137)	1 (urban)	1 (single)	2 (central)	5; Volume: 2160 m^3; Length: 162 m	3 (central)
18	Edzná	Canal (Structure 158)	1 (urban)	2 (connected)	2 (central)	5; Volume: 6633 m^3; Length: 282 m	3 (central)
19	Edzná	Canal (Structure 178)	1 (urban)	2 (connected)	2 (central)	5; Volume: 4436 m^3; Length: 212 m	3 (central)
20	Edzná	Canal 10 (Str. 194)	1 (urban)	3 (complex)	2 (central)	5; Volume: 60972 m^3; Length: 952 m	3 (central)
21	Edzná	Canal (Structure 195)	1 (urban)	3 (complex)	2 (central)	4; Volume: 488 m^3; Length: 291 m	3 (central)
22	Edzná	Canal (Structure 198)	1 (urban)	3 (complex)	2 (central)	3; Volume: 84 m ^{3}; Length 56 m	2 (medium)
23	Edzná	Canal (Structure 201)	1 (urban)	3 (complex)	2 (central)	3; Volume: 404 m^3; Length :370 m	2 (medium)
24	Edzná	Canal (Structure 202)	1 (urban)	2 (connected)	3 (central)	2; Volume: 24 m^3; Length: 22 m	1 (small)

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity Storage capacity/ Size of acreage	Builder 1= sm. group 2 =med. group 3= centr. control
25	Edzná	Canal 7 (Structure 223)	1 (urban)	2 (connected)	2 (central)	5; Volume: 43395 m^3; Length: 1,148 m	(central)
26	Edzná	Canal (Structure 259)	1 (urban)	2 (connected)	2 (central)	3; Volume: 236 m^3; Length: 156 m	2 (medium)
27	Edzná	Canal 6 (Structure 297)	1 (urban)	2 (connected)	2 (central)	5; Volume: 16196 m^3; Length: 281 m	3 (central)
28	Edzná	Canal 11 (Structure 320)	1 (urban)	3 (complex)	2 (central)	5; Volume: 904875 m^3; Length: 12,065 m	3 (central)
29	Edzná	Canal (Structure 372)	1 (urban)	2 (connected)	2 (central)	3; Volume: 90 m^3; Length: 50 m	2 (medium)
30	Edzná	Canal (Structure 373)	1 (urban)	2 (connected)	2 (central)	2; Volume: 23 m^3; Length: 34 m	1 (small)
31	Edzná	Canal (Structure 377)	1 (urban)	2 (connected)l	2 (central)	3; Volume: 56 m^3; Length: 56 m	2 (medium)
32	Edzná	Canal (Structure 379)	1 (urban)	2 (connected)	2 (central)	3; Volume: 107 m^3; Length: 106 m	2 (medium)
33	Edzná	Canal 5 (Structure 380)	1 (urban)	3 (complex)	2 (central)	5; Volume: 57355 m^3; Length: 569 m	3 (central)
34	Edzná	Canal (Structure 468)	1 (urban)	2 (connected)	2 (central)	3; Volume: 153 m^3; Length: 101 m	2 (medium)
35	Edzná	Canal 4 (Structure 471)	1 (urban)	2 (connected)	2 (central)	5; Vol: 122,860 m^3;m Length: 717 m	3 (central)
36	Edzná	Canal (Structure 482)	1 (urban)	2 (connected)l	2 (central)	3; Volume: 51 m^3; Length: 67 m	2 (medium)
37	Edzná	Canal (Structure 519)	1 (urban)	2 (connected)	2 (central)	3; Volume: 285 m^3; Length: 179 m	2 (medium)
38	Edzná	Canal 2 (Structure 522)	1 (urban)	2 (connected)	2 (central)	5; Volume; 44,880 m^3; Length: 748 m	3 (central)
39	Edzná	Canal 3 (Structure 523)	1 (urban)	1 (single)	2 (central)	5; Volume: 43,320 m^3; Length: 722 m	3 (central)
40	Edzná	Canal (Structure 554)	1 (urban)	2 (connected)	2 (central)	5; Voll: 8,685 m^3; Length: 235 m	3 (central)
41	Edzná	Canal 1 (Structure 555)	1 (urban)	3 (complex)	2 (central)	5; Vol: 107,850 m$^{3;}$ Length: 1438 m	3 (central)
42	Edzná	Canal 12 (Structure 567)	1 (urban)	2 (connected)	2 (central)	5; Volume: 36,468 m^3; Length: 296 m	3 (central)
43	Edzná	Canal (Structure 307	1 (urban)	2 (connected)	2 (central)	5; Volume: 15,542 m^3; Length: 319 m	3 (central)
44	Kinal	Western drainage canal	1 (urban)	3 (complex)	2 (central)	4	3 (central)
45	La Milpa	Canal of drainage 1	1 (urban)	2 (connected)	2 (central)	4	3 (central)
46	La Milpa	Canal of drainage 2	1 (urban)	2 (connected)	2 (central)	4	3 (central)
47	La Milpa	Canal of drainage 3a	1 (urban)	2 (connected)	2 (central)	4	3 (central)
48	La Milpa	Canal of drainage 3b	1 (urban)	2 (connected)	2 (central)	4	3 (central)
49	La Milpa	Canal of drainage 4a	1 (urban)	2 (connected)	2 (central)	4	3 (central)
50	La Milpa	Canal of drainage 4b	1 (urban)	2 (connected)	2 (central)	4	3 (central)
51	Comalcalco	Drainage canals	1 (urban)	3 (complex)	2 (central)	4	3 (central)
52	Cancuén	Southern drainage canal	1 (urban)	2 (connected)	2 (central)	4	3 (central)
53	Cancuén	Northern drainage canals	1 (urban)	2 (connected	2 (central)	4	3 (central)
54	Cancuén	Northwestern drainage canal	2 (residential)	2 (connected)	2 (central)	4	3 (central)
55	Copan	Rio Amarillo, Drainage canals	2 (residential)	1 (single)	1 (individual)	2	1 (small)
56	Uxul	Influx canal to Aguada Occidental	2 (residential)	2 (connected)	2 (central)	4	3 (central)
57	Uxul	Influx canal to Aguada Oriental	2 (residential)	3 (complex)	2 (central)	4	3 (central)
58	Uxul	Influx canal to Artificial Cave	1 (urban)	2 (connected)	1 (individual	1	1 (small)

Table 4: Tabular listing of the social setting of canal systems in the Maya Lowlands.

2. Terrace systems

In the case of terrace systems, the application of the previously presented evaluation criteria leads to more homogenous results. As Table 5 illustrates, the geographic location, the extent of interaction and the size of terrace systems suggest that they were mostly planned and constructed by small or medium sized groups. This result coincides with the opinion of most authors. Thus, Donkin (1979: 33) and Turner (1983: 112) emphasized that although singular terrace systems had required large labor investments, they could have still been constructed without a managerial cooperation or coordination by individual families. According to Donkin (1979: 33), terraces, as opposed to water reservoirs, could have been created gradually and in several stages. Following this theory, most later scholars argued that the documented terrace systems of the Maya Lowlands were the result of continuous development (Dunning and Beach 1994: 64; Kunen 2001: 342). Presumably, they were constructed and managed by individual peasants or smallholder families as a reaction to the production necessities of the local resource distribution (Fedick 1994: 124). As Table 5 illustrates, only the terrace system of Caracol indicates that it had been constructed under centralized control. Its layout, distribution and incorporation into the landscape furthermore suggest that the system was the result of a well-coordinated building program and organized labor inputs (Dunning and Beach 1994: 64; Healy 1983: 402; Kunen 2001: 328). Chase and Chase (1998: 73) reasoned that the documented terrace networks could not have built up naturally[213] and could not have been planned and built by individual families (Demarest 1992: 145; Netting 1993). Instead, they argued that the intricate network of residential areas, areas for agricultural production and water reservoirs would indicate a considerable amount of city planning and labor investment (Chase and Chase 1998: 61). In order to support this evaluation, Chase and Chase (1998: 61) referred to Healy's (1983: 402) observation that the terrace systems would have been built roughly at the same time. Moreover, they referred to Wilken (1987: 117) who had reasoned that the construction of large-scale terrace systems would have required a certain amount of centralized labor control for their maintenance and construction (Chase and Chase 1998: 73). Following this argument, Chase and Chase (1998: 73) also speculated that the construction of residential structures and terraces would have presumably gone hand in hand. As the acreages and residential areas of the "garden city" of Caracol overlapped on many occasions, Chase and Chase (1998: 74) further argued that traditional characterizations like "urban" or "rural" would be unsuited for the characterization of Maya settlement patterns.[214]

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity Size of acreage	Builder 1= small group 2 =med. group 3= centr. control
59	Río Bec Region	Dry slope terraces and check dam terraces	2 (residential)	1 (single)	1 (independent)	3	1 (small)
60	Far West Bajo	Footslope terraces and contour terraces	2 (residential)	1 (single)	1 (independent)	3	1 (small)
61	Dos Hombres	Dry slope terraces and box terraces	2 (residential)	2 (connected)	1 (independent)	3	2 (medium)
62	Maya Mountains	Dry slope terraces	3 (hinterland)	1 (single)	1 (independent)	2	1 (small)
63	Mountain Cow	Dry slope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)
64	Minanha	Dry slope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)
65	Caracol	Dry slope terraces	2 (residential	2 (connected)	2 (central)	4	3 (central)
66	Nakbe	Dry slope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)
67	San Bartolo	Dry slope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)
68	Tamarindito	footslope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)
69	Aguada Catolina	Dry slope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)
70	Copán	Río Amarillo, dry slope terraces	2 (residential)	1 (single)	1 (independent)	2	1 (small)

Table 5: Tabular listing of the social setting of terrace system in the Maya Lowlands.

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[213] Sanders (1979) had even argued that some of the published agricultural terraces of the Maya Lowlands would in fact be the result of collected silt or erosion (Chase and Chase 1998: 69).

[214] Crandall (2009: 40) and Murtha (2002: 295) reasoned that the modes of production in Caracol primarily would have been concentrated on the household level.

In summary however, the geographic location, composition and size of all other terrace systems indicate that they had been built without centralized control. As the maps provided in Chapter 5.3 indicate, most terrace systems show a close association to nearby residential areas. Together with Lohse (2004: 136), the author would like to argue that these terraces had been planned, constructed and used on a community level. Although there are no signs of restricted accessibility to these terrace systems, the close association to residential areas would have clearly signaled the rights of possession and usage.

3. Dam systems

Regarding documented dam systems, the small number of published features only enables some very general conclusions. Within the scope of Chapter 5.4, the reader was already introduced to the general distinction between dam systems with an association to permanent water streams (datasets 71-73) and dam systems without an association to permanent water streams (datasets 74-79; see Table 6). As indicated in Table 6, the application of the presented evaluation criteria suggests that all dam systems associated with permanent streams were planned and built by small individual groups. This conclusion is also supported by the assessment of Healy (1983: 154), who claimed that the dam wall of Blue Hole Camp (see dataset 71) would have been built by the commoner population when the increased demographic pressure exceeded the capacity of all natural water sources in the region.

On the other hand, the dam features without association to permanent water streams were obviously planned and constructed by larger social units. In this relation, it is important to emphasize that the functionality of these dam features relied on the connection to other hydraulic features – mostly reservoirs. Due to this functional connection, it is important to determine the "social setting" of these features both on the basis of the dam feature, and on the connected reservoir. This connection becomes most apparent in the case of the filter wall at the southern border of the Aguada Oriental in Uxul (see dataset 79). Although this dam wall has rather modest dimensions, its position and association to other hydraulic features shows that it had been planned and constructed in the same process as the other elements, which had most likely required central supervision.

Regarding other dam features without an association to permanent water streams (see datasets 74-79), the size of the dam walls coincides more or less with the size of the connected reservoirs. Thus, Dunning *et al.* (1997: 264) concluded that the dam wall of Tamarindito (see dataset 74) was the result of a "communal project" that would have represented a benefit for several households. Consequently, both the size of the feature and the opinions of the scholars documenting it indicate that this dam wall had been planned and constructed by a medium sized group. Larger constructions however, such as the Temple Reservoir Dam and the Palace Reservoir Dam of Tikal and the two main causeways of Copán were interpreted as the result of larger construction programs, which had been planned and conducted under centralized control (Davis Salazar 2006: 125; Scarborough *et al.* 1994: 104; 2012).

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, execution quality and complexity Storage capacity/ Size of acreage	Builder 1= small group 2 =medium group 3= central control
71	Blue Hole Camp	Dam wall	2 (residential)	1 (single)	1 (independent)	2	1 (small)
72	Copán	Dam wall	2 (residential)	1 (single)	1 (independent)	2	1 (small)
73	Candelaria River	Dam-systems	3 (hinterland)	1 (single)	1 (independent)	2	1 (small)
74	Tamarindito	Dam wall	2 (residential)	2 (connected)	1 (independent)	3	2 (medium)
75	Tikal	Temple Reservoir Dam	1 (urban)	3 (complex)	2 (central)	5	3 (central)
76	Tikal	Palace Dam	1 (urban)	3 (complex)	2 (central)	5	3 (central)
77	Copán	Main causeway 1	1 (urban)	1 (single)	1 (central)	4	3 (central)
78	Copán	Main causeway 2	1 (urban)	1 (single)	1 (central)	4	3 (central)
79	Uxul	Filter Wall of Aguada Oriental	2 (residential)	3 (complex)	1 (central)	2	3 (central)

Table 6: Tabular listing of the social setting of dam systems in the Maya Lowlands.

4. Drainage features

As Table 7 indicates, the drainage features of the Maya Lowlands have experienced the least amount of focused research of all hydraulic feature types. However, the few published features indicate a broad spectrum of approaches and complexity. The smallest of the published drainage features, the drainage system of Dos Hombres (see dataset 80), was most likely built by means of the intensive labor input of a household community, which had used it as a privately organized house garden (Lohse and Findlay 2002: 184). At the other end of the spectrum, there are the drainage features of Yaxhá, Nakum and Palenque, whose size, composition and extent of interaction indicate that they had been planned and built by a central controlling authority. Nevertheless, Hermes and Ramos (2004: 610) argued that the Calzada Blom in Yaxha would have been accessible to the commoner population and not only to the elites.

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= centr. control	Size, execution quality and complexity Storage capacity/ Size of acreage	Builder 1= small group 2 =med. group 3= centr. control
80	Dos Hombres	Drainage system	2 (residential)	1 (single)	1 (independent)	1	1 (small)
81	Yaxha	Calzada Blom, drainage feature	1 (urban)	2 (connected)	2 (central)	5	3 (central)
82	Nakum	Structure 14, Drainage feature	1 (urban)	3 (complex)	2 (central)	4	3 (central)
83	Palenque	Drainage features	1 (urban)	3 (complex)	2 (central)	5	3 (central)

Table 7: Tabular listing of the social setting of drainage features in the Maya Lowlands.

5. Reservoirs

In contrast to drainage features, the number of published water storage features is so extensive that their description requires a separate discussion for the smaller examples and those that are more extensive. Generally, it is advisable to draw a distinction between these water storage features of different sizes as they have been approached, documented and interpreted in different ways. This becomes apparent in the fact that many authors interpreted the formal variety and size differences as an indicator for a dichotomy between private and public water sources (Scarborough 1983a: 741). Consequently, the differentiation between private and public water sources was mostly based on the size of a particular hydraulic feature (Seefeld 2008: 129). Since the creation of smaller features such as small depressions, chultunes, wells or smaller reservoirs presumably required lower labor input, these features were usually interpreted to be the result of privately organized house groups (Domínguez Carrasco and Folan 1996: 175). Other scholars argued that a (hypothetical) connection to private house groups could also be interpreted as an indicator for "privately organized water reservoirs" (Dunning *et al.* 2006: 82). According to this idea, private sources of drinking water had been developed because the larger public reservoirs would have been exposed to a higher risk of contamination due to the greater population in their vicinity (Domínguez-Carrasco and Folan 1996: 176; Dunning *et al.* 2006: 82; Scarborough 1983a: 737). As Table 8 indicates, the small depressions and well features do indeed feature relatively moderate extensions and could generally only store limited amounts of water. As was already pointed out in Chapters 5.6.1, 5.6.2 and 5.6.3, the number of small depressions, chultunes or well features only represents a small fraction of the existing features. In order to enable a representative evaluation of the social effect of the different categories of water storage features, even the smallest documented landscape feature was identified and analyzed as a singular dataset.[215]

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[215] The only exceptions to this approach were the well features of Dzibilchaltun and Chunchucmil. In the case of Dzibilchaltun, the site was located in a region with easy access to the aquifer, which resulted in the documentation of more than 100 well features in the settlement area. In order to avoid a disproportionate correlation of the collected data, the well features of Dzibilchaltun were analyzed as a single dataset. Due to the same reasons, and the fact that some features represented recent constructions, the well features of Chunchucmil were also defined as a single dataset.

As Table 8 shows, the group of "small depressions" as defined by Weiss-Krejci and Sabbas (2002: 343) was only studied thoroughly in the Río Bravo region. In this region, it became apparent that some of these small depressions had been constructed and used by small individual groups. Despite their small size, Weiss-Krejci and Sabbas (2003: 343) argued that some of these water sources could have enabled a sufficient water supply even during the periods of highest demographic pressure.

With regard to smaller water storage features, the function and social role of chultunes is perhaps hardest to determine. Although thousands of chultunes have been mapped and described in the Maya Lowlands, only a tiny fraction of these landscape features have been studied in thorough archaeological excavations. Moreover, the difficulty in determining of the social role of chultunes is also caused by the fact that, in many cases, even thorough archaeological excavations are not able to define the function of a specific chultun feature. In Table 8, only those published chultun features with an obvious function as a water storage feature were included. These two features (datasets 88 and 89) are all located in residential areas and their small size suggests that they were constructed and used by small and independent social groups. In a general evaluation of the social role of chultunes, most scholars claimed that they showed links to household groups and thus interpreted them as privately organized water sources that served to store potable water (Scarborough *et al.* 1995: 115).

As is apparent in Table 8, the group of well features (datasets 91-132) received a slightly greater amount of scientific research. Interestingly, they could be documented in urban, residential and hinterland settings and featured a greater variety of sizes, forms and construction designs than the more or less formalized chultunes.

To a certain extent, this variety is also reflected in the well features of Margarita Maza (dataset 93) and Uaxactun (dataset 86), whose size suggests that they were either constructed by medium sized groups or larger households (see Table 8). Particularly interesting examples are the well features of Quirigua (data sets 97-104), which had been built in an area with a distinct excess of water (Ashmore 1984: 150). According to Ashmore's (1984: 151) assessment, the existence of a reliable water source "beside the doorstep" would have enhanced the comfort of living of the nearby populations. Furthermore, the filtered water of these wells would have even been cleaner than the water extracted from rivers (Ashmore 1984: 151). In general however, the size and extent of interaction observed in well features suggest that their construction did not require any central authority and that they were mostly built, used and managed by smaller social groups.

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2 = 2 onnected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality, and complexity Storage capacity	Builder 1= small group 2 =medium group 3= central control
84	La Milpa	Depr. 3, Wari Camp	2 (residential)	1 (single)	1 (inde.)	1 (228 m^3)	1 (small)
85	La Milpa	Depr. 4, Wari Camp	2 (residential)	1 (single)	1 (indep.)	1 (57 m^3)	1 (small)
86	La Milpa	Depr. 9, La Milpa East	2 (residential)	1 (single)	1 (indep.)	2 (151 m^3)	1 (small)
87	La Milpa	Depr. 15, East transect	3 (hinterland)	1 (single)	1 (indep.)	1 (37 m^3)	1 (small)
88	Chichén Itzá	Chultun	2 (residential)	2 (connected)	1 (indep.)	1	1 (small)
89	Labná	Chultun	2 (residential)	2 (connected)	1 (central)	2; 28 m^3	1 (small)
90	Tecolote	House cistern	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
91	Dzibilchaltun	Well features	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
92	Chunchucmil	Well features	2 (residential	1 (single)	1 (indep.)	1	1 (small)
93	Margarita Maza	Well feature	2 (residential)	1 (single)	1 (indep.)	3	2 (medium)
94	Los Angeles	Well feature 1	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
95	Los Angeles	Well feature 2	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
96	Uaxactun	Well feature	1 (urban)	1 (single)	1 (indep.)	2	1 (small)
97	Quirigua	Well feature 1	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
98	Quirigua	Well feature 2	2 (residential)	1 (single)	1 (indep.)	1	1 (small
99	Quirigua	Well feature 3	2 (residential)	1 (single)	1 (indep.)	1	1 (small
100	Quirigua	Well feature 4	2 (residential)	1 (single)	1 (indep.)	1	1 (small
101	Quirigua	Well feature 5	2 (residential)	1 (single)	1 (indep.)	1	1 (small
102	Quirigua	Well feature 6	2 (residential)	1 (single)	1 (indep.)	1	1 (small
103	Quirigua	Well feature 7	2 (residential)	1 (single)	1 (indep.)	1	1 (small
104	Quirigua	Well feature 8	2 (residential)	1 (single)	1 (indep.)	1	1 (small
105	Dzibilnocac	Well feature 1	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
106	Dzibilnocac	Well feature 2	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
107	Dzibilnocac	Well feature 3	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
108	Dzibilnocac	Well feature 4	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
109	Dzibilnocac	Well feature 5	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
110	Dzibilnocac	Well feature 6	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
111	Dzibilnocac	Well feature 7	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
112	Dzibilnocac	Well feature 8	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
113	Dzibilnocac	Well feature 9	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
114	Dzibilnocac	Well feature 10	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
115	Dzibilnocac	Well feature 11	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
116	Dzibilnocac	Well feature 12	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
117	Dzibilnocac	Well feature 13	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
118	Dzibilnocac	Well feature 14	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
119	Dzibilnocac	Well feature 15	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
120	Dzibilnocac	Well feature 16	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
121	Dzibilnocac	Well feature 17	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
122	Dzibilnocac	Well feature 18	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
123	Dzibilnocac	Well feature 19	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
124	Naachtun	Well features	3 (hinterland)	1 (single)	1 (indep.)	1	1 (small)
125	Dos Lagunas	Well feature	3 (hinterland)	1 (single)	1 (indep.)	1	1 (small)
126	El Cedro	Well feature	3 (hinterland)	1 (single)	1 (indep.)	1	1 (small)
127	La Milpa, Poza Maya	Well feature	3 (hinterland)	1 (single)	1 (indep.)	1	1 (small)
128	La Milpa, El Arroyo	Well feature	3 (hinterland)	1 (single)	1 (indep.)	1	1 (small)
129	Tamarindito	Well feature 1	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
130	Tamarindito	Well feature 2	2 (residential)	1 (single)	1 (indep.)	1	1 (small)
131	Itzán	Well feature	1 (urban)	1 (single)	1 (indep.)	1	1 (small)
132	Uxul	Well feature in Group H	1 (urban)	1 (single)	1 (indep.)	1	1 (small)

Table 8: Tabular listing of the social setting of small depressions and well features in the Maya Lowlands.

Since most theories on the social and political relevance of water management in pre-Hispanic Maya society use large-scale water storage features as the central reference point, the representative data on this feature group is much more extensive than it is for all other types of hydraulic features. According to most authors, larger constructions such as reservoirs or modified aguadas indicate larger labor inputs and could thus be identified as public water sources, which would have been used both for agricultural purposes and as potable water. As a consequence, many scholars focused their research and argumentation on these monumental features (Matheny *et al.* 1983: 76; Scarborough *et al.* 1994: 98). In light of this situation, it is particularly important to have an objective set of criteria for the evaluation of the social and political effects of these features.

As becomes apparent in Table 9, the water storage features defined as reservoirs by the respective authors still show a wide range of sizes. The size indications and storage capacities in Table 9 were determined by the respective scholars. As may be noticed, the builder of some reservoirs was determined as "central" even though the storage feature only had relatively modest dimensions. This case can be observed in the modified Cenote Ch'en Mul in Mayapán (dataset 272), the household cisterns in Structure 1 of Ek' Balam (dataset 274-300), the "Royal Pool" of Cancuén (dataset 303) and the northern reservoir of Cancuén (dataset 303; see Table 9). The size of all of these features suggests that they could have been constructed by small, individual groups. However, their urban location within the site and their association to palace areas indicates that they had formed part of large scale building programs, which had doubtlessly been under centralized control.

No.	Site	Hydraulic feature	Geographic. location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity Storage capacity	Builder 1= small group 2 =medium group 3= central control
133	San Bartolo	Aguada Los Loros	3 (hinterland)	2 (connected)	2 (central)	4; 1414 m^3	3 (central)
134	San Bartolo	Aguada Chintiko	3 (hinterland)	2 (connected)	2 (central)	4; 3436 m^3	3 (central)
135	San Bartolo	Aguada San Bartolo	1 (urban)	1 (single)	1 (independent)	3	2 (medium)
136	Xultun	Aguada Hormiguero	3 (hinterland)	1 (single)	1 (independent)	3	2 (medium)
137	Xultun	Aguada Delirio	2 (residential)	2 (connected)	1 (independent)	3	2 (medium)
138	Xultun	Aguada Los Tambos	3 (hinterland)	1 (single)	2 (central)	5; 10,053 m^3	3 (central)
139	Naachtun	Modified reservoir	1 (urban)	2 (connected)	2 (central)	4, 1,508 m^3	3 (central)
140	Dos Hombres	Transect B, Aguada	2 (residential)	1 (single)	2 (central)	5;	3 (central)
141	Dos Hombres	Agua Lluvia Group, Aguada	2 (residential)	1 (single)	1 (independent)	1; 71 m^3	1 (small)
142	Nakbe	Aguada Zacatal	2 (residential)	2 (connected)	2 (central)	5	3 (central)
143	Aguada Catolina	Aguada Catolina	2 (residential)	1 (single)	1 (individual)	3	2 (medium)
144	Xcoch	East Aguada	1(urban)	2 (connected)	2 (central)	5, 8,300 m^3	3 (central)
145	Xcoch	Aguada La Gondola	1 (urban)	3 (complex)	2 (central)	5; 79,200 m^3	3 (central)
146	Xcoch	South Aguada 1	3 (hinterland)	3 (complex)	2 (central)	5; 9,000 m^3	3 (central)
147	Aguada Maya	Modified Aguada	3 (hinterland)	2 (connected)	2 (central)	5; 125.000 m^3	3 (central)
148	Edzná	Reservoir (Str. 38)	1 (urban)	1 (single)	2 (central)	5; 2,000,000 m^3	3 (central)
149	Edzná	Reservoir (Str. 126)	1 (urban)	1 (single)	2 (central)	5; 14,130 m^3	3 (central)
150	Edzná	Reservoir (Str. 152)	1 (urban)	1 (single)	2 (central)	5; 15,653 m^3	3 (central)
151	Edzná	Reservoir (Str. 157)	1 (urban)	2 (connected)	2 (central)	5; 28,175 m^3	3 (central)
152	Edzná	Reservoir (Str. 187)	1 (urban)	1 (single)	2 (central)	5; 25,761 m^3	3 (central)
153	Edzná	Reservoir (Str. 197)	1 (urban)	1 (single)	2 (central)	5; 35,609 m^3	3 (central)
154	Edzná	Reservoir (Str. 200)	1 (urban)	1 (single)	2 (central)	5; 20,151 m^3	3 (central)
155	Edzná	Reservoir (Str. 204)	1 (urban)	1 (single)	2 (central)	4; 1,650 m^3	3 (central)
156	Edzná	Reservoir (Str. 243)	1 (urban)	1 (single)	2 (central)	4; 3,360 m^3	3 (central)
157	Edzná	Reservoir (Str. 256)	1 (urban)	1 (single)	2 (central)	5; 8217 m^3	3 (central)
158	Edzná	Reservoir (Str. 258)	1 (urban)	1 (single)	2 (central)	5; 15,195 m^3	3 (central)
159	Edzná	Reservoir (Str. 274	1 (urban)	1 (single)	2 (central)	4; 4,370 m^3	3 (central)
160	Edzná	Reservoir (Str. 279)	1 (urban)	1 (single)	2 (central)	4; 2,609 m^3	3 (central)
161	Edzná	Reservoir (Str. 289)	1 (urban)	2 (connected)	2 (central)	4; 4,821 m^3	3 (central)
162	Edzná	Reservoir (Str. 301)	1 (urban)	1 (single)	2 (central)	5; 17,283 m^3	3 (central)
163	Edzná	Reservoir (Str. 305)	1 (urban)	1 (single)	2 (central)	3; 717 m^3	2 (medium)

No.	Site	Hydraulic feature	Geographic location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity Storage capacity	Builder 1= small group 2 =medium group 3= central control
165	Edzná	Reservoir (Str. 307)	1 (urban)	1 (single)	2 (central)	5; 16,370 m^3	3 (central)
166	Edzná	Reservoir (Str. 374)	1 (urban)	1 (single)	2 (central)	4; 6,131 m^3	3 (central)
167	Edzná	Reservoir (Str. 375)	1 (urban)	3 (complex)	2 (central)	4; 2,153 m^3	3 (central)
168	Edzná	Reservoir (Str. 378)	1 (urban)	1 (single)	2 (central)	5; 30,783 m^3	3 (central)
169	Edzná	Reservoir (Str. 392)	1 (urban)	2 (connected)	2 (central)	4; 2,478 m^3	3 (central)
170	Edzná	Reservoir (Str. 520)	1 (urban)	2 (connected)	2 (central)	5; 17,870 m^3	3 (central)
171	Edzná	Reservoir (Str. 551)	1 (urban)	2 (connected)	2 (central)	5; 18,653 m^3	3 (central)
172	Edzná	Reservoir (Str. 562)	1 (urban)	1 (single)	2 (central)	5; 31,304 m^3	3 (central)
173	Edzná	Reservoir (Str. 565)	1 (urban)	1 (single)	2 (central)	4; 3587 m^3	3 (central)
174	Edzná	Reservoir (Str. 579)	1 (urban)	2 (connected)	2 (central)	5; 37,929 m^3	3 (central)
175	Edzná	Reservoir (Str. 610)	1 (urban)	1 (single)	2 (central)	5; 15,805 m^3	3 (central)
176	Edzná	Reservoir (Str. 3)	2 (residential)	1 (single)	2 (central)	4; 6,675 m^3	3 (central)
177	Edzná	Reservoir (Str. 5)	2 (residential)	1 (single)	2 (central)	4, 5,400 m^3	3 (central)
178	Edzná	Reservoir (Str. 8)	2 (residential)	1 (single)	2 (central)	4; 6,048 m^3	3 (central)
179	Edzná	Reservoir (Str.11)	2 (residential)	1 (single)	2 (central)	4; 7,050 m^3	3 (central)
180	Edzná	Reservoir (Str. 15)	2 (residential)	1 (single)	1 (independent)	3; 600 m^3	2 (medium)
181	Edzná	Reservoir (Str. 18)	2 (residential)	1 (single)	1 (independent)	3; 570 m^3	2 (medium)
182	Edzná	Reservoir (Str. 23)	2 (residential)	1 (single)	1 (independent)	3; 210 m^3	2 (medium)
183	Edzná	Reservoir (Str. 26)	2 (residential)	1 (single)	2 (central)	4; 6,075 m^3	3 (central)
184	Edzná	Reservoir (Str. 30)	2 (residential)	1 (single)	2 (central)	4; 1,112 m^3	3 (central)
185	Edzná	Reservoir (Str. 31)	2 (residential)	1 (single)	2 (central)	3; 468 m^3	2 (medium)
186	Edzná	Reservoir (Str. 34)	2 (residential)	1 (single)	2 (central)	4; 1056 m^3	3 (central))
187	Edzná	Reservoir (Str. 36)	2 (residential)	1 (single)	1 (independent)	3; 570 m^3	2 (medium)
188	Edzná	Reservoir (Str. 42)	2 (residential)	1 (single)	1(independent)	3; 683 m^3	2 (medium)
189	Edzná	Reservoir (Str. 50)	2 (residential)	1 (single)	2 (central)	4; 1,359 m^3	3 (central))
190	Edzná	Reservoir (Str. 52)	2 (residential)	1 (single)	1 (independent)	3; 900 m^3	2 (medium)
191	Edzná	Reservoir (Str. 55)	2 (residential)	1 (single)	1 (independent)	3; 840 m^3	2 (medium)
192	Edzná	Reservoir (Str. 58)	2 (residential)	1 (single)	2 (central)	4; 5,222 m^3	3 (central)
193	Edzná	Reservoir (Str. 70)	2 (residential)	1 (single)	1 (independent)	3; 923 m^3	2 (medium)
194	Edzná	Reservoir (Str. 74)	2 (residential)	1 (single)	2 (central)	4; 2,700 m^3	3 (central)
195	Edzná	Reservoir (Str. 94)	2 (residential)	1 (single)	1 (independent)	3; 765 m^3	2 (medium)
196	Edzná	Reservoir (Str. 96)	2 (residential)	1 (single)	2 (central)	4; 2,714 m^3	3 (central)
197	Edzná	Reservoir (Str. 105)	2 (residential)	1 (single)	2 (central)	4; 3,675 m^3	3 (central)
198	Edzná	Reservoir (Str. 110)	2 (residential)	1 (single)	2 (central)	4; 1,710 m^3	3 (central)
199	Edzná	Reservoir (Str. 111)	2 (residential)	1 (single)	2 (central)	4; 1,013 m^3	3 (central)
200	Edzná	Reservoir (Str. 113)	2 (residential)	1 (single)	1 (independent)	3; 243 m^3	2 (medium)
201	Edzná	Reservoir (Str. 116)	2 (residential)	1 (single)	2 (central)	4; 1,059 m^3	4 (central)
202	Edzná	Reservoir (Str. 118)	2 (residential)	1 (single))	1 (independent)	3; 230 m^3	3 (medium)
203	Edzná	Reservoir (Str. 131)	2 (residential)	1 (single)	2 (central)	4; 2,483 m^3	3 (central)
204	Edzná	Reservoir (Str. 132)	2 (residential)	1 (single)	1 (independent)	3; 675 m^3	2 (medium)
205	Edzná	Reservoir (Str. 163)	2 (residential	1 (single)	1 (independent)	3; 783 m^3	2 (medium)
206	Edzná	Reservoir (Str. 164)	2 (residential)	1 (single)	1 (independent)	3; 717 m^3	2 (medium)
207	Edzná	Reservoir (Str. 168)	2 (residential)	1 (single)	1 (independent)	3; 647 m^3	2 (medium)
208	Edzná	Reservoir (Str. 171)	2 (residential)	1 (single)	2 (central)	4; 5,217 m^3	3 (central)
209	Edzná	Reservoir (Str. 173)	2 (residential)	1 (single)	2 (central)	4; 1044 m^3	3 (central)
210	Edzná	Reservoir (Str. 177)	2 (residential)	1 (single)	1 (independent)	3; 510 m^3	2 (medium)
211	Edzná	Reservoir (Str. 182	2 (residential)	1 (single)	2 (central)	4; 4,305 m^3	3 (central)
212	Edzná	Reservoir (Str. 213)	2 (residential)	1 (single)	1 (independent)	3; 914 m^3	2 (medium)
213	Edzná	Reservoir (Str. 215)	2 (residential)	1 (single)	2 (central)	4; 1,044 m^3	3 (central)
214	Edzná	Reservoir (Str. 217)	2 (residential)	1 (single)	2 (central)	4; 1,565 m^3	3 (central)
215	Edzná	Reservoir (Str. 219)	2 (residential)	1 (single)	2 (central)	4; 1,370 m^3	3 (central)
216	Edzná	Reservoir (Str. 233)	2 (residential)	1 (single)	1 (independent)	3; 488 m^3	2 (medium)
217	Edzná	Reservoir (Str. 237)	2 (residential)	1 (single)	1 (independent)	3; 471 m^3	2 (medium)
218	Edzná	Reservoir (Str. 246)	2 (residential)	1 (single)	1 (independent)	3; 522 m^3	2 (medium)
219	Edzná	Reservoir (Str. 249)	2 (residential)	1 (single)	1 (independent)	3; 678 m^3	2 (medium)
220	Edzná	Reservoir (Str. 286)	2 (residential)	1 (single)	1 (independent)	3; 471 m^3	2 (medium)
221	Edzná	Reservoir (Str. 294)	2 (residential)	1 (single)	2 (central)	4; 2,283 m^3	3 (central)
222	Edzná	Reservoir (Str. 302)	2 (residential)	1 (single)	1 (independent)	3; 131 m^3	2 (medium)
223	Edzná	Reservoir (Str. 304)	2 (residential)	1 (single)	1 (independent)	3; 261 m^3	2 (medium)

No.	Site	Hydraulic feature	Geogr. location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity Storage capacity	Builder 1= small group 2 =medium group 3= central control
223	Edzná	Reservoir (Str. 304)	2 (residential)	1 (single)	1 (independent)		2 (medium)
224	Edzná	Reservoir (Str. 310)	2 (residential)	1 (single)	1 (independent)	3; 131 m^3	2 (medium)
225	Edzná	Reservoir (Str. 312)	2 (residential)	1 (single)	2 (central)	4; 1305 m^3	3 (central)
226	Edzná	Reservoir (Str. 314)	2 (residential)	1 (single)	1 (independent)	3; 261 m^3	2 (medium)
227	Edzná	Reservoir (Str. 315)	2 (residential)	1 (single)	1 (independent)	3; 522 m^3	2 (medium)
228	Edzná	Reservoir (Str. 317)	2 (residential)	1 (single)	1 (independent)	3; 255 m^3	2 (medium)
229	Edzná	Reservoir (Str. 393)	2 (residential)	1 (single)	2 (central)	4; 7,434 m^3	3 (central)
230	Edzná	Reservoir (Str. 396)	2 (residential)	1 (single)	1 (independent)	3; 261 m^3	2 (medium)
231	Edzná	Reservoir (Str. 397)	2 (residential)	1 (single)	1 (independent)	3; 263 m^3	2 (medium)
232	Edzná	Reservoir (Str. 399)	2 (residential)	1 (single)	1 (independent)	3; 126 m^3	2 (medium)
233	Edzná	Reservoir (Str. 559a)	2 (residential)	1 (single)	2 (central)	4; 1,976 m^3	3 (central)
234	Calakmul	Aguada No. 1	2 (residential)	3 (complex)	2 (central)	5; 105,000 m^3	3 (central)
235	Calakmul	Aguada No. 2	2 (residential)	2 (connected)	2 (central)	5; 33,000 m^3	3 (central)
236	Calakmul	Aguada No. 3	1 (urban)	2 (connected)	2 (central)	4	3 (central)
237	Calakmul	Aguada No. 4	1 (urban)	2 (connected)	2 (central)	4	3 (central)
238	Calakmul	Aguada No. 5	2 (residential)	1 (single)	2 (central)	4	3 (central)
239	Calakmul	Aguada No. 6	2 (residential)	1 (single)	2 (central)	4	3 (central)
240	Calakmul	Aguada No. 7	2 (residential)	1 (single)	2 (central)	4	3 (central)
241	Calakmul	Aguada No. 8	2 (residential)	1 (single)	2 (central)	4	3 (central)
242	Calakmul	Aguada No. 9	2 (residential)	1 (single)	2 (central)	4	3 (central)
243	Calakmul	Aguada No. 10	2 (residential)	1 (single)	2 (central)	4	3 (central)
244	Calakmul	Aguada No. 11	2 (residential)	1 (single)	2 (central)	4	3 (central)
245	Calakmul	Aguada No. 12	2 (residential	1 (single)	2 (central)	4; 1,250 m^3	3 (central)
246	Calakmul	Aguada No. 13	2 (residential)	1 (single)	2 (central)	4; 5,000 m^3	3 (central)
247	Tikal	Northern earthwork	3 (hinterland)	2 (connected)	2 (central)	5	3 (central)
248	Tikal	Bejucal reservoir	2 (residential)	1 (single)	2 (central)	4	3 (central)
249	Tikal	Causeway reservoir	1 (urban)	2 (connected)	2 (central)	5	3 (central)
250	Tikal	Tikal Reservoir	1 (urban)	2 (connected)	2 (central)	5	3 (central)
251	Tikal	Hidden Reservoir	1 (urban)	2 (connected)	2 (central)	4	3 (central)
252	Tikal	Palace Reservoir	1 (urban)	3 (complex	2 (central)	5; 74,631 m^3	3 (central)
253	Tikal	Temple Reservoir	1 (urban)	3 (complex)	2 (central)	5; 27,140 m^3	3 (central)
254	Tikal	Perdido Reservoir	2 (residential)	1 (single)	2 (central)	4	3 (central)
255	Tikal	Inscriptions Reservoir	1 (urban)	1 (single)	2 (central)	4	3 (central)
256	Tikal	Corriental Reservoir	2 (residential)	3 (complex)	2 (central)	5; 57,559 m^3	3 (central)
257	Kinal	Reservoir	2 (residential)	3 (complex)	2 (central)	4; 1,000 m3	3 (central)
258	La Milpa	Reservoir A	1 (urban)	2 (connected)	2 (central)	5; 4,230 m^3	3 (central)
259	La Milpa	Reservoir B	1 (urban)	2 (complex)	2 (central)	4	3 (central)
260	La Milpa	Reservoir C	1 (urban)	2 (connected)	2 (central)	4	3 (central)
261	La Milpa	La Milpa Aguada	2 (residential)	1 (single)	2 (central)	5	3 (central)
262	La Milpa	Aguada Turtle Pond	3 (hinterland)	1 (single)	1 (independent)	3	2 (medium)
263	La Milpa	Medicinal Trail Aguada	3 (hinterland)	1 (single)	1 (independent)	2; 88 m^3	1 (small)
264	La Milpa	Aguada Lagunita Elusiva	3 (hinterland)	1 (single)	1 (independent)	3; 450 m^3	2 (medium)
265	La Milpa	Aguada Misteriosa	3 (hinterland)	2 (connected)	2 (central)	4	3 (central)
266	Caracol	Reservoir A 79	2 (residential)	1 (single)	1 (independent)	1; 10 m^3	1 (small)
267	Caracol	Reservoir A 18	2 (residential)	1 (single)	1 (independent)	1; 15 m^3	1 (small)
268	Caracol	Reservoir A	2 (residential)	1 (single)	1 (independent)	3; 496 m^3	2 (medium)
269	Caracol	Reservoir B	2 (residential)	2 (connected)	2 (central)	4; 6,402 m^3	3 (central)
270	Caracol	Reservoir C	2 (residential)	2 (connected)	1 (independent)	1	1 (small)
271	Mayapán	Modified Cenote Ch'en Mul	1 (urban)	2 (connected)	2 (central)	2	3 (central)
272	Mayapán	Cenote Xcoton	2 (residential)	2 (connected)	2 (central)	4	3 (central)
273	Ek' Balam	Structure 1, Cistern D 1	1 (urban)	1 (single)	2 (central)	1	3 (cenral)
274	Ek' Balam	Structure 1, Cistern D 2	1 (urban)	1 (single)	2 (central)	1	3 (central)
275	Ek' Balam	Structure 1, Cistern D 20	1 (urban)	1 (single)	2 (central)	1	3 (central)
276	Ek' Balam	Structure 1, Cistern D 2	1 (urban)	1 (single)	2 (central)	1	3 (central)
277	Ek' Balam	Structure 1, Cistern D 3	1 (urban)	1 (single)	2 (central)	1	3 (central)

No.	Site	Hydraulic feature	Geogr. location 1=urban 2=residential 3=hinterland	Extent of interaction 1= single feature 2= 2 connected features 3= 3 or more elements	Planner 1= independent 2= central control	Size, quality and complexity Storage capacity	Builder 1= small group 2 =medium group 3= central control
277	Ek' Balam	Structure 1, Cistern D 3	1 (urban)	1 (single)	2 (central)	1	3 (central)
278	Ek' Balam	Structure 1, Cistern D 4	1 (urban)	1 (single)	2 (central)	1	3 (central)
279	Ek' Balam	Structure 1, Cistern D 5	1 (urban)	1 (single)	2 (central)	1	3 (central)
280	Ek' Balam	Structure 1, Cistern D 6	1 (urban)	1 (single)	2 (central)	1	3 (central)
281	Ek' Balam	Structure 1, Cistern D 7	1 (urban)	1 (single)	2 (central)	1	3 (central)
282	Ek' Balam	Structure 1, Cistern D 8	1 (urban)	1 (single)	2 (central)	1	3 (central)
283	Ek' Balam	Structure 1, Cistern D 9	1 (urban)	1 (single)	2 (central)	1	3 (central)
284	Ek' Balam	Structure 1, Cistern D 10	1 (urban)	1 (single)	2 (central)	1	3 (central)
285	Ek' Balam	Structure 1, Cistern D 11	1 (urban)	1 (single)	2 (central)	1	3(central)
286	Ek' Balam	Structure 1, Cistern D 12	1 (urban)	1 (single)	2 (central)	1	3 (central)
287	Ek' Balam	Structure 1, Cistern D 13	1 (urban)	1 (single)	2 (central)	1	3 (central)
288	Ek' Balam	Structure 1, Cistern D 14	1 (urban)	1 (single)	2 (central)	1	3 (central)
289	Ek' Balam	Structure 1, Cistern D 15	1 (urban)	1 (single)	2 (central)	1	3 (central)
290	Ek' Balam	Structure 1, Cistern D 16	1 (urban)	1 (single)	2 (central)	1	3 (central)
291	Ek' Balam	Structure 1, Cistern D 17	1 (urban)	1 (single)	2 (central)	2	3 (central)
292	Ek' Balam	Structure 1, Cistern D 18	1 (urban)	1 (single)	2 (central)	1	3 (central)
293	Ek' Balam	Structure 1, Cistern D 19	1 (urban)	1 (single)	2 (central)	1	3 (central)
294	Ek' Balam	Structure 1, Cistern D 20	1 (urban)	1 (single)	2 (central)	1	3 (central)
295	Ek' Balam	Structure 1, Cistern D 21	1 (urban)	1 (single)	2 (central)	1	3 (central)
296	Ek' Balam	Structure 1, Cistern D 22	1 (urban)	1 (single)	2 (central)	1	3 (central)
297	Ek' Balam	Structure 1, Cistern D 23	1 (urban)	1 (single)	2 (central)	1	3 (central)
298	Ek' Balam	Structure 1, Cistern D 24	1 (urban)	1 (single)	2 (central)	1	3 (central)
299	Ek' Balam	Structure 1, Cistern D 25	1 (urban)	1 (single)	2 (central)	1	3 (central)
300	El Tigre	Aguadas	1 (urban)	2 (connected)	2 (central)	4	3 (central)
301	Palenque	Artificial reservoirs	1 (urban)	2 (connected)	2 (central)	4	3 (central)
302	Cancuén	Southern reservoir "Royal Pool"	1 (urban)	2 (connected)	2 (central)	3	3 (central)
303	Cancuén	Northern reservoir	1 (urban)	3 (complex)	2 (central)	3	3 (central)
304	Cancuén	Northwestern reservoir 1	2 (residential)	2 (connected)	1 (individual)	2; 240 m^3	1 (small)
305	Cancuén	Northwestern reservoir 2	2 (residential)	2 (connected)	1 (individual)	1; 26 m^3	1 (small)
306	Uxul	Aguada Occidental	2 (residential)	2 (connected)	2 (central)	5; 10,000 m^3	3 (central)
307	Uxul	Aguada Oriental	2 (residential)	3 (complex)	2 (central)	5; 11,704 m^3	3 (central)
308	Uxul	Artificial Cave	1 (urban)	2 (connected)	2 (central)	3; 33 m^3	2 (medium)

Table 9: Tabular listing of the social setting of reservoirs in the Maya Lowlands.

In the case of Structure 1 of Ek' Balam, the intricate incorporation of small household cisterns in the general building structure proves that their construction already had to be planned prior to the actual creation. Thus, the general amount of labor invested into the greater structure or building program can be used as a basis for determining the "builder" of a connected hydraulic feature. In all other features represented in Table 9, the size of a particular construction correlates fairly accurately to the size of the social group responsible for its planning, construction, maintenance and usage.

Similar to the case of the smaller water storage features, the larger reservoirs were also constructed in fairly different geographic locations that include urban, residential and hinterland areas. However, as Table 9 indicates, the largest water storage features are not necessarily confined to urban areas. The table shows that a total of 98 reservoir features indicated that they had been constructed under central authorities (size-scales 4 and 5). Of these 98 reservoirs, 42 were located in urban areas, 50 in residential areas and 6 in hinterland areas. Thus, it seems like the pre-Hispanic Maya preferred to build their largest water storage features in residential areas (51%), while only 43% of the large-scale reservoirs were built in urban settings, and 6% in hinterland settings (see Figure 8.10).

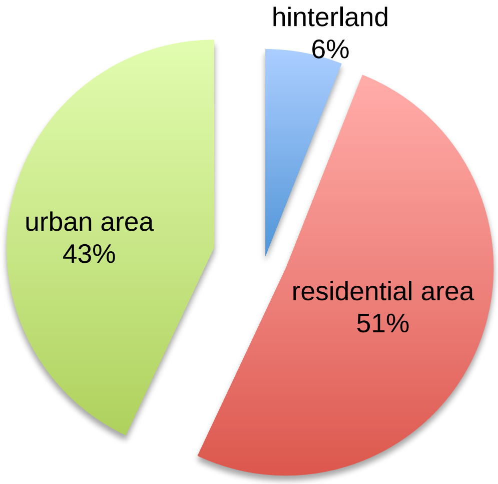
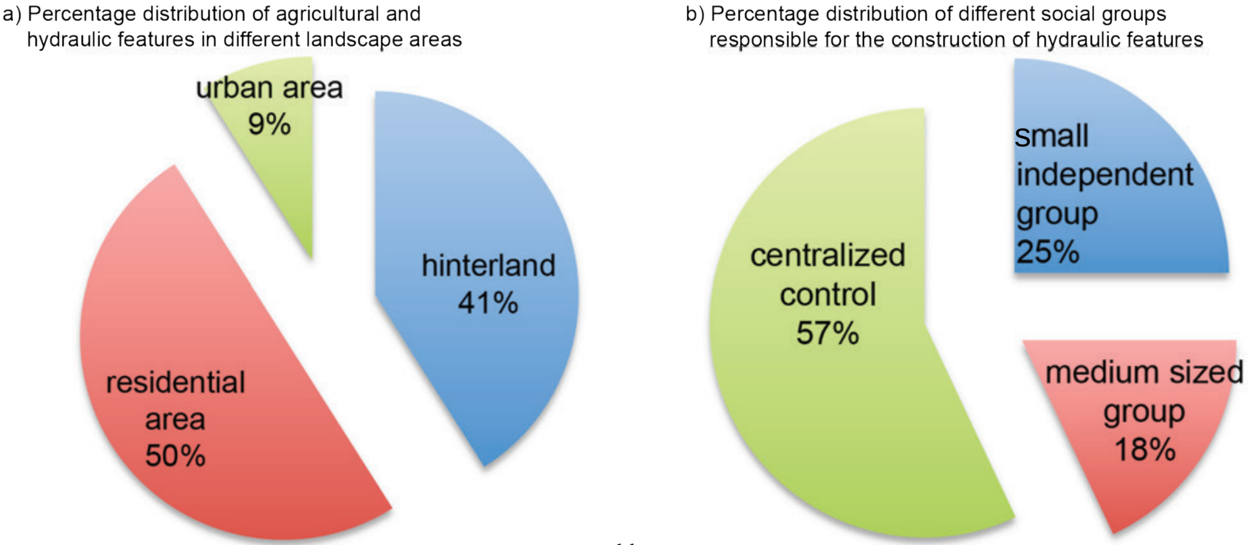


Figure 8.10: Percentage distribution of monumental reservoirs in different landscape areas.

In the author's opinion, these results indicate the general coexistence of public and private water sources in the entirety of the Maya Lowlands. While the monumental reservoirs were mostly concentrated in residential areas and could supposedly be used by all inhabitants of a settlement, some social groups decided to construct their own modestly sized reservoirs, which were most likely used exclusively by the members of the respective social group. As Tables 8 and 9 show, these modest reservoirs were apparently used as an addition to the public infrastructure and were homogenously distributed among the different areas of the settlement landscape. The relatively large variation in extension and quality of these small reservoirs might also be indicative of the varying social statuses of the groups, which had built, used and controlled these smaller water storage features.

8.7.1 Discussion of the documented organizational structure of hydraulic features

As the application of the developed evaluation criteria has shown, the comparison of the geographic location, extent of interaction and the size of different hydraulic features enable a very specific analysis. Of the 308 hydraulic and agricultural features included in this study, 41% (127 features) were located in urban areas, 50% (154 features) in residential areas and 9% (27 features) in hinterland areas (see Figure 7.11a). Based on the size and extent of interaction, it could also be determined that 25% of these features (78 features) were constructed by small independent social groups, 18% (55 features) by medium sized groups and 57% (175 features) under centralized control (see Figure 8.11b).


a) Percentage distribution of agricultural and hydraulic features in different landscape areas

b) Percentage distribution of different social groups responsible for the construction of hydraulic features

Figure 8.11: Percentage distribution of the location and the builders of hydraulic and agricultural features.

In order to enable a differentiated interpretation of agricultural and hydraulic features, the author also decided to analyze these features in two different groups. For this process, both the canal features associated with raised or drained fields and terrace features were defined as "agricultural" features. All canals associated with hydraulic systems, drainage features, dam features and reservoirs were defined as hydraulic features. Thus, 26 features were defined as "agricultural features" and 282 features were defined as hydraulic features.

Of the 26 agricultural features, 8% (2 features) were located in urban areas, 69% (18 features) in residential areas and 23% (6 features) in hinterland areas (see Figure 8.12a). Thus, the close association of agricultural features with residential areas emphasizes that cultivation areas were mostly controlled by the residents in their vicinity. Based on their size, it was determined that 65% of the agricultural features (17 units) had been constructed by small independent groups, 12% (3 features) by medium sized groups and 23% (6 features) under centralized control (see Figure 8.13b).

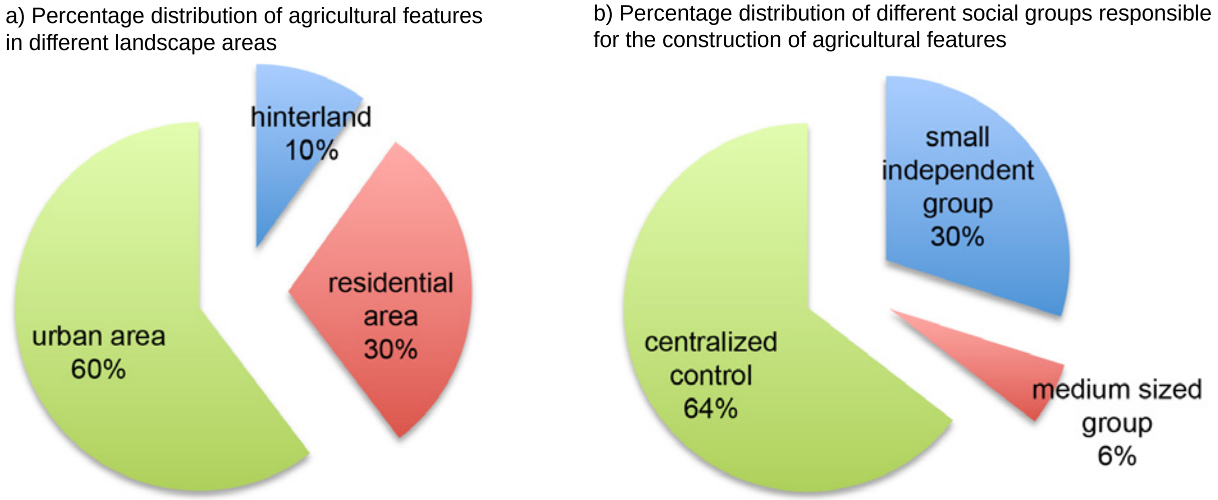


Figure 8.12: Percentage distribution of the location and the builders of agricultural features.

Of the 282 hydraulic features, 44% (125 features) were located in urban areas, 50% (140 features) in residential areas and 6% (17 features) in hinterland areas (see Figure 8.13a). Based on their size and extent of interaction, it could be determined that from the total of 283 purely hydraulic features, 22% (62 features) had been built by small independent groups, 18% (52 features) by medium sized groups and 60% (169 features) under centralized control (see Figure 8.13b).

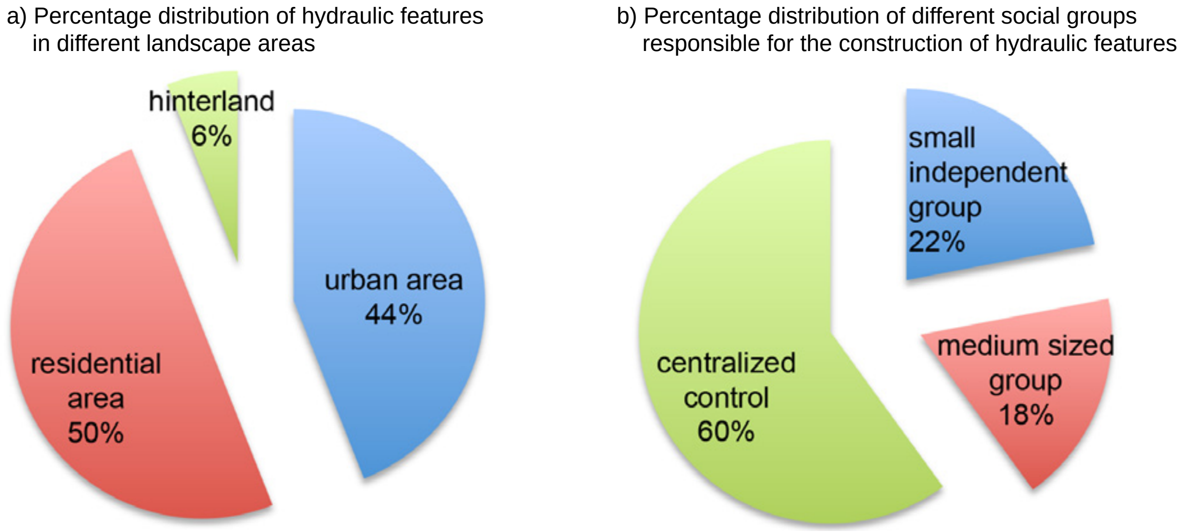


Figure 8.13: Percentage distribution of the location and the builders of hydraulic features.

In this context, the author would like to emphasize that the high percentage of hydraulic features constructed under centralized control is a reflection of the concentrated focus of most scholars on monumental hydraulic features.

8.8 Discussion of the social and political relevance of water management in the Maya Lowlands

While the aforementioned statistical data clearly indicate a series of patterns in the geographic distribution of hydraulic features, they also allow some inferences on the social relevance of water management in pre-Hispanic Maya society. In order to use the full interpretation potential of these obtained data, the validity of the explanations expressed in the centralization theories, the decentralization theories and the differentiated theories (see Chapter 8.4.3) will be determined based on the documented hydraulic features.

8.8.1 Centralization theories

As has been pointed out in Chapter 8.4.3.1 the centralization theories contain three basic hypotheses:

(1) Hydraulic systems caused the development of social differentiation and centralized power

(2) Elites and political rulers used hydraulic features as instruments of power

(3) Central water sources in urban areas attracted inhabitants of hinterland areas.

Hypothesis 1: Hydraulic features caused the development of social differentiation and centralized power

Due to the ambiguous chronology of the hydraulic features (see Chapter 7.3), it is difficult to reconstruct their development and potential relevance for the consolidation of social differentiation. Nevertheless, the observations of the previous chapters showed that control of hydraulic features was not only exerted by central rulers, but also by smaller social units such as household groups or lineages that had solidified their influence through their land holdings. As Crandall (2009: 39) correctly observed, political authority and control should not be considered essential prerequisites for investments in hydraulic or agricultural features (Lansing 1991; Netting 1993; Kirch 1994).[216] At the same time however, he also stressed that larger reservoirs had required far more labor hours than smaller reservoirs and, consequently, would have been created under centralized control (Crandall 2009: 31, 42).

In relation to this hypothesis, the author would like to remark that it is almost impossible to define water management as a necessary precursor of urban development or the central triggering factor of hierarchization. As the documented hydraulic features presented in Chapters 5 and 6 have shown, the pre-Hispanic Maya had invested considerable amounts of labor into the safeguarding of a constant water supply. Nevertheless, the author would like to modify the existing theories by stating that water management and urban development always went hand in hand. The extension of hydraulic systems would have most likely taken place only in situations of demographic stress. Therefore, the author would like to argue that hydraulic features should be defined as indicators of urban growth, not as the driving force.

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[216] Therefore, he claimed that the hydraulic system of Caracol would have been managed on a community level.

Hypothesis 2: Elites used water management as instruments of power

Because the application of the newly developed evaluation criteria showed an obvious coexistence of privately organized and public hydraulic features, the relevance of water management as instruments of power was in all likelihood limited. The extent to which rulers had employed the hydraulic features of their sites as instruments of power obviously varied from case to case. In relation to Brewer's (2007: 25) theory, according to which the controlling elites would have deliberately constructed hydraulic systems in the centers of Classic Period settlements in order to regulate access to water, the author would like to remark that the construction of artificial water sources in city centers was first and foremost necessary (Parry 2007: 165). Furthermore, the application of the evaluation criteria showed that the majority (51%) of the largest and thus most representative hydraulic features (size classes 4 and 5) were located in residential areas, whereas only 43% were located in urban areas (see Figure 8.10). These results indicate that, in contrast to monumental temple structures and other forms of public infrastructure, hydraulic features were most likely not directly used as expressions of political power.

Hypothesis 3: Central water sources in urban areas attracted inhabitants of hinterland areas

Similar to the first explanation, the imprecise chronology of hydraulic features limits the verification of the hypothesis that central water sources in urban areas would have attracted inhabitants of hinterland areas. Even though only 9% of all published agricultural and hydraulic features were located in hinterland areas, this distribution is doubtlessly the result of the overall lack of archaeological investigations in the hinterland areas of the Maya Lowlands.

Despite this research gap, the theory that the commodity of public water sources would have motivated settlers of the hinterland to move their residences closer to urban areas can be considered plausible (Ford 1996; Lucero 1999, 2000, 2002; Parry 2007: 200). It is however important to note that our current understanding of the usage of hinterland areas and the interactions between rural and urban areas is still highly underdeveloped. While we know little about the living conditions in the rural areas of the Maya Lowlands, we know even less about the interactions between Maya centers and their hinterland. Furthermore, Parry (2007: 196) also pointed out that the investigations of Sever and Irwin (2003) had shown that inhabitants outside the cities might have utilized other water sources or would have developed their own strategies for creating reserves of potable water (Johnston 2004a). In the author's opinion, it would be important to investigate what factors had motivated the pre-Hispanic Maya population to bind itself to urban settlements even though the hinterland areas would have potentially provided all necessary resources. Although this issue would still require more focused research, it seems plausible that urban settlements were considered attractive because they provided military security and a better availability of trade goods.

Critique of centralization theories

According to the author, one of the main issues of the centralization theories lies in the fact that, even though they may sound plausible, they may never be fully verifiable. In fact, they are just one out of the many ways to interpret the causality of prehistoric developments. This becomes apparent in the scenario that Lentz *et al.* (2015b: 290) developed for the social effects of water management in Tikal, in which they speculated that the early appropriation of scarce water sources would have given the earliest families a decisive advantage. In the author's opinion, the main issue of this theory lies in the fact that not only Tikal, but the majority of Maya polities in the Central Maya Lowlands did in fact feature few permanent water sources if any at all. In face of these conditions, the members of all social strata would have been forced to maximize the watersheds near their respective areas as well as possible. However, if the Classic Maya society did not have any cultural or legal prohibition against the construction of smaller reservoirs, it seems probable that many household groups took securing water into their own hands (Weiss-Krejci and Sabbas 2002: 353). Doubtlessly, the economic situations of the respective social strata would have resulted in private reservoirs of differing quality. As the analysis of Chapter 8.7 has shown, the relatively broad range in the extension and quality of small reservoirs is indeed reflected in the archaeological record. Consequently, the members of the Classic Maya society were obviously well aware of the issue of water scarcity and therefore took their own precautions by building roof gutters, household wells, household cisterns and chultunes.

At the current state of research, the analysis of the general geographic distribution of hydraulic features (see Chapter 8.7) indicates that they were distributed fairly homogenously throughout the different landscape areas. In summary, the author would like to argue that because virtually all water sources in urban contexts were artificially modified or constructed to a certain degree, every member of society would have had a basic knowledge of constructing reservoirs. In consideration of this, the members of less wealthy families who were (allegedly) forced to live in "less attractive" landscape areas such as bajos would not have actually had more difficulty building artificial reservoirs than those in other areas of the settlement landscape. Due to this inherent problem, the author would like to argue that the appropriation of water sources (Lentz *et al.* 2015b: 290) by the earliest families was not the source of their power. Instead, it seems more plausible that the essential and rarest resources of these families had been the agriculturally productive acreages.

8.8.2 Decentralization theories

Conversely, the patterns observed through the application of the evaluation criteria showed that many elements of the decentralization theories were supported by the distribution and layout of hydraulic features (see Chapter 8.7). As already pointed out in Chapter 8.4.3.2, one of the central aspects of the decentralization theories lies in the rejection of the universality claimed in the centralization theories (Kunen 2006: 100). Thus, Weiss-Krejci and Sabbas (2002: 343) claimed that the pre-Hispanic Maya society "could have relied on decentralized water sources". In their opinion, there had not been a necessity for centrally controlled constructions of hydraulic features since the numerous natural and artificial water sources such as reservoirs, aguadas, small depressions, wells or chultunes could have assured a sufficient water supply for the entire population (Weiss-Krejci and Sabbas 2002: 343). Instead, they advocated taking alternative and decentralized water sources into consideration before claiming the predominance and even necessity of centralized water resource control.

In a critique of these theories, Lucero (2002: 815) claimed that small depressions and hinterland aguadas lacked the necessary potential to support large populations throughout the dry season. Furthermore, she argued that smaller hinterland communities also lacked the incentive to plan, construct, maintain and extend functional hydraulic features that provided potable water (Lucero 2002: 816). Contradicting Lucero's (2002) theories, Akpinar-Ferrand and Dunning (2011: 118) argued that even the aguadas of hinterland areas had been heavily modified in order to collect runoff. To support this hypothesis, Akpinar-Ferrand and Dunning (2011: 119) referred to Weiss-Krejci and Sabbas' (2002: 353) calculation of daily water consumption and highlighted that most of the hinterland aguadas that they had studied were bigger than the depressions studied by Weiss-Krejci and Sabbas. Therefore, they concluded that the storage capacity of hinterland aguadas had been sufficient to provide a constant supply of water to its inhabitants (Akpinar-Ferrand and Dunning 2011: 119). In this context, it is also important to stress that surface depressions generally decrease in size due to erosion processes as they are naturally filled up with sediment over time. Consequently, the original catchment capacities of small depressions are not in danger of being estimated as too large based on ground surveys.

In light of this situation, the view of Weiss-Krejci and Sabbas (2002: 353) that some members of the Classic Maya society had constructed water storage features on the household level is clearly supported by the archaeological record. For the overarching question of the sociopolitical relevance of water management for the Classic Maya, these discoveries imply that rulers could not exert control over all water sources of a particular site. As the commoner population had installed a series of small-scale storage devices on a community level to spread out the risk of an ebbing water supply, only the reservoirs built under centralized control could have been used as instruments of power. Nevertheless, the current state of research also suggests that the complexity of reservoirs and the amount of labor invested into their construction decreased gradually as the distance from larger urban centers increased.

Generally, it is also important to note that the initial “definition” of small depressions as alternative water sources for the pre-Hispanic Maya society did indeed cause an increasing awareness for the general existence and importance of decentralized water sources. As a result of this development, many scholars initiated similar investigations of modestly sized water storage features, which lead to an ever increasing number of documented features and a slightly more balanced proportion between investigations of monumental and smaller hydraulic features. Ultimately, this systematic discussion of established ideas caused the development of more “differentiated theories”.

8.8.3 Differentiated theories

In consideration of the documented hydraulic features, the “differentiated theories” provide the best explanation for the patterns observed during the application of the evaluation criteria. As Lucero (2002: 815) suggested, agricultural features such as house gardens, milpa field plots, dams, canals and terraces were not under centralized control (Parry 2007: 31). As indicated in Chapter 8.7, this list could be complemented by a number of small to medium sized reservoirs that were most likely built, organized and maintained on a community level.

Generally, the application of the evaluation criteria indicated that the rulers of a particular Maya city only exerted limited control over the hydraulic features distributed over the settlement landscape. While the hydraulic systems of many Maya cities were most likely characterized by the coexistence of monumental and small-scale hydraulic features, the rulers had not apparently restricted access to the monumental and public reservoirs. Thus, it seems like the political system of the pre-Hispanic Maya society had not employed water as an instrument of power. Consequently, there are no reasonable grounds to state that water management would have caused the emergence of social stratification or that water management would have been a necessary prerequisite for the formation of central governance. Instead, it seems like the members of all social strata had undertaken efforts to construct hydraulic features that were controlled and used by the social units they belonged to. The location and layout of the more monumental reservoirs suggest that they had been commissioned by the rulers of the respective city. Even though the construction of these monumental reservoirs was centrally commissioned and controlled, these reservoirs were apparently not used as an instrument of power and did not represent essential prerequisites for the formation of centralized rulership in the Maya Lowlands.

8.9 Concluding evaluation of the social relevance of water management in pre-Hispanic Maya Society

In order to conclude this chapter on the sociopolitical relevance of water management in pre-Hispanic Maya society, the upcoming section will provide a summary and discussion of the main aspects that were presented and discussed in Chapter 8.

8.9.1 Models on agricultural production and water management in the Maya Lowlands

If we consider the course of scientific discussion regarding the development of agriculture and water management, it is surprising to note the vastly differing perspectives from which these two topics have been analyzed. First of all, it is interesting that the issue of agricultural production was mostly interpreted from an economic perspective. On the other hand, the clear focus on the political relevance of water management can be interpreted as an indication that most scholars are still highly influenced by the thought processes of Wittfogel's (1957) Oriental despotism.

The validity of the theories on the development of agriculture presented in Chapter 8.2.1 is mostly limited by a lack of systematic investigations and the low reliability of the chronology (Grazioso-Sierra *et al.* 2002: 206). This situation also complicates the evaluation of how the introduction of wetland cultivation could have resulted in widespread intensified agriculture, surplus production and a long-distance transport of agricultural products (Pyburn 2003: 127; Wilk 1984: 33).

8.9.2 Historical development of water management in the Maya Lowlands

Despite the difficulty in dating hydraulic features (see Chapter 7.3), the gradual increase of archaeological research on water management since the onset of the 21st century has shown that the introduction of new technologies and the increased investment in hydraulic features was mostly a phenomenon of the Classic Period. In this respect however, it should be emphasized that when faced with lacking datable material, many archaeologists simply designated hydraulic features as Late Classic constructions. Therefore, the historical development of hydraulic features in the pre-Hispanic Maya society largely remains an unresolved question. Nevertheless, the increased interest in water management, the more systematic investigations of hydraulic features and the application of new dating methods give hope that we will soon be able to develop more substantiated models on the technological development of water management in the Maya Lowlands.

8.9.3 Sociopolitical relevance of water management in the Maya Lowlands

In contrast to the models on the historical development of agriculture and water management, the models on the sociopolitical relevance of water management could be analyzed fairly well by the application of the newly developed evaluation criteria on the published hydraulic features. As pointed out in Chapter 5, the highly varying landscape forms and geologic zones of the Maya Lowlands had a very strong effect on the form, distribution and density of hydraulic features (Kunen 2001: 325).

As was presented in Chapter 5.2, the drained and raised fields were confined to the permanent wetlands (outer bajos) of Belize, southern Quintana Roo and southwestern Campeche. Terrace systems on the other hand had mostly developed in regions marked by long and moderate slopes (Dunning and Beach 1994: 62). Most scholars argued that terrace systems were managed by smallholders or corporate groups (Fedick 1994: 124; Kunen 2011: 342), a pattern that was also observed by the author after the application of the newly developed evaluation criteria. Apart from the features located in "urban contexts", the less frequently published dam systems and drainage features were apparently also created by household communities (Dunning *et al.* 1997: 263; Lohse and Findlay 2000: 184).

The extensive groups of reservoirs are marked by a wide range of forms and scales and could thus be found in almost all landscape areas of the Maya Lowlands. Although they are logically more prevalent in seasonally dry areas, they were also documented in regions, or specific portions of sites that showed excessive and permanent supplies of water (Ashmore 1984: 150). Most scholars used the size of a respective reservoir as the central reference point for the determination of the labor input and the amount of required organization (Domínguez Carrasco and Folan 1996: 176). Owing to this practice, most scholars concluded that smaller constructions, such as small depressions, chultunes and wells were the results of private initiatives (Scarborough *et al.* 1995: 115). On the other hand, the larger catchment capacity and the resulting labor input of larger reservoirs and hydraulic systems were mostly considered indicators for centrally organized planning and construction (Matheny *et al.* 1983: 76). Consequently, some scholars even argued that this hydraulic infrastructure could be identified as the catalysts for the formation and solidification of centralized power (Dunning *et al.* 2006: 96; Scarborough 1991: 135).

However, comparing these theories with the published hydraulic features showed that monumental reservoirs could not be identified as the precursors to the formation of centralized power (see Chapter 8.7). Besides this, many scholars argued that some of the alleged artificial reservoirs appeared to be of natural origin and had been modified later on to meet the demand of a growing population (Carr and Hazard 1961; Domínguez Carrasco and Folan 1996: 178; Matheny 1978: 204; Wahl *et al.* 2007: 216; Weiss-Krejci and Sabbas 2002: 350). Therefore, the purely cultural origin of these features cannot be proven in every case (Seefeld 2008: 134).

Generally, smaller hydraulic systems such as terraces and small water reservoirs were in all likelihood created and managed by small social units such as families or community groups in order to secure their own source of potable water (Seefeld 2008: 135). Canal systems are interpreted both as indications for centralized and decentralized organization. Larger reservoirs and hydraulic systems were apparently planned by a central authority and constructed by numerous workers. In the course of these public building programs, other structures also seemed to have been constructed along with the hydraulic systems. As was shown in Chapter 8.7, the majority of the monumental reservoirs were constructed in residential areas and had likely been accessible to the whole population. Consequently, these large scale hydraulic features had evidently not been the "catalysts for the formation and solidification of centralized political power" (Scarborough 1991: 135).

As pointed out in Chapter 3, most scholars focused their investigations on monumental hydraulic features until the mid 2000s, which resulted in an imbalanced view of the political relevance of water management. However, as current research approaches are aiming to address the entire scope of hydraulic features in the Maya Lowlands, it can already be anticipated that these investigations will soon reveal larger numbers of modest sized features. In any event, it can be asserted that the construction and management of hydraulic features had doubtlessly been a process that all different social strata of the pre-Hispanic Maya society had practiced. Indeed, the sum of the hydraulic features presented in Chapters 5 and 6 indicate that in pre-Hispanic Maya society, public water sources were created in close proximity to community based water sources.

Thus, the application of the evaluation criteria on the entire range of published hydraulic features indicates the coexistence of: (1) small scale reservoirs constructed, used and controlled by household groups, and (2) monumental reservoirs commissioned and supervised by the local ruler that were also accessible to the general public.

Then again, the location and size of the published hydraulic features also suggests that the constructions near to city centers had been modified through more intensive work inputs than those of the hinterland. This trend also becomes apparent in the fact that even in centers of medium sized polities such as Uxul, most of the larger hydraulic features had obviously been commissioned by a central political figure. In the author's opinion, the results obtained during the archaeological investigations of Uxul's hydraulic features resulted in a number of valuable conclusions on the social relevance of this system for its pre-Hispanic inhabitants. Of particular interest is the hypothesis that it was among the responsibilities of a ruler to ensure a constant water supply for the settlement. In the author's view, the relationship between the ruler and a commoner suggested for Uxul can also be observed in a number of other Late Classic sites.

For instance, Lentz *et al.* (2015b: 283) reasoned that the water shortages during the drought periods of the Terminal Classic had been "an immediate cause of the abandonment" of Tikal and claimed that in periods of extensive droughts, no kind of political leadership had been able to manage an overpopulated city. Similarly, Parry (2007: 222) noted that the various modifications of Naachtun's reservoir (see Chapter 5.6.4.3.3) indicated that the rulers of the polity had tried to maintain a constant water supply for their inhabitants. Another pattern that indicates that rulers had to ensure a constant water supply is the location of hydraulic features that served as luxurious amenities. As shown in Chapter 7.1, only the bathtub-like reservoirs of Ek' Balam (see Chapter 5.7.1) and the private "pools" near the palace compound of Cancuén (see Chapter 5.8.4) were clearly associated with elite residential areas. At the current state of research, it seems like most other "investments for convenience" could be used for the collective good. The fact that the rulers of a particular settlement theoretically had the authority to construct hydraulic features for their own private use, but mostly chose to make them accessible to the wider public indicates that they largely felt the responsibility or obligation to secure a constant water supply for all members of society.

9 Conclusions

The final chapter of this book aims to accomplish the following objectives: (1) highlight the significance of Uxul's hydraulic system, (2) recapitulate and merge the different results and discussions covered in the previous chapters, (3) define their relevance for the research objective of this book, (4) outline the current state of research, and (5) identify possible approaches and areas of future research.

9.1 Environmental factors for the issue of water supply

As pointed out in the introduction, the first research objective of this book consisted of determining of the factors causing temporal water scarcity and elaborating on the characteristic local and regional topographic variations in the Maya Lowlands. In Chapter 2, it is clear that due to the geological history, the Yucatán Peninsula is almost completely devoid of surface water (Dunning *et al.* 2006: 82; Wahl *et al.* 2007:214). Furthermore, the seasonality of rainfall leads to a pronounced dry season during which water becomes a critically scarce resource (Scarborough 1991: 125).

9.1.1 Distribution of water sources in the Maya Lowlands

Due to the geological history of the Yucatán Peninsula, the availability of water can vary considerably from one region to the next (see Chapter 2.1.4). As a general rule of thumb, the groundwater level is more easily accessible in the Northern Lowlands than in the Central and Southern Lowlands (Brewer 2007: 21). Consequently, the Central Lowlands are more heavily affected by the dry seasons even though they receive a higher amount of annual precipitation.

This effect of temporary water scarcity is further amplified by the fact that the permeability of the limestone bedrock leads to the immediate percolation of rainfall. Due to this factor, river systems are only fed by runoff from elevated portions of the Maya Lowlands and are thus confined to the northwestern coast of the Yucatán state, the Southern Lowlands, and the eastern and western border areas (Beach *et al.* 2015a: 14). As pointed out in Chapter 2.1.4.2, the drainage patterns of these river systems are heavily influenced by the Elevated Interior Region (EIR), which forms a north-south oriented rise in the center of the peninsula (Dunning *et al.* 2015: 5). Because the EIR forms this north-south oriented spine, the rivers originating in this area drain either to the west or the east and the actual land forming the EIR does not have surface water. This situation is further aggravated by the fact that still bodies of water such as lakes are also confined to the areas outside of the EIR (Parry 2007: 12). Consequently, aguadas are the most frequent and reliable water sources in the core zone of the Maya Lowlands (Nondédéo 2003). At the current state of research thousands of aguadas have been located and new features are being discovered every year, mostly along the edges of bajos (Beach *et al.* 2015a: 16; Dunning *et al.* 2015: 10). As pointed out in Chapter 2.4.3.3, the most decisive factor for the pronounced water scarcity in the EIR is its slightly elevated position ranging between 200 and 500 m above sea level and the associated limited access to the groundwater table (see Chapter 2.1.4.1). Furthermore, the distribution of the so-called inner bajos largely coincides with the extension of the EIR, where scarp-foot springs and natural aguadas represent the only forms of natural water sources (Johnston 2004a: 278; see Figure 2.1.4).

Outside of the Elevated Interior Region, access to sources of water was more readily available. This was due to the presence of river systems and/or the shallower depth of the groundwater table, which favored the formation of natural water sources, such as cenotes, and the construction of artificial wells. In the Southern Lowlands, the high rate of precipitation and widespread distribution of river systems also resulted in abundant water resources.

9.1.2 General trends in the climate history of the Maya Lowlands

As shown in Chapter 4.4, the current state of research on the Maya Lowlands' paleoclimate allows for three central conclusions:

Highland sediments were highly eroded during the Preclassic (1), severe droughts occurred at the end of the Late Preclassic and the Late Classic (2), and climatic conditions during the Late Classic Period were comparable to those of today (3).

Due to the erosion of highland sediments, which were largely a result of the extensive deforestation processes during the Late Preclassic, it becomes apparent that the pre-Hispanic Maya had drastically transformed the natural landscape, which required the development of specific adaptation strategies in later periods (Beach *et al.* 2009; Leyden *et al.* 2002: 98, Shaw 2003: 161).

Furthermore, most scholars agree that the Maya Lowlands were affected by pronounced drought cycles at the end of the Middle Preclassic (475-250 BC), and throughout both the Late Preclassic (25-210 A.D) and Terminal Classic periods (800-1000 AD) (Beach *et al.* 2003; Brenner *et al.* 2003; Curtis *et al.* 1998; Gunn *et al.* 2002: 298; Hodell *et al.* 2001; Lentz *et al.* 2015b: 283).

Of specific importance to this book is the acknowledgement that the climatic conditions during the Late Classic Period, the period with the highest demographic stress, were largely comparable to contemporary climatic conditions (Beach *et al.* 2015b: 279). This result indicates that the task of supplying water during the Late Classic entailed similar challenges as it does today (Dunning *et al.* 2006: 85).

9.1.2.1 Conclusions on the relationship between climate and the collapse of the Classic Maya civilization

Even though the effects of extreme drought periods coincide to some extent with the social and political transformations in the Early and Late Classic periods, the frequently quoted relationship between drought periods and the collapse of Classic Maya civilization has proven to be slightly short sighted (Beach *et al.* 2015b: 279). While this hypothesis was one of the most popular theories of the first decade of the 21st century, many scholars have criticized this idea, particularly over the last five years.

Golden and Scherer (2012: 74) argued that the core issue of Maya society would not have been the inability to produce food supplies after the downfall of the royal courts, but instead, that the maintenance of exchange and redistribution networks would have become dysfunctional and therefore would have caused a shortage of food[217] for everyone. In the author's opinion, the sophisticated hydraulic features developed by the pre-Hispanic Maya suggest that the inability to avert the abandonment of the Maya Lowlands was not a result of technological inadequacies, but of the dysfunctional social and political system. This observation is also shared by Golden and Scherer (2012: 75), who claimed that the collapse of Classic Maya civilization is rather the result of a "pattern of vulnerability", of systemic issues in the political and social system whose accumulated effects ultimately left little leeway to avert its ultimate downfall (Golden and Scherer 2012: 76; Lentz *et al.* 2015b: 283; Oliver-Smith and Hoffman 2002). If we consider the development of hydraulic systems in the Maya Lowlands, it becomes apparent that it was mostly driven by demographic pressure. However, the current state of research does not indicate that the pre-Hispanic climatic conditions strongly affected the political decisions to invest labor and resources into hydraulic systems.

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[217] In this case, the hypothesis of malnutrition is based on a broad study of stable carbon isotopes and nitrogen in the bones of individuals from Piedras Negras, which indicated a sudden deterioration of food supplies in all social strata (Golden and Scherer 2012: 75).

9.2 Summary of the geographic distribution and functionality of hydraulic features

As discussed in Chapter 5, the geographic distribution of the different types of hydraulic features in the Maya Lowlands is to a great extent the result of the availability of water, which in turn is mostly defined by the different geological regions of the Maya Lowlands. This becomes apparent in the fact that the highest concentration of reservoirs can be found in the Elevated Interior Region – the central portion of the Maya Lowlands that has the most difficult access to permanent water sources (see Figure 9.1).

Reservoirs can be found in a vast variety of sizes and contexts and all available data suggest that almost every member of the pre-Hispanic Maya society was aware of the risk of a ceasing water supply. Due to this awareness, the members of most social groups constructed their own water storage features. As illustrated in Chapter 8.7, several sites even showed a coexistence of privately owned and public water reservoirs. Even though the application of the newly developed evaluation criteria indicates that large-scale hydraulic features were not necessarily under centralized control, the geographical distribution of these large-scale features nevertheless indicates that their complexity and amount of invested labor gradually decreases the further they are from larger urban centers.

Furthermore, the sum of hydraulic features presented in Chapters 5 and 6 indicates that each hydraulic feature was highly adapted to the very specific conditions of the particular local landscape and that the pre-Hispanic Maya had highly developed experience in the construction of hydraulic features. In light of the general geographical distribution of the different types of hydraulic features, it becomes apparent that their location is largely determined by ecological factors and less so by cultural factors.

Thus, canal systems for agricultural purposes are concentrated along outer bajos and permanent streams. As already pointed out in Chapters 5.2 and 7.1, not a single canal system for agricultural use has been documented along an inner bajo habitat. The highest concentration of agricultural canals was documented along the outer bajos of Belize and southern Quintana Roo, while another cluster was observed along the Río Candelaria (see Figure 9.2).

The direct relationship between natural landscape characteristics and cultural adaptation is also apparent in the distribution of terrace systems, which, just as in most other regions of the world, are concentrated in hilly terrain with moderate slope gradients (see Figure 9.2). Due to these circumstances, the known terrace systems are confined to the Central and Southern Maya Lowlands (Dunning and Beach 1994: 62). However, regained interest in the cultivation methods of the pre-Hispanic Maya indicates that they might have originally covered more extensive parts of the Maya Lowlands (Beach *et al.* 2015a: 21). So far however, their existence could only be verified in the Vaca Plateau, the Maya Mountains, Northern Belize, the Petexbatun region and the Río Bec region (Beach *et al.* 2002, 2008, 2015a: 20).

As Figure 9.2 indicates, dam features could only be documented in a few cases. However, this small number of features is largely caused by the limited scientific interest in this feature type. To a certain extent, the same problem also applies to the few drainage features. Although they must have been installed in almost every site to prevent inundations, they have been the subject of very few focused investigations. According to their location within a site, these drainage features apparently served slightly different purposes. While they were sometimes only used to discharge water, in other instances they were used to deflect runoff around residential areas and direct it towards reservoirs.

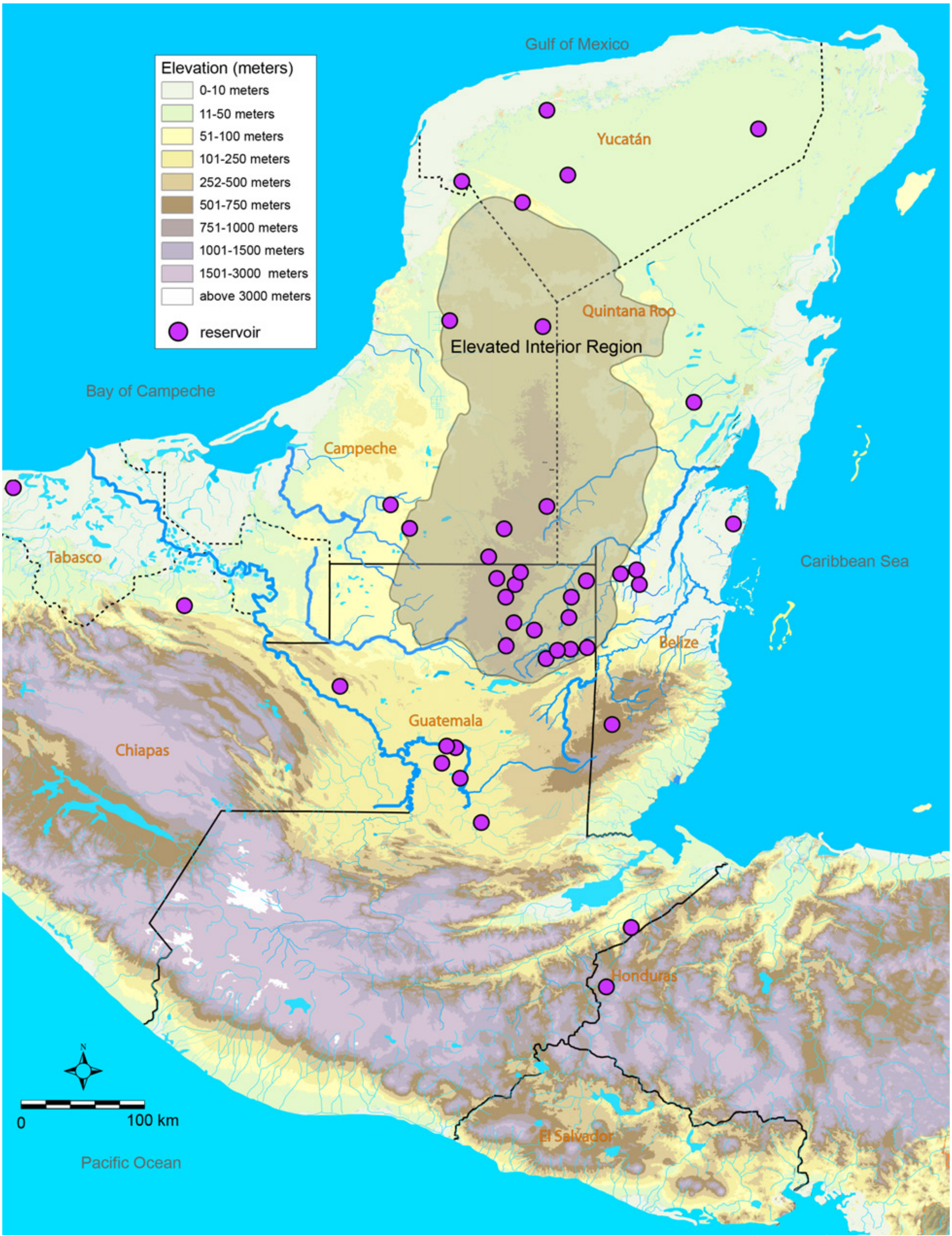

Figure 9.1: Map showing the correlation between the distribution of river systems and reservoirs (Map: N. Seefeld, modified from Witschey and Brown 2010) Reproduced with kind permission of Walter Witschey.

The drastic need for the construction of artificial reservoirs is apparent in their sheer numbers and the fact that they are prevalent in all regions of the Maya Lowlands (see Figure 9.2). As demonstrated in Chapter 5.4, artificial or culturally modified water sources may also be located in regions with abundant water supply. However, the areas with the most difficult access to water sources generally show the highest concentration of reservoirs. Furthermore, the reservoirs of the Elevated Interior Region also exhibit the most monumental dimensions. The hydraulic systems of many sites also show that more than one water source had been modified and/or constructed in order to spread and reduce the risks. Thus, the hydraulic systems of many Maya settlements show a coexistence of both monumental and modestly sized hydraulic features.

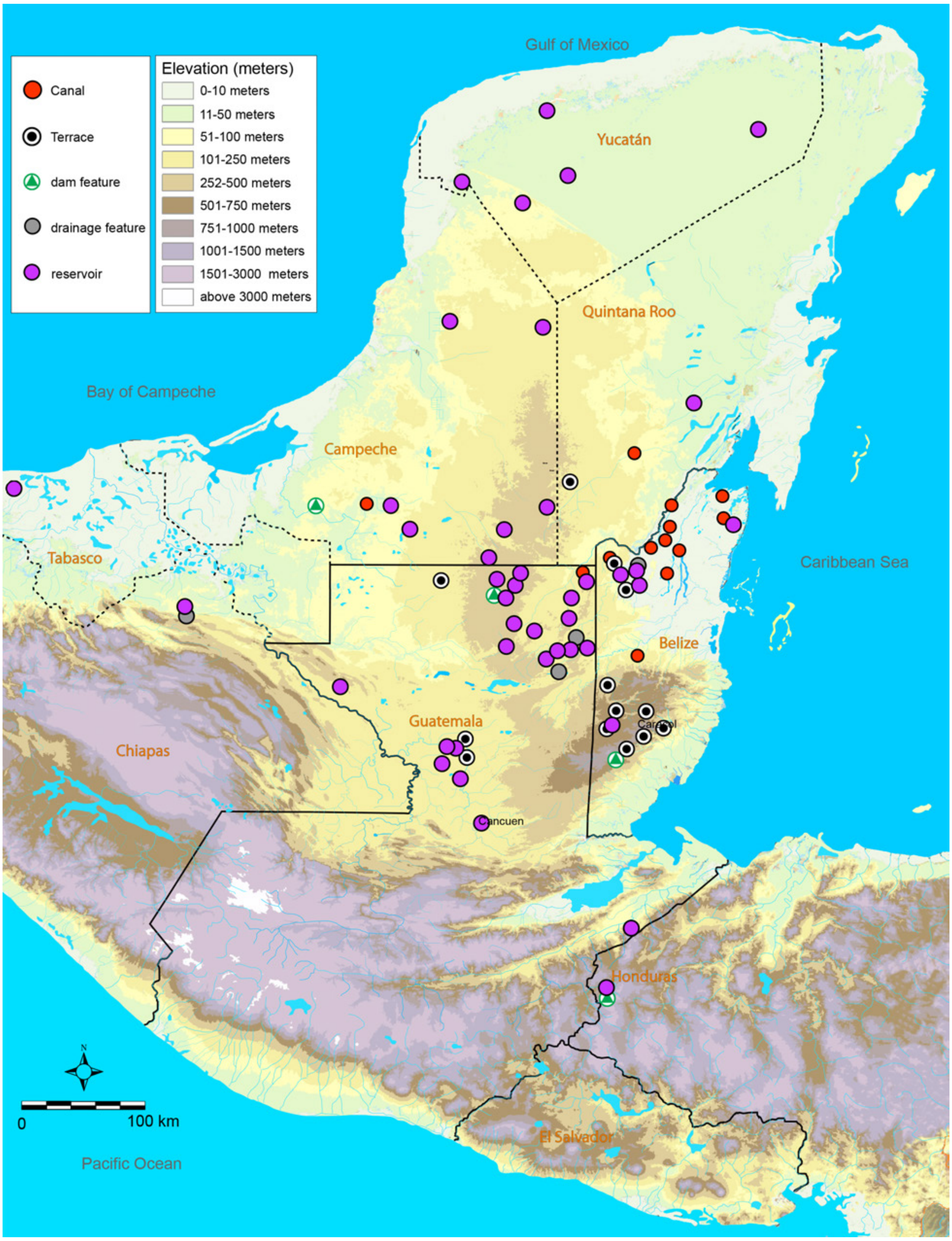

Figure 9.2: Distribution of the different types of hydraulic features in the Maya Lowlands (Map: N. Seefeld, modified from Witschey and Brown 2010). Reproduced with kind permission of Walter Witschey.

9.3 Conclusions on the history of research

As pointed out in Chapter 3, the scientific debate on the hydrology of the Maya Lowlands has always been closely interlinked with the theories on paleoclimatic conditions and the demographic development in the Late Classic Period.

Until the 1930s, scholars were highly interested in the landscape of the Maya Lowlands and the living conditions of its pre-Hispanic inhabitants. However, the publication of Cooke's (1931) theory that the climatic conditions during the Early and Late Classic periods were more humid caused a general disinterest in the adaptation strategies in later decades. Once the scientific community had agreed on the convenient assertion that the Maya Lowlands would have had a much more humid climate in Preclassic and Classic times, few scholars made serious efforts to investigate the subsistence strategies of the pre-Hispanic Maya population in the ensuing decades.[218]

By the 1970s however, the discovery of several previously unknown Maya sites had finally led to the realization that the population density of the Maya Lowlands had apparently been greater than previously expected (Haviland 1970; Puleston 1977: 450; Willey *et al.* 1965). This realization led to the intensification of settlement surveys, the investigation of intensified agriculture and the application of Wittfogel's (1957) concept of hydraulic societies. As a result of intensified settlement studies, more scholars took an interest in understanding the usage of the landscape and the cultivation and adaptation strategies of the pre-Hispanic population. Simultaneously, the investigation of intensified agriculture concentrated on wetland cultivation and agricultural terraces, while the application of Wittfogel's (1957) concept of hydraulic societies was mostly based on theoretical discussions that were regrettably not accompanied by field research.

In hindsight, it is apparent that during the 1970s and 1980s, the approaches to field investigations and the development of theories mostly focused on the issue of agricultural production. This discussion was triggered by the discovery of drained and raised fields along the Río Candelaria, a finding that resulted in additional field studies that led to the identification of comparable features in southeastern Quintana Roo and northern Belize (Turner and Harrison 1983b; Weller 2006). Based on these new discoveries, some scholars developed the idea that wetland agriculture would have represented the most integral component in the agriculture of the pre-Hispanic Maya and that it would have also been practiced along the inner bajos of the Central Lowlands (Denevan and Turner 1974: 24). During this period of research, most scholars still assumed that the climatic conditions during the Classic Period would have been more humid and thus would have also resulted in higher agricultural productivity of inner bajo landscapes. This theory was further encouraged by a publication by Richard Adams (1980: 221), in which he presented several linear features in radar images of the Maya Lowlands that were interpreted as canals and considered proof for the agricultural relevance of inner bajos (Adams 1991: 6323). However, as the existence of these "canal systems" had not been checked in ground surveys, and the results of paleoclimatic studies did not indicate the prevalence of more humid conditions during the Classic Period, the theory of intensive agricultural usage of inner bajo landscapes had to be discarded. What remained, however, was the common consensus that the pre-Hispanic Maya had indeed practiced intensified agriculture through agricultural terraces and irrigated fields along the outer bajo landscapes of the Río Candelaria, southeastern Quintana Roo and northern Belize (Pope and Dahlin 1989: 89). During the 1970s and 1980s, most studies on the cultivation methods of the pre-Hispanic Maya adapted elements of Stewards' culture ecology (Parry 2007: 33).

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[218] Notable exceptions to this trend were the excavations projects in Uaxactun and Tikal. In 1936, Smith studied two reservoirs in Group B of Uaxactun (Weiss-Krejci 1999: 138; see Chapter 5.6.4.3.4). As the results of these excavations were not published before 1950, their implications were only recognized in later decades. In Tikal, Carr and Hazard (1961) had highlighted different sets of paved plazas and excavations of hydraulic features in the site core took place in the 1960s. However, the reports were stored in the Tikal Archives without being officially published. The first official publications on Tikal's hydraulic features were published in the 1990s (e.g. Scarborough and Gallopin 1991).

A broader investigation and discussion of the issue of water supply did not begin until the 1990s. The delayed analysis of this topic was caused by the increasing awareness of the demographic pressure in pre-Hispanic times and the fact that more and more results of paleoclimatic studies indicated that the climatic conditions of the Classic Period had been comparable with those of today. Once the scientific community had grasped the scope of the problem, several projects began the first focused explorations of hydraulic systems in sites like Tikal (e.g. Fialko 1999), Kinal (Scarborough *et al.* 1994), Calakmul (e.g. Folan *et al.* 1995a), and La Milpa (Scarborough *et al.* 1995; Weiss-Krejci and Sabbas 2002). At the same time, the paleoclimatic studies of the 1990s also refined the understanding of the development of climate and landscape in pre-Hispanic times and indicated the occurrence of extreme drought periods during the Late Preclassic and Terminal Classic (Dunning *et al.* 1998; Hodell *et al.* 1995: 391). The concept of the *built environment* was also introduced in the 1990ies. This had a rather small influence on the current concepts of Maya water management, but helped to increase the general awareness of hydraulic features and thus laid the foundation for the more integrated approaches of the 21st century.

Fortunately, the inquiries regarding resource procurement and subsistence strategies with the incorporation of environmental information provided a more profound understanding of the organization of a greater cross section of pre-Hispanic settlements and pre-Columbian society (Davis-Salazar 2001; French 2002). At the same time, the investigations of the 1990s also began to take notice of the specific topographic characteristics of the different sub-regions of the Maya Lowlands and thus enabled a more problem-oriented discussion on the social relevance of water management. Furthermore, the investigations of hydraulic features extended beyond the monumental hydraulic features located in urban contexts and began to acknowledge the existence and relevance of small-scale reservoirs in urban, residential and hinterland settings (Weiss-Krejci and Sabbas 2002). Indirectly, these approaches also led to a more differentiated evaluation of the social relevance of water management, in which hydraulic features were interpreted as an indicator for the drastic need of additional water sources in pre-Hispanic times.

Shortly after the first archaeological investigations of hydraulic systems, some scholars developed the theory that water management would have been a "triggering effect for the development of central political power" (Scarborough and Gallopin 1991: 661), an interpretation that clearly indicated the reapplication of Wittfogel's (1957) concept of hydraulic societies. Furthermore, many archaeologists began to take interest in the interplay between the natural environment and the development of Classic Maya civilization, and to this end, started to incorporate the findings of paleoclimatic studies (Gunn *et al.* 1994).

During the first decade of the 21st century, the general population became more aware and interested in prehistoric climatic transformation processes, a circumstance that many archaeologists used in order to carry out interdisciplinary research projects in cooperation with geographers and paleoclimatologists (e.g. Beach *et al.* 2008; Geovannini Acuña 2008; Torrescano-Valle and Islebe 2015). The investigations over the last five years continued the same interdisciplinary approaches of the last decade and are focused on identifying the specific characteristics of the sub-regions of the Maya Lowlands. The recent publication of LiDAR imagery from the Petén in early 2018 has revolutionized our understanding of the pre-Hispanic settlement landscape and the geographic distribution of hydraulic features (Brewer *et al.* 2017). The coming years will show how the processing of the LiDAR data will modify the knowledge presented in this book.

9.3.1 Theories on the historical development of water management

Even though the research projects of the last decade have led to a more substantiated understanding of the adaptation strategies of the pre-Hispanic Maya, the relatively small number of studied features and the uncertain chronology of hydraulic features limit the reliability of all theories on the historical development of water management. Furthermore, most of these theories were not based on empirical evidence, but rather tried to adapt archaeological findings of hydraulic features into established concepts of Maya history (see Chapter 8.3). However, if the current interest in water management features continues, the reconstruction of the historical development of water management in the Maya Lowlands may achieve greater validity. Currently however, most scholars see the development of settlement and subsistence strategies as a clear chronological sequence of three stages. In a simplified manner, this sequence is:

(1) Foundation of settlements (colonization process)

(2) Development of intensified agriculture

(3) Development of hydraulic features.

9.3.2 Theories on the sociopolitical relevance of water management

In the author's opinion, the theories on the sociopolitical relevance of water management have changed very little over the last decades as they have mostly used the size and complexity of a respective feature in order to determine its social relevance. Despite the more recent approaches that try to encompass the entire range of hydraulic features, the vast majority of scholars focused on monumental hydraulic features in urban settings. Consequently, the majority of theories on the social relevance of water management implied that the construction of hydraulic infrastructure would have required central planning and supervision (see Chapter 8.4.3.1).

One of the main issues of most of these theories was the fact that they were only based on a small number of hydraulic features and, consequently, were not differentiated enough to provide a thorough assessment of the social relevance. Instead of developing a differentiated evaluation, most scholars emphasized the centralizing effect of water management. In this process, only a few scholars (e.g. Lucero 2002: 815; Scarborough and Valdez 2003: 3; Weiss-Krejci and Sabbas 2002) developed theories that took the coexistence of monumental and small-scale, and urban, residential and hinterland hydraulic features into consideration.

In order to develop a more differentiated evaluation of the social relevance of water management based on the greatest possible number of hydraulic features, the author developed a new set of evaluation criteria (see Chapter 8.5). The application of these criteria showed that most reservoirs with modest extensions had been constructed and used by small and medium sized social groups that controlled the access to them. The monumental reservoirs on the other hand were (most likely) still accessible to everybody, which indicates the coexistence of water sources built by household groups and those built under centralized control. In the author's opinion, the modestly sized and privately organized reservoirs were homogenously distributed throughout the different areas of the settlement landscape and can be interpreted as an addition to the public and monumental reservoirs.

By following the stipulation of Weiss-Krejci and Sabbas (2002) to be mindful of the entire scope of hydraulic features throughout the settlement landscape, the application of these evaluation criteria revealed that a large portion of reservoirs were obviously managed on a household level and therefore would not have been suitable as instruments of power (Crandall 2009: 19). Consequently, a central authority could have only exerted power over the reservoirs built under his command, but not those constructed and managed on a household level. Owing to this realization, the author considers it inappropriate to define water management as the central instrument of power for the rulers of Classic Period Maya polities. Instead, it appears that most pre-Hispanic inhabitants of the Maya Lowlands had managed their own hydraulic systems on a community level. Despite the assessment of Golden and Scherer (2012: 71), who claimed that centrally controlled hydraulic systems would have been a phenomenon confined to large sites such as Tikal and Calakmul, the author would like to object by noting that even medium-sized Maya centers such as Uxul had apparently developed hydraulic systems commissioned and constructed under centralized control.

9.4 Significance of Uxul's hydraulic system for the discussion of water management in the Maya Lowlands

In the author's opinion, the results gained from the archaeological investigation of Uxul's hydraulic system have both solidified previously existing theories and patterns, and provided new insights into the technical structure, functionality and social relevance of water management in pre-Hispanic Maya society. On a technical scale, the fundamental research carried out in the Aguada Oriental showed that the Classic Maya did indeed cover the entire base of their reservoirs with stone pavements. Based on this result, future investigations by other archaeologists documenting similar pavements in less extensive trenches will have evidence that the entire reservoir was sealed with a pavement.

The design and dimensions of Uxul's hydraulic system clearly indicate that the pre-Hispanic inhabitants had experienced drastic water scarcities during the dry seasons, which forced them to construct several artificial water sources that could satisfy the needs of a growing population (Seefeld 2013a: 76). Through the intensive investigation of the hydraulic features, the author was able to calculate that each of the two central reservoirs was able to store at least 11,000 m^3 of water (Seefeld 2013a: 76; see Chapter 6.3.6). Furthermore, the high quality of execution reflected in the documented constructions indicates that either the local population or the city planners had advanced experience in the construction of hydraulic features, something indicative of a long history of learning to work on and with these features. In the case of the three major hydraulic features (Aguada Occidental, the influx canal to Aguada Occidental and Aguada Oriental), the sophistication also indicated the necessity of centralized control for the planning, construction and maintenance of these features (Seefeld 2013a: 78).

Since the excavations of the Uxul Archaeological Project also led to the discovery of some minor hydraulic features in residential areas, it seems reasonable to state that the social setting of Uxul allowed for the coexistence of monumental public reservoirs and smaller reservoirs that were created, managed and owned by individual families or household groups. Nevertheless, the monumental public reservoirs apparently required centralized supervision. In the settlement of Uxul, the ruler of the site had obviously decided to invest some of the available workforce into the construction of public reservoirs. In the author's opinion, this decision indicates that the assurance of water supply for the city's commoner population was among the ruler's responsibilities. Finally however, the local population of Uxul had apparently been so highly dependent on the public infrastructure of the monumental reservoirs that they were no longer able to maintain a constant water supply after the downfall of the political system at the onset of the Terminal Classic. This becomes apparent in the fact that scattered inhabitants of the Terminal Classic were evidently unable to build additional artificial reservoirs and were furthermore lacking the social cohesion to protect the infrastructure that had originally enabled their survival in this environment (Seefeld 2013a: 78).

In the author's opinion, the development, functionality and shape of Uxul's hydraulic features indicate that the social setting of Uxul was marked by a form of interdependency between rulers and commoners (see Chapter 8.6). In this relationship, the ruler had to satisfy the basic needs of his subordinates, which in turn enabled his privileged position (Seefeld 2013a: 78). Consequently, a ruler was not in possession of "total power" despite his privileges. Nevertheless, the commoners were indeed dependent on the authority of a centralized ruler, whose position enabled the design, enforcement and supervision of construction of the vitally important infrastructure.

It is the author's opinion that the relationship of interdependency between rulers and commoners and the relevance of the public infrastructure for the survival of the settlement might help to explain why the process of collapse developed so rapidly (Seefeld 2013a: 78). The neglected maintenance of existing infrastructure in combination with the absence of new constructions may have caused a domino effect, which would have accelerated and aggravated the process of collapse (Seefeld 2013a: 78).

9.5 Evaluation of the current state of research

While the previous sections provided a brief review and discussion of the topics covered in this book, the concluding section of this chapter highlights the approaches of the current state of research. However, it is important not to overlook the serious systemic issues that marked the investigation of Maya water management in the past.

9.5.1 Previous research issues

In the author's opinion, the limited knowledge of the adaptation strategies of the pre-Hispanic Maya is the result of four central research issues:

(1) General transfer of local findings or conditions to the entire Maya Lowlands,

(2) Deficient documentation and/or publications of hydraulic features,

(3) Focus on conservative archaeological research approaches, and

(4) Lack of scientific interaction between different scholars.

As noted throughout this book, many scholars assigned the observations of local paleoclimatic conditions or specific archaeological features to the whole of the Lowlands even though the great ecological and cultural variety of this landscape was largely acknowledged by the majority of the scientific community (Culbert *et al.* 1978: 58; Dunning *et al.* 2006: 81; Pope and Dahlin 1989: 89; Seefeld 2008: 137).

Another pressing issue for the adequate identification and evaluation of pre-Hispanic adaptation strategies is the quality of documentation and/or publication material of hydraulic features, which does not match the standards of other areas of Maya archaeology or other archaeological disciplines. Unfortunately, these insufficiencies are apparent in both the documentation and publication of topographic surveys and archaeological excavations. Due to these insufficiencies, it is often challenging, if not impossible, to retrace the functionality of some hydraulic features or even check the plausibility of arguments or hypotheses based on the published documentation material. Even though it should be acknowledged that these insufficiencies are partially caused by the scarce research budgets, the lowering costs of current technology, i.e. digital cameras, no longer make it excusable that graphically deficient documentations of hydraulic features continue to be published.

To a certain extent, the deficient documentation quality of hydraulic features is also caused by the fact that many of these constructions were discovered by accident. As stressed in Chapters 3 and 5, hydraulic features have only been granted focused archaeological investigations over the last two decades. In the author's opinion, the negligent investigation of hydraulic features is a direct result of the "elite-heavy" focus of Maya archaeology that is regrettably still rooted in the traditional and conservative approaches of the 19th century. To this day, most archaeological projects are concentrated on recurrent, media-effective pyramidal complexes, palace complexes, classic stelae and royal tombs (Dunning *et al.* 2015b: 3). In many cases, the concentration on these aspects provided a good understanding of the living conditions of the inhabitants of the palace structures and the chronology of the site centers. However, most of the "traditional" projects did not attempt to investigate the actual subsistence strategies of the respective Maya site, or the connection to its hinterland (Dunning *et al.* 2015b: 3). Finally, the lack of scientific interactions between different scholars – a problem affecting all too many scientific fields – has also slowed the acquisition of knowledge on the adaptation strategies of the pre-Hispanic Maya. Luckily however, many of the current projects focused on the identification of pre-Hispanic adaptation strategies have recognized these previously existing research issues and have therefore modified their research approaches.

Thus, many scholars have developed an increased awareness of the ecological variability in the Maya Lowlands, a pattern that becomes apparent in the more differentiated statements on the relevance of local climatic conditions. Furthermore, most current projects practice more interdisciplinary approaches that are no longer entirely focused on the living environments of the elites, but also try to investigate new aspects of Maya society (Dunning *et al.* 2015b: 2). In the author's opinion, the newly awakened interest in the hydraulic features of the pre-Hispanic Maya can be seen as a reflection of the public's current interest in the topic of climate change and its impact on human societies. Finally, the last decade has also experienced increased scientific interaction between different scholars, a process that was to a substantial degree enabled by the extensive publication of smaller research reports or Master and PhD theses in electronic form.

9.5.2 Summary of the current state of research

Due to these positive trends, the research of the past 15 years has doubtlessly resulted in the most extensive and important gain of knowledge regarding Maya water management since the inception of Maya archaeology. Despite these positive trends, the current understanding of adaptation strategies is still drastically underdeveloped in comparison to other aspects of the Classic Maya society. This circumstance is obviously the result of the elite-heavy research approaches in Maya archaeology.

Currently, one of the most pressing unresolved issues is the aspect of agricultural production in the different region of the Maya Lowlands (Jacob 1995: 188). While the discussion of the agricultural potential of wetlands dominated the 1970s and 1980s, most current approaches do not investigate the issue of agricultural production. Thus, the core of the problem has still not been satisfactorily clarified (Fedick and Ford 1990: 19; Pope and Dahlin 1989: 89).

Fortunately however, the increased awareness of the environmental and cultural variability of the Maya Lowlands has resulted in a less polemic, and more problem-oriented discussion in the scientific community enabling a more differentiated evaluation of the climatic conditions in pre-Hispanic times and the social relevance of hydraulic features (Rejmankova *et al.* 1995: 34; Seefeld 2008: 136; Turner and Harrison 1983b: 251).

Due to this awareness, current approaches try to reconstruct the climatic conditions specific to a single region and identify the adaptation strategies of its pre-Hispanic inhabitants. In this process, most scholars have acknowledged that the landscape was subject to highly differing hydrological and climatic conditions over time (Dunning *et al.* 2006: 84; Pope and Dahlin 1989: 89).

As a result of the larger corpus of archaeologically investigated reservoirs, most of today's scholars agree that their sheer size and the apparent amount of labor invested in their construction illustrates their important role for the survival of pre-Hispanic Maya society (Geovannini Acuña 2008; Akpinar 2011: 19; Crandall 2009; Folan *et al.* 1995; Gunn *et al.* 2002; Matthewson 1977; Scarborough and Gallopin 1991). Therefore, most scholars interpret them as indicators for the extent and severity of water scarcity during the dry seasons. Also, the recently published LiDAR imagery of the Petén cearly illustrate the ubiquity of hydraulic features and will hopefully increase the renewed interest into the adaption strategies of the pre-Hispanic Maya.

9.6 Desiderata for future research

As indicated above, the current interest in hydraulic features and the focus of most current research projects shows a welcome direction that will hopefully enable the reconstruction of water management techniques to be based on broader empirical evidence in the near future. Nevertheless, the author would like to suggest that a more systematic investigation should still incorporate the following six approaches:

(1) Improvement of documentation standards,

(2) Improvement of theoretical models,

(3) Continuing differentiation of local variability in the Maya Lowlands,

(4) Continuing reconstruction of paleoclimatic conditions in the Maya Lowlands,

(5) Systematic investigation of the social relevance of specific hydraulic features, and

(6) Closer collaboration and integration of datasets from different scholars and fields of research.

As already pointed out, one of the central issues in the investigation of Maya water management was and still is the deficient documentation and/or publication of hydraulic features, an issue that could certainly be overcome through the application of newly developed methods for documentation and graphical representation.

In the author's opinion, the investigation of water management in the Maya area would also be more productive if the theoretical models on the historical and social relevance of water management were based on a larger number of actual hydraulic features. In the past, many theories tried to reconstruct the social relevance of water management based on a handful of hydraulic features. In other instances, theoretical models were unable to withstand thorough analysis and proved to be circular arguments. In consideration of short term projects, scholars oftentimes lack the opportunity to place a specific observation into the broader context. Furthermore, archaeologists always feel compelled to use the full information potential of recently discovered features. However, archaeological features are naturally limited with regard to the extent of information we can glean from them. In order to improve the validity of the theories on the historical and social relevance of water management, it would therefore be appropriate to heed the advice of Gordon Willey (1980), who pleaded for a more holistic Maya archaeology (Garrison and Dunning 2008: 536). To this end, it would be fruitful to identify the catalysts for ecological and cultural transformations that have been observed by different scientific disciplines in the Maya Lowlands (Garrison and Dunning 2009: 547).

As stated throughout this book, the identification of specific local conditions should focus both on the natural landscape and on the cultural adaptation strategies. In order to refine the understanding of local variability, future investigations should therefore continue to carry out precise surveys of the local topography and develop a stronger sensitivity for pre-Hispanic landscape modifications and hydraulic features (Seefeld 2008: 138). One of the main insights that arose from the investigations of Uxul's hydraulic system is that a profound assessment of potential hydraulic features always goes hand in hand with a good knowledge of the local landscape. While this remark might appear self-evident, the importance of detailed topographic surveys and ground-inspections cannot be stressed enough. In previous decades, many scholars have had a tendency to overlook or completely miss "invisible features" (Healy *et al.* 2007: 28). Therefore, the investigation of hydraulic features should never be based solely on topographic surveys and/or remote sensing (Culbert *et al.* 1991: 120; Seefeld 2008: 139, Webster *et al.* 2007: 61; Weiss-Krejci and Sabbas 2002: 352). The author's experience during the topographic survey of the Uxul Project has shown that archaeological excavations outside of visible architectonical features not only revealed "invisible features" (e.g. the Artificial Cave of Group Q), but also provided a more profound understanding of how the "visible structures" and Uxul's inhabitants could be sustained. The latter assertion once more illustrates the legitimacy of Weiss-Krejci and Sabbas' (2002: 353) demand, which required that the entire landscape be surveyed for potential water sources. Luckily, the initial investigation of small depressions in the Río Bravo region led to a series of similar studies over the last decade (see Chapter 5.6.5.3.8). At this point, the series of investigations in the Río Bravo region now represents the most intensive regional survey and excavation project of hydraulic features in the whole Maya area.

As discussed in Chapter 8.7, some sites maintained a coexistence of privately owned and public reservoirs. In the author's opinion, a promising topic of future research would be the identification of the different social groups that may have used a particular water source or a refinement and application of the evaluation criteria presented in Chapter 8.5 to other sites or hydraulic systems. A consequent application of these evaluation criteria could thus be a first step towards a more systematic and objective evaluation of the social relevance of hydraulic features in specific sites, regions and the Maya Lowlands in general.

Finally, the author would like to highlight once again that future research projects should increase the interchange of datasets from different sites and academic disciplines in order to improve the usability and validity of the social and historical theories. In this respect, it should also be a goal to use the advantages of interdisciplinary research approaches to their full potential. For a more precise elaboration of interdependencies between human settlements and the natural landscape, it would be fruitful to disassociate from the overt concentration on the site core and instead incorporate the entire landscape into the study (Dunning *et al.* 2006: 98). Theoretically, such an interdisciplinary study would have to include the topographic survey of the settlement landscape. This would not only concentrate on cultural features such as potential reservoirs, chultunes and other landscape modifications, but also identify the different soils, vegetation and drainage patterns (Culbert et a. 1991: 122). In this process, it would also be rewarding to define a more holistic approach to the adaptation strategies, which would concentrate both on the issue of water supply and that of agricultural production.

In order to gain a more comprehensive understanding of pre-Hispanic Maya settlements and their relation to the natural landscape, the recently published LiDAR imagery of the Petén should be intensively processed (Akpinar Ferrand and Dunning 2011: 117; Chase *et al.* 2011; Webster *et al.* 2007: 63). The analysis of the LiDAR should also be complemented by an extensive ground-inspection of the landscape features identified by remote-sensing. A promising example of how research projects may combine the results of different research disciplines is the article by Garrison and Dunning (2009) on the environmental and cultural history of San Bartolo and Xultun. This work is an excellent example of an investigation integrating different datasets that enabled a more informative assessment of the environmental and cultural history of these two sites in pre-Hispanic times.

9.7 Closing remarks

> *"Archaeologists should often come to distrust the tales they tell about the past, because the alchemy of repetition transmutes fragmentary evidence and anecdote into unquestioned archaeological fact"* (Webster *et al.* 2007: 46).

In order to conclude this book, it must be stressed that despite unresolved research questions, the investigation of hydraulic features has made significant progress since the 1970s, particularly over the last 15 years. Due to the increased awareness of ecological and cultural variability and a sensitivity for differentiating different regions of the Maya Lowlands, the research since the onset of the 21st century has provided the most extensive gain of knowledge on Maya water management since the inception of Maya archaeology. Due to the intensified archaeological investigation of hydraulic features in the Maya Lowlands, we have gained a more profound understanding of the basic adaptation strategies for a constant water supply (Seefeld 2013a: 79).

For the overarching research question of this book, the investigations of Uxul's hydraulic system have provided fundamentally new insights into the practical solutions for securing a constant water supply, the development of the public infrastructure over time, and their relevance for the pre-Hispanic inhabitants. The archaeological investigations, which were carried out with the objective of developing a functional model of water supply for the settlement, revealed new constructional methods and forms of hydraulic structures, whose scale and accurate execution made clear the importance that was attributed to them. Moreover, the possible interdependence between rulers and commoners, which may be expressed in the formation and demise of public infrastructure, bears an interesting potential for ongoing research since it might help to explain why the process of the collapse occurred so rapidly (Seefeld 2013a: 79).

In the general field of research, the approaches and results of various interdisciplinary projects have illustrated the possibilities of archaeological research in an interdisciplinary network with geography, pedology, geology, and remote sensing technology (Seefeld 2008: 140). In some instances, the results of these interdisciplinary projects have even been able to show that the insights into the adaptation strategies of the pre-Hispanic Maya still hold a practical value for today's inhabitants of the Maya Lowlands (Jacob 1995b: 175). As modern population waves are once again threatening the ecologic equilibrium of the Maya Lowlands, some of the sustainable adaptation strategies developed by the pre-Hispanic Maya could be used as examples for new cultivation methods that conserve the fragile landscape (Gliessman *et al.* 1983: 91; Scarborough *et al.* 2012: 12413). Thus, the discoveries of the agricultural potential of wetland cultivation and terrace agriculture might be considered and promoted as alternatives to the extensive swidden agriculture that currently represents the predominant form of cultivation in this landscape (Dunning and Beach 1994: 64; Hansen *et al.* 2002: 290). Here, the new LiDAR data provide promising opportunities. In the author's opinion, the decisive factor for the sustainability of pre-Hispanic agricultural techniques consisted of the application of labor-intensive wetland and terrace cultivation, which ensured the long-term conservation of the natural environment (Macrae and Iannone 2011: 188).

Therefore, it seems justified to conclude that the adaptation strategies presented in Chapters 5 and 6 indicate that the pre-Hispanic Maya had made wise decisions regarding sustainable usage of their landscape. This resulted in the evident resilience and reduced negative effects for the biophysical environs (Beach *et al.* 2008, 2009, Burney and Burney 2010; Diamond 2005; Dunning and Beach 1994; Dunning *et al.*1998, 2002; Golden and Scherer 2012: 68; McNeill 2009, 2011, McNeill *et al.* 2010; Scarborough *et al.* 2012: 12413). This is also apparent in the fact that some pre-Hispanic features, such as the well features in and around Dzibilchaltun, had apparently been used in Postclassic times and even after the conquista (Maldonado *et al.* 2012: 56). In the author's opinion, these observations indicate once again that the most intriguing aspect of the hydraulic features in the Maya Lowlands is not their relation to the process of the collapse. Instead, the building programs of Early Classic and Late Classic Maya rulers indicate that their far-sighted political decisions laid the foundation for the settlements under their control to prosper for astonishingly long periods and to sustainably adapt to the natural environment.

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