

IRRIGATION in
EARLY STATES
NEW DIRECTIONS

Edited by
**STEPHANIE
ROST**

THE ORIENTAL INSTITUTE OF THE UNIVERSITY OF CHICAGO
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Stephanie Rost

with contributions by

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Papers from the Oriental Institute Seminar

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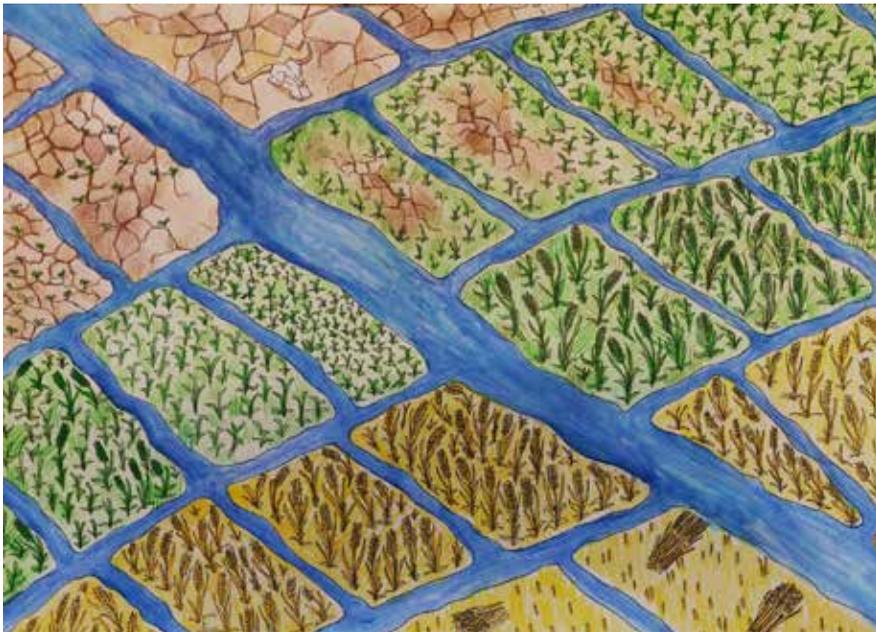
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Preface

This volume is the result of the annual postdoctoral fellow conference held at the Oriental Institute (OI) of the University of Chicago on March 3–4, 2016. The conference, “Irrigation in Early States: New Directions,” brought together experts in the field of irrigation studies and covered a wide regional and temporal scope. The case studies presented take the reader around the globe, from South and North America to Africa and West, Central, and Southeast Asia. The book and its individual chapters reexamine the long-held debate about the role of irrigation in the formation of early states. Because many early civilizations developed in large river valleys, earlier approaches argued that their evolution followed a similar trajectory as a result of their dependency on irrigation. Our enhanced knowledge of ancient civilizations, however, has taught us that the evolution of social and political complexity is neither linear nor the result of an interplay among a set of predictable prime movers leading to a similar outcome in various parts of the world. There is a consensus that the circumstances under which civilizations emerged are characterized by both diversity and similarity and that irrigation cannot have been the sole driving force behind the development of social and political complexity. Once the evolutionary perspective was taken out of the investigation of ancient irrigation, space was created for renewed investigation of the multiple functions that irrigation may have had in the development and functioning of early states. The conference made use of this space in conducting a cross-cultural study of ancient irrigation with a larger quantity of data and, more importantly, the goal of highlighting the diversity of functions that irrigation had in early states and the variety of conditions under which it developed. We hope that the contributions in this book inspire new directions in the investigation of ancient irrigation and ultimately lead to a more nuanced understanding of the past.

The conference, and the publication of the participants’ contributions, could have not been realized without the generous support of many people. I thank, first and foremost, Arthur and Lee Herbst for their continuing and generous financial support of the annual postdoctoral fellow program. I thank Gil Stein, former director of the OI, for giving me the opportunity to work and undertake research at the OI; Chris Woods, professor of Sumerology and former director of the OI, and now Williams Director of the University of Pennsylvania Museum of Archaeology and Anthropology, for being a true and supportive mentor; and Mariana Perlinac, assistant to the director of the OI, and Brittany Mullins, the OI’s former associate director of development, not only for providing support for the conference but also for helping me get settled at the OI and in Hyde Park. I also express special thanks to the OI publications office’s former managing editors Tom Urban and Charissa Johnson, former editor Leslie Schramer, and current managing editor Andrew Baumann and editorial assistant Rebecca Cain, whose tremendous editorial support and continued assistance made the organizing process of the conference and the publication of this book smooth sailing. I thank Kiersten Neumann, curator, for giving the conference

participants a great tour of the OI Museum galleries; Knut Boehmer, IT support specialist, for excellent technical support; and Charles Derbigny for logistical support in running the conference. I am also grateful to Morag Kersel, associate professor of anthropology at DePaul University; Richard Payne, associate professor in ancient Near Eastern history at the University of Chicago; and James Osborne, assistant professor of Anatolian archaeology at the University of Chicago, for functioning as session chairs. My gratitude also goes to Steve Camp, the OI's former executive director; D'Ann Condes, former financial manager; and Nathaniel Francia for handling the financial aspects of the conference. Many thanks also to two previous postdoctoral conference organizers, Ilan Peled and Miriam Mueller, to whom I could always turn for advice. I also thank my postdoctoral colleague Lynn Welton, who was very generous in helping and providing input. Finally, I thank all the speakers for being such a pleasure to work with and for providing truly excellent contributions to this volume.



Watercolor rendering of an irrigation system by Johanna Rost

Introduction

ANCIENT IRRIGATION AND the formation of early states have been the focus of a considerable body of research and theoretical literature in the fields of archaeology, anthropology, and history. The fact that many early civilizations, particularly of the Old World, emerged in large river valleys (e.g., Euphrates-Tigris, Indus, Nile, Yangzi) led scholars to assume a causal relationship between the organization of large-scale irrigation and the development of social and political complexity. The earliest studies on ancient irrigation management argued that those civilizations followed a similar trajectory in their evolutionary history due to their dependence on irrigation. Thus, ancient irrigation management was very much understood in terms of an environmental determinism reflective of the paradigm of its time that went along with identifying (through cross-cultural comparisons) the prime movers responsible for the social and cultural evolution of humankind. Hence, Julian Steward¹ called for a cross-cultural comparison of these “hydraulic civilizations” in order to understand and explain the mechanism behind this allegedly similar evolutionary history, which was thought to be found in the managerial requirements of large-scale irrigation (e.g., construction/operation, water distribution, conflict resolution). Most scholars at the time assumed that the organization of large-scale irrigation systems required centralized control. This need for centralized control led to the development of institutions whose political control was expanded to other aspects of social life and gave the impetus for the formation of the state.²

These early studies on ancient irrigation were very much influenced by the work and writings of Karl Wittfogel.³ He presents a wide array of case studies from the Orient and Far East in his book *Oriental Despotism* to show that water control on a large scale will inevitably lead to the formation of despotic forms of governance. The “hydraulic hypothesis” formulated by Wittfogel insists that the construction and maintenance of “massive hydraulic devices” was institutionally decisive *if* it was conducted on large-scale irrigation (“hydraulic agriculture”) and took place in an arid or semiarid river plain.⁴ To be successful, massive hydraulic devices are needed for (1) irrigation (preparatory operations) and (2) flood control (protective operations).⁵ The construction and maintenance of hydraulic devices would require tremendous amounts of labor, which could only have been recruited and supervised by a central “directing authority.”⁶ Further, the need for centralized oversight led to greater political integration. The control of access to water and land in a

1 Steward 1955.

2 Childe 1950, 8; Millon 1954, 178; Steward 1955, 2; Sanders and Price 1968, 177–87.

3 Wittfogel 1957.

4 Wittfogel 1957, 18–19, 23–24.

5 Wittfogel 1957, 23–24.

6 Wittfogel 1957, 18, 25–29, 50–54.

semiarid setting eventually allowed for the concentration of power in the hands of a single despotic ruler.⁷ Wittfogel does not suggest, as a number of scholars have mistakenly assumed, that the performance of irrigation per se led to political centralization, but rather that a series of conditions, including large-scale hydraulic structures, led to this result.⁸

Wittfogel's hydraulic hypothesis has been an unwearied engine for the study of irrigation both ancient and recent, even though it did not aim to provide an explanatory model for the formation of early states. Instead, Wittfogel's research was motivated by a political agenda: to discredit Karl Marx's claim that the nationalization of all means of production was a cure for the grievances caused by an unregulated capitalistic market economy. Wittfogel's hypothesis was based in part on the concept of the "Asiatic mode of production" developed by Karl Marx, which claimed that government-directed water control gave birth to the Asiatic state.⁹ While Marx acknowledged that the means of production in an Asiatic society was owned by the state, Wittfogel claims¹⁰ that he deliberately obscured its despotic nature. He did so, according to Wittfogel,¹¹ because he must have realized that "as a member of a group that intended to establish a total managerial and dictatorial state and was ready to use 'despotic measures' to achieve its socialist ends, Marx could scarcely help recognizing some disturbing similarities between Oriental despotism and the state of his program." He believed that examination of ancient and historical cases of state-controlled water management not only described the origins of despotic forms of governance but also explained the despotic nature of communist regimes, which he saw in the nationalization of all means of production. As such, the fairly dogmatic nature of his writings, which also drew a problematic dichotomy between West (Europe) and East ("Orient"), provoked scholars from various disciplines to challenge his hypotheses.¹²

Ethnographic research, in particular, provided ample evidence that centralized control in the management of irrigation systems is just one choice of many and that the social organization of water control is far more complex than had hitherto been realized. Cultural anthropologists documented a wide array of management forms, ranging from communally organized to centrally managed systems with varying degrees of state involvement. More importantly, these studies revealed that the motivations of states to opt for—or abstain from—assuming centralized control varied drastically from case to case.¹³ Most decisive was Robert C. Hunt's¹⁴ comparative study, which showed that there was no direct correlation between the size of a system and how it is managed. His sample included a system of 458,000 ha that was organized by the local irrigation community, while another system of much smaller size (700 ha) was state run.

7 Wittfogel 1957, 100ff., 187ff., 303–48.

8 Mitchell 1973.

9 Wittfogel 1957, 374.

10 Wittfogel 1957, 387.

11 Wittfogel 1957, 387.

12 Wittfogel 1957, 369.

13 Downing 1974; Fernea 1970; Glick 1970; Gupta 1998, 4–15; Lees 1974, 124; Netting 1974; Sagardoy, Bottrall, and Uittenbogaard 1986, 140.

14 Hunt 1988b.

Similar observations have been made archaeologically. Irrigation systems of the Hohokam period (450–1450 CE) found in the Phoenix basin in Arizona were of considerable size (>8,000 ha), though operated by a Neolithic society that had not yet reached statehood.¹⁵ Research by Li Min et al. (in this volume) on late fourth-millennium BCE Liangzhu mound centers in ancient China makes a similar observation: large-scale water management structures predate the advent of the state. Thus, as Mitchell¹⁶ rightfully stated four decades ago, “any society may or may not direct its irrigation activities centrally; such direction is not necessary.” In turn, centralized control cannot be assumed based on the physical attributes of an irrigation system (e.g., its size or technical complexity) but needs to be empirically demonstrated.¹⁷

With Wittfogel’s hypothesis debunked, Michael J. Harrower¹⁸ rightfully asks, “Should water and irrigation be excluded as significant contributors to state formation?” The insights provided by the contributors to this volume argue strongly against such a conclusion. However, as Harrower further notes, “Even though the hydraulic hypothesis has been repeatedly refuted, no clearly articulated alternative explanation of water’s influence has appeared to replace it. The hydraulic hypothesis thus continually and unhelpfully reappears in scholarly dialogue contributing perpetual attention to whether centralized control of irrigation was *required* or not when this issue merely distracts from reappraisal of water’s role in the genesis of civilizations.”¹⁹

This shortcoming has been due in part to a declining scholarly interest in the cross-cultural study of ancient irrigation, until recently.²⁰ As a result, many important questions have been only partially answered. We do not know how—and even more importantly, why—states may have assumed, or abstained from assuming, control over irrigation management. Moreover, the consequences of either choice have never been systematically investigated in a cross-cultural comparison.²¹

As this volume will show, irrigation fulfilled various functions in early states. It played a key role in the intensification of agriculture and the production of surplus to support early states. However, as the contributions of Hunt and Hervé Reculeau in this volume show, the matter is far more complex than has hitherto been realized. As few attempts had been made to quantify input and output of irrigated agriculture in antiquity, its economic importance in early state formation may have been overstated.²² The quantification of both Hunt and Reculeau shows that an array of conditions needs to be met (e.g., ample water supply, sufficient labor) for irrigation to be an effective method for producing a significant

15 Hunt et al. 2005; Woodson 2016; Woodson and Hunt, in this volume.

16 Mitchell 1973, 533.

17 Downing and Gibson 1974; Fernea 1970; Goldfrank 1945; Hunt 1988b, 1988a, 1996, 2007; Kelly 1983; Mitchell 1973.

18 Harrower 2016, 77.

19 Harrower 2016, 77.

20 Harrower 2016; Hritz 2010; Kaptijn 2010, 2015; Rost 2011, 2015, 2017, 2019, 2020; Rost and Hamdani 2011; Rost, Wright, and Woodson 2017; Ur 2005; Woodson 2016.

21 Except for Scarborough 2009.

22 Adams 1965, 1981; Butzer 1976; Dales 1965; Doolittle 1990; Lowdermilk and Wickes 1942; Millon 1954; Park 1983.

agricultural surplus. Hence, the economic function of irrigation needs to be assessed on a case-by-case basis.

Irrigation can also have an ideological function to serve political ends. For example, the “hydraulic mission” of the early twentieth century CE had a strong ideological character that was often at odds with economic rationale or needs.²³ Large-scale hydraulic projects (e.g., dams for irrigation, flood control, and hydropower) in the context of the Cold War were portrayed as national symbols of superiority of the economic/political system in countries such as Russia, China, and the United States. In addition, the establishment of state water bureaucracies, or “hydrocracies,” became the driving force of the hydraulic mission as a means of self-preservation and asserting their position among other state bureaucracies. As a result, many projects were outsized and failed to deliver the publicized economic benefits, and many resulted in significant environmental destruction.²⁴

Moreover, as shown by Harrower²⁵ and Kathleen D. Morrison,²⁶ the social and political capital gained from assuming patronage over the construction of hydraulic devices of monumental size—clearly visible in the landscape—was of equal or greater importance than economic development. Morrison²⁷ shows that it was not only states that exploited the ideological dimensions of irrigation for political ends. Investments in the construction of mid-fourteenth to late sixteenth-century CE reservoirs in the Vijayanagara region in India were made primarily by members of local elites and not by the crown. The costs of the elaborate architectural embellishments and monumentality of the reservoirs’ sluice gates were disproportionate to the revenues recovered from the rice cultivation these reservoirs supplied water to. Thus, Morrison²⁸ argues that these reservoirs represent claims about the power and authority of these local elites. The sluice gates resembled temple doorways; as many temples were under royal patronage, sluice gates evoking temple architecture reflected a claim of “royal-like” power by local and nonroyal elites over the local populations.

Irrigation also has a cosmological dimension, as the work of J. Stephen Lansing²⁹ shows. He was able to describe how irrigation management was tied to the larger cosmological and mythological belief system in Bali. It included regular rituals at water temples, located at major and minor intersections of the irrigation infrastructure. The kind of rituals, their timing, and the temple at which they were carried out aided the management of the system such that they underpinned the scheduling of agricultural/irrigation tasks but at the same time reinforced what Lansing³⁰ calls “hydraulic solidarity,” in particular between upstream and downstream users. In addition, the ritual of holy water performed at the beginning of the agricultural cycle annually reinstates the “hydro-logic” of the water allocation hierarchy—from the gods to the people via the earthly administrators of the gods (priests). As such, this ritual cements the power of the temples and the greater high

23 Scarborough 2009, 3.

24 Ertsen 2006; Molle, Mollinga, and Wester 2009.

25 Harrower 2009, 2016.

26 Morrison 2006, 2012; Morrison and Lycett 1994.

27 Morrison 2012.

28 Morrison 2012, 166–67.

29 Lansing 1991, 2012.

30 Lansing 1991, 48.

priest (Jero Gde Duuran) necessary to arbitrate water conflicts and make decisions affecting the system (e.g., opening up new agricultural land). In addition, the engineered irrigated landscape follows cosmological principles—an aspect that has largely been overlooked by earlier studies of ancient irrigation systems.

These few examples indicate that the prime focus of earlier studies testing Wittfogel's hydraulic hypothesis led scholars to overlook many functions that irrigation may have had in the formation and workings of early states. The conference "Irrigation in Early States: New Directions" and the present volume were designed to address these shortcomings. However, contrary to earlier approaches, the goal was not to define yet again a cross-cultural regularity in the role that irrigation played in early state formation, but rather to investigate the multiple ways in which it may have contributed to this process. With a much larger body of empirical data now available, the time is ripe to define new directions in the investigation of ancient irrigation and its role in the formation of early states. As the case studies presented in this volume show, defining those new directions has the potential to greatly enhance our overall understanding of early states.

The subject of water management for irrigation and other purposes is also a topic of great relevance to our modern world. As Hunt³¹ notes, 40 percent of the world's agricultural production is based on irrigation, and the largest gains in the efficiency of existing systems are now seen in improvements in management. Given the importance of irrigation in the world economy, it is essential that we understand how these systems are organized. Moreover, given the looming global water crisis (in terms of both water scarcity and flooding), there is an increasing demand for scholarship on ancient irrigation and water control. The diachronic depth of the case studies examined by anthropologists, archaeologists, and ancient historians is relevant to the understanding of how cooperation among water users (or users of a common resource more broadly) can be maintained over time and why and how systems remain resilient to environmental and political change.³² Archaeologists study systems, which differ considerably in the duration of their use, with some being short-lived while others have extraordinary longevity. In Iraq, for example, the massive and heavily state-sponsored irrigation systems of the Sassanian period (224–651 CE), such as the Nahrawan canal, which was ca. 300 km long, were relatively short-lived compared to the earlier and much smaller herringbone-patterned irrigation systems that consisted of fairly short primary canals (1–2 km) arranged alongside a larger river channel. There is evidence that such systems were in use for up to 5,000 years—possibly because of greater flexibility in their management in response to environmental and political change.³³ Seeking answers to modern-day water issues in ancient/traditional methods of water management without critical evaluation can be problematic.³⁴ However, paying close attention to the sociopolitical and environmental conditions under which these ancient systems developed and how they changed over time has the potential to inform solutions for current and future water crises.

31 Hunt 2007, 106.

32 Pokharel, in press.

33 Wilkinson et al. 2012.

34 Bauer and Morrison 2008.

Defining those variables requires us to pay close attention to the “features of irrigation” because systems are highly diverse—both physically and, more importantly, in how they are managed. We also need to understand the relationship between the “Features of Irrigation” (part I of this volume) through diligent “Empirical Investigation of Ancient Irrigation” (part II) and to describe more accurately “The Economic Function of Irrigation” (part III), “The Sociopolitical Function of Irrigation” (part IV), and “The Cosmological Dimension of Irrigation” (part V) to understand irrigation’s role in early states and thereby gain valuable knowledge about modern-day water issues.

FEATURES OF IRRIGATION

The features of irrigation are the physical properties of the system of water conveyance to crops. The technical and organizational complexity of an irrigation system varies not only according to size but also according to the local topography (e.g., river valleys, hill terraces) and the controlled water source (e.g., river, ground water, runoff). Crops differ in their timing, the amount of water they need, and how the water is applied (e.g., rice vs. barley), which in turn regulates the physical layout of an irrigation system.³⁵ Despite the considerable differences, a set of common tasks needs to be performed in nearly every system.³⁶ A system needs to be constructed in the first place and later maintained (e.g., sediments removed, water-control structures repaired). Water needs to be allocated to its users, which involves a water delivery schedule and fees and/or labor duties related to water use, which may at times lead to conflict. In particular, downstream water users can be affected by users upstream, and there are usually sociopolitical arrangements in place that regulate these relationships. If these agreements are violated, a legal authority must resolve disputes promptly because prolonged conflict can cripple the functioning of an irrigation system. The operation of an irrigation system also requires a fair amount of administration, as each task has a manual and an administrative component. For example, construction and maintenance requires canals to be dug and sediments to be removed, but it also requires an assessment of the work to be done so that work can be divided among the water users. The administration may or may not be based on accounting, but records of water allocation are usually kept to keep track of who received water, paid the fees, and fulfilled labor duties.³⁷ The construction, maintenance, and administrative costs are greatest at the level of the primary canal and decrease down the system. In cases where states are involved in the management of the system, the focus tends to be on managing either certain aspects of irrigation (e.g., conflict resolution, water distribution) or specific parts of the system (e.g., the primary canal).³⁸

The terms “large scale” and “small scale” are commonly used to refer to the size of an irrigation system even though the distinction is rarely quantified. In addition, how the boundaries of an irrigation system (and thus its size) are defined varies. Some scholars define the size of an irrigation system based on the total length of its feeder

35 Ertsen 2010.

36 Hunt 1988a, 1988b.

37 Hunt 1988a, 1988b; Ertsen 2010.

38 Fernea 1970; Lees 1974.

and supplier canals, the number of irrigators it serves, or the size of its command area.³⁹ Because scale has remained ill defined, the relationship between size and social organization has rarely been systematically studied. An exception is the study by Hunt,⁴⁰ whose definition is based on the areal (physical) extent of an irrigation system and is thus universally applicable. Within that definition, a system covering 10,000 ha is considered large and has to have a facility (headgate) that diverts water from a source to be allocated to the crops via a system of water-control devices (e.g., canals of varying size, inlets/outlets, weirs).

The systems presented by Maurits Ertsen, Vernon L. Scarborough and Christian Isendahl, and Martin Sterry, David J. Mattingly, and Andrew Wilson in part I of this volume capture the diversity of physical layouts, features of irrigation systems, and methods of water control. The systems discussed by Ertsen are all open-surface canal systems with a large river as the source of water—for example, the Rio Chile in Peru, the Euphrates and Tigris in Iraq, and the Blue Nile in Sudan. Scarborough and Isendahl describe irrigation systems of the Khmer Dynasty in ancient Cambodia (see also Stark, in this volume) and the Maya Civilization on the Yucatan Peninsula in Central America. Both systems developed in semitropical or “wet and dry” forest environments, whose climate is (or was) characterized by cycles of droughts and rainy seasons with an overabundance of highly seasonal precipitation. Hence, water storage was of pivotal importance. Sterry, Mattingly, and Wilson describe an irrigation system based on underground water channels (foggaras, also known as *qanats* in other parts of the world) in ancient Libya that tapped the elevated groundwater table at the foothill of rock escarpments and plateaus.

The cases presented by Ertsen, Scarborough and Isendahl, and Sterry, Mattingly, and Wilson differ greatly from one another in regard to environmental setting, physical layout and construction, and maintenance demands. As the authors show, these factors had consequences for the social organization of each system’s management, as well as the duration of its use. The irrigation systems presented by Ertsen show that the amount of available water determined whether irrigators organized themselves to regulate water usage. The case presented by Scarborough and Isendahl suggests that “highly engineered wetlands” may have been associated with a more dispersed settlement pattern, in contrast to compact population aggregates associated with irrigation practiced alongside perennial streams. Scarborough and Isendahl argue that this “low-density, agrarian-based urbanism” presented a highly sustainable lifestyle that may have ensured the survival of the Maya Civilization for at least 1,500 years and of Khmer for half a millennium. Sterry, Mattingly, and Wilson’s case study, on the other hand, shows that irrigation based on the labor-intensive construction of underground channels flourished only under very specific circumstances: an ample supply of slave labor acquired by the Garamantian state through active participation in the trans-Saharan trade.

Even given these differences, Ertsen cautions us to take into consideration that the material agency of an irrigation system does not necessarily take precedence over human agency when understanding how the system is operated. Rather, Ertsen says, “irrigation is an interplay between human agency—action of individuals and groups—and material

39 Hunt 2007, 105–28; Hunt et al. 2005, 125.

40 Hunt 1988a.

agency—canal, water flows, sediments.” While earlier approaches may have overstated the material agency of irrigation systems (e.g., large scale vs. small scale in regard to management), their layout, size, and technical complexity need to be taken into consideration to effectively describe the function of irrigation for early states. For example, the interfaces between canals of different sizes/categories and water-control devices are loci of decision making and control, and consequently the physical properties of a system—whether it is small or large, as well as its mode of water allocation (e.g., continuously, on rotation, or on demand)—will have a structuring effect on its management,⁴¹ at least at the local level. In addition, the administrative and logistical complexity of constructing, maintaining, and managing a system increases with size.

THE EMPIRICAL INVESTIGATION OF ANCIENT IRRIGATION

Our limited knowledge about the physical properties of ancient irrigation has considerably hampered our understanding of the various functions of irrigation in early states. The lack of data is partly due to the difficulty of detecting and determining the size and duration of a system archaeologically. The archaeological record always represents the endpoint of a period of development, and it can be difficult to establish which part of the system was in use at which point in time. Moreover, as Jason Ur discusses in this volume, the physically larger systems of later periods tend to obliterate earlier versions of the agricultural landscape. Hence, the start date of a particular irrigation system, when and how it was modified over time, and when it went out of use are difficult to establish. This shortcoming is problematic because the size and duration of a system are central to how the functions of irrigation in early states were (and still are) conceptualized. Labor input and economic output vary according to the size of a system. Not knowing the duration and major developmental stages of an irrigation system makes it difficult to determine which factors are responsible for the system’s evolution. Lacking such data makes it difficult to assess the possible sociopolitical ramifications of managing systems of different sizes and technical complexity.

Thus, better empirical data on the size and layout of an irrigation system and a tighter control of its chronology are highly desirable for understanding the function of irrigation in early states. While we may have to accept that the archaeological traces of the earliest irrigation systems are lost forever, new research tools and methods have led to a considerable increase in the amount of available data and have allowed more precise and far-reaching empirical observations on ancient irrigation. The cases presented by Ur, M. Kyle Woodson, Marco Madella and Carla Lancelotti, and Stephanie Rost in part II of this volume provide a fairly representative sample of the new research tools and methods that have, in the past couple decades, considerably advanced our understanding of ancient irrigation. In providing a bird’s-eye perspective, remote sensing in particular has significantly improved our ability to detect relict watercourses, canals, and fields and provided a more comprehensive image of the size and layout of ancient irrigation systems.⁴²

⁴¹ Ertsen 2010; see also Ertsen, in this volume.

⁴² Alizadeh and Ur 2007; Cole and Gasche 1999; Hritz 2010; Hritz and Wilkinson 2006; Kouchoukos 2001; Pournelle 2003; Rost, Wright, and Woodson 2017; Showalter 1993; Ur 2005.

Ur rightfully notes that irrigation systems are “geographically large phenomena” that require a remote perspective to be able to detect the physical dimensions of a system, which are important for conclusions about economy and society. The case studies he presents show how remote-sensing techniques allow canals known from historical sources to be traced and provide the dimensions needed to fully understand the magnitude of the hydraulic project initiated by Assyrian rulers. Moreover, given the regional perspective, remote sensing is an important tool to better understand the taphonomic development of landscapes, in which later irrigation systems obliterate traces of earlier agricultural landscapes.

In contrast to Ur’s macro perspective, Marco Madella and Carla Lancelotti present the micro perspective of detecting ancient water management strategies in the archeobotanical record of the Indus Valley Civilization. Much progress has been made in inferences about the watering conditions under which a crop was grown by analyzing weed ecology, stable carbon isotopes, and phytoliths. While, as Madella and Lancelotti note, much research is still needed to perfect these methods, they show great potential—especially when used in combination with other research methods—to provide detailed insight into past irrigation practices.

Woodson’s study discusses a wide array of methods ranging from remote sensing to ground survey, geomorphology, and geophysical prospecting, as well as conducting test excavations that have been applied in the study of Hohokam irrigation systems of the Salt and Gila River valleys in Arizona. The case studies Woodson describes are the most comprehensively documented systems archaeologically, and their researchers pioneered many new approaches in the study of canals and ancient irrigation systems (e.g., reconstructions of stream flow using tree-ring data, optically stimulated luminescence dating of canal sediments). Woodson discusses the array of methods available for the study of various aspects of irrigation (e.g., size of irrigation systems, dimension of canals, date of various water-control features) and shows that the results acquired can be used together with hydraulic modeling to gain deep insights into the development and management of these systems.⁴³ As such, Woodson’s study, written in the manner of a research manual, can function as a research model for the investigation of ancient canal irrigation systems. While the archaeological examples presented by both Ur and Woodson may not derive from early-state societies, their studies are crucial in describing the methodological approaches to studying irrigation in early states.

Rost’s study discusses observations on an early-state irrigation system from written records of late third-millennium BCE Mesopotamia. She discusses the extraordinarily detailed insights into the social organization of an irrigation system that can be gained from written records. However, her case study also shows that the textual information is sometimes difficult to interpret and cannot be exploited to its full potential without its physical (archaeologically recorded) counterpart. As such, her study resonates with the other three in emphasizing why an interdisciplinary approach using a variety of research methods is needed to collect sufficient empirical data to make conclusions about the role of irrigation in early-state societies.

43 Ertsen 2010; Hunt et al. 2005; Woodson 2016.

THE ECONOMIC FUNCTION OF IRRIGATION

Economic importance is the most frequently cited role of irrigation in the development and functioning of early states, as it allowed for the production of the agricultural surplus needed to maintain the very feature of statehood (see above). This assertion, however, has never been systematically studied. It has become clear that the features of irrigation (e.g., environmental context, size, duration, population, management) have consequences for labor input, material costs, and economic output and dictate the rhythm of tasks performed to ensure watering efficiency.⁴⁴ Although insight into the relationship between the features and functions of irrigation can be gained only from historical cases or direct observation, there have been few efforts to develop methodologies to research this relationship. Hence, the case studies presented by Hunt and Reculeau in part III of this volume are particularly informative, as both show that irrigation does not necessarily lead to the production of agricultural surplus. Hunt's simulation of irrigated maize production for the Snaketown irrigation system of the Hohokam period of the Gila River valley illustrates that water supply was too low to produce a substantial surplus that would have been institutionally decisive. Hunt poses the question whether this may have been why the Hohokam never fully developed into a state society. This case study also clearly shows that the managerial requirements of large-scale irrigation systems, such as the Hohokam, do not necessarily have the sociopolitical consequences argued by Wittfogel and others and certainly does not require centralized control.

The study presented by Reculeau further disproves Wittfogel's assertion that state-run irrigation inevitably leads to greater political integration. Reculeau uses written sources derived from second-millennium BCE Upper Mesopotamia to evaluate the input and output of palace-organized irrigation along the Euphrates and Habur Rivers. His analysis shows not only that the palace was rarely able to produce a substantial surplus but also that the costs of irrigation and cultivation sometimes exceeded the actual yield produced. Reculeau identifies the inability of the palace to recruit sufficient labor as the main problem. This finding hints at a general problem of early states lacking the necessary political control over their territory. While the written sources tend to make us believe that state control was absolute, careful investigation suggests that the political landscape of the second millennium BCE was characterized by states with fairly underdeveloped sovereignty.⁴⁵ Reculeau's study clearly shows that the centralized organization of irrigation did not lead to greater political integration, as Wittfogel suggests,⁴⁶ but failed because of a lack thereof. Both Hunt's and Reculeau's studies show the importance of investigating other aspects of ancient irrigation besides how it was organized and provide entirely novel insights into its potential roles in early states.

Similarly, in her detailed study of physical remains as documented on satellite imagery, Emily Hammer questions the political and economic role that some scholars have attributed to irrigation in the rise of the Urartian state. Along with increasing agricultural surplus, state investment in irrigation has been thought to have turned a previously mobile

44 Ertsen 2010.

45 Richardson 2012.

46 Wittfogel 1957.

population into a settled and hence more controllable one. However, by means of two detailed landscape studies, Hammer shows that state investment in irrigation was limited to highly visible hydraulic projects (e.g., the Menua canal) whose primary function appears to have been to provide water for major Urartian cities. Hammer suggests that irrigation was organized by local initiatives prior to and during the Urartian period and was not a centrally orchestrated effort by the state with alternate political and economic motives. Moreover, her case studies add a new dimension to the understanding of the role of irrigation in early states: as a means to increase fodder for animals. She rightfully notes that research has unduly focused on the connection between state power and irrigation and agricultural crops and has failed to consider other products of irrigation, such as animal feed. The importance of the cavalry in both the Assyrian and Urartian empires warrants such an investigation, adding a largely overlooked aspect of irrigation to our understanding of its role in early states. Hammer's work also exemplifies the importance and potential of the use of new research methods in evaluating long-held scholarly views.⁴⁷ Her analysis successfully shows that the size and technical complexity of certain hydraulic features (e.g., the Səḍərəkqala canal) have been grossly overestimated, leading to unfounded conclusions about local versus state investment in their construction and maintenance.

THE SOCIOPOLITICAL FUNCTION OF IRRIGATION

Irrigation also has a sociopolitical function, bringing together individuals and social groups that enter sociopolitical arrangements to participate in and coordinate the operation of the system.⁴⁸ Irrigation schemes can, however, also be used to serve political ends. Investing in irrigation schemes can be politically motivated in the process of settling (and re-settling) people on the landscape (e.g., the Ur III and Neo-Assyrian periods).⁴⁹ It has further been argued that a settled and concentrated population could both be more easily controlled and provide access to much-needed labor, particularly in areas of low population densities.⁵⁰ Moreover, colonizing conquered land with subjects solidified the state's claim of control over its territory. How these processes were realized is still not well understood but is important to consider when trying to understand the role of irrigation in the state-formation process. While coercion is frequently assumed, state investment in irrigation systems as a public good could also have been the means to create economic incentives as well as ideological motivations to entice people to voluntarily join a polity.⁵¹

The exploitation of the symbolic dimension of mega-waterworks to serve political ends is illustrated in Michael J. Harrower's study on ancient Yemen in this volume. Water management, in particular the construction of the world-renowned dam of Ma'rib, played an important role in the process of the formation of the Sabean state in ancient Yemen. Harrower convincingly argues that the dam did not serve "any particularly agricultural importance," as rain-fed cultivation in Yemen's western highlands and small-scale

47 See also Hritz 2006.

48 Ertsen 2010, 166; Lansing 1991, 40–48.

49 Ur 2005; Rost 2015.

50 Stone 1998; Trigger 2003.

51 Rost 2015, 248; see also Blanton and Fargher 2010, 285.

irrigation could have provided the food necessary to sustain ancient states. However, the “mega-waterworks . . . held a tremendous symbolic and political significance,” which was exploited rhetorically and ultimately for political ends.⁵² Harrower argues that earlier hypotheses have been largely debunked because they focused on aspects of irrigation and water management that were of little or less consequence to the state-formation process (e.g., managerial requirements, economic potential). Working with the concept of spatial heterogeneity, he argues instead that the role of irrigation and water management in the state-formation process may be found in their potential to be exploited rhetorically and politically, in legitimizing and instituting royal/state power. Playing on the anxieties caused by the scarcity and spatially uneven distribution of water sources across the landscape, leaders and elites are able not only to promise abundance of water and agricultural wealth by investing in water-control structures but also to provide “proof” of those pledges with a “vivid green spectacle of prosperity amidst the drab and hostile background of hyperarid deserts” (Harrower, in this volume). In addition, irrigation works become not only highly concentrated areas of agricultural production but also the “center-point of political rhetoric, social logic, and ideological magnetism that bound growing populations together in shared ideals and common enterprise.”⁵³ Royal patronage over monumental water-control devices (e.g., the dam of Ma’rib) as a motive has also been observed in royal rhetoric of ancient Mesopotamia.⁵⁴

In their study in this volume, Li Min, Liu Bin, Wang Ningyuan, Lang Jianfeng, and Wei Yi provide a similar argument based on the findings of large-scale water management features associated with third-millennium BCE Liangzhu mound centers along the lower Yangzi River in Eastern China. They argue that irrigation/water management did in fact contribute to the state-formation process, though not in the way envisioned by Wittfogel.⁵⁵ While the Liangzhu material culture can be found over an area of 1,500 km along the Hangzhou Bay and the Yellow Sea with evidence of social differentiation, monumental architecture, and craft specialization, it is not considered a state-level society. However, the construction of raised mounds, which functioned as central places, indicates the existence of some form of centralized authority that elites exercised over the rural populace.

The water management features and strategies found in the area consisted of draining marsh areas to build raised settlement mounds and a network of canals, causeways, and dams to avert runoff flash floods from the nearby mountain range during the monsoon season. The water management system described by Min et al. not only served the irrigation of rice but also provided flood control and transportation, an aspect that has also been observed for Mesopotamia.⁵⁶ Min et al. conclude that water management in Liangzhu did in fact contribute to the state-formation process, as the earliest forms of complexity in ancient China, such as protourbanism, status hierarchy, and craft specialization, were based on large-scale water management. They argue that water management would have required the mobilization of labor on a fairly large scale and, to a certain extent, centralized

52 Harrower, in this volume; see also Harrower 2016.

53 Harrower 2016, 159.

54 Winter 2007; see also Ur, in this volume.

55 Wittfogel 1957.

56 Rost 2019.

planning. Even so, as this case shows, it did not lead, as Wittfogel argued,⁵⁷ to the emergence of state bureaucracies that gradually extended control over other sectors of public life. Liangzhu culture never developed into a state society, but it provided a repertoire of social complexity (in particular craft specialization) based on the management of water, which functioned as a template for later Bronze Age early states that themselves did not practice irrigation.

While Harrower's and Min et al.'s studies focus on the role of rulers and elites in irrigation management and its sociopolitical consequences, Juan Carlos Moreno García's study in this volume draws attention to the impact of locally managed irrigation initiatives by private individuals. Moreno García notes that Egypt has frequently been presented as a prime example of a "hydraulic" civilization in the Wittfogelian sense, even though there is very little (if any) evidence of direct involvement of the state in irrigation management until the Hellenistic period. Instead, Moreno García discusses a wealth of formerly overlooked evidence of what he calls "micro-hydraulics," consisting of local and opportunistic investments in water control and irrigation by private individuals. Investments in wells for the irrigation of date palms appears to have been a lucrative and economically significant private enterprise, with the state being its largest consumer. Many administrative documents show that dates were regularly given to state employees as remuneration, and the state could only have acquired them from these individual producers.

Moreno García's study stands out in providing vivid insight into the diversity of an early state economy that consisted of both private/domestic and institutional production strategies. He rightfully notes that previous descriptions of land use and agricultural systems in ancient Egypt adopted a narrow perception of the Nile flood as watering primarily grain fields controlled by the state. The effects of the Nile flood on the surrounding flood plain, leaving behind numerous pockets of water and inundated grounds fostering vegetative growth, thus allowing for a wide array of opportunistic pastoral and agricultural activities, have largely been overlooked but were nevertheless of economic importance. Moreno García's case is one example of how local and private irrigation management contributed to the health of an economy capable of sustaining the features of early statehood. His study also demonstrates the new insights that can be gained by investigating irrigation in its larger environmental and socioeconomic contexts.

THE COSMOLOGICAL DIMENSION OF IRRIGATION

More recent studies have paid closer attention to the cosmological dimension of irrigation. Morrison⁵⁸ showed that reservoir sluice gates in the Vijayanagara region of India not only evoked "royal-like" power (see above) but also were a metaphorical link between the concept of cosmic ocean and the locus of divine presence. Irene Winter,⁵⁹ on the other hand, showed that royal investments in the irrigation infrastructure evoked the concept of being the provider of natural and agricultural abundance that is usually attributed to gods. Thus,

57 Wittfogel 1957.

58 Morrison 2012, 160–66; see also Lucero and Fash 2006.

59 Winter 2007.

the cosmological dimension of water control provided not only royal legitimacy but also sacredness to hydraulic projects.

Miriam Stark's study in this volume, on water management during the Khmer Dynasty in the lower Mekong basin in Cambodia, shows that the use of water and the layout of water-control infrastructure were deeply rooted in Khmer religion and cosmology. Water occupies a central role in various kinds of rituals, and religious festivals are closely linked to water and agricultural events. For example, two major festivals of the Khmer cultic calendar were held during peak flooding of the Tonle Sap River and at the beginning of the monsoon rainy season. The water management system for watering crops (mainly rice) in ancient Cambodia consisted not of formalized canal irrigation systems but of an elaborate system of flood control for flood recession agriculture. The most impressive state-sponsored waterworks of the Khmer Dynasty were located in Greater Angkor and consisted of massive above-ground reservoirs designed to protect the urban epicenter from the flood while also providing water during the dry season. Earlier interpretation of these reservoirs viewed them as a highly centralized, state-run water management system that the state used to store water to be released during the dry season to irrigate rice fields on the southwest outskirts of the city.

This interpretation has been called into question, and Stark's study draws attention to the close connection between Khmer cosmology and the hydrological landscape. For example, while the reservoirs certainly had a practical function, they appear to have been of minor agricultural significance. The agrarian foundation of the Khmer state economy seems to have been based on very localized, small-scale measures of water control of rural communities predating and outliving the rise and fall of the Khmer civilization. Similar to the cases presented by Harrower and Morrison, Stark argues that the state-sponsored waterworks had greater symbolic value than economic or agricultural significance. In particular, the mammoth reservoirs of Greater Angkor are so-called cosmograms, or symbolic spectacles of earthly representation of a cosmic universe rooted in Indic religion (with the temple and its surrounding moats representing the central continent, Mount Meru, as the divine seat of the gods and the cosmic ocean). Hence, the engineered hydraulic landscape was a sophisticated blend of practical/hydrological and cosmological (even astrological) principles. The latter was particularly important in lending the necessary symbolic capital that Khmer rulers could draw on in portraying themselves not only as providers of agricultural prosperity⁶⁰ but also as worthy rulers safeguarding the cosmic order of which the engineered (sacred) landscape gave testimony.

JoAnn Scurlock's study in this volume explores Mesopotamian concepts of water coming from the heaven (rain) versus other water sources coming out of the earth. As water was so fundamental to survival in ancient Mesopotamia, it comes as no surprise that the origins of the celestial and terrestrial sources of water are deeply rooted in the Mesopotamian creation myth *Enūma Eliš*. Scurlock shows that Mesopotamians envisioned the world as encircled by rivers and/or cosmic waters trapped between several layers of heaven and earth (e.g., upper, middle, and lower heaven versus lower, middle, and upper earth). While, as Scurlock shows, Mesopotamians were aware that the sources of rivers are frequently found in mountains, the source of rain appears to have been harder for them to explain.

60 See also Winter 2007.

Hence, Mesopotamians believed that the world was surrounded by water—a concept found in other cultures as well—and pathways or interconnections allow the exchange of water. Scurlock’s study is a starting point to further investigate the close connection between practical, day-to-day water management and its cosmological dimension, which may not have been two separate entities in ancient Mesopotamia.

NEW DIRECTIONS

The renewed engagement with ancient irrigation in various regions and historical periods drove our thinking about its role in early states in new directions. The pitfall of earlier comparisons was the goal to define cross-cultural regularities—that irrigation functioned in the same way in all early states regardless of their environmental, sociopolitical, economic, and historical particularities. However, acknowledging that irrigation may have had multiple functions (economic, sociopolitical, cosmological) and comparing those cross-culturally brought to light the complexity and diversity of the roles irrigation played in ancient states. The outcome of this exercise, however, gave a strong impetus to push this approach even further. There was a strong consensus among the speakers and audience at the “Irrigation in Early States: New Directions” seminar that meaningful contributions to the understanding of irrigation in early states can be made only when the broader contexts in which irrigation was carried out are considered. Thus, the new direction that was felt to be most productive was to perceive what has been defined as the functions of irrigation (economic, sociopolitical, cosmological) as the broader contexts in which it should be analyzed. Hence, rather than narrowly defining the economic function of irrigation in an early state, more insights can be gained from describing irrigation within the larger economic context in which it was carried out. In that regard, as Irene Winter⁶¹ rightfully remarked, we avoid perceiving the subsystem as a system of its own. While isolating a phenomenon from its broader context is necessary for the purpose of study, keeping the broader context in mind allows us to put the results of our investigations into proper perspective. The call for analyzing irrigation in its broader context was made for each theme of the conference.

Thinking about the features of irrigation, Robert C. Hunt⁶² rightfully stated that the case studies presented by Scarborough and Isendahl and by Stark encouraged us to leave the dry river valleys (which had been the prime focus of earlier studies) and to consider tropical environments and places with wet and dry climates—all of which had examples of ancient irrigation and cases of early state formation. While the irrigation technologies employed in these disparate environments (e.g., canal and field systems, water-control devices) may be relatively similar, the management of water that supplied these systems can be drastically different. Focusing on the irrigation systems alone would mask differences that may be of great importance for our understanding of irrigation in early states. Thus, Hunt posed the question whether it might be more productive to make water management the starting point of our investigations. He noted that even Wittfogel’s hypothesis recognized the need to manage water for flood control as much as for irrigation. It is the understanding of the different components of water management—not only for irrigation

61 Winter, personal communication 2016.

62 Hunt, personal communication 2016.

but also for flood control, transportation, domestic use, craft production, and rituals—that will allow us to contextualize irrigation to better describe the role it played in earlier states.

Maurits Ertsen, Jason Ur, M. Kyle Woodson, and Gil Stein all urged paying close attention to the archaeological context in our empirical investigation of ancient irrigation/water management systems.⁶³ The use of satellite imagery, aerial photography, and computerized mapping (alongside other novel methods and tools) is an established new direction in the way spatially large phenomena (such as ancient irrigation systems) are now investigated. It has revolutionized the field by allowing archaeologists to get a better handle on space in the same way that radiocarbon dating allowed archaeologists to get a better handle on time.⁶⁴ Nevertheless, as Ur⁶⁵ commented, the most visible systems, archaeologically speaking, are those large-scale systems that were frequently initiated and funded by states. In addition, the construction of these systems often obliterated early versions of the irrigated landscapes that would provide the data to reconstruct how irrigation systems evolved over time and to identify the conditions that might have been responsible for the very specific evolution of particular ancient systems. The evolution of an irrigation system, according to Ertsen's study in this volume, has to be understood as a dynamic interplay between human agency (of those who operate a system) and material agency (of the water-control structures and environments involved) with a wide range of motivations, constraints, and feedback loops. Understanding the particular evolution of a system is important, according to Gil Stein,⁶⁶ as states did not invent irrigation but in most cases made use of an already fully developed technology. However, describing the role of irrigation in early states depends on knowing the kind of technologies they took possession of and transformed in specific ways to serve their particular needs.

The needs or motivations that prompted states to get involved in water management varied considerably, as the conference session on the economic role of irrigation in early states showed. For one, considering the broader economic context revealed that irrigation's significance in early state economies may have been drastically overstated. Vernon L. Scarborough⁶⁷ remarked that agricultural surplus in early complex societies remains an enigma. As many irrigation systems were fairly short-lived, the necessary agricultural surplus(es) could not have derived primarily from irrigated agriculture. He further noted that in tropical environments such as those inhabited by the Maya and Khmer civilizations, food storage was nearly impossible. Hence, relying on one food-production strategy (irrigation) would have been associated with great risks. The success of these early state economies may thus be found in "scheduling"—strategically harvesting the landscape for wild resources and food-production opportunities (e.g., flood recession versus irrigation) with stacked harvest periods. Moreover, moving foodstuffs via waterborne transportation to destinations of consumption becomes of tremendous value for the economic organization that was capable of supporting these early states.

63 Ertsen, personal communication 2016; Ur, personal communication 2016; Woodson, personal communication 2016; Stein, personal communication 2016.

64 Harrower, personal communication 2016.

65 Ur, personal communication 2016.

66 Stein, personal communication 2016.

67 Scarborough, personal communication 2016.

This observation resonates well with Moreno Garcías's study in this volume, which shows that formalized irrigation was one of many food-production strategies that, in concert, allowed ancient state economies to prosper. Similarly, Hervé Reculeau⁶⁸ discusses written sources from the early second-millennium BCE kingdom of Mari (modern Syria) that describe harvesting fish caught in dead Euphrates meanders during the flood. Clearly, the palace competed with private individuals with commercial interests in these natural resources, which adds another layer to our understanding of early state economies and the interplay between state and private activities.

The case studies presented and the discussion that followed also brought to light that reducing the economic function of irrigation to the production of agricultural crops is shortsighted. Emily Hammer⁶⁹ mentioned the role of pastoralists in irrigation management for the production of animal feed. She also mentioned the possibility that *qanats* (underground water channels) in Achaemenid Iran may have been constructed to irrigate meadows for horses used in the army. Thus, state investment in irrigation was motivated by warfare, not agricultural surplus—an aspect that has not yet entered the general discourse about ancient irrigation. Robert C. Hunt⁷⁰ further drew attention to the great importance of textiles in most ancient state economies. Two known sources of fiber for textile, cotton and flax, would have required irrigation in dry river valleys, which again is an aspect of irrigation that has not yet received adequate attention. Scholars also have paid little attention to the economic value of the “side products” of irrigation. Kathleen Morrison⁷¹ mentioned written sources from medieval India that clearly delineate responsibilities for cleaning irrigation features, as well as the rights to side products such as clay for brickmaking and vegetative growth along canals for fodder, fish, and the like. All of these insights draw a very different picture of the economic role that irrigation may have assumed in early state economies.

With regard to the sociopolitical role of irrigation, Michael Harrower⁷² noted that Wittfogel's hydraulic hypothesis has led scholars to overlook the many different ways states could be interlinked with water management (other than being directly involved in the construction and maintenance of the system itself). Considering political rhetoric as part of the larger social and political context in which irrigation was carried out highlights a very different role that irrigation/water management had in the state-formation process. It was not the economic capital that was of relevance but the symbolic one. By focusing solely on what the state did or did not do in operating these water-control structures, this observation could not have been made.

Similarly, considering the cosmological context in which irrigation was carried out, as Miriam Stark did, revealed that choices of hydraulic engineering were motivated as much by practical considerations as by a cosmological belief system reproduced in a given landscape. Taking the larger cosmological and/or religious context into account is particularly important for understanding the motivations of the behaviors that led to specific

68 Reculeau, personal communication 2016.

69 Hammer, in this volume; personal communication 2016.

70 Hunt, personal communication 2016.

71 Morrison, personal communication 2016.

72 Harrower, personal communication 2016.

outcomes. In addition, as Hunt⁷³ rightfully noted, we do not know—but should ask—what the economic function of these enormous bodies of water for ritual purposes was. This remark hints at the possibility that the factors of production of ancient state economies might be found not in material and services alone but also in the symbolic value of anthropogenic landscapes.

Analyzing irrigation in its broader context(s) to understand the complexity of interconnections is the framework that Carrie Hritz⁷⁴ felt could be our biggest contribution to inform solutions for modern-day water issues. The discussion of our potential contribution to current problems was rather pessimistic, as many specific examples were cited where the application of traditional/ancient water management techniques did not provide adequate solutions. Modern conditions (e.g., food preferences, demography, mechanization of food production and water harvesting, modern economies) are so drastically different that the traditional/ancient water-control strategies are often not viable solutions for modern-day water problems. Hence Hritz's⁷⁵ point was well taken, that what we can contribute is our training as archaeologists and anthropologists to describe the complex whole of environmental, social, political, cultural, and religious dynamics that shape water management strategies. She further argued that it is the inability or disregard for analyzing a problem within its larger natural and anthropogenic contexts that is often the reason proposed solutions fail. Thus we ought to strive for an approach, as Winter⁷⁶ so well summarized, that moves from looking at archaeological signatures to better data, higher-level questions, and hydraulic modeling. Individual case studies will not bring the more complex contextual issues to the surface that are crucial for a more nuanced understanding of the relationship between irrigation/water management and early states. But striving for a more holistic approach to the study of irrigation and other matters of inquiry will allow real contributions to the field of archaeology and anthropology to be made, and more importantly to the solution of environmental issues that threaten our very existence.

Stephanie Rost

73 Hunt, personal communication 2016.

74 Hritz, personal communication 2016.

75 Hritz, personal communication 2016.

76 Winter, personal communication 2016.

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PART I

FEATURES OF IRRIGATION

1 **A Leak in the Irrigation System May Not Be Seen: How To Connect Agency and Long-Term Effects in Irrigation**

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IN SANTIAGO DEL ESTERO, Argentina, one morning in the southern hemispherical summer of 1991, two Dutch students and some staff members of the San Isidro Experimental Station of the Instituto Nacional de Tecnología Agropecuaria in Santiago were ready to irrigate a set of experimental fields. Irrigation water had been ordered for that morning from the management of the Canal San Martín, which was part of the larger Proyecto Rio Dulce (PRD) irrigation scheme. Given the size of the canals and the somewhat unpredictable behavior of the PRD staff, water could always be late. But when, many hours later, it still had not arrived, the students walked upstream along the canal to see where their water was. They found it soon enough, a few kilometers upstream flowing in the canal toward San Isidro. They also encountered a wet field along the canal. As there had been no rain that morning or the week before, the field must have received irrigation water from the shared canal, though all involved in the experiment at San Isidro were pretty sure they had been the only ones who were allowed to irrigate after a week without rain.

This little story about the experience of these students—one of whom was me—may sound like a trivial, one-time event. In fact, as I will argue, such events are fundamental for irrigation development in the long term. In this chapter, I discuss how a focus on short-term, small-scale interactions between agents of different kinds in irrigation can yield insights into human/nature interactions. I propose considering irrigated environments through the work of Bruno Latour,¹ the French sociologist and philosopher who has argued that human decision making and the development of societal institutions are always a local activity accomplished through actor networks.

Consider a simple setting that is typical for irrigation, and similar to the experience of the author in Argentina—an irrigation canal with a user who waters her crops and then closes the gate. This gate change affects water flowing to a downstream user, who may not want this extra water—perhaps because it has arrived too early. So this downstream user closes her own gate, which has hydraulic effects upstream. Thus the actions of an upstream user can result—through the actions of a downstream user—in a change upstream. If this sequence happens within just a few hours, the users may not have time to relate flow changes to users' actions elsewhere. However, if users relate their hydraulic changes to

1 Latour 1991, 1996, 2000, 2007, 2013.

the actions of other agents, the social relations between these users may be influenced—perhaps resulting in unwillingness to cooperate in the near or distant future. As such, a trivial, one-time sequence of events of different agencies may be of fundamental value for successful irrigation development in the long term.

In this study, I will start by discussing three irrigation systems in southern Peru to review how the agencies of humans and nonhumans may play out in real-life situations. We will discover that irrigation decisions and their material expressions are important phenomena for us to study further. Armed with this knowledge, we will move to ancient northern and southern Mesopotamia to discuss the emerging irrigated landscapes of both regions. I will argue that these two areas need to be studied in similar ways, though we have good reasons to assume each irrigated its landscape in a different way. My argument will be that local irrigation, community-based irrigation, and imperial irrigation need to be understood in similar terms. I will sustain that argument with a brief reference to the Gezira irrigation scheme in Sudan, a large-scale colonial effort that began in the twentieth century. For a more detailed discussion of how the perspective that I sketch in this chapter can be developed in much more detail for ancient Mesopotamia, I refer to an earlier publication of mine.² I will close with some general remarks on irrigation agencies and how to study them, including a test of our knowledge of baseball. But let us move first to modern-day Peru.

EXPRESSIONS OF POWER?

Close to—and partially in—the city of Arequipa in southern Peru, we find an irrigation system that covers approximately 2,600 ha, cultivated by about 2,100 water users. All fields receive water from the Canal Madre Zamácola, which diverts water from the Rio Chile. On average, the Canal Madre Zamácola brings 2.7 cubic meters per second (m^3/s) to the area, which means that each hectare should be entitled to about 1 liter per second per hectare (l/s/h). In actual practice, however, the area farthest upstream, Acequia Alta Cayma, and the area immediately downstream from it, Zamácola, receive about 1.2 l/s/h . Farther downstream, the area Alto Cural is left with only 0.6 l/s/h , on average. Apparently, the two upstream areas manage to divert more water to their fields than the downstream area does.³

When we take a closer look at the three areas, we encounter another difference among them. In Zamácola, located in the middle between upstream Alta Cayma and downstream Alto Cural, most farmers have constructed farm reservoirs. Apparently these farmers have tried to become less dependent on short-term flow changes and want to ensure that the total volume per week or month available to them remains more or less secure—because otherwise they would not invest money in expensive reservoirs. In downstream Alto Cural, we find no reservoirs—probably because there is no water to strategize about. Similarly, in upstream Alta Cayma, reservoirs are not found because enough water is available to the farmers when they need it—they have the same first choice as our illegally irrigated field close to San Isidro in Argentina.

In the irrigated area of the Canal Madre Zamácola, we find a pattern that one expects in systems where water needs to pass other users first before farmers downstream can

² Ertsen 2016a.

³ Ertsen 2014.

water their crops. Even though we know of situations where downstream users manage to have an advantage over upstream farmers,⁴ in general it is to be expected that downstream users have a harder time getting their water than those upstream do. Even then, the exact shape of upstream–downstream patterns depends on the outcomes of continuous negotiations between human and nonhuman agents—where outcomes are never stable anyway.

Irrigated agriculture is the main resource for economic activity in Yarabamba, a region in the high mountains of the Andes above Arequipa in southern Peru, where valley altitudes in the 366 sq km area range between 2,500 m and 3,000 m.⁵ Precipitation is scarce; although precipitation up to 200 mm can be experienced between December and April, the rainfall is often much less. Snow melt and infiltrated water from the Lagunas Salinas, a large lake system located close to the Pichu Pichu, provide water to the many small rivers in the region. With water being diverted into several small irrigation systems along the rivers and irrigation water partially reemerging downstream from the area through groundwater, the hydrology of the subbasin is a mix of natural flows and human-induced redistribution patterns through irrigation.

The different irrigated areas are rather similar and close to one another, but even in this remote and isolated area, the upstream areas manage to take advantage in diverting water. Even with water being redistributed to downstream areas, Yarabamba water availability is unequal. Most crops grown at these altitudes are local varieties, resistant to almost constant water scarcity, but even within this range we find important differences. Crops of higher economic and nutritional value include corn, onions, garlic, potatoes, and beans, but the predominant crop grown is alfalfa, with 55–68 percent coverage on the land. Alfalfa is perennial and relatively well adapted to conditions of water scarcity. As a result, the alfalfa acts like a reservoir, in the sense that it is able to respond to periods of drought as long as a certain amount of water does reach the field.

Another example of storage through crop growth can be found in the irrigation system of La Joya Antigua, which is located slightly farther away from the city of Arequipa.⁶ Irrigation in La Joya Antigua started in 1939, in an area of average annual rainfall of around 20 mm—a desert area. Within a total area of just under 4,600 ha, a licensed irrigation area of almost 4,000 ha receives gravity irrigation through a network of lined canals. The main crops planted in La Joya Antigua are (again) alfalfa, as well as Tuna Blanca (the local name for prickly pear cactus). Tuna Blanca is not grown for its fruit. The cactus plant acts as a medium for cochineals to live on. The mature female cochineal body contains an acid ($C_{22}H_{20}O_{13}$) that can be made into a natural dye that is in high demand in industries such as clothing, cosmetics, food, and medicine. The harvest of cochineals occurs every four months.

Tuna Blanca is different from a normal crop. The cactus is—obviously—extremely tolerant to water stress, but very sensitive to waterlogging as well. A minimum amount of irrigation water that can keep the cactus alive is sufficient. As a result, Tuna Blanca has a much lower crop water demand than other crops. Obviously, for all farmers, the economic importance of Tuna Blanca is a factor to be considered, but in La Joya Antigua the

4 See Ertsen and Van Nooijen 2009 for the example of the Canal San Martín in Argentina.

5 Swiech, Ertsen, and Pereyra 2012.

6 Zhang 2012.

percentage of Tuna Blanca increases as one proceeds downstream along the canals. Tuna Blanca is grown to deal with the lower availability of irrigation water downstream. Again we encounter a material expression of power relations in irrigation, this time in a cactus.

POWER MATTERS?

I hope to have shown that irrigation systems like the ones in Arequipa and Santiago del Estero are both expressions of and a basis for evolving social relations. Perhaps we might go so far as to state that the irrigation infrastructure is a social relation,⁷ but we do not need to go that far to be able to conclude that there is a close relation between physical properties and relations of power in irrigation. Irrigation systems have agency. I used to refer to this agency as “structuring properties” but would not use that term anymore because I now reserve the term “structure” for physical entities alone.⁸ Obviously, the physical does not prescribe any actual expression of power; suggesting that would be too simplistic and ignore the observation that power relations can change over time for a given physical shape—such as irrigation. Nevertheless, physical properties exert considerable influence on relations of power, as it is not guaranteed that any desire can be realized with any physical shape. For example, one cannot jump with a canal.

Once we have established that power relations are expressed materially, irrigation power may be characterized through its “capillary properties” in the sense that—even though the term was used in the context of sport—power circulates within actor networks. It is the ability of power to behave in a “capillary” way, moving through different channels (literary and as a figure of speech), transforming specific shapes along the way, thus allowing power to be reenacted and reconfirmed all the time.⁹ What I will argue below is that the capillarity of irrigation power is not restricted to the modern age of sports, but can be perceived as a basis for human civilization as we know it.

Before going further back in time, there is one final issue we need to solve first. “Material expressions of power” sounds like something rather final, but we would do well to realize once again that power is “never a capital that can be stored in a bank. It has to be deployed, black-boxed, repaired, maintained.”¹⁰ In power, we encounter the need for continuous negotiations between human and nonhuman agencies¹¹ to determine what power means in practice. As Latour argued long ago, the material shape of power allows power to survive as social structures, because social relations without a material component would have more difficulty surviving, given that they are more prone to continuous renegotiation.¹²

As such, the relations we encounter in the course of our lives predate our arrival. They are expressed in buildings, bank accounts, and pipelines: material stuff, infrastructures, physical expressions. The material is an expression of power as much as it is an agent

7 See Ertsen 2016c.

8 See Ertsen 2016c.

9 See Hargreaves 1986.

10 Latour 1991, 118; see also Høstaker 2005.

11 Latour 2013, 1996.

12 Strum and Latour 1987; see also Latour and Strum 1986.

in itself. Material expressions of power—like upstream–downstream patterns in gravity irrigation systems—provoke responses from agents: responses that may break, but often confirm, the original expression. Managing irrigated farms under scarcity has been extensively documented, with one possible strategy for farmers being to increase storage capacity close to their farms.¹³ And indeed, we have seen storage reservoirs. We have even seen examples of such a strategy in the irrigation systems farther away from Arequipa, though not shaped like the reservoirs of Zamácola.

With storage in the shape of cacti, we are warned to stay alert when looking for material expressions of power relations, and to allow agents we may not expect on stage to play their part in our irrigation stories—such as cacti. The cacti and their cochineals in La Joya Antigua were the material agent that many downstream farmers enrolled in their strategies of response to water scarcity. Even with prices of the harvested animals fluctuating between 11 USD/kg (price level January 2010) and 80–100 USD/kg (price level April 2011), cochineal farming could easily provide a farmer with tens of thousands USD each year¹⁴—a considerable sum in a country with a minimum wage of about 200 USD per month (level February 2011). It is not surprising that fields with Tuna Blanca are occasionally the target of thieves and are therefore guarded: introducing one material agent may provoke the response of other agents and their supporters.

Through a discussion of irrigation-based actor networks in ancient Mesopotamia in similar terms of action and reaction—as much as the archaeological data allow such detail—I will assess how human user strategies impact the (agency of the) hydraulics of a system, which affects (constrains and enables) new human actions. After exploring a system’s agencies in more detail for my Mesopotamian case studies, I will suggest that we may need to reconsider our terminology when we study agencies within and with material environments—which is, after all, a major focus in archaeology. The remaining irrigation stories below allow me to explore what it may mean that irrigation emergence is local and constructed within actor networks that are continuously created and re-created by human actors engaging with other human and nonhuman agents. With creation happening simultaneously at different localities, micro and macro are irrelevant concepts, as the micro shapes the macro while being created by the macro. Social reality is continually constructed—or performed—by agents who “violate ‘levels’ in their process of ‘work.’”¹⁵

IMPERIAL MESOPOTAMIA?

In archaeology, the timeframes we can encounter in irrigation systems like that in Arequipa are impossible to study. In archaeology, a century is an event; our analysis is typically based on settings with proven irrigation development over centuries and millennia—and ultimate “collapse”—such as in the ancient Near East, which may obscure the short time step that along my line of reasoning would be key to understanding why irrigation systems did not fail every day. Archaeology’s long-term irrigation developments and reconstructions have long been analyzed within frames based on, or close to, Wittfogel’s thesis

¹³ Venot et al. 2010; see also Molle et al. 2010.

¹⁴ Zhang 2012.

¹⁵ Strum and Latour 1987, 784.

of Oriental Despotism,¹⁶ with a state exercising strict control over irrigation-related labor in terms of construction, maintenance, and water use. Wittfogel's claim that large-scale irrigation development preceded state formation has been heavily criticized,¹⁷ but until recently alternative theories of irrigation emergence and control in Mesopotamia have not been on offer.

The early urban settlements and societies that we know from northern Mesopotamia all developed in the rainfall-richer areas in the north of the region, where variability in rainfall must have existed, but with less effect than farther south given that guaranteed minimum amounts of rain were higher. Much of northern Mesopotamia has always been considered marginal, as a zone of uncertainty for rain-fed agriculture. The average amount of rainfall might be 200–400 mm per year, but the high spatial and temporal variability from year to year would not have allowed the production of predictable surpluses in much of the area. It is only in the later territorial empires (Neo-Assyrian to Abbasid) that irrigated agriculture in combination with new settlement expansion extended into the marginal areas to the south of the rain-fed belt. Supplementary irrigation could stabilize (rain-fed) crop production and increase (predictability of) yields in the former zone of uncertainty. As such, state control and power could be expanded—or developed—through irrigation.

Therefore, if there is one area where we may be able to find the hydraulic state in the sense as close as possible to how Wittfogel would have liked it, it is along the Tigris River in northern Mesopotamia, in the shape of the Assyrian and Sassanian empires.¹⁸ Emerging in the early first millennium BCE, the Neo-Assyrian state created its imperial core around modern Mosul, in a process of regaining control over those territories that once had been part of the Middle Assyrian state at the end of the second millennium BCE. The Assyrian core territory was enlarged through additions of territories along its boundaries, in the shape of provinces or client states. The imperial core area itself, especially its cities, appears to the modern observer as carefully planned.¹⁹ Without a doubt, it was carefully planned, but as we will explore below, that does not make it different in terms of analysis compared to our small-scale community activities in Peru.

Assyrian kings were also eager to commission the construction of large canals and dams. Redirecting surface water flows from the Assyrian hinterlands toward the cities seems to have been a national sport. To be sure, these canals must have provided water for elite areas, such as urban parks and gardens, but evidence suggests that along the same canals, which ended in the cities, irrigation would have been practiced at a distance from the capitals.²⁰ In (modern) eastern Syria, we find a pattern of evenly spaced Neo-Assyrian settlements, possibly filling the voids of earlier settlement patterns.²¹ Through (forced) resettlement, the labor required to use the irrigation systems was made available, allowing agricultural intensification. As such, surplus production would have been made possible,

16 Wittfogel 1957.

17 See Harrower 2009.

18 See Lawrence et al. 2016, 2017.

19 Wilkinson et al. 2005; Ur et al. 2013.

20 Ur 2005.

21 Wilkinson et al. 2005.

though we still need to study what “surplus” meant in relation to the costs of those interventions in the shape of dams, tunnels, and canals.

Despite these caveats, we cannot really doubt that the creation of the Neo-Assyrian landscape involved quite a bit of planning over several centuries.²² However, just as studying a series of actions of local communities requires a local perspective, larger-scale top-down projects such as centrally planned colonial efforts—whether Assyrian canal systems or modern highways—require a local perspective as well: colonial efforts are likewise continuously in the making and stay “unfinished” as a matter of principle.²³ Whatever we encounter in the archaeological record of Assyria and other empires, we need to start with the premise that it was shaped by daily actions. Production of power spaces—such as irrigation systems—is not a process that produces space and social structure, like a predefined plan. It is for a brief perspective of such daily construction of (imperial) irrigation that we move to my final example, in colonial Sudan.²⁴ The Gezira Scheme is a large-scale irrigation scheme that officially opened in 1925 under British colonial rule. Gezira’s purpose was to grow cotton for the British cotton mills. As could be expected from an imperial initiative, Gezira had many characteristics of an imposed production regime, in terms of both appearance and procedures. Straight canals brought water in predefined rhythms to square plots, where British field personnel had to ensure that Sudanese farmers grew the cotton exactly as they should.

What Gezira shows, however, is that power, space, and empire are produced and reproduced through cooperation, struggle, conflict, and contradiction, which are shaped within the many engagements between the human and the nonhuman—among agents of different kinds. In imperial Gezira, the British planned to grow cotton with diseases, farmers, and water under close British control. In practice, the exact meaning and execution of “control” was much less straightforward than that. Rainfall disturbed planned irrigation turns, threatened to drown the cotton plants, and created muddy roads that made traveling in Gezira impossible. Farmers tried to minimize their effort, as the possibility of growing food crops alongside cotton was much more interesting to them than the colonial cotton. Crop diseases forced the British to change the amount and rhythm of cotton cultivation, which created new room for negotiation between the Sudanese and the British. Each and every day, the Gezira actor network was reconstructed—as it had to be reconfirmed, but was changed—by agents as varied as British staff, Sudanese farmers, canals, sediments, and water. Building and running Gezira was definitely an act that involved close control by the colonial state, but the agencies of humans and nonhumans had to produce and carry through that control. Gezira was planned out and made up as the agents went along. My interpretation of such top-down projects suggests that a centrally planned colonial effort was continuously in the making and as such unfinished.²⁵ I would argue that Mesopotamian imperial systems were shaped by strings of daily actions as well, in offices and fields, in political debates, and in symbols and through buildings, gold, and canals. As such, Mesopotamian or modern colonial imperial irrigation systems

22 Ur et al. 2013; see also Adams 1981; Altaweel 2008.

23 Ertsen 2016b; compare Darwin 2012.

24 See Ertsen 2016b, 2016c.

25 Ertsen 2016a.

should be understood in similar terms—which is obviously not an argument to suggest that these systems were the same.

COMMUNAL MESOPOTAMIA?

Many millennia before the Assyrians, and 1,000 km farther south, someone must have started tilling the rich soils in the southern Mesopotamian region; initiatives to exploit the water from rivers and levees must have started somewhere. Given the many resources available in the marshlands, how could they not have been used by early inhabitants? Obviously, finding a missing link between a “pristine” landscape and the densely populated Mesopotamian area is impossible—if only because that same Mesopotamian area was itself heavily influenced by a retreating sea that changed the character of the marshy environment²⁶—but we have some ideas and evidence for a gradual intensification of using the landscape. In his most recent work, the late Tony Wilkinson argued that the development of smaller agricultural systems yielding positive returns in terms of food and energy allows an understanding of southern Mesopotamia’s emerging story. In southern Mesopotamia, seasonal floodwater may have been used to plant crops.²⁷ Possibly starting as a local activity—perhaps one of adaptation of natural breaches—new small-scale water systems would have gradually filled the landscape.

Exactly how this landscape was filled with human-enhanced water features is still open to many research questions. What we are increasingly certain about is that southern Mesopotamia’s watery environment was (and is) a mixture of natural and human-produced water courses.²⁸ Today, the landscapes of southern Mesopotamia appear to us as “hydraulic landscapes, because water is the specific structuring agent in what is actually a complex array of rivers, canals, distributaries and marshes which dominate and in part create the landscape.”²⁹ We need only think about the Khuzestan levee irrigation areas in ancient Iran, where canals tap water from very long and wide levees flowing through the landscapes. The short side canals allow water to flow along the levee slopes to irrigate fields.³⁰ Originally water flowed through—actually above—the landscape on natural levees, but over time distinguishing between what we could call “natural” and “human-enhanced” levees has become rather difficult.

Tracing the exact history of development of the larger-scale landscape is tricky as well, but it seems safe to assume that a model of gradually developing water systems would allow for tracing how southern Mesopotamian society was created. In contrast to parts of the north, rainfall in the south is negligible for agriculture. However, within a landscape of high levees and low marshes, with low-gradient levees allowing lands to be watered along the steeper levee side slopes, crop production does not need rain when the water present in the levees can be mobilized. This is exactly what would have happened

26 Bertman 2003.

27 Wilkinson, Rayne, and Jotheri 2015; see also Scott 2017.

28 See Jotheri, Allen, and Wilkinson 2016.

29 Wilkinson, Rayne, and Jotheri 2015, 398.

30 Wilkinson et al. 2012; see also Alizadeh et al. 2004; Heyvaert and Baeteman 2008; Heyvaert et al. 2012; Walstra et al. 2011.

in the model of agriculture that started to be practiced at locations where levees would breach, with crevasse splays creating mini alluvial fans.³¹ Flood recession agriculture—or a system similar to spate irrigation?—may have allowed early cereal production. Within such a landscape, with gradually changing water levels and ample availability of material to close (smaller) breaches, new flood recession systems at other locations along the levee could have been created by communities looking for new opportunities. Over time, a cropping pattern would have developed with palm gardens close to the levee top and cereals farther downslope. The lower marshes, with their higher salinity, would have acted as a natural limit for agricultural activities.³²

These gradual steps of local communities filling in a landscape with short parallel canals along a long levee could very well have led to what we now consider to be more formalized herringbone systems (so called because the series of short canals taking off from a single linear feature resembles a herringbone), including the ones we still observe in Khuzestan. What appears to us as a complex landscape or even as a single irrigation system would have started as a series of local activities. As such, although the outcomes of water development processes in southern Mesopotamia are (most likely) known to us, with many systems managing to survive over a longer time, we do not necessarily need a model of central power—like the Wittfogel thesis—to explain larger-scale landscape changes, especially once we allow time for such emerging realities. With continuity as a common finding in the archaeological record, it is very likely that mechanisms for conflict resolution were in place. In a model of many (small) communities exploiting the same levee(s), one or more varieties of common pool resource management is likely.³³ We should not assume that common pool rules always ensure water system success, but as these models are usually based on sets of actions that need to be performed, we are able to study conditions for longer-term success or failure. Different cooperation strategies within different conditions could have been more or less successful.³⁴

The same levees that brought water (and sediments) to crops (and communities) must have played a role as trade routes. The low-gradient channels must have been used to transport bulk products from very early times—which actually creates another option for expansion, as easy bulk transport would have allowed moving farther away from any original, possibly more densely cropped, area. It could also have created options for social groups not growing crops themselves to survive, as soon as the rich landscape in southern Mesopotamia started to produce a predictable surplus. In this line of reasoning, (urban) elites may have been able to control connections among different communities and to create new connections in the levee-based water network. As such, elites would not necessarily have had close control over crop production, but were able to exploit the (movement of the) yields. As Wittfogel stated, urban and rural in Mesopotamia were intimately connected, but the model that urban elites had encompassing control over rural environments may not necessarily hold.

31 Wilkinson, Rayne, and Jotheri 2015; Ertsen and Wilkinson 2014.

32 Wilkinson, Gibson, and Widell 2013.

33 Ostrom 2012.

34 Carballo, Roscoe, and Feinman 2014; Gerrard 2011; Guillet 1992; Hunt 1988; Hunt and Hunt 1976; Janssen, Anderies, and Cardenas 2011; Nelson et al. 2010.

Recent work on Mesopotamia indeed suggests that urban elites invested in the levee system, but not just to control irrigation.³⁵ Levee channels were managed for irrigation, but also for navigation and flood control—with the flood season also being the harvesting season. Two of those functions could go together very well: navigation and irrigation were well served with full channels. It could very well be that elites were only interested in transport, but that this interest also supported irrigation with the same canals. With the third function of preventing the peak flood from disturbing harvesting, things are a little different. Preventing floods would have required more active control of levee flows and channels, which may have needed more labor too. In flood protection and the possible reconstruction of channel features afterward, we encounter a possible model of closer control by elites as important as—but different from—irrigation.

Combining the model of Wilkinson and his colleagues with the work of Rost³⁶ may actually offer a possible scenario of emerging social “complexity.” Rost found that in the Early Dynastic and Ur III periods, the state was heavily involved in managing agricultural land. In the preceding Akkad Period, however, the state granted land to social agents in return for a share in the yields; the state did not actively engage in arranging cultivation of the land itself. Exactly when representatives of early states managed to increase their control over irrigated production—and when that increased control became visible in the archaeological and textual record³⁷—remains an intriguing and important research question. However, such increased state control would have developed from a landscape setting with local communities growing their crops. Reasoning forward again, we may start exploring the model that some members of certain communities started trading surplus yields—possibly to groups outside the direct areas of production. With the wealth created from these trading activities, elite numbers may have grown.³⁸ This line of reasoning would allow us to explore southern Mesopotamian state development as a process of improvised planning similar to the one I proposed for the Assyrian state.

SMALL DECISIONS?

Apart from providing a fairly representative sample of the regions, times, and irrigation systems that I work on, my examples here have served to show that—and how—irrigation is an interplay between human agency (actions of individuals and groups) and material agency (canals, water flows, sediments). This activity is continuously performed by all these agents on different spatial and temporal scales. The material provides the spatial and temporal link between different agents. We encounter persistency in the presence of (former) others through the continuous presence of material agency—in the shape of canals, roads, houses, bank accounts—which explains why certain choices are available, which ones are forged, and which ones do not lead to anticipated results.³⁹

35 Rost 2015; see also Rost and Hamdani 2011.

36 Rost 2015; see also Rost, this volume.

37 Nissen, Damerow, and Englund 1993.

38 Cf. Flannery and Marcus 2014.

39 See Biggs 2010; Winiwarter, Schmid, and Dressel 2013.

Irrigation systems bring water to fields and users; they exist in many different shapes—terraced rice fields in Asia, irrigated plains in the United States, green center-pivot circles in the Middle East, and small irrigated gardens in West Africa. What we know is that any irrigation system needs a source of water and needs to divert water from that source with some kind of intake structure (weir, pump, tube). Once water flows from the intake into something such as canals or pipes, water can travel to irrigated areas and fields. Irrigation manipulates water flows, aiming to adapt water availability in time and space. As such, irrigation infrastructure transforms fluctuations in available flows—hydrology—into system behavior—hydraulics. Obviously, both of these rhythms are heavily influenced by socio-political arrangements to coordinate human actions. Irrigation is emerging as an interplay among hydrology, hydraulics, and humans.⁴⁰

Human strategies in response to hydrological properties manipulate those same features, creating a new reality that in turn constrains and enables new human actions, in a process recently termed by the hydrological community as “sociohydrology.”⁴¹ Spatial and temporal aspects of water systems—and as such, hydrology—are socially reproduced, and such reproduction is a continuing source of struggle, conflict, and contradiction, especially with resources under pressure from droughts, floods, and environmental degradation. One obvious concern of the hydrological community is the “tension between focusing on ‘the here and the now’ as opposed to longer-term (larger scale) dynamics,”⁴² as much of its work is guided by concerns of policy advice. Within archaeology, the order of the tension may be exactly the opposite (from the larger-scale, longer-term dynamics back to the “there and then”), but the theoretical issue of how to meaningfully link the two is the same.

Within sociohydrology, competition between humans and environment is a key topic. Two issues—or problems, as I see them—are usually raised. Typically, the approach is that “the competition between water for humans and water for the environment is ultimately mediated by humans alone, acting for themselves and acting for the environment (which cannot speak for itself).”⁴³ In this chapter, I have argued that we have to acknowledge human and nonhuman agency alike within our analytical frame. Second, observed long-term dynamics are seen as the net result of a competition between—or coevolution of—feedback loops, such as an “economic-population loop” (in which water, land, and humans produce economic gain) and an “environment-sensitivity loop” (the reaction of the environment to land and water exploitation).⁴⁴ Such a focus on feedback loops leads to—or is based on—the idea that these larger-scale phenomena govern short-term actions. One may as well argue that it was the Enlightenment that made people do certain things, even though nothing like the concept of Enlightenment existed at the time. Obviously, once identified as a concept, the agency of the Enlightenment must have had effects on other agents.

Within policy-related studies, a focus on larger-scale feedback builds on a plea for “a holistic rather than reductionist perspective . . . to avoid the undesirable, cumulative effects

40 Ertsen 2010.

41 Ertsen et al. 2014; see also Troy et al. 2015.

42 Sivapalan 2015, 4797.

43 Sivapalan 2015, 4799.

44 Sivapalan 2015.

of small decisions.”⁴⁵ Following Kahn,⁴⁶ who seems to have introduced the term, this “tyranny of small decisions” describes situations where a series of small, individually rational decisions can (and usually do) result in less desirable effects—for example, by negatively influencing the context of subsequent choices. A classic and often adduced example of the tyranny of small decisions is Hardin’s tragedy of the commons.⁴⁷ However, this example is less suitable, as Hardin did not distinguish between common property and open-access resources, with common property typically under strict rules.⁴⁸

At the same time, Hardin’s description of the commons in England actually showed that it was a gradual process of enclosing the commons by individuals that destroyed the commons in return. As such, the process of the “tyranny of small decisions” seems to be rather normal, and it usually leads to results we do not like. Through “hundreds of little decisions and the conversion of hundreds of small tracts of marshland, a major decision in favour of extensive wetlands conversion was made without ever addressing the issue directly.”⁴⁹ As I have argued, this is exactly what our latest insights would allow us to understand about irrigation development in southern Mesopotamia. A fairly typical response to the “tyranny” is to argue for better coordination—something nobody can actually be against. However, as imperial decisions and actions are theoretically similar to small decisions—at least, that is what I argued—pleas to “strengthen and protect the upper levels of environmental decision-makers”⁵⁰ are easier said than done. This is usually recognized in policy discussions, but immediately bypassed as an unfortunate situation that needs to be changed.

I would argue that there is nothing that can be changed about it: small decisions produce the longer-term effects, not the other way around. The approach I have developed here would overcome the standard theoretical stalemate on “agency” and “structure” as much as acknowledge that small decisions rule society. Society is continuously “composed, made up, constructed, established, maintained, and assembled”;⁵¹ once a relatively stable relation emerges, the nonhuman material accounts for much of this stability.⁵² Irrigated landscapes are made in a process “of gathering . . . entities together,”⁵³ but the only guarantee any agent in that process has is that there is “the possibility of holding society together” for that same moment.⁵⁴ After all, both communal irrigation and imperial domination need to (re)produce their own continuity every day. Irrigation is like a unicorn: it exists only when enough people are convinced that it is real.⁵⁵

45 Odum 1982, 728.

46 Kahn 1966.

47 Hardin 1968.

48 Ostrom 2012.

49 Odum 1982, 728.

50 Odum 1982, 729.

51 Latour 2000, 113.

52 Latour 1991; Latour and Strum 1986; Strum and Latour 1987.

53 Latour 2007, 140.

54 Latour 1991, 103.

55 Unicorn example taken from Latour 1991, 128.

HOME RUN?

This chapter discussed irrigation as something emerging from the interplay of human and nonhuman agency. Elsewhere, I have offered new ideas about suitable methodological approaches to studying actual irrigation situations.⁵⁶ One option is to immediately and exclusively move to the largest societal and environmental clustering possible, which would be something like “society” and “climate.” Such an approach allows testing of certain theories and analogies.⁵⁷ The other option builds on this chapter and faces human agency squarely, directing attention to the agency of human individuals and the smallest appropriate hydrological level and time step, typically daily or hourly rain and/or flows. This allows us to discover which cultural/organizational constraints would facilitate certain social realizations—or not.

The key of this approach is to predefine as few aspects as possible in the agents or expected outcomes. Scarborough⁵⁸ suggests that differences between small-scale (local) and large (imperial) systems can be related to the wetness and dryness of their respective worlds. The dry would yield imperial systems built on “techno-tasking,” whereas the wet would allow the emergence of smaller-scale “labor-tasking” realities. Along that line of reasoning, the dry Old World yielded empire—though more so in the north, which would be the wetter part of Mesopotamia in terms of rain—whereas the wet New World remained local.⁵⁹ In this chapter, I have suggested that wet and dry are indeed relevant concepts—as they are expressions of materiality, in areas as different as Argentina, Peru, and Mesopotamia—but wet labor and dry technology are both built on local interactions between human and nonhuman agents, producing outcomes that cannot be explained based on the results that we observe afterward.⁶⁰

In a final attempt to hammer this point home, I propose to end this chapter with the important question of why the New York Giants could play in the 1951 World Series. Sahlins⁶¹ discusses this important issue using the original analysis of Hexter;⁶² both compare the experience of the Giants in 1951 with the American League championship of 1939 won by the New York Yankees. Together, the two baseball stories would show the importance of differentiating between individual and collective agency and kinds of historical change—the well-known “structure or event” debate. Sahlins’s key remark for the example is simply that there “are structures *of* and *in* history.”⁶³ To him, the Yankees’ winning the series in 1939 was developmental or evolutionary, whereas the Giants’ efforts in 1951 were “evenemential” or revolutionary.⁶⁴ The difference between the two positions is that the Yankees dominated the 1939 season from beginning to end, whereas the Giants struggled

56 Ertsen et al. 2014.

57 See Pande and Ertsen 2014.

58 Scarborough 2003.

59 See also Scarborough and Lucero 2011.

60 See Dobres and Robb 2000; Gardner 2007.

61 Sahlins 2004.

62 Hexter 1971.

63 Sahlins 2004, 128.

64 Sahlins 2004.

throughout the season and only came on top of the league in their final game. The Yankees' championship was almost boring, a real collective effort, "without the necessity of referring to individual exploits or particular games."⁶⁵ The way the Giants won, in contrast, was full of drama, with an individual hitting home runs at exactly the right moment in the decisive game.

What is the point of this baseball story? I certainly do not want to suggest that the experience of the Giants is the same as that of the Yankees: clearly they are not. Spectators may remember the Giants' epic series much better than the Yankees' straight road to victory. On the other hand, I still remember the 1980 Dutch soccer competition, with the team that ultimately became the champion winning almost all their games—apart from the first one. Each and every game, however, was an event, if only because everyone—not least the players themselves—wondered whether they would win again. History may be "retelling from the beginning of an outcome already known, that knowledge guiding the selection (from the archive) of the successive events of the narrative,"⁶⁶ but that should not give permission to use our knowledge of what happened before to guide our explanations of what happened. Boring series of winning games may become boring over time, but for the agents that had to produce the games, boredom was not an option.

As much as the Giants and the Yankees had to go through each and every game in their respective seasons to become champions, our large-scale irrigated landscapes in northern and southern Mesopotamia were created by agents acting in the short term as well. Both landscapes took time to be constructed, with labor and resource mobilization being key for both communal and state-led initiatives, though most likely through very different mechanisms. Southern Mesopotamian landscapes developed through a series of local actions, yielding both crop surplus and urban elites controlling trade. Wet, northern Mesopotamia yielded something close to a hydraulic civilization, though it originated from rain-fed surplus. However, even when we think we know the different outcomes of both trajectories, we should realize that northern empires were as much based on day-to-day action as their nonimperial friends (or enemies) in the south.

65 Sahlins 2004, 128.

66 Sahlins 2004, 131; see also Hexter 1971 for an interesting exploration of writing in history.

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2

Cross-Cultural Archaeology and the Role of the Tropics in Informing the Present

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OUR BLUE-GREEN PLANET is in trouble through no fault of its own. We humans seem hell-bent on confronting the environmental systems from which we are inseparable. We have driven numerous living things to extinction, ravaged rainforests, and significantly degraded several other kinds of ecosystems. Our promiscuous use of fossil fuels has made possible technological innovation and asymmetrical economic growth in leaps and bounds at a velocity that has left the benefiting minority speed-blind and carefree of the social and environmental trade-offs involved. The global community has, however, become acutely aware of at least one trade-off of the industrial revolution and the great economic acceleration: the emission of carbon dioxides into the atmosphere causes long-term climatic warming that threatens our future existence—and this in a world in which the global population is exploding, especially in densely inhabited cities. Over the past few centuries—a mere blink of an eye in geological time—we have developed an odd set of social beliefs and values that emphasize the ruthless exploitation of natural resources of all kinds, rewarding short-term gains over long-term sustainability. We once enjoyed a staggering abundance of useful resources and their human-refined end products, which are now in dangerously short supply. It is hard to understand just how our ability to innovate and plan, to solve problems large and small, and our gifts for logical argument have gotten us to this critical point. Or, perhaps, it is a perfectly understandable historical trajectory given those precise human attributes. Either way, we have a “wicked” problem on our hands today.

For much of human existence, society’s worst enemies were our Hobbesian neighbors. Hobbes’s *Leviathan* has recently been carefully revisited by Steven Pinker, who suggests that our ancient past was indeed brutish with constant warfare driven by a presumed need for resources and the property of others (a zero-sum game without highly developed trade networks or incentivized and inventive R & D efforts), the fearful perception that a neighbor was about to pounce to obtain these resources, or something akin to prowess—the role of honor and shame—allowed by way of overpowering a neighbor.¹ And though the early role of cooperation in our species is poorly articulated by either author,² Pinker does make a compelling argument that relatively recent developments in our collective

1 Hobbes 1651/1957; Pinker 2011.

2 Contra Boehm 2012; Fry 2006; Hrdy 2009; Stanish 2017.

behaviors have significantly diminished not only the role of the great “hemoclysms” such as the American Civil War and World Wars I and II but also the many deaths associated with smaller war-torn states. A heightened awareness of empathic behavior and the value of other beings, as manifested in individual investments in personal hygiene, rules of societal etiquette, and the like, has changed the manner in which we have treated one another over the past several centuries. Gruesome spectator sport broadly defined is seldom permitted, and when it does occur it is globally condemned. Clearly every life matters, and significantly so, but Pinker attempts to place the complexity of numbers in a context of scale. He might suggest that in a group of hunters and gatherers, murdering or abducting half the members in a group of fifty—depending on age and gender ratios—risks reproductive extermination. When population is in the realm of millions (or billions), hemoclyms—which remain rare—spike mortality rates, but they are much less impactful to global humanity and our longitudinal survival. What could wipe the slate clean, however, are environmental degradations and significant climate warming inducing millions, and perhaps more, to perish. If Pinker is correct, then it is our assessment that our most pressing global concerns focusing on sustainability and well-being now hinge on a managed and developed awareness of the biophysical environment, as opposed to the egregious posturing and horrifying outcomes precipitated by either past or present warlords and despots—though this is not to suggest any less intolerance for or vigilance against rogue caliphates or lawless failed states. While the horrors some people inflict on others are every bit as gruesome today as they were in the past, there are now forces of global humanitarian optimism that declare that these actions need, should, and can be stopped.

We are archaeologists, as are some of our closest colleagues, and we have, perhaps by necessity, an interdisciplinary perspective that has given us a somewhat unusual view of social processes in a number of ancient civilizations. In our investigations of the human past, we have found that we are generating important insights relevant to current global concerns and challenges on at least two unique accounts. First, the long-term perspective endemic to archaeology is necessary to elucidate the dynamic interplay between process and event, elements of continuity and contingency, and the longer historical trajectories of social change. Second, archaeology provides a myriad of case studies featuring opportunities and challenges that humans have faced that otherwise would be unknowable. As a result of this experience, we believe that archaeologists can provide a few analogies and insights that may inform our futures in broader contexts than merely that of relatively recent technological and, dare we say, social progress.³ From our vantage point, it remains clear that many of the linked social and environmental issues we face today are both contextually quite different and yet often very similar to those that people and their societal institutions faced in the past. In that intellectual space between the empirical knowledge of the past, the experience and understanding of the present, and the unknowable future, there is a place for projecting the possible and probable. This is where archaeologists engage with the broader discourse of planning for a sustainable future. Over tens of thousands of years, what we have achieved as humans would surely impress the inhabitants of other sentient worlds. We have done much to engineer our environments and to build humanly created landscapes. In doing so, we have succeeded in extending individual life

³ Isendahl and Stump 2019; Scarborough 2016.

expectancies in a dramatic fashion, and we have significantly enhanced our collective ability to do conscious good. However, that potential and promise have always been offset by the complexities of the human psyche and our social behaviors, which frequently manifest themselves in free riders, greed, and significant sociopolitical corruption.

Near the center of this behavioral ambivalence lies our relentless population growth, most of which has taken place since the industrial development of the eighteenth and nineteenth centuries. Preindustrial civilizations wrestled with population scales or pressures, but it was perhaps the challenges posed by short- and long-term climate conditions that were of pivotal importance in extending institutional stability or instability over generations. Although greed and social corruption remain stand-alone threats to global well-being, longstanding drought and acute flooding frequently compound social inequities and volatility.⁴ Nevertheless, one of the insights gained from cross-cultural comparative archaeology is that societies may react very differently to climate conditions; there is no certain outcome for how climate change or a series of climatic anomalies relate to social change. That said, the great accomplishments of human culture as we know it today—inclusive of agriculture, cities, states, technology, healthcare, educational systems, global trade, and so on—are strongly framed within the relatively warm, wet, and stable climatic conditions of the Holocene and recent Anthropocene. Within the broad boundary conditions of the Holocene, climate change variations, anomalies, and instability have persistently presented challenges to the resilience and sustainability of social systems. People have addressed these challenges within certain social and environmental constraints, when recognized, but frequently in different ways and with varying degrees of efficacy. Given the absence of advanced technologies in the past to buffer a population from the elements, and despite efforts to significantly raise the carrying capacity exploitable from a newly invented, complex, and highly engineered environment as a result of a labor force, societies were fragile and dependent on homegrown resources.⁵ When populations did experience growth and institutional transitions in infrastructural capital and social relations of production, they left themselves vulnerable during these times of transition.⁶

A principal base issue is, and was, proximity and access to water; climate change is fundamentally water-abundance change. Several archaic societies overstressed their environments and underwent profound, sometimes catastrophic, transitions. The stakes were high within the confines of the Nile valley,⁷ Mesopotamia,⁸ and Cambodia's Tonle Sap.⁹ Our archaeological colleagues can describe innumerable menacing situations where a combination of social and environmental factors involving both inequality and drought led to catastrophe—even social collapse. The partial implosion of Classic lowland Maya civilization in Guatemala's Petén during the tenth century CE is a case in point.¹⁰ But the challenges faced by our industrialized and socially digitized world with its megacities

4 Cf. Riede and Sheets 2020.

5 Yoffee 2005.

6 Scarborough and Burnside 2010.

7 Hassan, in press.

8 Kaniewski, Van Campo, and Weiss 2012.

9 Buckley et al. 2010.

10 Iannone 2014; Kennett et al. 2012; Scarborough et al. 2012.

that operate in a globally interconnected space are on an unimaginably larger scale. Although we are facing a global crisis of uncontrolled ecological and social stressors that threaten the future of humanity's well-being, we have confronted not dissimilar environmental overexploitation and exogenously induced societal changes in the past, though clearly at more regional scales. The anthropogenic decisions made then, when coupled with the less societally dependent trajectory of biophysical agents in our environments, are infrequently assessed or understood; our living ecology reflects a dependency on previously built niche constructions and engineered landscapes.¹¹ Whether consciously or less so, our past societal pathways haunt us and warrant thoughtful assessments and reconstructions to best understand the range of unintended consequences posed by our present and future actions.

Rather than describe many examples of how, and perhaps why, we have arrived at this potentially catastrophic crossroads in human experience, we want to analyze a few examples from more recent preindustrial history where we humans may have done the right things. These are cases where society and environment came together in such a way that their consequences provide a set of guidelines for a more sustainable future. The impact of water access on livelihoods implicitly undergirds our institutional infrastructure in both the past and the present. Our charge here, in part, is to elucidate the role of an understudied set of global regions that seasonally receive a great deal of rainfall and are identified by a different kind of irrigation schedule and allocation method than are frequently associated with other more arid and temperate settings. The issue of sustainable biophysical environs and our societal complement are emphasized, with the view that zones drawing on highly engineered wetlands tend to reflect more dispersed settlement and land-use adaptations as compared to those built landscapes based on highly constrained annual precipitation rates, formal diversion of perennial stream systems, and more compacted population aggregates. In this context, the present volume is a study in explicitness and the need to accent water's availability and management as a leading influence in the decisions that both society, and culture more broadly, have to and will have to make.

Not that long ago, in places like ancient Cambodia or the Yucatan Peninsula in Central America, urbanism looked very different than it does today. Both the Khmer and Maya civilizations developed in semitropical settings with a wet-dry tropical forest environment. In both places, the people lived with highly seasonal rainfall. A four- to five-month dry season brought intense drought cycles that frequently offset the overabundance of precipitation from the rainy season.¹² As a result, these early cities worked to store seasonal water supplies, realizing that they were a critical resource. Both flourished in environments of remarkable biological diversity, which one can still witness in Costa Rica or on New Caledonia in the southwestern Pacific. A blinding array of colorful animal and plant forms from within the tropical biome makes up 70 percent of living species on the globe. However, they flourish on only 40 percent of its land surface. What is seldom noted in these settings is that the natural world has controlled the fecundity of the tropics by keeping the individual numbers—the richness of a species occupying a microenvironment or

11 Scarborough 2015, 2016.

12 Scarborough and Lucero 2011.

patch—within minimal limits.¹³ For example, the mahogany tree or the jaguar of the tropics does not occur in groves or herds, the settings we usually associate with field grasses like ancient wild wheat or gregarious populations of ancestral cattle. And what are humans to do in such a world of dispersed organic resources, in a world of high temperatures, humidity, and rapid decomposition?¹⁴

A very different way of living on the land developed in the lower latitudes. Humans adapted to the rhythms and reach of natural resources by mimicking their distributions early in their horticultural trajectory; and though early residential urbanism and associated agricultural space could be engineered into a denser interfingering of the two landscape spheres, dispersion remained the overwhelming cultural construct. Although humans are highly evolved social animals, our big brains allow us great flexibility in deciding how we might live together in what are otherwise constraining environments. Nevertheless, a successful and sustainable tropical society frequently had to play by the same rules directing all other forms of life.¹⁵ Above all, this involved modifying the human propensity for living at close quarters, in propinquity, and in more dispersed ways.¹⁶

To best elucidate the tendency for tropical societies to disperse, contextualizing water and land use by way of a coupled human/nature dynamic may be appropriate. Because of the biological turnover in the hot and wet tropics, organic matter is metabolized at a much faster rate than under temperate or arid conditions. One way to monitor and perhaps slow this otherwise rapid respiration and decay rate is to substitute human-use plants and animals for those initially colonizing and subsequently dominating an environmental setting. Such selective conservation practices may or may not have led to domestication, a developmental alteration made possible only through repeated use of specific species and in association with the intrinsic predisposition of an animal's or plant's genetic constitution. By controlling the growing conditions of both conserved and domesticated plants, for example, humans can provide more or less shade, water, or even soil admixtures to a set of productive species like maize, beans, and squash in the tropical New World and significantly curb their loss to pests or disease vectors year after year.¹⁷ By partially repopulating those areas between households with fewer species and investing in those with food or fiber import to humans, a human niche was initiated and advanced.¹⁸ By limiting the myriad diverse organic pathways apparent in an otherwise less humanized environment, the rate and process of metabolized resources were controlled, monitored, and harvested in a sustained manner.¹⁹ Nevertheless, organizing space and the harvesting of resources to accommodate settled humanity in the tropics remains a challenge.

Given the seasonal overall abundance of rainfall in semitropical settings, water harvesting involved a different set of adaptations and infrastructures than under several other climatic regimes. The deliberate modification of microcatchment basins with runoff

13 Scarborough and Burnside 2010.

14 Scarborough and Valdez 2009, 2014.

15 Scarborough 2010.

16 Scarborough and Burnside 2010; Scarborough and Lucero 2011.

17 Wilken 1987; Scarborough 2012.

18 Scarborough 2015.

19 Ford and Nigh 2014.

directed toward storage reservoirs and holding tanks during the rainy season allowed year-round availability, a condition much more difficult to accommodate in more arid settings unless perennial rivers and streams allowed such diversion.²⁰ In the latter instance, reservoirs were relatively less frequently employed because of extreme surface evaporation concerns—unless they were deep, and even then obtaining enough precipitation away from the perennial streams made their recharge vulnerable except when in proximity to seeps and springs. However, in seasonally abundant water settings, both large and small reservoirs and tanks were deployed widely on the engineered landscape. Note that we are not suggesting that reservoirs were a less significant landscape feature in semiarid settings—their construction and maintenance were of import to societies as far-flung as the desert Hohokam,²¹ the Chimu,²² and the many cultures occupying and passing through the Near East;²³ what we are suggesting is that their infrastructural function was different.

The wide distribution of reservoirs in the semitropics frequently required comparably sized runoff-catchment areas. The dispersed settlement patterns associated with these settings were likely accented to accommodate these micro watersheds, landscapes partially altered to funnel water into low-lying depressions. Today, after a season of rainfall, the terrain of the southern Maya lowlands is a dispersed scatter of small watering holes—*aguadas*—some artificially dug, others altered and augmented from the natural karst terrain, and many (perhaps most) of pre-Columbian origin.²⁴ Because of the pocked, porous, and jointed limestone bedrock, few perennial surface drainages of consequence course over the Maya lowlands before their runoff flows percolate downward and are lost without the use of modern water pumps. In the large centers of the Classic period Maya (200–900 CE), water systems were less insular than those small-scale *aguadas* with abundant reservoir waters frequently cascading one tank to another within the elevated central precinct of a site designed as the principal water catchment (see the semitropical systems of rural Sri Lanka for a present-day analogy).²⁵ The need to quickly dispose of organic waste before rot and infection was always a concern in the tropics, so keeping plazas, courtyards, and living spaces clean was a necessary prerequisite for longevity. The canted and raised plaster surfaces—from pyramids to ball courts to the courtyards themselves defining the great center of Tikal, Guatemala—are the archetypical components of a runoff catchment system or a “convex micro watershed”—the ultimate manifestation of the numerous, widespread, and singular rural *aguada* systems.²⁶

Formal irrigation by way of kilometers of canal leads was never an option in the Maya area, in part because of the same karst bedrock conditions that prevent lengthy river systems from carrying the abundance of seasonal rainfall to the sea. Nevertheless, shorter

20 Scarborough 1993, 1994, 2003a; Scarborough and Gallopin 1991; Scarborough et al. 2012.

21 Bayman 1992; Bayman et al. 2004; Fish and Fish, in press.

22 Moseley, in press.

23 Wilkinson 2003.

24 Beach and Dunning 1997; Chase 2016; Dunning, Beach, and Lazzadder-Beach 2012; Weiss-Krejci and Sabbas 2002.

25 Scarborough 1994, 1998; Scarborough and Gallopin 1991; Scarborough et al. 2012; Scarborough and Grazioso Sierra 2015.

26 Scarborough 1994, 2007; Scarborough and Burnside 2010.

drainage canals controlled by sluices leaving some reservoirs were clearly defined,²⁷ while other reservoirs were likely well sources for nearby pot-irrigated agricultural plots.²⁸

For the ancient Khmer and its great urban center of Angkor, the semitropical wet-dry forests were identified a bit differently than those of the ancient Maya.²⁹ The Tonle Sap and the Mekong River were in proximity, but their fluctuating water tables may well have affected how Angkor developed its own highly complex water management system.³⁰ Although at least an order of magnitude larger than any site area in the Maya lowlands—including Tikal—Angkor had numerous (hundreds of) moated mound complexes (*trapeangs*) with rectangular east–west-oriented reservoirs over the 1,000 sq km cityscape, likely the largest preindustrial city in the world at 800–1200 CE.³¹ Although much more integrated into the orbit of the grand city than anything the ancient Maya developed by way of the myriad of *aguadas* across their karst landscape, a runoff catchment arrangement was necessary;³² it simply adds to what Roland Fletcher³³ has coined as “low-density agrarian-based urbanism” and household dispersal tendencies associated with even this most complex and sizable of semitropical cities.

The city core itself, however, was supplied by the seasonal flux of the streams and rivers issuing from the north- and east-flanking Kulen Hills; they diverted and rerouted to accommodate several huge east–west-oriented rectangular reservoirs or *barays*, just one of them large enough to completely enclose the entire 16 sq km of what is the mapped core limits of Tikal.³⁴ Unlike the Maya lowlands, Angkor rests in a low-lying, soft sandy zone—marshlike prior to the ascendancy of the Khmer. To accommodate this overabundance of water, the landscape was engineered to capture monsoonal runoff moving north to south by way of these huge, elongated east–west-oriented reservoirs—the West and East Barays bisecting half the city end to end, each approximately 2 km north–south by 8 km east–west. These tanks were less adapted to formal canal surface release during the dry season; rather, the porous underlying sands allowed for elevated groundwater recharge to a slightly lower, surface-gradient rice crop located between the very low lying Tonle Sap and the *barays* themselves. The elevated but mostly subsurface movement of water from the reservoirs not only permitted an extension of the rice-growing season immediately below the *barays*³⁵ but also kept the sands saturated enough to prevent the many huge monumental *wats* (temples) from sinking—the latter a current problem as a partial result of more recent water diversion schemes.³⁶

For both the ancient Khmer and the Maya, this landscape transformation meant a set of adaptations that represent a different trajectory from what we see as normal and

27 Scarborough and Grazioso Sierra 2015.

28 Ferrand et al. 2012.

29 Scarborough and Lucero 2011.

30 Evans et al. 2007; Fletcher et al. 2008.

31 Evans et al. 2007.

32 Kumm 2009; Penny et al. 2006.

33 Fletcher 2009; but see Graham and Isendahl 2018.

34 Carr and Hazard 1961; Carr et al. 2015.

35 Ortloff 2010; Scarborough 2011.

36 Coe 2003.

ordinary today. Twenty-first-century industrial civilizations live in large, dense, urban aggregates, with people frequently stacked high in apartment complexes and business buildings. We know from archaeology that this urban trajectory developed from long Euroasian traditions preserved in familiar semiarid and, subsequently, temperate settings. The Western urban tradition is firmly rooted in conditions established in residentially dense, Near Eastern desert cities as early as the third millennium BCE; the ancestral tell cities of Uruk, Kish, and Ur are literally built on top of one another.³⁷ Today's industrial cities are thriving hubs for rapid and highly reified information and material exchange resulting in powerful innovation—from cutting-edge artistic expression to still-novel technologies.³⁸ As is well known, in spite of these synergies, there are serious environmental and sustainability problems associated with the densely populated modern industrial city. Pollution has risen to levels that affect not only the air we breathe and the water we drink but also the world's climatic system. Indeed, the cities of today, whether industrial or postindustrial, are subsidized by fossil fuels for their basic metabolic survival, in effect extending the urban environmental footprint well beyond the city limits itself. Living in today's cities also triggers psychological and social stresses with which our evolutionary history of mind and body has likely not yet developed to cope.

Resources are dispersed widely in tropical environments; there are no long-term, residentially dense, modular-constructed (apartment-like) tells of antiquity. For thousands of years, human societies large and small have adapted to this reality by dispersing. Such adaptations developed over many centuries—not in sudden surges of success but in fits and starts, with both failures and retrenchments. There was no such thing as instant adaptation, the historical trajectory of tropical civilizations being as fully convoluted as that of Western civilization, or, viewed from a narrower compass, that of Classical Greece or Rome. For all the faltering progress, we can discern two tropical-setting developments that co-occurred. One was the construction of roadways, defined by linear paths or pavements not unlike the familiar highways of the West. Another was the canalization of rivers and streams, inclusive of a few seasonal catchments as noted above, that enabled light, shallow draft canoes to move goods, services, and ideas in addition to irrigating field systems. In the New World, a hemisphere without the technological development to invest in the wheel, the sail, or beasts of burden (with the exception of the recalcitrant llama), humans carried their valuables and ideas on their backs or plied watery highways.³⁹ In settings like the immense expanse of the Amazon, new research is revealing lost worlds of ancient towns and interconnected waterways that flourished in the early first century CE.⁴⁰ Sophisticated modifications to swamp and wetland environments fostered a huge expansion in exchange and trade based on canoe traffic. In the Maya lowlands, over 40 percent of a zone the size of the United Kingdom comprised seasonally flooded wetlands.⁴¹ Almost certainly similar, but still underreported, canoe traffic thrived in these environments.⁴²

37 Scarborough and Grazioso Sierra 2015; Yoffee 2005.

38 Florida 2002; Glaeser 2011.

39 Scarborough 2000, 2010.

40 Erickson, in press.

41 Dunning et al. 2012; Scarborough 2003a.

42 Scarborough and Valdez 2014.

We are also learning the vast extent of pre-Columbian terrestrial road building in grand urban-scapes like Caracol in present-day Belize,⁴³ and we are gaining new insights into the interlinking of community connections, near and far.

The other somewhat opaque but long-studied trait identified in some early tropical civilizations is their calendrical capabilities. In both the Maya world⁴⁴ and ancient Cambodia,⁴⁵ the latter with near-living representation on the Indonesian island of Bali,⁴⁶ the multifaceted dimensionality of time consumed the energies of both elites and scribes. In their most mundane applications, beyond attempts to wed kingship with the deities via the temporal movements of the heavens, these calendars may well have been the scheduling glue for routine and practical activities across a landscape of seasonally less predictable rainfall and altered waterways.⁴⁷ Rainfall was never uniform across a semitropical region, making some subregions water rich and others water poor from year to year and necessitating regional coordination from centralizing nodes such as Tikal or Angkor.⁴⁸

Trade is a significant artifact of any society, and archaeologists have identified numerous luxury items displaced from their known origin of manufacture. But for the ancient Maya, the more perishable comestibles like maize or beans grown for near-immediate consumption in an unforgiving environment of rapid decomposition and rot could be transported over distances too.⁴⁹ Scheduling or calendrical timing was particularly important. Local and insular village economic development is a zero-sum game when only land and limited technological innovation are associated with agricultural yields; trade significantly changes that equation.⁵⁰ The heat and humidity of the tropics made it near impossible to store perishable foods and other organics for any length of time once harvested and marketplace ready. Delivering food from harvest to household in urban settings before it rotted required different types of economic and social coordination than in the more arid settings of both the Old and New Worlds.⁵¹

What does the ancient world, with its low-density states, have to offer to today's industrialized world? In the fast-moving and carefully scheduled realm of the ancient Maya lowlands, for example, several archaeologists have implied that an incrementally evolving set of societal institutions affected by their own causal and sometimes unintended actions to the engineered landscapes resulted in a dynamic but sustainable human/nature coupling over the centuries.⁵² The societal side of the equation continuously sought a "perfect order" in a ceaselessly sliding scale of modification and change.⁵³ A sprawl of relatively

43 Chase and Chase 2014.

44 Coe 1992.

45 Coe 2003.

46 Lansing 1991, 2006; Lansing and Cox 2019.

47 Scarborough and Valdez 2014.

48 Scarborough and Lucero 2011.

49 Scarborough and Valdez 2009, 2014.

50 Gunn et al. 2017; Pinker 2011.

51 Scarborough and Valdez 2014.

52 Chase and Scarborough 2014; Demarest 2004; Scarborough 2003b.

53 Lansing 2006.

high-density, rural “resource-specialized communities”⁵⁴ interacted with a variety of low-density urban settings, resulting in a mutual interdependency that ensured the most effective exploitation of both land- and water-based resources.⁵⁵ Working within the context of the higher-density “cities,” these rural communities harvested their hinterlands or simply specialized in a craft or two and cultivated a matrix of shared regional exchanges likely coordinated by major, low-density population concentrations⁵⁶—low-density, agrarian-based urbanism. The tropics were, and remain, an organically rich setting with rates of biological exchange several times higher than arid or even temperate animal and plant turnovers. Much of the world’s tropical landscape has now been brought into the modern economic system with little difference in structural character or settlement density between a Bangkok, Bogotá, or Benin. But in the past, only a few centuries ago in some cases, low-density cities with relatively high-density rural hinterlands mapping out complex agro-urban landscapes⁵⁷ were a highly effective, frequently sustainable adaptation to the unique and harsh realities of tropical environments.

Low-density ancient cities developed and flowered because of roadways and meticulous scheduling that was in tune with the natural environment. Can one retrofit aspects of this increasingly well-known, low-density model for today’s capitalistic world? Of course, many would argue that the Khmer and Maya were low-tech, preindustrial civilizations that could only have flourished in much less densely populated environments than today’s civilizations, so their experience has no relevance to current urban problems. But is this really true? One has only to look at the longevity of both the Khmer and Maya civilizations to argue the contrary.⁵⁸ Generations of archaeological research have shown that several tropical societies had very long and successful runs. Maya civilization flourished for some 1,500 years, Khmer cities for a least half a millennium. In the end, like all civilizations, they fragmented as a result of both ecological and social changes. But they were highly successful by any historical standard; indeed, the chance that Western civilization will last as long as that of the Maya remains an open question. Besides, many contemporary concerns are timeless, and we face the same challenges as our brothers and sisters of the past: water and food security, societal reproduction, and peaceful intergroup interaction and exchange.

Nevertheless, the game has changed in an increasingly linked, internet-driven world. This revolution in communication is undermining aspects of several social structures and challenging hierarchical relationships in unpredictable ways. The hegemonic nation-state is struggling like never before, and definitions of corporate resource control and centralization are undergoing some of the most acute reevaluations ever because of wide-open information access, as exposed by Edward Snowden’s 2013 revelations about the use of big data. Our entire banking and corporate underpinnings are under review because of formerly well-concealed operating strategies that are now open to civic scrutiny, such as the Panama Papers exposed to the general public in 2016. Although our economic spikes in veiled concentrations of money and the resources they represent were in part attributable

54 Scarborough and Valdez 2009, 2014.

55 Isendahl 2012; Chase et al. 2014; Isendahl and Barthel 2018.

56 Sheets 2000.

57 Isendahl 2012; Graham and Isendahl 2018.

58 Scarborough and Grazioso Sierra 2015.

to tech wizards and inside traders with highly developed electronic expertise, the crash of the past decade was induced by their hubris. And now the internet is more transparent—even democratic—than ever. Channels of communication and exchange are welling up from deep below the thin air of our CEOs and benevolent dictators.

The internet is connecting all of us in evolving ways. So, might we then wish to invest in a communication model that mimics a hinterland where real resources are cultivated, enhanced, refined, and allowed to develop in a manner that also allows their marketed access—a model not unlike our ancient tropical analogue? Here, the internet accommodates a production rate in sync with rapidly changing demand and in the context of a global marketplace. Production schedules are paced to fit the desires of a highly diversified set of consumers. Entire hinterland communities, perhaps organized into local cooperatives producing a product—from flowers and textiles to forest products or rare earths—are then connected to the world of exchange.

Of course, these resource-specialized communities require concrete ways to move and distribute their products, and the centralizing influence of urban nodes would continue to act as that catalyst. The new city of this ancient and future world would coordinate the exchange, perhaps most influentially through a series of energy-efficient investments in light railways laid in a dendritic pattern throughout an engineered landscape. The network of existing highway and interstate truck traffic would pave or ease the transition to a more energy-acceptable arrangement, not unlike the ancient roadways that knit together the resource-harvesting and resource-producing hinterlands of the Khmer and the Maya and their valued rural communities that were perhaps less compromised than today.

The heavily occupied and steeply hierarchical governance structures of today's cities may well level out somewhat and make the anathema of "sprawl" something other than homogeneity and sameness. By occupying and reharnessing the physical resources and labor potential of the rural setting globally, society would redefine its "space" and cultivate a different kind of understanding of our earthly environs. Communities could develop in ways that are quite unlike how we understand them today. The centrality of the water hole or well has been noted in numerous ethnohistoric and ethnographic accounts as a place of community and associated information exchange for centuries. Ensuring the potability of the source for rural communities by accounting for catchment and groundwater pollutants using our understanding of the archaeological record would surely aid in knitting together a fragmented and currently compromised rural identity. Would an informed team of anthropologists or archaeologists have best approached the extreme crowding and arsenic contaminations in the poorly drained Bangladeshi communities of tropical South Asia? Maybe. Notions of well-being require reassessment. Commitments to one another and the ecology of place, including in urban landscapes, would be the logical outcome for forming a less-stressed place for both humans and their landscape.

Much has been written about common-pool resources and their implications for the economies of the world. Most ancient societies never had this conversation or real challenge, though they frequently realized the limits of their resource base. In the tropics, perhaps in spite of their fragility and another society's ability to quickly cut or burn away one's generational livelihood, dispersed groups like the Maya lasted for well over 1,500 years, sustaining a population approaching ten million, ten times the present population of the Maya lowlands, on such a landscape—a powerful testament to their enduring resilience.

One should not romanticize the archaic state or any complex, low-density city. The Maya are the poster child, along with the Roman Empire, of acute social and environmental collapse, of an ultimate socioecological pathway leading to destructive ends. And though we need to look at both legacies of the past—sustainability and resilience juxtaposed with social fragmentation and collapse—neglecting a clear assessment of the former prevents us from making a clear-eyed assessment of how the experience of ancient tropical civilizations with their dispersed settlement patterns can help us tip our profligate ways of life toward much greater, longer-term sustainability.

We are at a juncture in our critical use of resources today. With global warming trends unlikely to change anytime soon, and with well over two-thirds of the megacities on the planet situated on coast margins, rising sea levels will result in significant urban restructuring. Perhaps an opportunity to review and revisit aspects of the past is in order. Can an ancient engineered tropical landscape provide any insights? We think so.

Note that earth systems will adjust with or without us. The nonhuman meek may well inherit the earth; and though the planet will be much grayer than its past blue-green vitality for humans and our animal cousins for a while, it will happily soldier on in one form of life's complexity or another. Might a lesson or two from our past human ecological record be worthy of at least a discussion? Perhaps a need to lift the veil of disbelief that archaeology cannot participate in this dialogue is long overdue.⁵⁹

59 Chase and Scarborough 2014; Isendahl and Stump 2019; Sabloff 2008.

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3 Foggaras and the Garamantes: Hydraulic Landscapes in the Central Sahara

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THE CENTRAL SAHARA is a hyperarid environment with less than 50 mm annual rainfall, high rates of evaporation, and scorching summer temperatures. Yet, in a number of places and epochs, it supported oasis populations that numbered in the tens or hundreds of thousands and, in a small number of cases, urban centers and complex societies that can be considered states.¹ Examples of these Saharan states include the Garamantes, the Banu Khattab, the kingdom of Kanem, the Awlad Muhammad,² and the city-state of Ghadames.³ The oases of Fazzan feature prominently in the histories of these states, and it is here, in the Wadi al-Ajal, that the Garamantes were located, with their capital of ancient Garama, modern Jarma. During the early first millennium BCE, the progressive aridification of the Sahara impelled mobile pastoral groups progressively to coalesce around relict lakes and other permanent water sources, and it would appear that the Garamantes emerged from these groups as a sedentary, agriculturally based civilization well before the fifth century BCE, when the Greek historian Herodotus refers to them. Archaeological fieldwork has shown that they possessed a writing system (rock inscriptions in a script related to later *tifnagh* scripts), developed fortified towns and villages often showing a degree of planning, and practiced irrigated agriculture.⁴ Roman sources suggest that their power extended over the three oasis belts of Fazzan and the northern Libyan Sahara; on several occasions in the first century CE, they were involved in conflict with Rome, sending ambassadors to Rome when they were defeated. A Roman expedition to Fazzan in the later first century CE seems to have ushered in a more peaceful era that saw flourishing trade between the Roman world and the Garamantes. We know very little about their internal organization, but both Roman and early Arabic sources identify kings who ruled from Garama in this period. Garama and one or two other large centers were certainly of urban scale, and agricultural settlements were distributed along the oasis depressions. In and around Jarma, the funerary record provides evidence of inequality in the society and widespread access

1 Mattingly and Sterry 2013; Sterry and Mattingly 2020.

2 Mattingly 2013; Mattingly, Sterry, and Edwards 2015.

3 Mattingly and Sterry 2010.

4 Mattingly 2003, 2013.

to traded goods from the Mediterranean. During their heyday in the first to sixth centuries CE, the Garamantes sat at the heart of Saharan and trans-Saharan trading networks that reached both the northern and southern fringes of the Sahara.⁵ Archaeological fieldwork and remote sensing have located the remains of hundreds of settlements dating to this period, along with more than 2,000 km of foggara networks (underground irrigation channels; see below) and 100 sq km of relict field systems.⁶ Irrigation and intensive agriculture were essential features of this society. This is therefore an ideal case study to examine the features of irrigation and their relationship to states.

Fazzan is traditionally divided into three main oasis groups—the Wadi ash-Shati to the north, the Wadi al-Ajal in the center, and the Wadi Barjuj, Murzuq, al-Hofra, and ash-Sharqiyat depressions to the south (fig. 1). Beyond these are a number of smaller clusters of oases: the Wadi Hikma in the southeast, Tmassa in the east, a group of salt lakes and paleolakes in the sand sea between the Wadis ash-Shati and al-Ajal, and Sabha/al-Bawanis and al-Fuqha to the northeast. The region is hyperarid and receives minimal rainfall, and prior to mechanization and the digging of wells hundreds of meters deep, it comprised just 40 sq km of cultivated land and palm groves and a population of about 30,000. The so-called Green Sahara dates much earlier than our period of interest, and by the first millennium BCE the region was a desert, though potentially with slightly more rainfall than today.⁷

BACKGROUND

In Fazzan, there are five sources of water for irrigation: artesian springs, nonartesian springs, balance wells (*shaduf* or *khattara*), animal-operated wells (*dalw*), and foggaras (the North African name for gently sloping underground channels commonly known in the Middle East as *qanats*). Their distribution reflects the complex natural hydrology of Fazzan. The foggaras in Fazzan range in length between 0.5 km and 6.5 km and are largely cut through sand and gravel, although some shafts close to the *hamada* (rock escarpment and plateau) are cut through solid sandstone (fig. 2). The friable soils, which slump easily, have contributed to very close spacing of access shafts that are typically only 5–10 m apart (by comparison, spacings of 20–30 m are not uncommon in the *qanats* of Syria and Iran). In the Wadi ash-Shati, there are some natural artesian springs, and many more have been dug into the natural aquifer (277 were recorded in the 1930s⁸), but the soils are susceptible to salinization. The best soils are instead found in the Wadi al-Ajal, which is characterized by a narrow corridor between the sandstone escarpment and *hamada* to the south, and the dunes of the Ubari sand sea to the north. There are no longer any perennial springs in this wadi, though there may have been a small number up until the second or first millennium BCE. Prior to the introduction of diesel pumps, the groundwater was at a depth of only a few meters, where it was accessible to both *dalw* and *shaduf* wells. Under the escarpment, the water level is higher than the central valley floor, making it highly suited to foggara

5 Liverani 2005; Mattingly et al. 2017; Wilson 2012.

6 Mattingly 2007, 2010; Mattingly et al. 2020; Sterry and Mattingly 2011, 2013; Sterry, Mattingly, and Higham 2012.

7 Drake et al. 2011.

8 Scarin 1934.

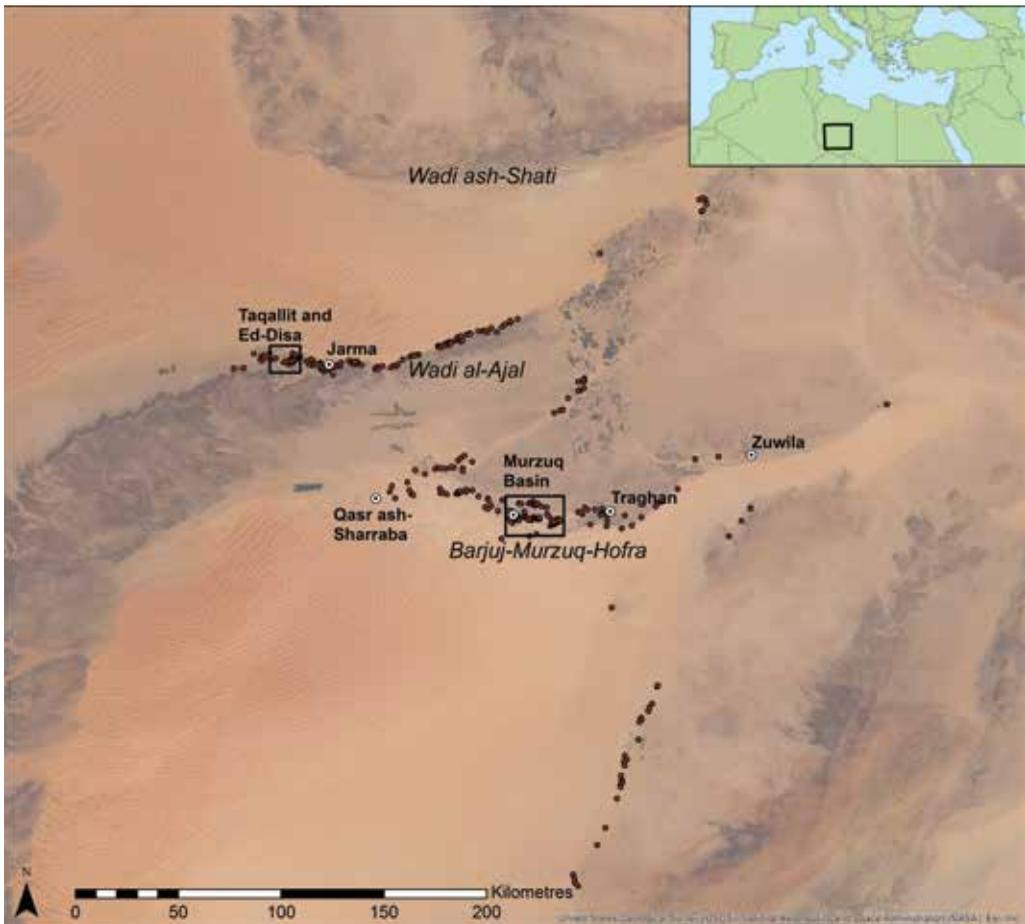


Figure 1. Location map and sites mentioned in text. Red dots mark other Garamantian sites.

construction. The Barjuj-Murzuq-Hofra depression is relatively flat and also has groundwater close to the surface, which in the lowest parts forms a number of *sabkhas* or playas; the shallower *shaduf* wells and to a lesser extent the *dalw* wells were traditionally popular in this part of Fazzan up until the 1960s.

Owing to the lack of rainfall in recent millennia, there is no substantial recharge of the groundwater in Fazzan, which when coupled with the fact that the aquifers under Fazzan are continually draining through natural processes means that the groundwater table has been dropping for several thousand years. This has evidently been exacerbated, particularly at the local scale, by the tapping of these fossil waters for irrigation. These factors all point to a hydrology in which different water sources were potentially available at different times subject to climatic and environmental factors. For example, we suspect that parts of the Murzuq depression close to the medieval capital of Traghan would have been swamp-like in antiquity, while the Garamantian town of Qasr ash-Sharraba is now fully 25 km from the nearest irrigable sources of the Wadi Barjuj. Further contributing factors determining the use of different irrigation strategies are the availability of types of technology, the local and regional impacts of prior uses of irrigation, and the role of social

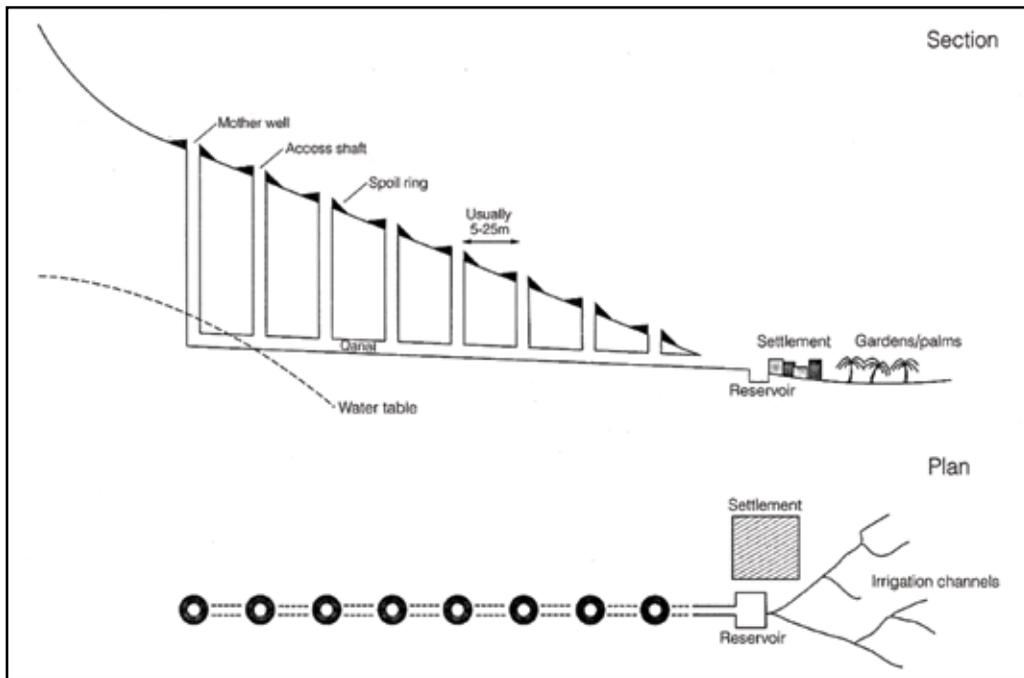


Figure 2. Schematic section and plan of a foggara.

aspects such as ownership, investment, and the intended use. When considering archaeological distributions in Fazzan and indeed in the wider Sahara, we must be aware of this dynamic environment, in which there were windows of potential opportunity for the development of oases, each with its own distinctive character. The interplay of environment, technology, and people in each window led to a diverse range of hydraulic landscapes.⁹

The development of irrigation is strongly correlated with the development of settlement in Fazzan. The earliest-known settlements date to the early first millennium BCE and line the escarpment edge of the Wadi al-Ajal. The best-explored site is the hill fort of Zinkekra, which was excavated in the 1960s by Charles Daniels. Here, deposits from in and around small oval houses showed evidence of the earliest-known cultivation of cereals and date palms in the central Sahara. No contemporary, manmade irrigation systems have yet been located, but four gypsum deposits dated by uranium-thorium suggest that there may have been some active springs at this time.¹⁰ By the late first millennium BCE, settlements were increasingly located on or close to the floor of the wadi (e.g., Jarma, Tinda). This movement to lower elevations was accompanied by an increase in population as evidenced by larger and more numerous settlements, a growth of cairn cemeteries on the escarpment edge, and our earliest direct evidence for irrigation. Dried plant fibers extracted from the mud-brick lining of a foggara shaft at al-Hatiya (ELH013) have returned an accelerator mass spectrometry (AMS) date of 391–206 cal BCE (OxA-26746, 2243±26) (fig. 3). Further

⁹ Cf. Wilkinson and Rayne 2010.

¹⁰ Drake et al. 2004.



Figure 3. Mud-brick lining of foggara shaft at al-Hatiya (Wadi al-Ajal, Fazzan); organic material from one of the mud bricks produced an AMS date of 391–206 cal BCE.

evidence comes from a number of tombs and settlements with associated ceramics of the first century CE that appear to have respected preexisting foggara shafts. The first to sixth centuries CE show a definite spike in population in the Wadi al-Ajal around Jarma, which was now an urban-scale settlement. Though we lack direct dating, the close spatial relationship between these settlements and the outlets of the majority of foggaras suggests that the two phenomena are connected. In general, we consider that the vast majority of foggara systems in this region were constructed and maintained between 400 BCE and 600 CE.

The introduction of irrigation technologies should also be seen against a broader backdrop of technological transfers and innovations in the Sahara. Excavations at a sequence of sites of the first millennium BCE/CE have retrieved botanical data for a number of Mediterranean/Nilotic plants and some sub-Saharan crops: pearl millet, sorghum, and cotton (table 1). This is also the same period in which we can identify the earliest central Saharan metalworking, the replacement of saddle querns with rotary querns,¹¹ and new faunal species (horses, pigs, chickens, and camels). The cultivated crops all require significant levels of water, and the sudden uptake of these cultivars implies a corresponding development of irrigation facilities.

HYDRAULIC LANDSCAPES OF THE GARAMANTES

Foggaras are the most prominent form of irrigation to have been practiced in Fazzan, especially in the Garamantian heartlands of the Wadi al-Ajal around the capital of Garama/

¹¹ Parton 2013.

Table 1. Archaeobotanical evidence for cultivated crops from sites in Fazzan (data from Pelling 2013; Van der Veen 1995; Van der Veen and Westley 2010).

	Zinkekra (c. 900–500 BCE)	Tinda and Jarma (500–1 BCE)	Jarma (1–400 CE)
Bread wheat	X	X	X
Durum wheat			X
Emmer wheat	X	X	X
Barley	X	X	X
Pearl millet		X	X
Sorghum		X	X
Pea			X
Indeterminate pulse			X
Fig	X	X	X
Grape	X	X	X
Date	X	X	X
Watermelon			X
Almond			X
Pomegranate			X
Olive			X
Sesame			X
Cotton		X	X

Jarma. The surface remains of the shafts make them easily recognizable either as a series of spoil rings (or, if close together, two parallel lines of spoil) or as a rough line of vegetation. Our archaeological survey in Fazzan has located a foggara network of more than 2,000 km (fig. 4). The exceptional preservation conditions in the Sahara allow all parts of the system to be identified, including the reservoir, channels, gardens, and divisions at the output of the foggara in some cases (fig. 5). Their presence is strongly correlated with the distribution of Garamantian settlements that typically cluster close to their outlets. As such, it is easy to draw a direct parallel between the functioning of the foggaras and the growth of

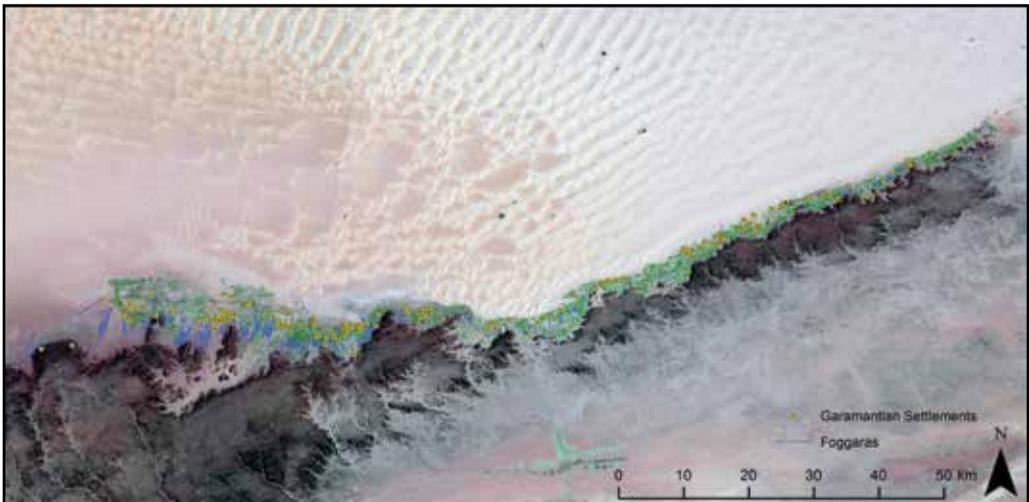


Figure 4. Map of foggara channels in the Wadi al-Ajal, Fazzan.

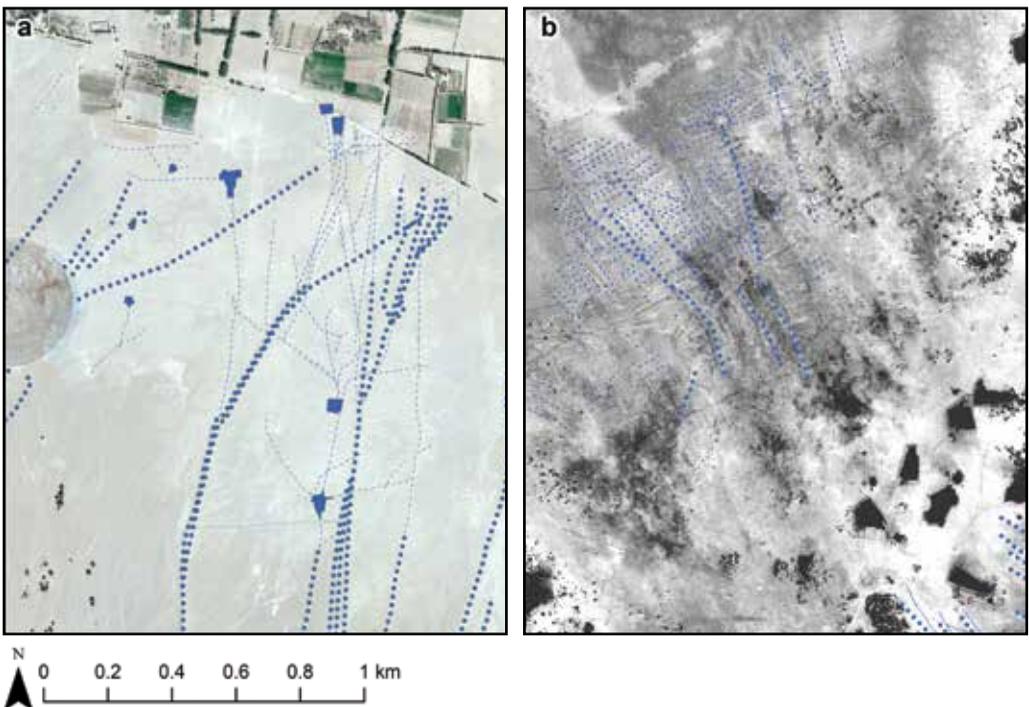


Figure 5. Example of channels and gardens at the output of a foggara (WorldView-2 image, January 14, 2013, copyright DigitalGlobe).

Garamantian populations and therefore the well-being of the Garamantian state. However, to the south in the Barjuj-Murzuq-Hofra basins, the environment is far less suitable for foggaras but was still seemingly prosperous during the first millennium CE.

Around the settlements in this region are the remains of field systems that were irrigated by hundreds of wells (most likely the balance well), with only occasional use of foggaras. To demonstrate the complexity of the irrigation strategies of the Garamantes, we will therefore detail the hydraulic landscapes of two contrasting regions: the Taqallit peninsula and the Murzuq basin.

THE TAQALLIT AND AD-DISA AREAS

The best-preserved area of foggaras is found in the Taqallit district, an area bordering the *hamada* between Jarma and Ubari. The area was surveyed between 2009 and 2011, and the following analysis is based on this fieldwork.¹² In this area, there are approximately 200 individual foggara channels (including tributary and feeder branches) with a combined length of at least 160 km along a front of 10 km. These form clusters so that, at their densest, the spoil heaps from the tunneling merge into an area of disturbed ground tens of meters across. In some places, the channels were either open or possibly covered with perishable materials (e.g., palm branches). These normally superficial features are visible in areas where they have been cut through a salty crust of a palaeolake. Despite this preservation, the hydraulic landscape is still heavily truncated at its northern end by modern agricultural development, while in aerial photographs from the 1950s the resolution and contrast of the images is not sufficient to reconstruct the end points of most of the channels. Settlements that sit largely to the north of the foggaras, and extensive funerary areas to the south on the slopes of the *hamada*, imply that this area was densely populated between the fourth century BCE and the sixth century CE, with burials continuing as late as the tenth century CE.

It is immediately apparent from a cursory look that the foggaras do not represent a single cohesive system in use at a specific time, but are rather a palimpsest of channel digging. There are many examples of channels crossing each other (some evidently at different depths), recuts of the same channel, or cross branches linking channels together. Less certain, but also likely, are instances of channels that have been extended farther south into the *hamada* to augment supply. Over time, many foggaras had to be deepened, with the result that their outlet points migrated farther north, where the ground surface was lower; this can be seen from successive terminal reservoirs on some surface channels. There are also some examples of short sections of tunnels that do not appear to go anywhere and may relate to failed or otherwise abandoned foggaras that were never completed.

In lieu of direct dating (beyond the single AMS date mentioned above), part of the sequence of foggaras can be deciphered from evidence of their construction. Investigation of shafts close to the escarpment demonstrated that they were cut through solid sandstone. Although the gallery was no longer visible because of fallen sand, the topmost layer of spoil around several of the upper shafts, a bluish-gray clay or purple siltstone, probably represents the aquiclude stratum at the base of the water table (where the gallery was dug).

¹² Interim reports can be found in Mattingly, Lahr, and Wilson 2009; Mattingly et al. 2010.

In two of the shafts near the escarpment, an additional siltstone or clay layer was identified at a depth of just 2–3 m below the surface. In these cases, the gallery (and the bluish-gray clay or purple siltstone) was at least 8 m deeper still. This implies that there are multiple layers that may have acted as aquicludes with earlier, shallower foggaras tapping a higher perched aquifer until it was exhausted or otherwise became insufficient. Analysis of the spectral qualities of the spoil mounds on satellite imagery might be able to distinguish between the materials of the different aquicludes and thereby indicate shaft depth, though further research would be required to confirm and refine this. In any case, the earliest foggaras should be the shallowest and therefore have mother wells farther away from the escarpment and terminal points at the southern edge of the oasis. Later foggaras in the same area should be longer, running from deeper mother wells set back into the escarpment and extending farther north into the lowest part of the oasis depression.

Multiple phases can be identified in both the Taqallit and ad-Disa areas (fig. 6). In a putative first phase of the Taqallit area, foggaras were constructed with their mother wells 100–900 m north of the escarpment base and ran for 1–1.5 km with very little evidence of intercutting or cross-links in this group. Either the aquifer they tapped was exhausted or the irrigation needs of the (probably growing) population outstripped it. Subsequent foggaras were dug into the sandstone of the escarpment itself to reach the deeper aquifer. Although their end points were often only a few meters lower, these later foggaras required shafts more than 20 m deep and galleries 2–5 km long. The foggaras were not constructed at the same time or in the most cost-effective arrangement. There are a few examples of foggaras that take long and circuitous paths, and one in fact crosses ten other channels. This suggests that water rights were socially mediated and that land and water rights affected their planning, digging, and ownership. The implication is thus that foggaras and aquifers were proprietary, perhaps owned at the level of the community or even an extended household, given their relationship to settlements rather than houses. This expansion appears to represent the greatest size of the foggara system (in terms of flow), but foggara digging evidently continued for a much longer period. A number of later foggaras are identifiable, as they capture the headwaters of adjacent foggaras to augment their own flow. This process was probably ongoing but would eventually have entailed a reduction in the number of functioning outlet points. Finally, there is evidence of other forms of irrigation through the digging of balance wells in some of the areas irrigated by the foggaras. In ideal conditions, a foggara should easily outperform a balance well, so this most likely represents the phase at which the foggaras dropped out of use. However, a caveat should be added that whereas a foggara is obviously a major endeavor and investment for a community, a balance well requires little initial outlay and is within the reach of those with even modest means; hence balance wells cannot always be seen as an indication of foggara abandonment.

In the ad-Disa area, phasing is possibly apparent in the gradual northerly movement of the reservoirs and distribution channels. An interesting aspect is a number of smaller settlements that are close to the terminal distribution reservoirs, while larger settlements are located at the end points of distribution channels where farming must have taken place. The reservoirs may have functioned in a similar manner to those found in the Tuat oases in Algeria. Here, the foggaras would fill the basin during the day, and then at night the water would be distributed sequentially into a number of surface channels, which

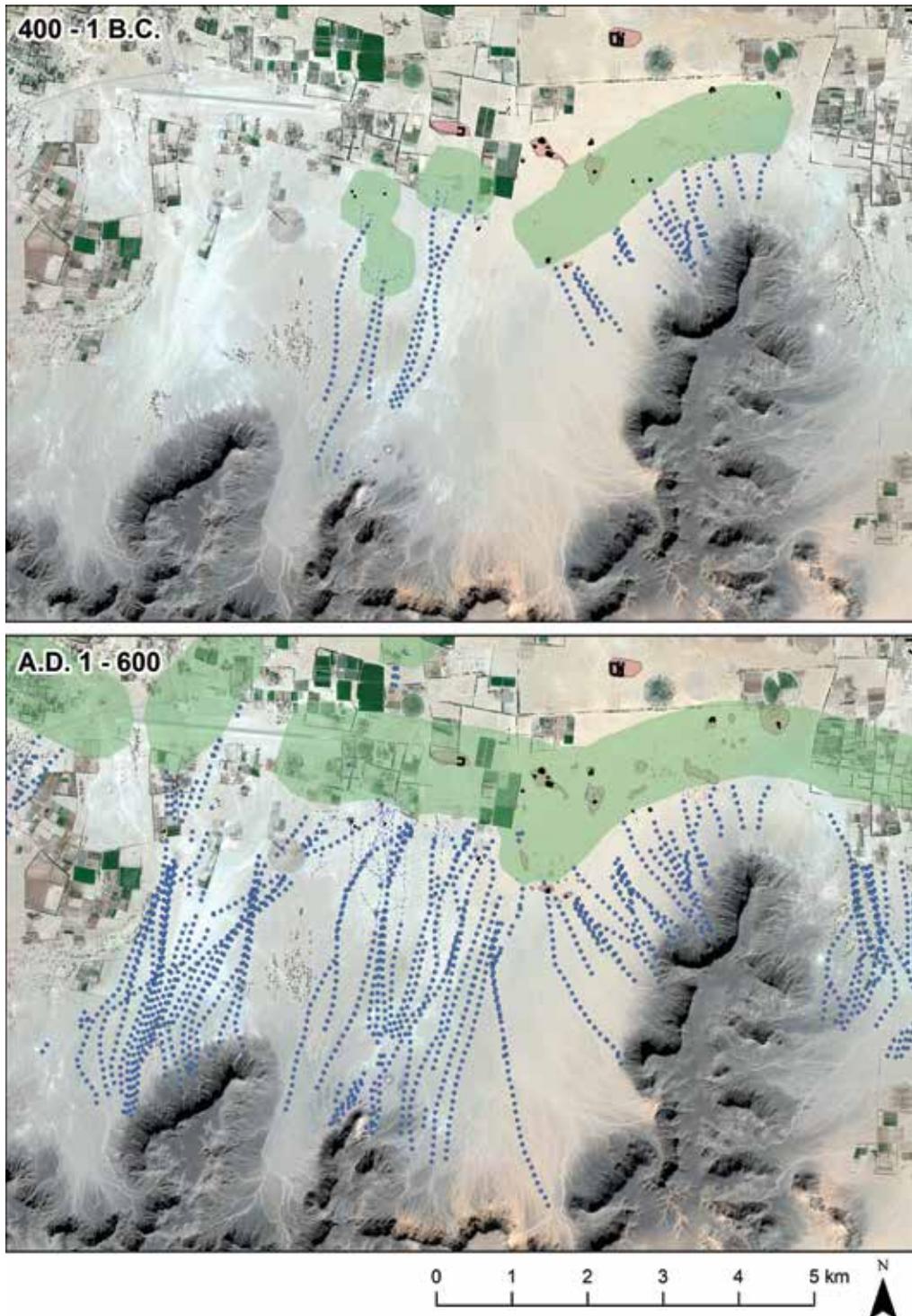


Figure 6. Possible phasing of the Taqallit and ad-Disa foggara systems (WorldView-2 image, January 14, 2013, copyright DigitalGlobe).

would in turn irrigate individual gardens. Unlike the Murzuq basin (see below), the field boundaries have not survived, and it is not clear if this is due to preservation factors or the use of perishable materials to define their extent.

THE MURZUQ BASIN

The Murzuq basin has the highest densities of fortified villages (*qsur*) known anywhere in the central Sahara¹³ and rivals those found in Western Algeria.¹⁴ All the more remarkably (and in contrast to similar densities known elsewhere in North Africa), they were supported almost entirely by well-based agriculture. The ideal taphonomic conditions in this region have preserved not only the remains of the *qsur* but also the buildings around them, the surrounding gardens, the wells in the center of the gardens, and the channels and field divisions that they fed. The whole system is preserved, and only in the past decade or so has modern development started to impinge. In this region, there are the remains of thirty settlement clusters and associated gardens that together total 60 ha of settlement and 20 sq km of field systems (fig. 7). The earliest sites that we know of are from the HHG006-9 cluster (fig. 8), which comprises four *qsur* (radiocarbon dated to the second to fourth/fifth centuries CE) that sit within an open settlement of mud-brick houses and compounds. There is a group of what appear to be foggaras that run from the southwest into a playa to the northeast (fig. 8). These have the characteristic lines of access shafts, but the shafts themselves are very small and have little or no spoil rings around them (some occur at the southwest end), and the tunnel must run close to the surface because the elevation change from their start to the playa is only 6 m over a distance of 3.6 km (the majority in the last 800 m). Unlike the foggaras of the Wadi al-Ajal, it is doubtful that these could ever have carried enough water to support all the gardens of the associated villages. At some point during the occupation of the settlement, the channels were built over and presumably abandoned. There are also many well shafts around the settlements, and although there are only occasional traces of field boundaries, these can be used to delineate an area of cultivation of circa 200 ha. During the fourth to sixth centuries CE, the number of settlements in the region appears to have roughly doubled. Newly built villages were now regularly enclosed with a towered enceinte, in addition to the central *qasr*. This greater emphasis on enclosure and fortifications is also reflected in the field systems, which were much better defined with rectilinear mud-brick field walls enclosing gardens of 300–600 m². Typically, these gardens are rectangular and contained between one and three wells. None of the later settlements can be associated with the earlier group of foggaras in the basin. This expansion may have been short-lived, as we have been unable to identify any settlements that were constructed between the eighth and fourteenth centuries CE, and only one that may have been built in the seventh century. Settlements dated to the fifteenth to seventeenth centuries, including the capital of the new Awlad Muhammad dynasty at Murzuq, are exclusively built on the edge of playas. The implication is that the hydrology had changed substantially in the intervening time and that the Garamantian well-based irrigation systems were no longer viable. Some *shaduf* irrigation was recorded in the area

13 Sterry and Mattingly 2011, 2013; Sterry, Mattingly, and Higham 2012; Mattingly et al. 2020.

14 Chekhab-Abudaya 2016; Echallier 1972.

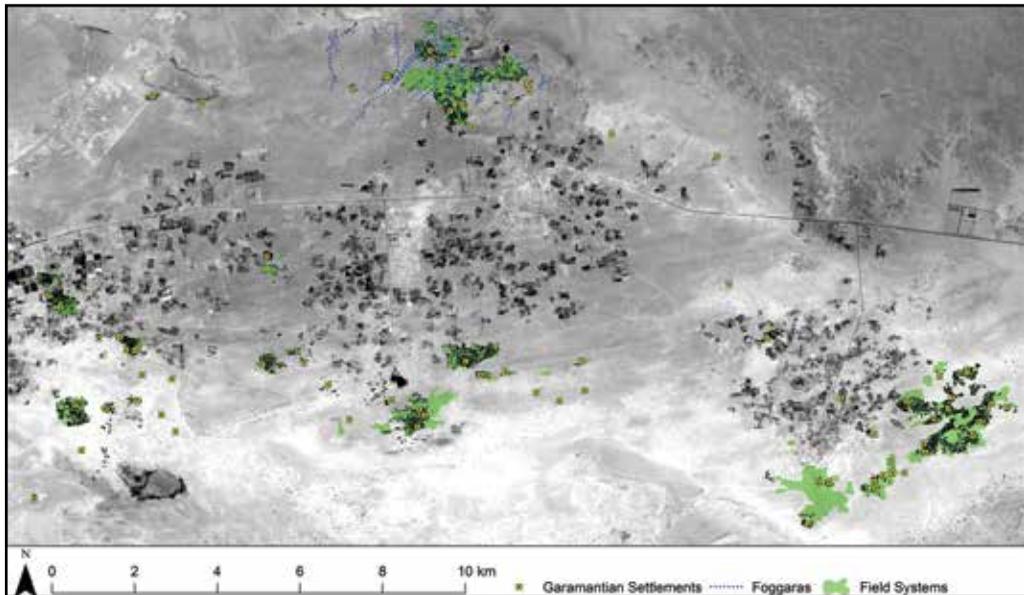


Figure 7. The Murzuq region.

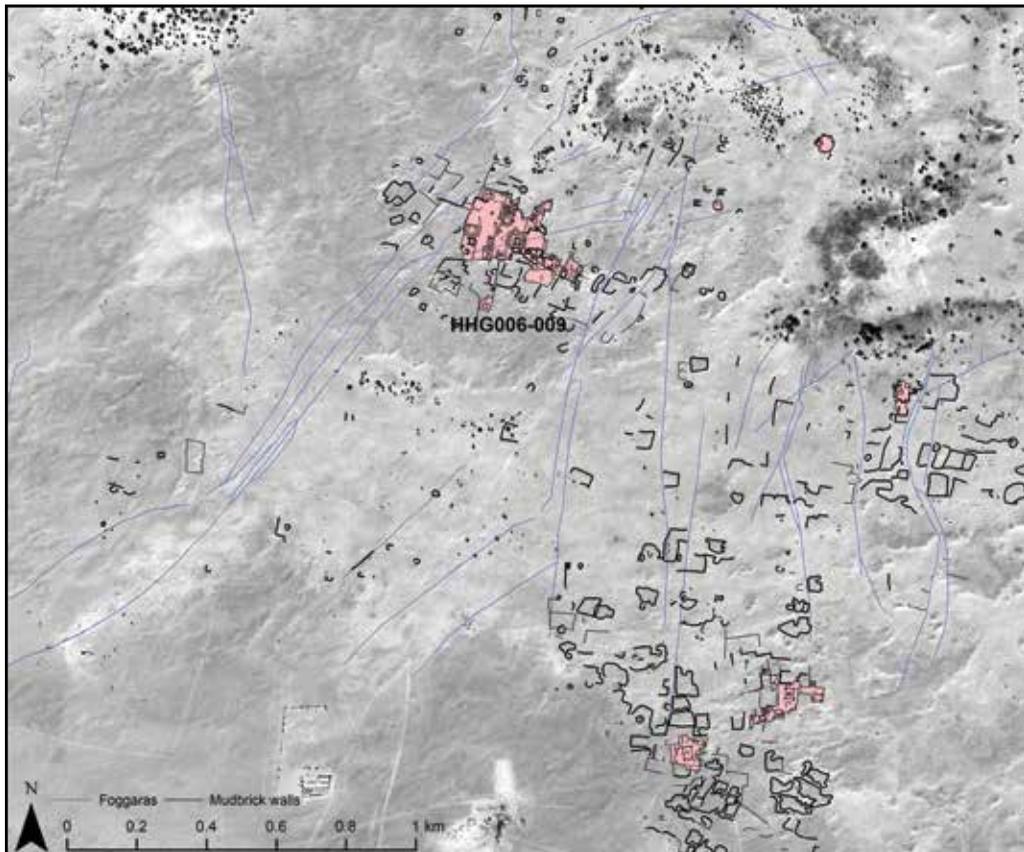


Figure 8. Foggaras at HHG006-9 (Quickbird image, December 26, 2011, copyright DigitalGlobe).

in the early twentieth century and is still visible in aerial photos from 1958. However, the irrigated area of these wells (50–250 m²) is far smaller than that implied by the Garamanian field systems.

THE DEVELOPMENT OF THE FIRST OASIS FARMS

The shift from pastoralism to oasis agriculture in parts of the Sahara may be linked to the climatic changes and aridification that took place between the third millennium BCE and the first millennium CE.¹⁵ Fertile zones shrank, putting pressure on areas of pasturage and polarizing communities. Some chose to develop permanent, fortified hilltop settlements at the few remaining reliable water sources (e.g., at Zinkekra). Conversely, other communities may have increased their pastoral ranges to make best use of thinly spread and seasonal resources. From the first millennium BCE onward, there is evidence of greater connectivity with regions outside the Sahara and technological transfers from the Nile and Mediterranean, and in the first millennium CE from sub-Saharan Africa. We would suggest that the increased connectivity in this period was a major factor in the development of the earliest agricultural communities in the Sahara. Of all the technological introductions, it is the date palm in the early first millennium BCE that appears most transformative. Not only is it a major food source in and of itself, but large groves have a climatic cooling “oasis effect”¹⁶ and provide the shelter that allows other crops and animals to prosper in desert conditions. Even with springs, some irrigation technology would be essential to develop the spring and to control water distribution to crops on a daily basis. Initially, agriculture may have remained fairly close to the fortified hilltop sites, but the falling water table and increasing hydraulic needs seemingly encouraged the adoption of new technologies such as the foggaras in the late first millennium CE. As at Taqallit and ad-Disa, they spread widely in a phase of agricultural expansion and population growth that is also associated with the earliest examples of mud-brick settlements in the oasis depressions. It is also not coincidental that we start seeing around this time the first material evidence of regular trade links across the Sahara, with Punic imports to Fazzan common by the second century BCE.

AGRICULTURAL EXPANSION

Whereas the earliest settlements relied on knowledge of springs and bodies of water, subsequent phases of expansion seem to have involved the movement of sedentary oasis farmers over larger distances and often into different and more difficult hydrological zones. This implies both prior knowledge and investment in order to develop successful settlements and their associated infrastructure (one wonders how many such enterprises failed). The existing Saharan pastoral groups could have provided good societal knowledge of the water sources that had supported them for millennia. However, their knowledge of springs, gueltas, wadis with vegetation supported by mountain runoff, lakes/playas, shallow groundwater, and other hydrological sources would not directly translate into successful irrigation schemes. Hardesty’s model of landscape learning in relation to mining

15 Cremaschi 2003.

16 Oke 1987; Potchter et al. 2008.

rushes (itself derived from Kirch's evolutionary model of adaptation) is perhaps useful in this context.¹⁷ He describes three stages of learning: the first is the prior knowledge about natural resources and existing technologies; the second is the diversification of knowledge through geological discoveries, innovations, and information exchanges; and the third stage reflects the selection and use of knowledge to assign meaning to landscape elements in the environment. The degree of migration and colonization in the central Sahara is an open question, but we know that the main irrigation technologies and oasis crops were introduced from Egypt. Foggaras were in use in the oasis of Ayn Manawir in the Western Desert of Egypt in the middle of the fifth century BCE, and presumably the technology reached Fazzan along emerging trade routes.¹⁸ The first oasis farmers needed knowledge of technologies and access to an agricultural package developed elsewhere, and it seems highly probable that the formation of Garamantian society represented the fusion of some knowledgeable "colonists" from the eastern Sahara with local pastoral peoples in the central Sahara. The former presumably brought with them standardized knowledge of the environment (where the water is), technology (how to reach it), and social relations (who they are and how to organize themselves). Once people were established, we might then expect the diversification of these categories with a better understanding of the water sources, how to access them, and changing social relations within and between groups (perhaps seen through the development of *qsur*). Finally, in the third stage, we might expect the proliferation of the most effective irrigation strategies and the legendary origins that often accompany them.

Technological choices were driven by pragmatic and empirical knowledge, not by an evolutionary schema from the simplest to most complex. To give two examples of the use of foggara irrigation, the limitations of the main spring at Ghadamis (an oasis far to the north of Fazzan) constrained the absolute development of the size of the oasis and its population. At various times, attempts were made to create additional irrigated gardens around the periphery of the oasis through the construction of foggaras and wells. By contrast, in the Murzuq region, described above, the earliest settlements used a form of foggara technology that was seemingly abandoned in favor of well-based irrigation by the fourth or fifth century CE, probably due to the unfavorable flat terrain, low performance of the foggaras in this area, and depletion of the aquifer. Well-based irrigation was then used in subsequent agricultural expansions in the area.

THE ABANDONMENT OF THE FOGGARAS

As evidenced by the above case studies, abandoned and unused irrigation features were a part of all systems. As hydrologies and irrigation needs changed, some foggaras and wells were abandoned and some altered. The use-life of any one system may have been quite variable, and there are examples of what appear to be unfinished or unsuccessful projects. The numbers of irrigation systems and gardens may also have been deliberately inflated to keep spare capacity so that in ideal situations, extra gardens could be cultivated.¹⁹ This

¹⁷ Hardesty 2003, 83; Kirch 1980.

¹⁸ Wilson and Mattingly 2003; Wilson 2005, 2012, 421–22; Wilson, Mattingly, and Sterry 2020.

¹⁹ See also the discussion by Ertsen in this volume.

is similar to the current situation in Saharan oases where there are areas of gardens that are well irrigated, gardens that are poorly irrigated (with dying palms), gardens that are fallow but could be brought back into use, abandoned gardens, and gardens that were laid out but never cultivated. This also partly reflects a general tendency to invest in new agricultural projects even if their financial returns may be poor.²⁰ The reasons for investment in a desert environment may be diverse (e.g., cultivation of desert crops such as dates, oils, or cotton; provisioning trade routes or mining endeavors; extending religious networks; or conspicuous displays of wealth). In the case of the Garamantes, there is certainly evidence for the cultivation of dates, cotton, and other irrigated crops (table 1), and the spread of the foggara system is intimately connected to the development of Saharan trade. Indeed, the foggaras of the Fazzan can only be understood as part of wider economic systems and networks of which they are a necessary component.²¹

The behavior of the water table in Fazzan is still not well understood; in particular, the relative combination of local rainfall recharge and remote recharge from the “continental intercalaire” is unclear. Although it appears that the aquifer was progressively depleted during the Garamantian period, and now (following the introduction of pumped wells in the twentieth century) stands at a much lower level, the possibility of some periodic resurgence during the intervening period cannot be ruled out. But while a declining water table would have been a controlling factor determining the continued viability of the foggaras, other socioeconomic factors are also likely to have come into play. At some point, probably in late antiquity, the numbers of abandoned foggaras overtook the construction of new irrigation systems (or modification of existing systems). Dating the disuse of foggaras is difficult, but there is a dramatic drop-off in inhabited settlements and new tombs after the sixth century CE, which must indicate a drop in population. By the medieval period, there are no records of foggara irrigation, and the available settlement evidence suggests that the population had dropped to perhaps a third or a quarter of its Garamantian peak (e.g., in the Wadi al-Ajal, survey has identified 125 Garamantian sites vs. 39 medieval and early modern sites).²² A drop in available labor could have exacerbated the problem of the declining water table. If foggaras are not cleaned, they become clogged and unusable; similarly, gardens can suffer from salinization if neglected and become difficult to bring back into cultivation. Insufficient labor (or organization) could therefore have contributed to the collapse of these systems.

IRRIGATION AND THE ROLE OF THE STATE

Connectivity and trade are key to understanding the Garamantian state. We have argued elsewhere that urban-sized centers in the Central Sahara are unsustainable without some form of outside investment. This is because of the increased stress of supporting even a small nucleated population in an environment in which all water for drinking and irrigation had to come from wells or foggaras.²³ However, these urban centers were not simply

²⁰ Pascon 1984; Scheele 2010.

²¹ Wilson 2005, 2006, 2012; cf. Pascon 1984; Scheele 2010.

²² Mattingly 2013, 525–44.

²³ Mattingly and Sterry 2013, 515.

imposed; rather, they gained a preeminent position by mediating access to external resources and environments (in this case the irrigated oasis). Their success was determined by their ability to remain part of trade networks that spanned the Sahara rather than by their overall size or agricultural potential (indeed, the clusters of settlement, irrigation, and gardens discussed above at Taqallit and the Murzuq basin are of comparable size). Sites such as Jarma controlled Mediterranean access to the trans-Saharan trade in slaves and commodities and also the access of trade caravans to water, food, and camels. In this model, one of the important functions of the agricultural hinterland of the town was to support large transitory populations. The main sources of wealth in this society were therefore external rather than internal and agricultural. The introduction of foggaras and other irrigation systems to Fazzan was therefore essential to early state formation in the Sahara, but state formation was not essential to the development of hydraulic landscapes in Fazzan, at least not directly. Some state-backed constructions are certainly possible, and medieval Marrakech provides a North African example of how a new dynasty furnished its capital with foggaras. This may have been possible immediately around the Garamanian urban center of Jarma. However, recent descriptions of foggara construction in the Algerian oases emphasize the role of the local community in planning and funding the construction of individual systems in line with their personal resources and needs. Distinguishing among these different types of ventures is difficult, but we can note that in those oases where foggaras are less connected to one another, they tend to be smaller in size and found marginal to the main oasis core, suggesting that they were more independent ventures. The concentration of foggaras in the Wadi al-Ajal is the second largest (after the Tuat-Gourara region in Algeria) and arguably the most complex system in the Sahara, but those foggaras linked to urban settlements account for only a small percentage. The majority instead feed into a settlement and agricultural system characterized by dispersed fortified communities of small size. Certainly, as Kirchner has demonstrated, peasants are perfectly capable of constructing complex irrigation systems, including foggaras, without state involvement.²⁴

However, the relationship between the foggaras and the Garamanian state went beyond supporting the needs of a settled population through irrigated agriculture and the provision of drinking water; the connectivity created by the state produced conditions by which oasis goods could be marketed. Hence the state could have encouraged the development of irrigation systems for salt production and the cultivation of cash crops such as cotton. The classic pattern of trans-Saharan trade was the production of salt by evaporation from mineral-rich groundwater, to be exported southward to sub-Saharan Africa in exchange for skins, ivory, and—most importantly—slaves. Those goods and slaves that were not consumed or used in Fazzan were exported northward in return for trade goods from the Mediterranean world—olive oil and wine amphorae, glass, and table wares are the most prominent items in the archaeological record, but there were undoubtedly perishable goods too. But the link between the foggaras and trans-Saharan trade goes beyond enabling the production of evaporite salts for export; the construction of over six hundred foggara channels implies an enormous investment in manpower. It is overwhelmingly likely that the foggaras of Fazzan were built largely with slave labor, given the difficult and

24 Kirchner 2009, 152.

unpleasant nature of the tunneling work. The Garamantian state is also an obvious candidate for providing the investment needed to create new irrigation systems or the security to support outside investors. The expansion of settlement and agriculture into new locales such as the Murzuq region implies high levels of migration from elsewhere in the wider Sahara region and an initial outlay of food, labor, and other resources. Examples from more recent history in the Sahara suggest that oasis and irrigation development can be both state-sponsored and entirely independent of the state. Both are possible in Garamantian Fazzan, but it is likely that Garamantian kings had at least some interest in the systems that supported their state. After all, the majority of foggaras were constructed when the Garamantian state and its trade with the Mediterranean were at their apex.

SUSTAINABILITY

The gradual abandonment of the foggaras, probably during the middle or late first millennium CE, is likely to have been the result of a combination of depletion of the aquifer over several centuries, the onset of more severely arid conditions in the fifth century, and the falloff in trans-Saharan trade from the fourth century onward, when the cities of the Tripolitanian coast, at the northern end of the trade routes, went into decline. Leptis Magna, Sabratha, and Oea formed the terminal points of trans-Saharan routes that linked this trade with pan-Mediterranean trading networks, and when they were hit by earthquakes and tribal raids in the fourth century, the Saharan trade must have been badly affected. This is reflected by a drop in pottery imports to Fazzan from the Roman world after the third century, though some realignment of the main trading activity along routes leading to Egypt is perhaps implied by continuing, albeit reduced, import of pottery and amphora forms from Byzantine Egypt until the seventh century. This disruption to the northward element of Saharan trade could be expected to have had knock-on repercussions for trade with the kingdoms to the south, reducing the supply of fresh slaves to maintain the foggaras. If, at the same time, the climate was becoming more arid and the aquifer was being depleted through overextraction, there would be an increased need for labor to deepen the foggara channels, to extend them southward back into the aquifer, or to dig extra tributaries to increase their catchment. But if a decline in trade was restricting the available slave labor at the same time that a falling water table necessitated more maintenance work, some foggaras would have had to be abandoned. As the disrepair of the foggaras fed through into reduced agricultural yields, a vicious cycle would have been created, with an impact on population levels and increased stress on social organization. That such stress did indeed arise is suggested by the increasingly fortified appearance of Garamantian settlements, the abandonment of settlements in the Wadi al-Ajal in favor of parts of eastern and southern Fazzan, and the general decline in categories of material culture in the urban center at Jarma. These seem to reflect a fragmentation of control of the wadi, and increasingly uncertain or unstable political conditions.

On this view, then, the combination of a declining water table and manpower problems caused by disruption to trans-Saharan trade gradually led to the abandonment of most foggaras in the early medieval period, and a shift to smaller-scale agriculture supported by wells worked with *shaduf* and *dalw* machines. The process seems to have been complete by the twelfth century CE, and perhaps much earlier; in the twelfth century the geographer

al-Idrisi recorded that irrigation around Jarma was done by means of the *shaduf*, implying that the foggaras had ceased to be used by then.²⁵ Wells and water-lifting devices were to remain the sole irrigation technology in Fazzan until the introduction of pumping machines in the twentieth century; but the amount of land under cultivation and the population they could sustain was far less than that which could have been supported by foggara agriculture. Just as the foggaras enabled the formation of the Garamantian state in the first place, when hydrological and economic conditions led to their abandonment, the Garamantian kingdom fell apart.

CONCLUSION

The hydraulic history of Fazzan is complex and diverse, such that it is best to understand the oases as a set of interconnected microecologies, each with its own dynamic water source. At no point in time were there “ideal conditions” for agriculture or states, nor was there ever an equilibrium between people and water. Conditions, people, and water were always in flux with irrigation systems in use, abandoned, and in varying states of construction. While we might conceive of the Garamantian state as a “foggara state,” it is a form that was never repeated elsewhere because it was a product of historical circumstance, the nexus of a specific set of social, economic, technological, and environmental conditions. If there are commonalities between Saharan states, it is through their high levels of connectivity and trade, distance from larger territorial states, and a predictable and expandable hydrology that could form the basis for agricultural expansion.

25 Dozy and De Goeje 1866, 42; cf. Wilson and Mattingly 2003, 271–72.

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PART II

THE EMPIRICAL INVESTIGATION
OF ANCIENT IRRIGATION

4 Remote Sensing of Ancient Canal and Irrigation Systems

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ONE OF THE ATTRACTIONS of historical archaeology is the possibility to combine textual data with the archaeological record. In the world of Near Eastern archaeology, however, often the evidence of texts is taken to be the more reliable source, and elaborate historical reconstructions are occasionally made with little or no archaeological input. Such an imbalanced scenario is particularly dangerous with regard to ancient water systems, but the most successful attempts for Mesopotamia have been multidisciplinary collaborations,¹ often incorporating ethnographic or ethnohistoric data.²

Despite the perceived limitations of archaeological data, the most successful irrigation studies have involved them, for several reasons. The written sources on irrigation derive mostly from royal inscriptions.³ These texts reflect the priorities of the royal households that commissioned them, priorities that emphasize the legitimization of existing power structures. They describe not an objective reality (if such a thing is ever possible), but rather an idealized situation that supports the political agendas of the text-producing elite. Rarely do the political interests of the text producers correspond to the academic interests of modern scholars. For instance, royal inscriptions will emphasize the agency of the king in creating water systems (often acting with the blessing of the gods) but fail to mention the preexisting systems that the king expanded, or the local systems of water sharing that brought water to individual fields.

Very often, the empirical elements of water systems were not considered significant enough to be mentioned. Yet, for archaeologists, the physical dimensions of those systems are important for conclusions about economy and society. Elements of system scale (e.g., width and depth of canals, length of system, volume of water, irrigated area) are rarely described, but such elements are critical for assessing the extent of political authority, whether through the control of land or through the ability to mobilize the labor necessary for system construction. The absolute scale of an irrigation system can help archaeologists determine whether it was a critical element of the subsistence economy or a vanity project. When analyzed on a regional scale, archaeological evidence can overturn major theories of

1 E.g., Gasche and Tanret 1998; Wilkinson, Gibson, and Widell 2013.

2 E.g., Rost and Hamdani 2011.

3 Bagg 2000.

social evolution; for example, the once-influential hydraulic hypothesis of Karl Wittfogel⁴ has fallen largely out of favor, since Robert McCormick Adams demonstrated that urban settlement patterns preceded major irrigation systems by a millennium.⁵

THE IMPORTANCE OF A REMOTE PERSPECTIVE

Elements of water systems can be found via ground-based observations. In the north of Iraq, many monumental elements of the Neo-Assyrian systems of the ninth to seventh centuries BCE were already known by the early twentieth century; indeed, some were already known to Layard. These features were built elements such as dams, aqueducts, tunnels, and associated rock reliefs.⁶

The canals themselves, however, tend to be far more ephemeral, especially if they are small or used for a short term, and therefore lack the upcast mounds that are the product of long-term maintenance. Such canals are easily removed by subsequent activity, whether natural (wind deflation, water erosion) or cultural (agriculture, newer irrigation systems). Faced with such challenges, earlier landscape archaeologists reconstructed river and irrigation systems by “connecting the dots” between archaeological sites of the same time period.⁷ This method can propose the locations of primary canals, but secondary or tertiary canals are impossible to reconstruct in this manner.

If they survive at all, ancient canals require a remote perspective for detection. The canals themselves are most often buried and can be detected only by proxy. For example, an infilled and plowed-out canal may still have some microtopography that collects moisture, and therefore a dark, linear soil mark may be visible under certain rainfall conditions. The buried canal bed may still arrest water infiltration, and therefore deep-rooted plants such as *Prosopis* often grow in disproportionate abundance compared to surrounding areas. These soil and vegetation marks can be recognized on the ground only with difficulty, but they are often strikingly clear from the vertical perspective of an airplane or space. With distance, features that seem to be isolated when detected on the ground are often revealed to be part of larger and coherent systems of features.

REMOTE-SENSING DATA SOURCES FOR IRRIGATION SYSTEMS

If one agrees that archaeological data for irrigation systems are important, and that a vertical/remote perspective is the best way to acquire such data, the question is then how to find remote-sensing data. Fortunately, remotely sensed imagery of the earth has never been more inexpensive and widely available. Although aerial archaeology is more than a century old, early coverage was focused on individual sites rather than full landscapes and was not very systematic. As Middle Eastern countries attained independence from European powers, their governments became less likely to share aerial imagery with

4 Wittfogel 1957.

5 Adams 1981.

6 Bachmann 1927; Jacobsen and Lloyd 1935; Reade 1978.

7 E.g., Adams 1981.

foreigners, including archaeologists, who had acquired a reputation for working with intelligence agencies.

Beginning in the 1970s and into the 1980s, government-operated scientific satellite sensors, such as the US Landsat and the early French SPOT, became available. The spatial resolution of their imagery was, however, too coarse to detect most archaeological phenomena. With the launch of commercial high-resolution satellites in the late 1990s, imagery with resolution of 1 m or less became available, though at high costs that were prohibitive for most archaeologists. Some of these satellites (e.g., Ikonos, QuickBird, GeoEye, WorldView) also could image the visible and even near-infrared parts of the spectrum. Their major drawback, apart from cost, was the fact that they showed the contemporary landscape, which was heavily transformed by settlement expansion and land-use intensification in the 1960s and 1970s.

When photographs from CORONA, the first US intelligence satellite, were made available via the US Geological Survey in 1998, they precipitated a great expansion of regional-scale landscape research in the Near East. CORONA, which operated from 1959 to 1972, has been discussed extensively.⁸ More recently, photographs from the high-resolution GAMBIT satellite became available in 2000. In 2013, imagery from HEXAGON, the CORONA successor that ran from 1971 to 1986, was released to the US National Archives and Records Administration (NARA). In the past decade, and with little fanfare, film from various U2 aerial missions (1958–60 for Middle Eastern missions⁹) has also been released to NARA. The imagery from these latter programs are all high-resolution grayscale film negatives, with GAMBIT, HEXAGON, and U2 imagery as good as 0.5 m (fig. 1). They can be challenging to use in a geographic information system environment because of the geometric distortion involved, especially in CORONA and HEXAGON satellite photographs. U2 photographs are difficult to acquire; since NARA does not distribute digital versions, researchers must view them in the Cartographic Reading Room in the NARA II facility in College Park, Maryland.

CASE STUDIES IN REMOTE SENSING OF PREMODERN IRRIGATION

The three following case studies give a sense of how remote-sensing analysis, especially using declassified intelligence imagery, has enabled reconstruction of premodern irrigation systems and allowed insight into the social and economic systems within which they were created.

THE KISIRI CANAL ABOVE NINEVEH (CA. 700 BCE)

Of all of the Neo-Assyrian kings, Sennacherib (704–681 BCE) was the most prolific commissioner of canal systems,¹⁰ many of which have now been documented via satellite photographs and ground observations. One of the earliest of these systems is mentioned in many of his royal inscriptions. For example:

⁸ Casana, Cothren, and Kalayci 2012; Fowler 2013; Ur 2013a, 2013b.

⁹ See Hammer and Ur 2019.

¹⁰ Bagg 2000; Reade 1978.

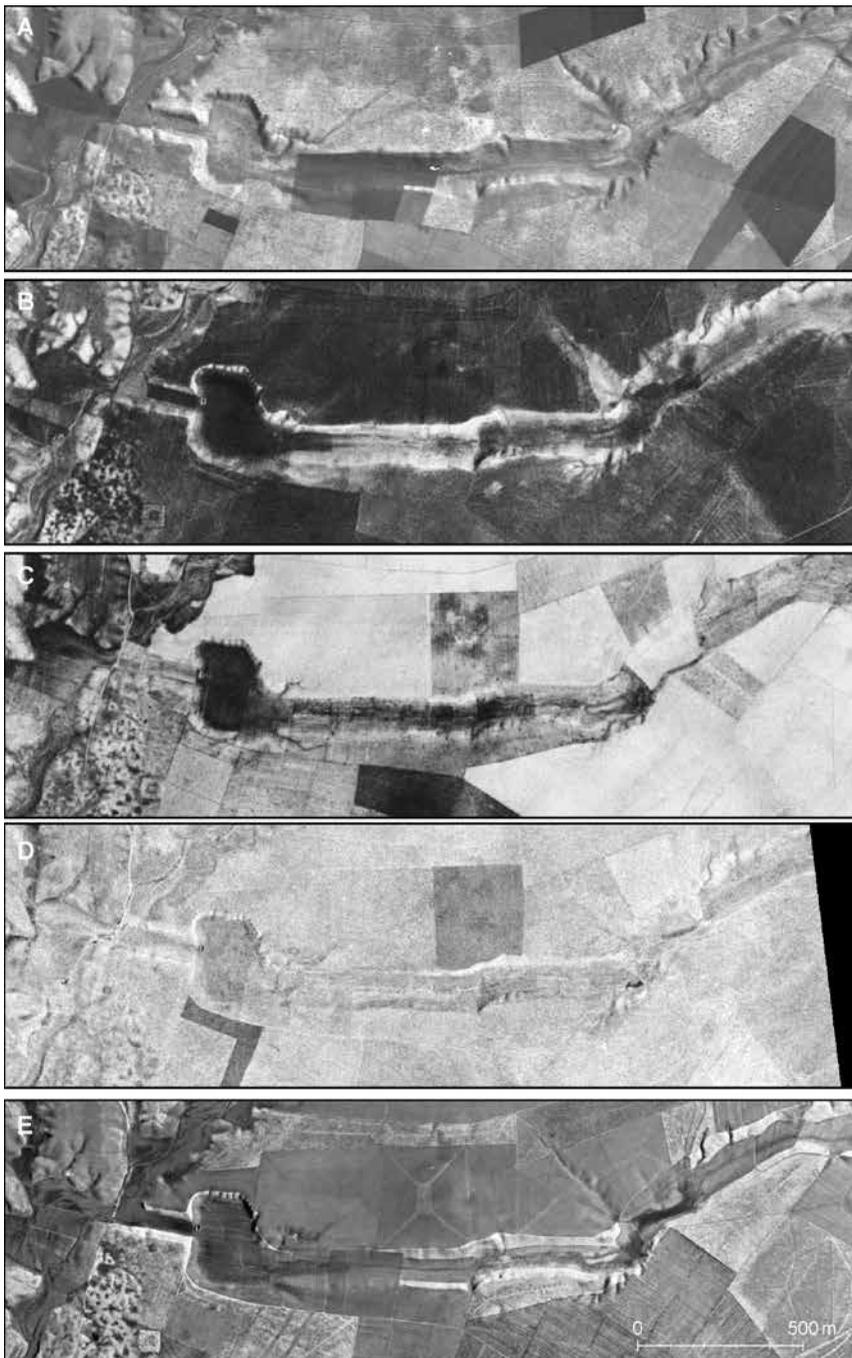


Figure 1. Comparison of declassified intelligence images at the likely cross-watershed earthwork on the Erbil Plain in Assyria (Ur and Osborne 2016). A. U2 aerial photograph (mission 1554, January 29, 1960). B. KH4A CORONA satellite photograph (mission 1039, February 28, 1967). C. KH4A CORONA satellite photograph (mission 1046, March 19, 1968). D. KH4B CORONA satellite photograph (mission 1104, August 16, 1968). E. KH9 HEXAGON satellite photograph (mission 1202, February 1, 1972). All to the same scale.

To plant gardens, I subdivided the meadowland upstream of the city into plots of 2 *pānu* each for the citizens of Nineveh and I handed (them) over to them. To make (those) planted areas luxuriant, I cut with iron picks a canal straight through mountain and valley, from the border of the city of Kisiri to the plain of Nineveh. I caused an inexhaustible supply of water to flow there for a distance of one and a half leagues (*beru*) from the Ḫusur River (and) made (it) gush through feeder canals into those gardens.¹¹

Archaeologists have attempted to use the distance measure in the inscription (roughly 16 km) to estimate the location of the Assyrian town of Kisiri. Thorkild Jacobsen equated Kisiri with a mound called Tell Inthah,¹² whereas Julian Reade¹³ proposed to seek it near a restored but probably ancient dam with the Arabic name al-Shallalat near the village of Beybokht.

With these potential starting points in mind, it was possible to locate nearly the entirety of the Kisiri canal on a series of CORONA satellite photographs,¹⁴ and now to extend and improve that reconstruction with HEXAGON, GAMBIT, and U2 imagery. On photographs from these sources, the canal itself is visible as a dark line that disregards modern roads and field boundaries, an important clue that the feature is premodern. On the earliest imagery, the downslope side of the canal is visible as a light line, probably because it was originally slightly raised. The dark line of the canal appears to be roughly 10 m wide, in the places where it can be measured.

Recently available imagery suggests that the canal began farther upstream than earlier reconstructions afforded.¹⁵ The canal appears to have originated from a weir at a bend in the Khosr river 800 m southeast of Tell Najmok (fig. 2). For its first two kilometers, it ran closely along the right (west) bank of the Khosr, after which it turned to the southwest, following closely the natural contours of the landscape, until it passed over a wadi at the village of Sayid Lar (fig. 3). From there, it ran southward, more than a kilometer distant from the Khosr, and more than 30 m above the level of the river today (which has certainly cut down into its bed in the past millennia), still weaving in and out of the natural right-bank drainages. Around 1.5 km from the northern corner of Nineveh's city wall, the canal appears to flow into a natural drainage, which had been captured and redirected to Nineveh's northern corner. At this point, its waters could have flowed around the city via a moat (visible into the 1960s along its northeastern and northwestern walls) into an artificial marsh, or even into the city itself). A poorly preserved western branch may have flowed into a Tigris drainage above the city, making water available for fields to the northwest.

The empirical description of the Kisiri canal is more than an illustration of a feature known from texts. It enables a critical assessment of how royal inscriptions depict reality. The inscription describes the landscape in two ways that appear to exaggerate the difficulty of the engineering undertaking. First, the canal cut through a "mountain" (written with the logogram KUR). To the contrary, the course of the canal was almost wholly dictated

11 Sennacherib 1 lines 88–90; Grayson and Novotny 2012, 39.

12 Jacobsen and Lloyd 1935, 33.

13 Reade 1978, 64.

14 Ur 2005, 322–24.

15 E.g., Ur 2005, 322; Reade 1978, 64.

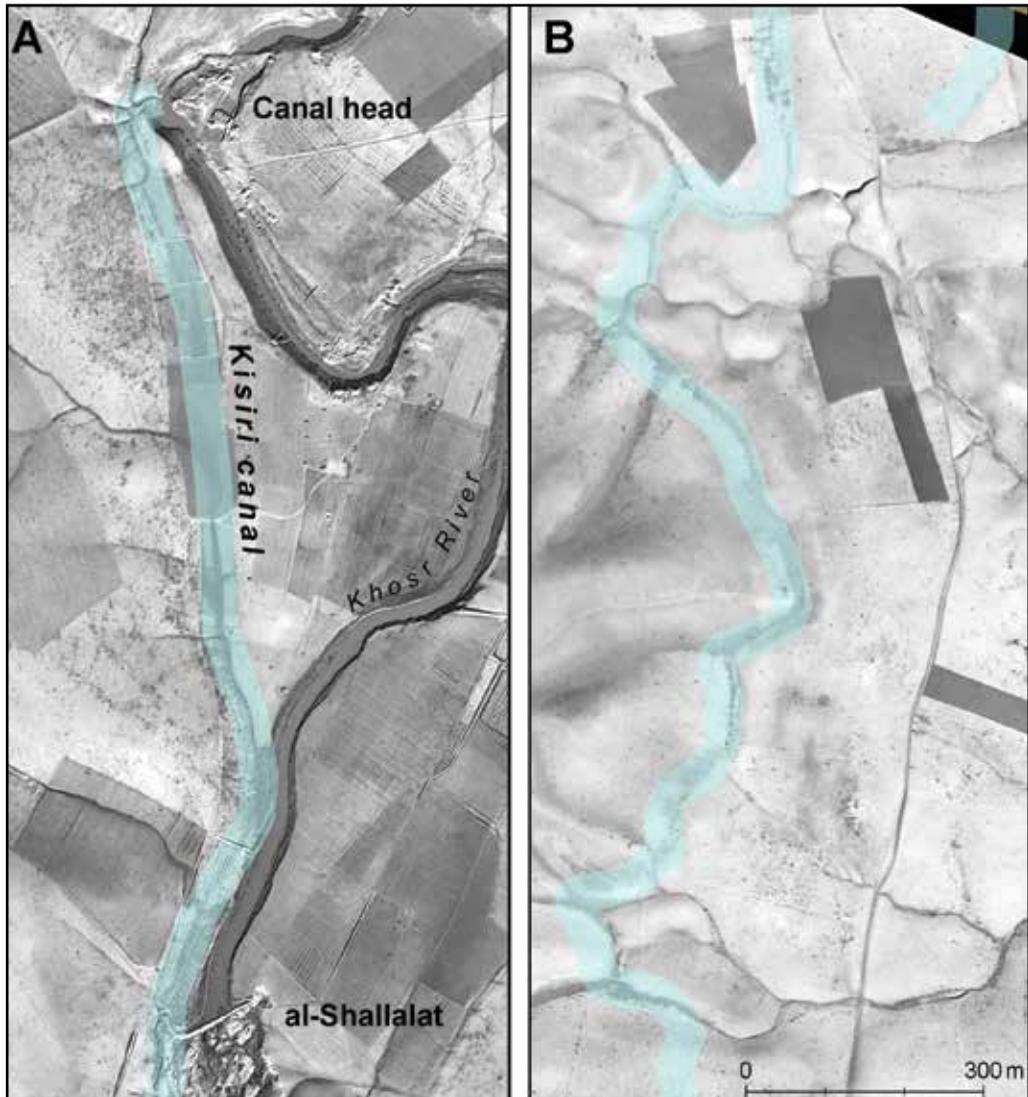


Figure 2. The Kisiri canal on U2 aerial photography (mission 1554, January 29, 1960). A. The canal head. B. The canal near Nineveh. Both photographs to the same scale. See figure 3 for locations.

by the terrain. It may be the case that, in places, its engineers cut into the sides of the hills surrounding the Khosr River valley, but it is doubtful that any person living in the shadows of the Zagros foothills would consider the gently rolling land above Nineveh to be mountainous. The canal is said to go “straight through mountain and valley.” As just described, the canal was anything but straight. For example, the straight-line distance between Sayid Lar village and the point at which the canal descends toward Nineveh is 3,500 m, but the length of the canal between those points is 4,400 m.

Most striking, however, is the overall modest size of the Kisiri canal (see fig. 3). At 15.8 km long, it was much shorter than, for example, Ashurnasirpal’s canal for Nimrud,

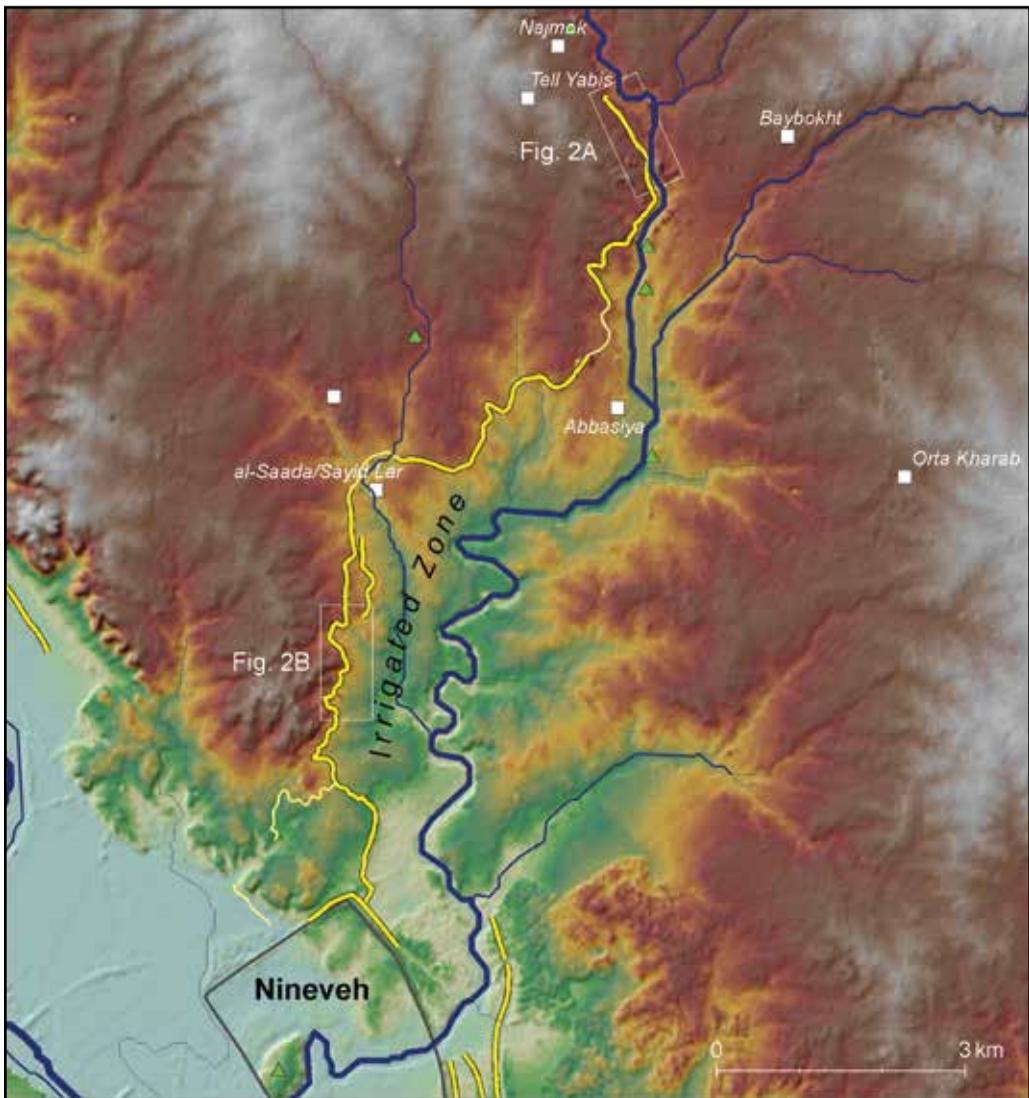


Figure 3. Plan of the Kisiri canal, north of Nineveh.

which was at least 21.6 km and may have been as long as 40 km.¹⁶ It was also dwarfed by the enormous systems commissioned later in Sennacherib's reign, especially the 90 km Khinis-Jerwan canal.¹⁷ The maximum irrigated area of the Kisiri canal (not counting Tigris floodplain fields, which cannot be estimated) was not quite 12 sq km. This area was about half the size of the terrace-irrigated area of the Nimrud canal, and only a fraction of the more than 100 sq km potentially irrigated by the Khinis-Jerwan canal on the Navkur Plain.

¹⁶ Ur and Reade 2015.

¹⁷ Ur 2005, 335–39; Jacobsen and Lloyd 1935, 31–43.

THE EARLY ISLAMIC ESTATE AT TELL BRAK (CA. 800 CE)

Tell Brak was a long-inhabited settlement that took a variety of urban forms over five millennia.¹⁸ Most research has concentrated on its earliest phases,¹⁹ but ironically it is only in its final settlement that irrigation seems to have arrived. At the northeastern corner of the Brak settlement complex is the “Castellum,” so named by the Jesuit priest and archaeologist Antoine Poidebard, who photographed a square fortified feature from the air and made small soundings.²⁰ Most subsequent scholars have followed Poidebard’s dating of the site to the late Roman period, based on his interpretation of its architecture.²¹

With more recent field investigations, the Castellum has proven to be one of the most complex elements of Brak’s already-complex settlement landscape. Surface collection²² recovered no Roman material whatsoever; the Castellum is in fact an Early Islamic fortified estate, with a town outside its walls, covering 14 ha. The settlement complex is only one element of its landscape, however. An enclosure north of the fortified structure walled off a 10 ha area, perhaps for a garden or paddock. Linear trackways extended outward from the complex in nearly every direction. Finally, a series of small canals extended from the nearby Jaghjagh River.

Brak’s offsite landscape is a complex palimpsest of modern and recent tracks, field boundaries, and plow envelopes²³ overlaying at least 4,000 years of earlier features, most of which are wide hollow ways dating to the Early Bronze Age (ca. 2600–2000 BCE) and narrower ones contemporary with the Early Islamic settlement.²⁴ These premodern features all appear as dark lines that disregard the modern landscape elements. Further complicating the palimpsest is a number of features that appear superficially similar to hollow ways but avoid elevated terrain. These features are canals, and at Brak they are closely associated with the Castellum.²⁵

The Early Islamic system began at a weir across the Jaghjagh, approximately 6.3 km to the northeast of Brak (fig. 4). The canal, which appears approximately 15 m wide, flowed first through a large early Islamic town (BKS-39²⁶) before turning to the south. It ran for about 6 km between the Jaghjagh to its left (east) and an elevated area of gravel hills to its right (west). Once the terrain allowed it, the canal turned to the southwest and ran in the direction of the town, making a slight bend to the south to accommodate the southern end of the gravel hills. The canal reached the northeast corner of the town and flowed through it, much like it had at BKS-39; a narrower canal may have flowed around its southern edge as a sort of moat, rejoining the main canal where it emerged from the town to the

18 Ur 2014.

19 Oates et al. 2007.

20 Poidebard 1934.

21 E.g., Oates and Oates 1990.

22 Ur, Karsgaard, and Oates 2011, 15–16.

23 For the latter, see Ur 2010, 131.

24 Wilkinson et al. 2010.

25 Ur, Karsgaard, and Oates 2011, 16.

26 See Wright et al. 2006–7; Poidebard 1934, pls. II–III.

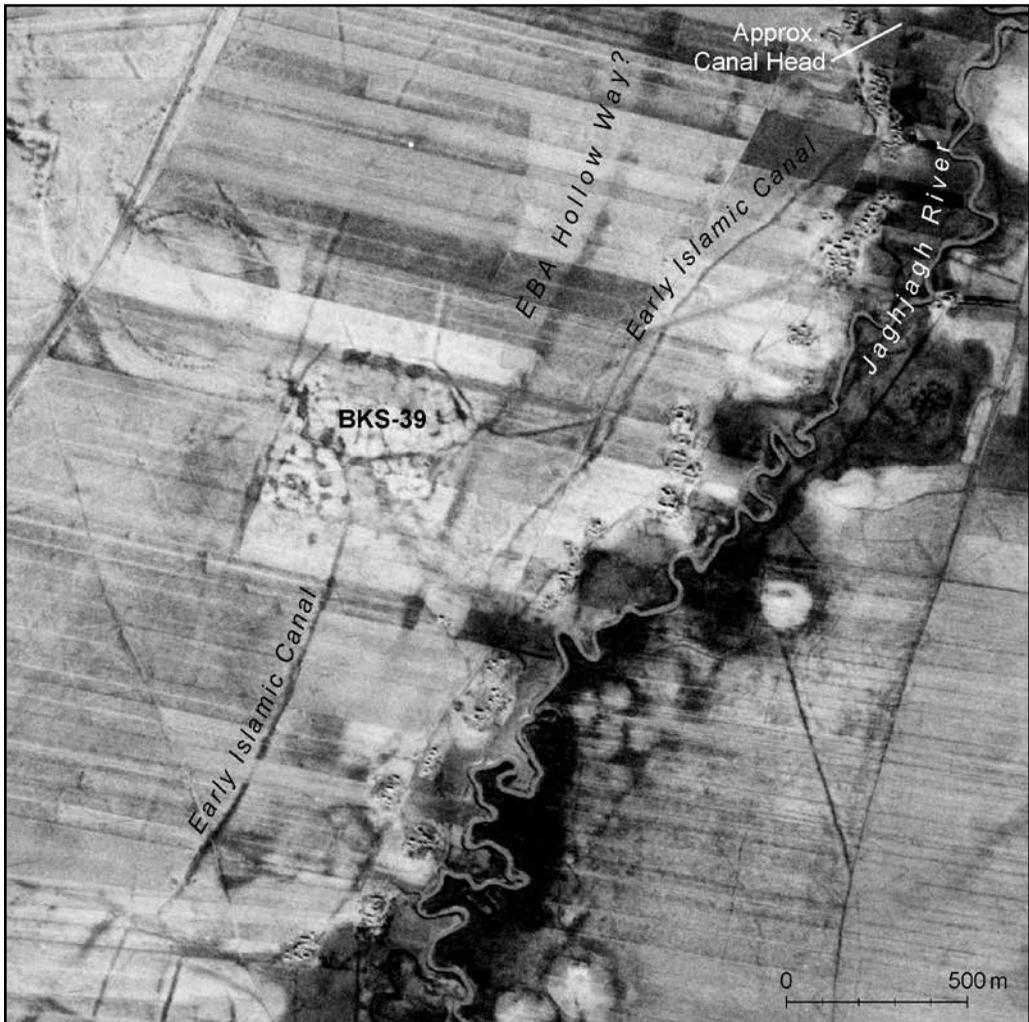


Figure 4. KH4A CORONA photograph of the Early Islamic canal head at BKS-39 (mission 1045, February 6, 1968).

northwest. At that point, the canal continued into the long-since-abandoned ruins of the main Tell Brak site, navigating the low relief of Bronze Age brick pits and hollow ways. Segments of the canal are probably to be seen running west and southwest from Brak's fourth- to second-millennium lower towns, but they are difficult to distinguish on imagery from trackways of the Early Bronze Age and Islamic periods (and indeed were probably actively using the former).

Along the canal segment between the Jaghjagh terrace and the Early Islamic town, three offtakes flowed to the south (fig. 5). One of these distributaries can be traced for over 2 km. Although water flowed all about the Brak settlement complex, the area southeast of the Early Islamic town was intensely irrigated. It therefore is much less puzzling that the Early Bronze Age landscape features that survive in abundance on all other sides of Tell

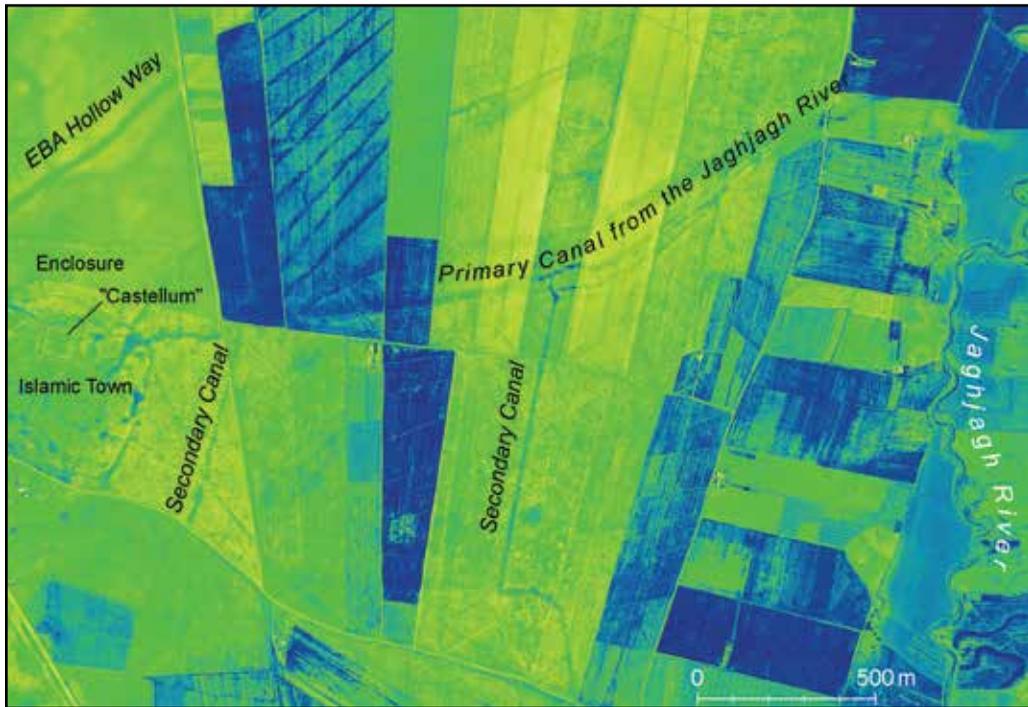


Figure 5. False-color KH9 HEXAGON photograph of primary and secondary canals east of the Early Islamic Brak town (mission 1215, May 5, 1979).

Brak are not present in this area: few of the abundant hollow ways are present, and the density of field scatters (a by-product of manuring in the Early Bronze Age) is much lower.²⁷

Tell Brak gives a glimpse into a surprisingly vibrant Early Islamic rural landscape, with towns and fortified estates connected by small (in comparison with Assyrian) local canal systems (fig. 6). The Brak system is of interest in its own right, but it is also of interest for its taphonomic impact on earlier landscapes. The zone of Early Islamic intensive irrigation agriculture corresponds precisely with a lacuna in Brak's otherwise vivid Early Bronze Age system of fields and trackways. This void would be otherwise inexplicable. Indeed, irrigation continues to be a destructive force on landscape features around Brak. Since the 1980s, diesel pumps drawing on the water table have rendered nearly all surfaces potentially irrigable, and local cultivators have taken advantage. The monumental elements of the Early Bronze Age landscape have persevered, but the more fragile Early Islamic canals have been completely effaced. Today they survive only as marks on historic satellite and aerial photography.

THE IRRIGATED HINTERLAND OF NISIBIN

The final irrigation case study is the most monumental but also the most enigmatic. The context of this system is the southern hinterland of the city of Nisibin, first known to

²⁷ Ur, Karsgaard, and Oates 2011, fig. 6.

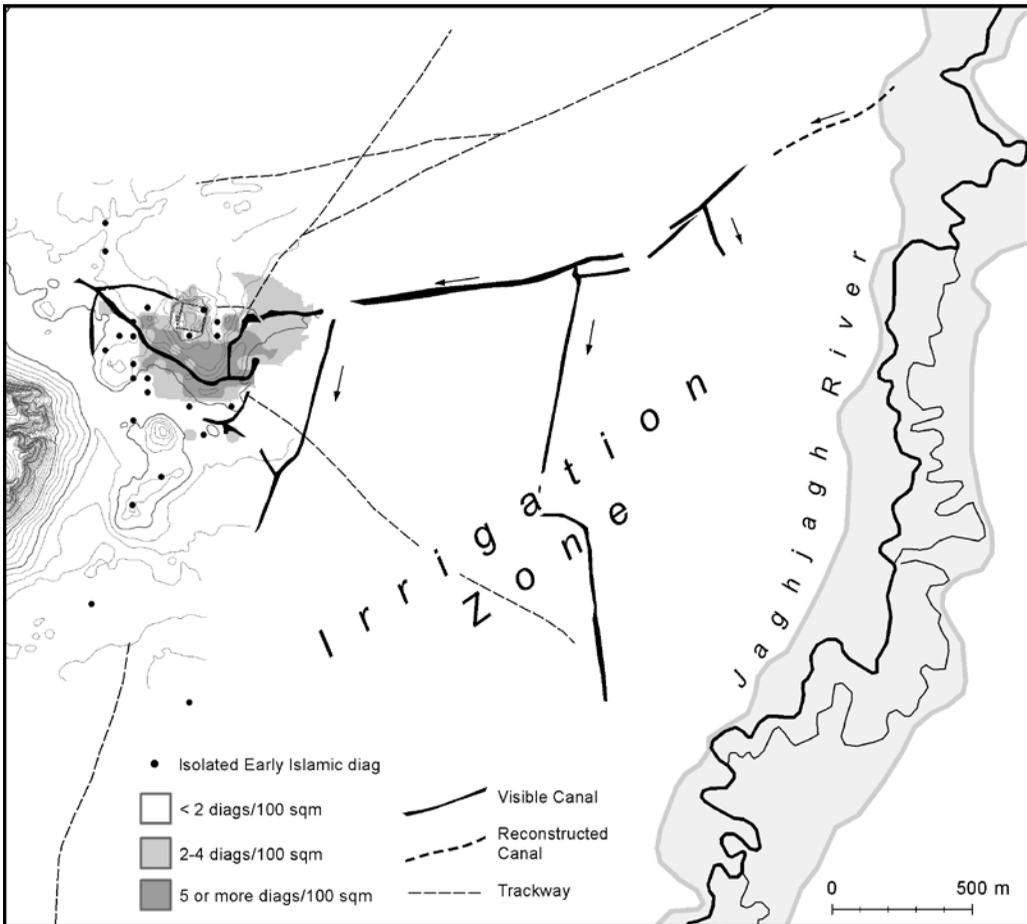


Figure 6. The Early Islamic landscape of Tell Brak.

history as the Neo-Assyrian provincial capital Nasibina in the early first millennium BCE.²⁸ It was occupied continuously since that time, and was an important frontier town in Roman-Parthian times and through late antiquity.²⁹ It was the capital of the Ottoman *livā* of Nişibîn in the sixteenth century.³⁰ Today, the border between Turkey and Syria runs across the archaeological site, and modern settlement is divided between the town of Nusaybin in Turkey and Qamishli in Syria. The Syrian part of Nisibin has been surveyed,³¹ as has its southern hinterland,³² but the latter project largely disregarded post-Bronze Age settlement.

28 Streck 1999.

29 Dillemann 1962.

30 Göyünç and Hütteroth 1997, 61–64.

31 Lyonnet 2000.

32 Meijer 1986.

Despite the importance of Nisibin over the past three centuries, no archaeologist or historian, with one exception,³³ has remarked on the traces of a massive canal system extending nearly 30 km to its south, irrigating the watershed between the Jaghjagh River and the wadis to its east. Elements of this system appear in a 1:200,000-scale French Mandate era map, but its details and extent are fully reconstructable from CORONA, GAMBIT, and U2 photographs (which are abundant because of the airfield south of Qamishli, which was of great interest to the US military).

The signature of most of the canals in the Nisibin system is very different from that of the Kisiri and Brak canals. While some have the dark linear appearance of those systems, most of the Nisibin canals appear as meandering lines, similar to the behavior of natural rivers and wadis in the region. They meander, however, within very narrow and linear belts, and often in parallel and redundant channels (fig. 7). This signature arises when artificial canals cease to be maintained and silt up, but still carry water for at least some time. At the time the photographs were taken (between 1959 and 1972, for those used in this study), the canals had not fully silted up, nor had they been removed by expanding rain-fed fields.

The primary canal can be traced for about 25 km. It flowed along the top of the watershed, so its waters were available to irrigate the lands on either side. The system has not been mapped completely, but it could have irrigated at least 700 sq km below Nisibin (fig. 8).

We owe the survival of the Nisibin irrigation system to two factors. First, the system must have gone out of use relatively recently, as most channels have not had time to silt up. Second, when the area southeast of Nisibin was recolonized by sedentary agriculturalists, they used the former channels to demarcate their fields. Hence the former channels, though no longer flowing, were fossilized by the modern patterns of land tenure.

It is difficult to date the use of this system without targeted survey. Nisibin was important already in the Neo-Assyrian period, and other western provincial capitals are known to have had extensive irrigation systems,³⁴ but an Assyrian origin is purely hypothetical. More solid is a date in the Ottoman period. The tax records of the region in the sixteenth century record abundant rice production in the *livā* of Nisibin.³⁵ Rice farming is very water intensive and would require abundant and reliable water that only artificial irrigation could supply.

The Nisibin system is another example of the impacts of irrigation on the landscape palimpsest. The Upper Khabur basin has perhaps the most extensive premodern system of trackways, mostly from the Early Bronze Age but also the Early Islamic period, which extend in aggregate over 6,000 km.³⁶ The area below Nisibin has a pronounced void in the trackway network. One might assume that movement had been minimal, or that the agricultural intensity that drove trackway formation was not at play in the Early Bronze Age. To the contrary, it seems that once again the taphonomic effects of later irrigation have fragmented the earlier landscape record. The Bronze Age survives mostly as a series of prominent tells that stood above the Ottoman fields and channels; all else was wiped clear.

33 Dillemann 1962, 51–55.

34 E.g., Ergenzinger and Kühne 1991.

35 Göyünç and Hütteroth 1997, 113–15.

36 Ur 2010, 129–46, maps 2–3.



Figure 7. KH7 GAMBIT photograph of meandering relict canals southeast of Nisibin (Qamishli, Syria)(mission 4022, October 1, 1966).

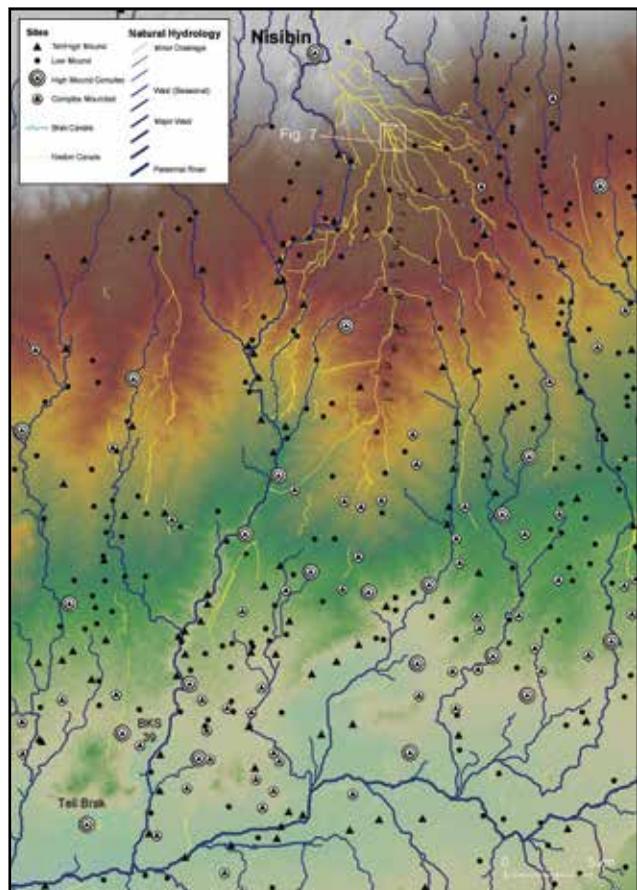


Figure 8. The canal system below Nisibin (yellow). Canal traces derived from KH7 GAMBIT and U2 imagery. For scale comparison, note the Early Islamic canal system around Tell Brak (blue) at lower left.

CONCLUDING THOUGHTS ON REMOTE SENSING OF IRRIGATION

In a case study–based review such as this one, it is probably not prudent to make wide-ranging conclusions. Nonetheless, several generalizations seem reasonable. It should not be surprising to conclude that remote sensing is, generally, a critical component of any study of irrigation or water management. An empirical data set grounded in archaeological observation is both a critical check on the pronouncements of royal inscriptions and a necessity for investigating the questions that historians and archaeologists ask, which rarely coincide with the information that inscriptions provide.

Fortunately, remote-sensing sources are more available than ever, and new digital technologies have enabled sophisticated analytical methods. Not all images are equally useful, however. The case studies presented here have relied heavily on the earliest photographs available. Commercial imagery of very high resolution and in true color has been available for the past twenty years, but it is of limited use in these case studies. Most of the Kisiri canal, for example, is beneath the al-Sukar and al-Baladiyat neighborhoods of Mosul, and development continues to creep northward (fig. 9). Brak's Early Islamic canal system has fallen victim to aggressive deep plowing, though many of its Early Bronze Age hollow ways have persevered. Even with early imagery, much depends on good ground conditions at the time the photograph was taken; most of the canals discussed in these case studies fade to invisibility under the hot and dry conditions of summer.

Early imagery is powerful, but it still has its limitations. The reader will note that the earliest case study presented here comes from the last century of the Neo-Assyrian Empire; the other two cases fall within the past 1,500 years, assuming that the Nisibin system is largely early Ottoman. Excepting massive primary canals, irrigation systems tend to be ephemeral. They are subject to environmental and cultural destruction, and all things being equal, the less time has passed since they went out of regular use, the more likely they will survive for archaeologists to document them. The archaeologist who aims to identify the canals involved in the third-millennium BCE Lagash-Umma boundary dispute is going to be disappointed, but with good imagery and proper field survey, that same archaeologist could probably make great strides toward reconstructing the irrigation economy of the Sassanian state.

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Figure 9. The destruction of the Kisiri canal by the expansion of Mosul, 1960 to present. *A.* U2 aerial photograph (mission 1554, January 29, 1960). *B.* Sentinel-2 image (March 8, 2016).

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5

The Archaeological Excavation and Explanation of Ancient Canal Irrigation Systems in Southern Arizona, USA

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THE PURPOSE OF THE STUDIES in this volume is to discuss methodological and theoretical approaches that might lead to a more nuanced understanding of the function of irrigation in early states. To achieve such an understanding, we must bring to bear a range of techniques from varied disciplines. Because the generation of more primary data on ancient irrigation in early states will largely be provided by archaeological investigation, it is critical to take advantage of new developments in archaeological methods. In this chapter, I present archaeological examples from irrigation studies in the Sonoran Desert in southern Arizona that can offer a robust methodological approach to the excavation and explanation of irrigation in early states. Advances in archaeological survey, excavation, and analysis methods over the past fifty years have produced a surge of new information on ancient canal irrigation systems in Arizona. These discoveries occurred largely during projects conducted in compliance with the National Historic Preservation Act (NHPA), enacted in 1966 and celebrating its fifty-year anniversary at the time of writing.

I discuss the techniques used to detect and document the archaeological signatures of irrigation features, including canals, reservoirs, water-control devices, and fields (fig. 1). Studies have given us better data not only on the size, structure, and chronology of canal systems but also on higher-level questions concerning demography and sociopolitical organization. This information can be used together with hydraulic modeling to enhance our understanding of irrigation management. These examples from Arizona do not derive from early state societies, and there exist no written records for these prehistoric Neolithic cultures. Nevertheless, the investigative techniques can be used in any area where relict canal systems are available for archaeological study.

SONORAN DESERT AND THE HOHOKAM CULTURAL TRADITION

The Sonoran Desert is situated in southern Arizona, USA, and northern Sonora, Mexico (fig. 2). Evidence of human occupation in the desert spans the past 12,000 years, but agricultural products did not appear until about 4,000 years ago.¹ Archaeologists now know

¹ Mabry 1998.



Figure 1. Photograph of relict segment of prehistoric Canal Casa Grande, near Coolidge, Arizona. Men in photo are standing about 56 feet apart on the crests of the canal embankments (c/o Cultural Resource Management Program, Gila River Indian Community).



Figure 2. Map showing the location of the Sonoran Desert in the southwestern United States and northwestern Mexico (c/o Cultural Resource Management Program, Gila River Indian Community).

Figure 3. Photograph of a partially excavated segment of an Early Agricultural Period canal (San Pedro phase) at Las Capas in Tucson, Arizona. Jim Vint is pictured (photo by the author).



that the earliest irrigation canals in Arizona are over 3,000 years old and were developed independently of the earliest canal construction in Mesoamerica.²

These Early Agricultural Period canals are found primarily in the Tucson basin (fig. 3). The canals were relatively short and fed small-scale field systems. Yet, the excellent preservation of these canal systems has revealed details such as individual fields, planting holes, and, most recently, a set of footprints left by ancient farmers in an irrigated field.³ The discovery of irrigation canals dating as early as 1500 BCE and maize around 2100 BCE has revolutionized our understanding of cultural and agricultural development in the US Southwest.

Most of the investigated canals in the Sonoran Desert are related to the Hohokam tradition, a culture of sedentary agriculturalists that flourished for a millennium between roughly 450 CE and 1450 CE.⁴ The core of the Hohokam cultural tradition was in the Phoenix basin, which includes the lower Salt River and middle Gila River (fig. 4). The Hohokam are renowned for their earthen public monuments (ball courts and platform mounds) and distinctive craft items such as red-on-buff pottery and marine shell jewelry. The Hohokam sphere of influence grew to include almost all of south-central Arizona in a regional system that appears to have been linked through a network of ball-court villages.

The Hohokam are noted especially for the construction of hundreds of miles of canals in numerous canal systems that irrigated thousands of acres of land in the basin (fig. 5). The Hohokam built the most extensive canal irrigation systems in the pre-Hispanic Americas north of Peru, and it is thought that these systems could irrigate up to 70,000 acres

² Huckell 1995; Mabry 2008.

³ http://tucson.com/news/science/ancient-footprints-found-at-tucson-road-construction-site/article_031cae8e-ab3b-5dd7-952b-96892390e4e4.html (accessed July 2016).

⁴ Bayman 2001; Fish and Fish 2007; Gumerman 1991; Haury 1976.

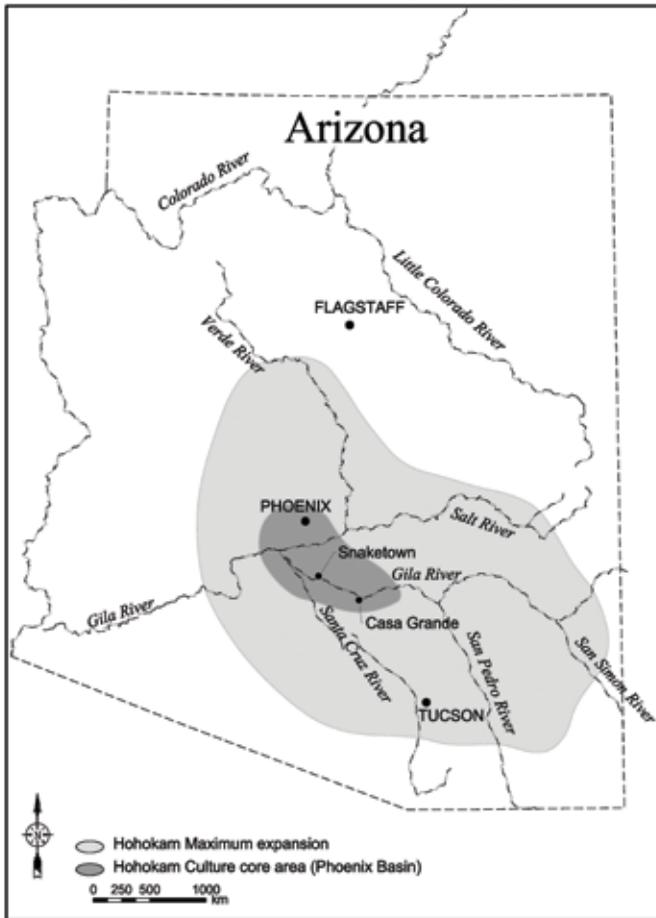


Figure 4. Map of southern Arizona showing the Hohokam region (c/o Cultural Resource Management Program, Gila River Indian Community.)

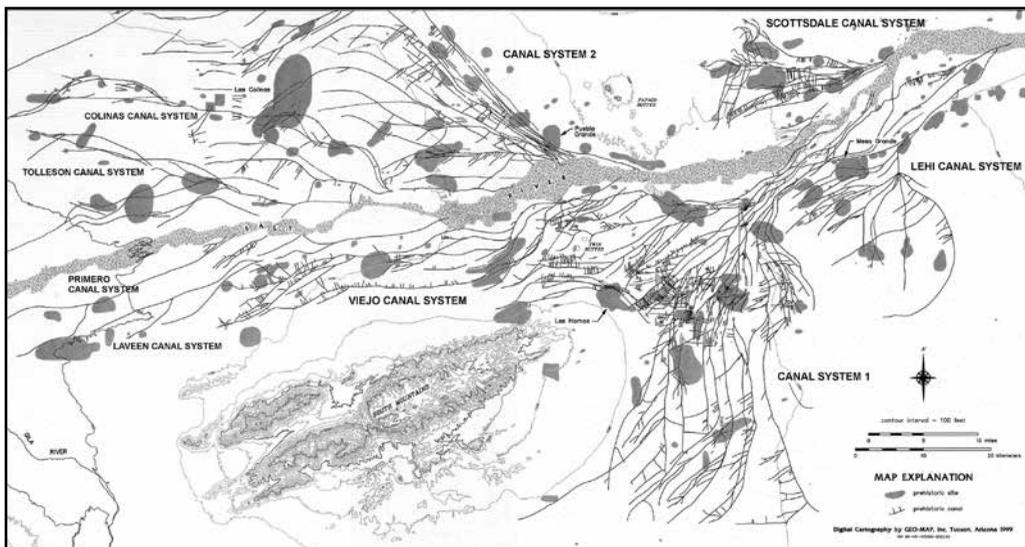


Figure 5. Map of prehistoric Hohokam canals in the lower Salt River valley, Arizona (Howard 1992, c/o Jerry Howard).

(28,000 ha) of land or more.⁵ The map in figure 5 depicts the totality of known canals and canal systems in the lower Salt River valley in the Phoenix metropolitan area.⁶ The most notable locales are Canal System 1 (on the south side of river) and Canal System 2 (on the north side), both of which integrate multiple main canals taking water out of the river. A tremendous amount of labor was needed to build and maintain these canal systems.⁷ The coordination of that labor and management of the canals also were formidable tasks.

A consensus exists that the Hohokam did not achieve a state level of sociopolitical development. However, researchers have found that the Hohokam conform poorly with neoevolutionary models of social complexity.⁸ Recent theorists posit that the Hohokam maintained a corporate or communally oriented egalitarian ideology throughout their existence, but by the late Classic period, they had developed complex internal ranking and institutionalized leadership positions that indicate a significantly more complicated sociopolitical structure than would be acknowledged through a neoevolutionary perspective.⁹ That the Hohokam culture is not considered a “state” also masks the extent and complexity of their canal systems and their achievements in irrigation management.

BRIEF HISTORY OF IRRIGATION RESEARCH IN ARIZONA

The extensive canal systems in the Hohokam core have drawn the attention of researchers for over a century.¹⁰ Early archaeological studies were privately funded investigations in the late 1800s and early 1900s, and were focused on mapping the location of prehistoric canals. Pioneering efforts by Adolf Bandelier (1892); Frederick Hodge (1893); Matthews, Wortman, and Billings (1893); Herbert Patrick (1903); and Jesse W. Fewkes (1913) culminated in the excellent work of Omar Turney and Frank Midvale (fig. 6). Their work provided a context for studying Hohokam archaeology in the Salt River and Gila River valleys. Turney’s work, including *Land of the Stone Hoe*¹¹ and the first book on the Hohokam, *Prehistoric Irrigation in Arizona*,¹² provided the first public appreciation for the prehistory of the Phoenix basin. Midvale (1935, 1946, 1963, 1965, 1968, 1972) made significant contributions to the mapping of canals and settlements during his survey efforts between 1918 and 1971.

In academia, research on prehistoric irrigation moved at a slow pace. The pioneering 1934–35 work of Harold Gladwin and Emil Haury (with Gila Pueblo) at Snaketown provided the first well-documented excavation of a Hohokam canal (fig. 7).¹³ Richard Woodbury (1960), with the University of Arizona, conducted important excavations at Park of the Four Waters in Phoenix, establishing some of the first scientific archaeological approaches

5 Fish and Fish 2007, 5.

6 Howard 1992.

7 Howard 1993; Neitzel 1991; Woodson 2016; Woodson in press.

8 Fish and Yoffee 1996; Fish and Fish 2000a, 2000b.

9 Fish and Fish 2000b; Elson and Abbott 2000.

10 Ackerly, Howard, and McGuire 1987; Howard and Huckleberry 1991; Howard and Woodson 2018; Woodson and Huckleberry 2002.

11 Turney 1924.

12 Turney 1929.

13 Haury 1937.

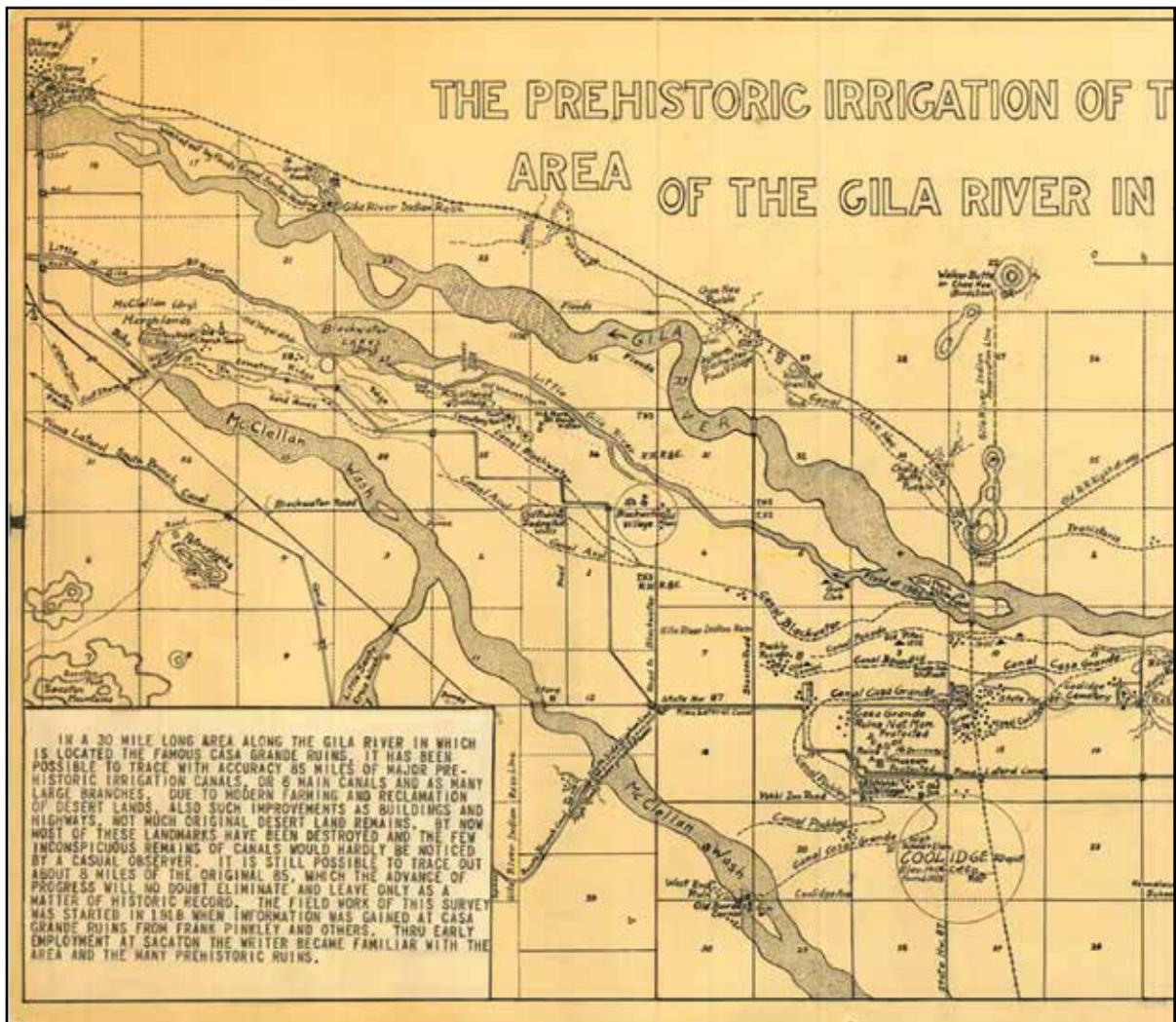


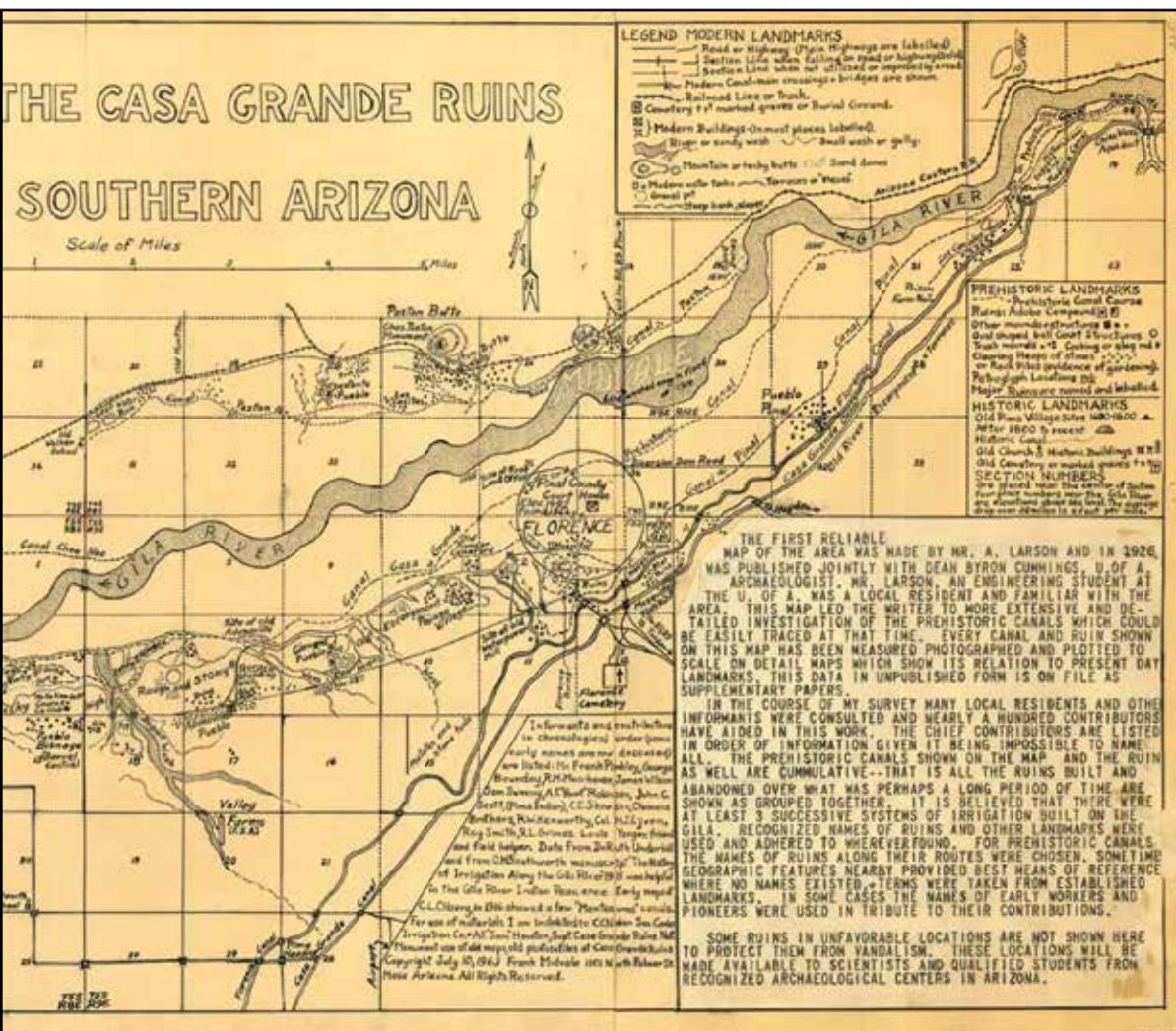
Figure 6. Frank Midvale's 1963 map of Casa Grande Ruins area in southern Arizona (c/o Arizona State University Libraries, Special Collections, call no. CM MSS-147:B/3.225b).

to canal studies. These were followed by Haury's pioneering 1964–65 second round of work on irrigation features at Snaketown.¹⁴ Still, only seven or eight prehistoric canals had been tested by the mid-1960s.¹⁵

Archaeological research in the United States changed with the passage of the NHPA in 1966. By requiring archaeological studies in conjunction with federal undertakings, the law provided a new source of funding for research and jobs, which led to the advent of cultural resource management (CRM) and vastly accelerated Hohokam archaeology. Research

¹⁴ Haury 1976.

¹⁵ Masse 1976, 38.



groups dedicated to compliance with Section 106 of the NHPA were established, at first within the academic setting but quickly within the private sector. Canal studies were few at first, with a notable early CRM effort by the Arizona State Museum, led by Bruce Masse (1981), at Park of the Four Waters adjacent to Pueblo Grande (fig. 8). But full recognition of the importance of irrigation research did not occur until the early 1980s with the initiation of the Las Colinas and La Ciudad Projects, which were funded by the Arizona Department of Transportation (ADOT) in advance of new freeway construction in Phoenix.

The Las Colinas Project integrated an advanced research design for studying irrigation features and their environmental context (fig. 9).¹⁶ The project identified large canals and settling basins within Canal System 2. The study addressed issues such as Hohokam irrigation technology, water distribution techniques, labor requirements for canal construction,

16 Nials and Fish 1988; Nials and Gregory 1989; Nials, Gregory, and Graybill 1989.



Figure 7. Photograph of Emil Haury standing in excavated segment of Snaketown Canal at Four Canal Station (Canal Test 1), Snaketown (AZ U:13:1 [ASM]), Gila River Indian Community, Arizona, December 1964. Photo by Helga Teiwes (ASM 78719) (c/o Arizona State Museum, University of Arizona).



Figure 8. Photograph of Bruce Masse standing next to lower channel of Canal 3 in Park of the Four Waters, adjacent to Pueblo Grande, Hohokam Expressway Project (AZ U:9:2 [ASM]), Arizona, March 1976. Photo by Helga Teiwes (ASM C-8236) (c/o Arizona State Museum, University of Arizona).



Figure 9. Photograph of Jennifer Strand and Michael Bartlett preparing to photograph clay-settling basin in Trench 9-3, southwest face at Las Colinas (AZ T:12:10 [ASM]), Arizona, January 1984. Photo by Helga Teiwes (ASM Las Colinas PR-2-381) (c/o Arizona State Museum, University of Arizona).

and the use of geomorphology in the study of canals. This project also included the pioneering reconstruction of the Salt River's past streamflow using tree-ring data.¹⁷

The La Ciudad Project likewise pushed the boundaries of irrigation research through the discovery and documentation of large canals, reservoirs, and a diversion structure.¹⁸ One legacy of the La Ciudad Project was the development of a long-term research project by Jerry Howard to study Canal System 2. This resulted in several important outcomes, including a revised map of the prehistoric canals and villages in the Salt River valley,¹⁹ the continued use of trained geomorphologists in canal studies (Gary Huckleberry, Fred Nials), the use of open-channel equations to calculate channel velocity and discharge of individual canal features,²⁰ and progress on dating canals using ceramics, radiocarbon dating, and archaeomagnetic dating of canal clays.

Many other projects pushed the boundaries of irrigation research, and now there are thousands of excavated irrigation features in Arizona. Important milestones include the Price Road Freeway Project in Tempe, which excavated one of the most complex areas of intersecting canals ever seen.²¹ The Scottsdale Canal System was elucidated during an

¹⁷ Graybill 1989.

¹⁸ Ackerly, Howard, and McGuire 1987.

¹⁹ Howard 1992; Howard and Huckleberry 1991.

²⁰ Howard 1990, 1993.

²¹ Ackerly and Henderson 1989.



Figure 10. Photograph of Kathy Henderson standing by an excavated segment of a large prehistoric canal in Sky Train Project area in Phoenix, Arizona. Photo by Connie Darby (c/o Desert Archaeology, Inc., Tucson, Arizona).

ADOT highway project.²² The Phoenix Sky Harbor International Airport Center Runway Project²³ and Sky Train Project²⁴ also made great strides in understanding Canal System 2, including the use of optically stimulated luminescence (OSL) dating to obtain the absolute dates of canal sediments and the discovery of unprecedented evidence of a field system (fig. 10). These projects helped to refine and advance canal excavation, analysis, and dating techniques.

On the Gila River, NHPA projects initially were not as numerous as in Phoenix but included notable studies for the Salt-Gila Aqueduct Central Arizona Project²⁵ and the Grewe site.²⁶ Irrigation research increased dramatically with the creation of the Gila River Indian Community's CRM program in 1993, investigating prehistoric irrigation across the vast reservation landscape under funding from the Bureau of Reclamation in conjunction with the Pima-Maricopa Irrigation Project.²⁷ Two decades of research have provided a comprehensive map of canal systems on the middle Gila River (fig. 11) and detailed information

22 Hackbarth, Henderson, and Craig 1995.

23 Henderson 2004.

24 Henderson 2015.

25 Crown 1984.

26 Phillips and Craig 2001.

27 Woodson 2010, 2013, 2016.

on hundreds of excavated canals, dozens of reservoirs, and multiple locales with irrigated fields and field systems.²⁸

Section 106 compliance work also expanded knowledge of canal irrigation in areas outside the massive canal systems in the Phoenix basin.²⁹ Most of these canal systems were considerably smaller than those in the Phoenix basin, and many were unknown prior to the NHPA work. In the Tucson basin, Jonathan Mabry and others identified a long tradition of irrigation agriculture that started over 3,000 years ago, prior to the advent of the Hohokam, and defined the Early Agricultural Period.³⁰ This work established the existence of canals of much greater antiquity than had been considered, and also resulted in one of the largest holes ever excavated in Arizona (at Las Capas, excavated in advance of improvements to a water treatment plant in Tucson; fig. 12). These studies demonstrated that indigenous people were farming with canal irrigation in most of the areas in the Sonoran Desert along perennial or semiperennial streams with sizable floodplains.³¹

CANAL DETECTION AND INVESTIGATION METHODS

The investigation of relict prehistoric canal systems and irrigation features may be envisioned as a process of discovery, documentation, analysis, and interpretation. It is critical that archaeologists adopt a broad perspective in the study of irrigation features to facilitate interpretation, integrating a wide range of environmental and cultural contextual data. Here I provide an overview of the techniques used to detect and document the archaeological signatures of irrigation features, including canals, water-control devices, and fields. These run from large- to small-scale perspectives and involve remote-sensing imagery, ground survey and geophysical prospecting, and testing and excavation.

REMOTE SENSING

The use of remote-sensing technology is critical to many investigations of ancient irrigation features, and most archaeologists have used these techniques to some degree. As Jason Ur discusses elsewhere in this volume, remote sensing has the advantage of providing the researcher with a regional view and access to land-cover information contained in wavelengths of the electromagnetic spectrum beyond the range of the human eye. The computerized manipulation of remote-sensing data, such as spectral filtering and stretching methods, allows detection of archaeological features that are not visible from the ground or in aerial photographs.³² The use of remote-sensing data has proven particularly useful in the investigation of buried or obfuscated linear features because the bird's-eye perspective provided by satellite imagery improves the scope for their detection.

A wide variety of remote-sensing technologies is available to archaeologists. They include various satellite imaging sources such as CORONA, IKONOS, Landsat ETM+

28 Miles, Wright, and Woodson 2010; Woodson 2010, 2016; Woodson et al. 2015.

29 Woodson and Huckleberry 2002.

30 Mabry 1998, 2008; Vint and Nials 2015.

31 Woodson and Huckleberry 2002; see also Nials, Gregory, and Hill 2011.

32 Kouchoukos 2001; Menze and Ur 2007; Showalter 1993; Ur 2013.

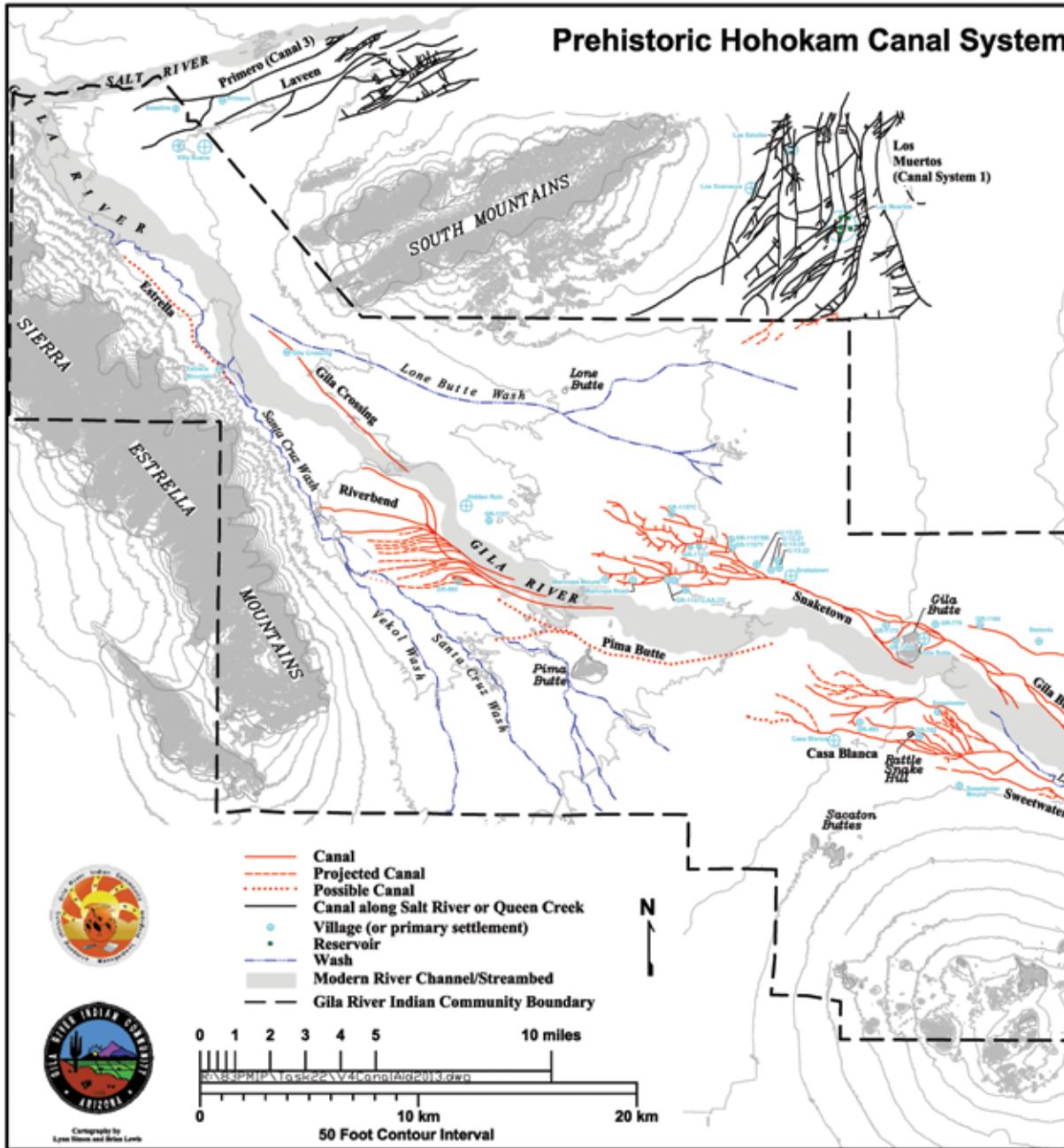


Figure 11. Map of Hohokam canal systems along the middle Gila River, Arizona (Woodson 2013, c/o Cultural Resource Management Program, Gila River Indian Community).

Canals in the Middle Gila Valley

Map Reference:

Woodson, M. Kyle
2013 Map of Prehistoric Hohokam Canal Systems in the Middle Gila Valley. 4th edition. Cultural Resource Management Program, Gila River Indian Community, Sacaton, Arizona.

Note: This map shows the prehistoric Hohokam canal systems in the Middle Gila River Valley that headed on the Gila River or Little Gila River, a tributary branch of the main river channel. There is solid documentation for 13 canal systems, and inferential support for two other systems. Villages or primary settlements and reservoirs also are shown on the map. The map presents a reconstruction of the system based on the most recent findings of a long-term study of prehistoric canal irrigation in the middle Gila Valley conducted by the Gila River Indian Community's Cultural Resource Management Program. Building from previous canal studies and maps (primarily by Frank Midvale and Keith Henry), this study incorporates the findings of projects conducted over the last 40 years both inside and outside the Gila River Indian Community. Data are taken from various sources including archaeological surveys; surveys of linear features that appear to represent relict canals; examination of aerial photographs for probable canal alignments; and excavations of canals.

Canals heading on the lower Salt River were digitized from Howard, Jerry B. (1992). Maricopa County, Arizona, Central Phoenix Basin, Archaeology Map. Soil Systems, Inc., Phoenix, AZ and GEO-MAP, Inc., Tucson, AZ.

Canals along Queen Creek were digitized from Dart, Allen (1983). Agricultural Features. In Hohokam Archaeology along the Salt-Gila Aqueduct, Central Arizona Project, Vol. 3: Specialized Activity Sites, edited by L. S. Young and P. L. Crown, pp. 345-373. Archaeological Series No. 150. Arizona State Museum, University of Arizona, Tucson, AZ.

This 4th edition of the prehistoric canal map was completed in 2013 with the assistance of GRIC-CRMP staff Craig Ferritman, Scott Phelan, and Wesley Miles. Revisions were made to some canal alignments in the Blackwater, Santan, Gila Butte and Casa Blanca canal systems.

Sequence of Canal System Headings Along Gila River (from upstream to downstream):

1. Grewe-Casa Grande
2. Poston
3. Chee Nee
4. Blackwater
5. Sweetwater (heads on Little Gila River)
6. Casa Blanca (heads on Little Gila River)
7. Granite Knob
8. Sacaton
9. Santan
10. Gila Butte
11. Sankotown
- possible canal: Pine Butte
12. Riverhead
13. Gila Crossing
- possible canal: Estrella

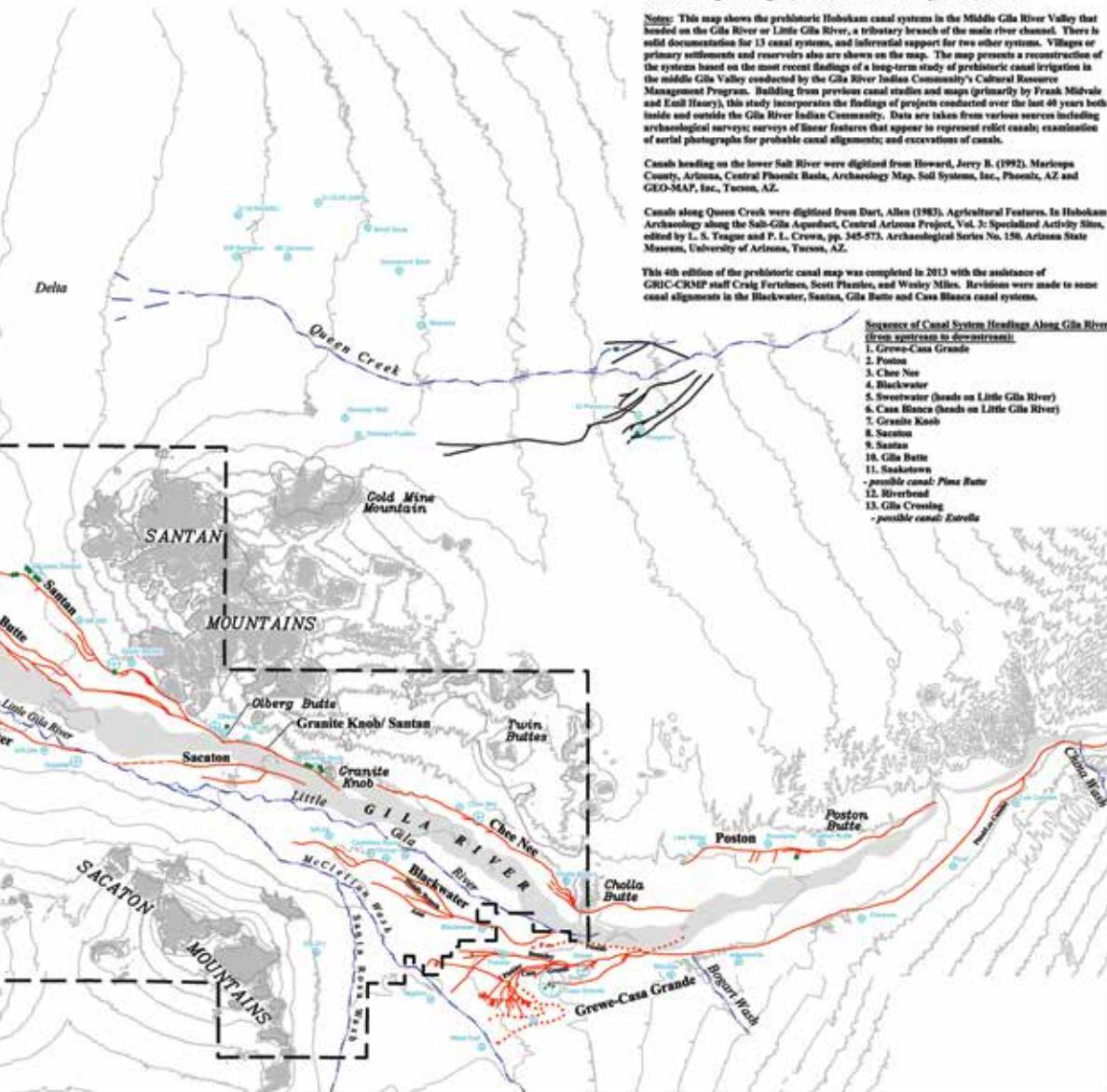




Figure 12. Aerial photograph of Las Capas, excavation Area E in Tucson, Arizona, showing a section of an Early Agricultural Period canal system with fields (outlined in white paint). Photo by Henry Wallace (c/o Archaeology Southwest, Tucson, Arizona).

[Enhanced Thematic Mapper Plus], ASTER, LIDAR, and Google Earth/Pro (QuickBird satellite).³³ Standard aerial photography is a mainstay of regional surveys and can be a key component of irrigation research (fig. 13). Using aerial images from multiple years provides a temporal dimension that can greatly aid in such studies. Multispectral imagery facilitates a more enhanced analysis of the landscape. The pooling, or fusing, of several image types can be particularly rewarding.³⁴ For instance, LIDAR can penetrate forest canopies and other ground-covering vegetation, and the use of infrared spectrum can detect features buried under flat vegetated surfaces and create high-resolution digital elevation models of archaeological sites that can reveal microtopography otherwise hidden by vegetation.

Other useful resources are historic maps, geological/geomorphological maps, and soil maps. Historic maps provide a range of information on past usage of a study area that often is quite useful, and that in many cases is critical to the correct interpretation of the signatures of irrigation features. Geological and geomorphological maps are invaluable for helping to define areas of the landscape that were most suitable for ancient irrigation. Soil survey maps can not only help to identify locales that may have been suitable for irrigation but also reveal actual areas of ancient irrigation or canals themselves. Since irrigation can have a significant and long-term impact on local soils and the environment, soil surveys can record pedological evidence of previously irrigated soils. In some areas, the formation

33 Rost, Wright, and Woodson 2015; Ur 2005, 2013; see also Ur in this volume.

34 Menze and Ur 2007.

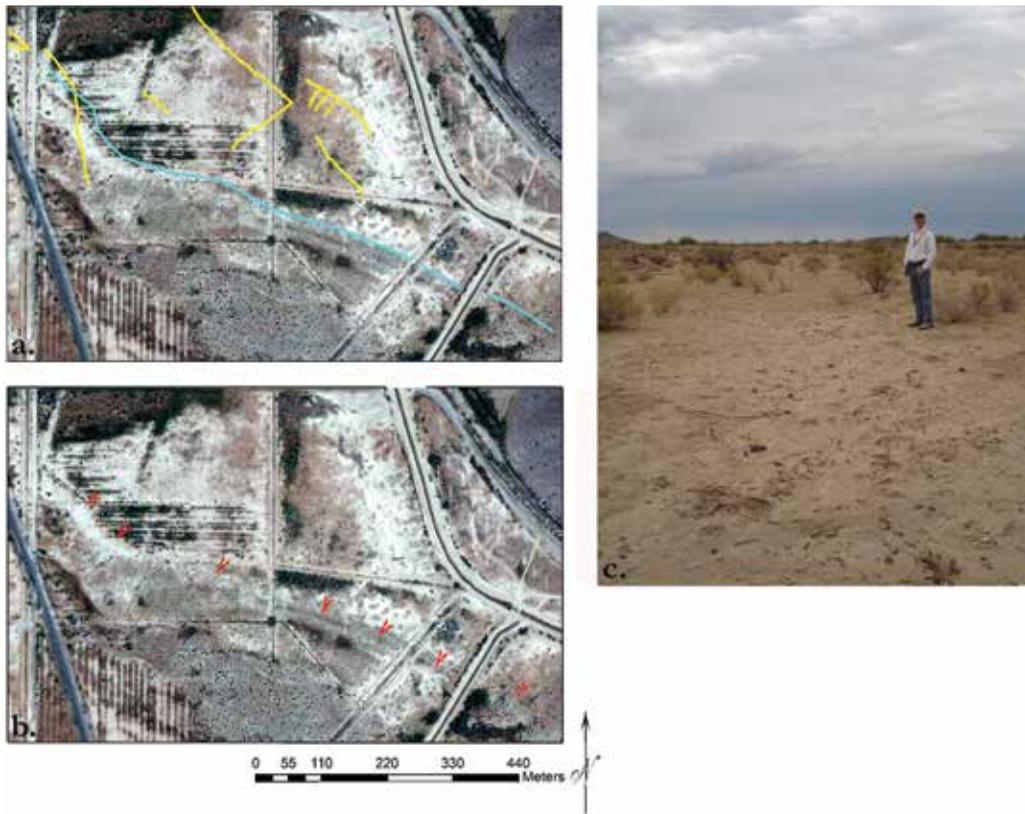


Figure 13. Satellite image and ground-truthed view of a known prehistoric canal on the Gila River, Arizona (see blue line in top image, red arrows in bottom image; yellow lines are false positives) (from Rost, Wright, and Woodson 2015).

of irrigated soils by irrigation is reflected as a soil phase on modern soil maps (fig. 14).³⁵ Dart found that low ridges of sediments that mark the courses of prehistoric Hohokam canal systems along Queen Creek (in the eastern part of the Phoenix basin) and in a portion of the lower Salt River valley have been independently mapped by the US Soil Conservation Service as discrete soil phases.³⁶

The data provided through these remote-sensing methods can provide excellent overview maps and images, as well as details of potential irrigation features that are not visible with standard imagery or on the ground. One drawback can be the “information overload” in these images. Retrieving archaeologically informative results from the information depends greatly on the researcher’s familiarity with the local archaeology, history, and environment. This entails not only an understanding of the nature of surface traces of the archaeological features in question but also a knowledge of the postdepositional processes, such as geomorphological landscape changes (i.e., alluviation) or anthropomorphic impacts (i.e., plowing and development), that may have altered the surface traces.

³⁵ Woodson et al. 2015.

³⁶ Dart 1986.

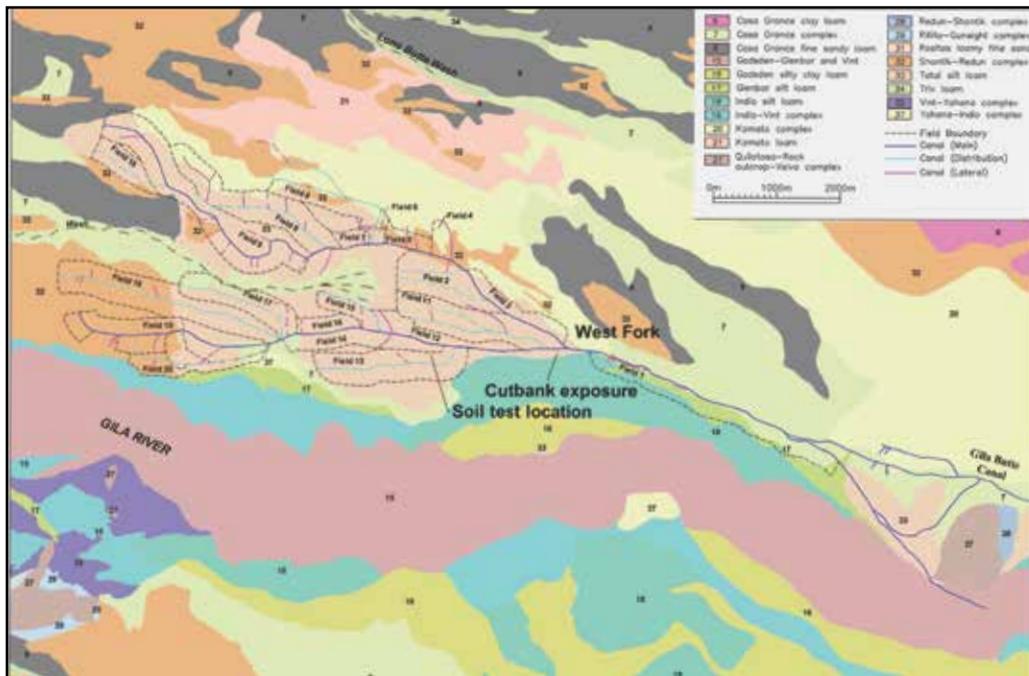


Figure 14. Map of prehistoric Snaketown Canal System overlaid on soil map, showing correspondence between soil map units and inferred irrigated field areas (from Woodson et al. 2015).

SURVEY AND GEOPHYSICAL PROSPECTING

Potential irrigation features identified through remote sensing should be inspected and documented through ground pedestrian survey, where feasible (some study areas are clearly inaccessible, such as in parts of the Middle East). Survey can help to ground-truth and refine the interpretation of possible irrigation features identified in remote-sensing images.³⁷ Archaeologists need to be familiar with the surface expression of irrigation features in their study-area landscape. Relict irrigation features can be visible on the ground as linear mounds or depressions, linear artifact scatters, areas of different soil color and texture, or areas of different vegetation color or type, among other manifestations. Surface or low-elevation digital photography/photogrammetry, now including the use of drones with cameras, can further refine the images derived from higher-elevation remote-sensing devices and also create 3D maps of a localized study area.

Several geophysical prospecting techniques have proven useful for localized investigation of subsurface irrigation features, particularly where surface evidence of such features has been obscured. These methods include ground-penetrating radar,³⁸ ultrashallow

37 Rost, Wright, and Woodson 2015.

38 Conyers 2004.

seismic reflection imaging,³⁹ magnetic gradiometry or magnetometry,⁴⁰ and electromagnetic induction. The utility of these techniques is dependent on local soil and landscape conditions; for instance, soil salinity and metallic inclusions in soil can inhibit the effectiveness of some techniques. As shown in figure 15, magnetic gradiometry used at La Playa in Sonora, Mexico, provided clear documentation of subsurface irrigation features in a highly eroded landscape.⁴¹ If these techniques are properly paired to the study area conditions, results can be excellent.⁴²

TESTING AND EXCAVATION

The identification of subsurface irrigation features is best accomplished through controlled archaeological excavation. *Backhoe trenching* has proven to be the most effective excavation technique for this task in Arizona. In some cases, whether or not they are anticipated, irrigation features are encountered in the normal course of excavation projects. However, excavation strategies may be developed to target specific areas with a higher probability of containing canals and other irrigation features. Knowledge of the geomorphic and pedological setting can help guide excavation and facilitate recognition of subtle irrigation features. *Mechanical scraping* of horizontal exposures of irrigation features with a backhoe also can be informative, particularly in complex areas of a canal system such as sections with multiple canals and fields (e.g., Las Capas, Sky Harbor). Excavation strategies vary with the specifics of the canal system or site under investigation, but all excavations should be designed to document canal alignment, stratigraphic relationships between canals and other archaeological features, and longitudinal variation in channel geometry.

Once a potential subsurface irrigation feature has been discovered, how does an investigator confidently identify it as a relict canal or other irrigation feature? The main characteristic of canals is the presence of a depression with a layer or successive layers of alluvial sediments (sands, silts, clays). Canal shape and size can be quite variable, but the shape is generally parabolic to trapezoidal in cross section. Other irrigation features, such as reservoirs and settlement basins, also contain alluvial sediments but differ morphologically from canals. In some cases, distinguishing between a canal and a natural fluvial channel can be problematic and requires additional scrutiny⁴³—for instance, showing that the course of the presumed canal does not mimic the course of a natural drainage or arroyo, showing a clear physical connection between the presumptive canal and the drainage from which water was obtained for the canal, or excavating enough cross sections to demonstrate that the channel is continuous over some distance.⁴⁴ In addition, it may be difficult to distinguish between prehistoric and historic and modern canals. In the absence of artifacts, materials, or stratigraphic relationships that can be dated (see below), many canals have regional morphological traits that can be used as general distinctions.

39 Hildebrand et al. 2007.

40 Aspinall, Gaffney, and Schmidt 2008.

41 Cajigas 2015.

42 Hildebrand et al. 2011.

43 Ackerly 1995.

44 Ackerly 1995, 285.

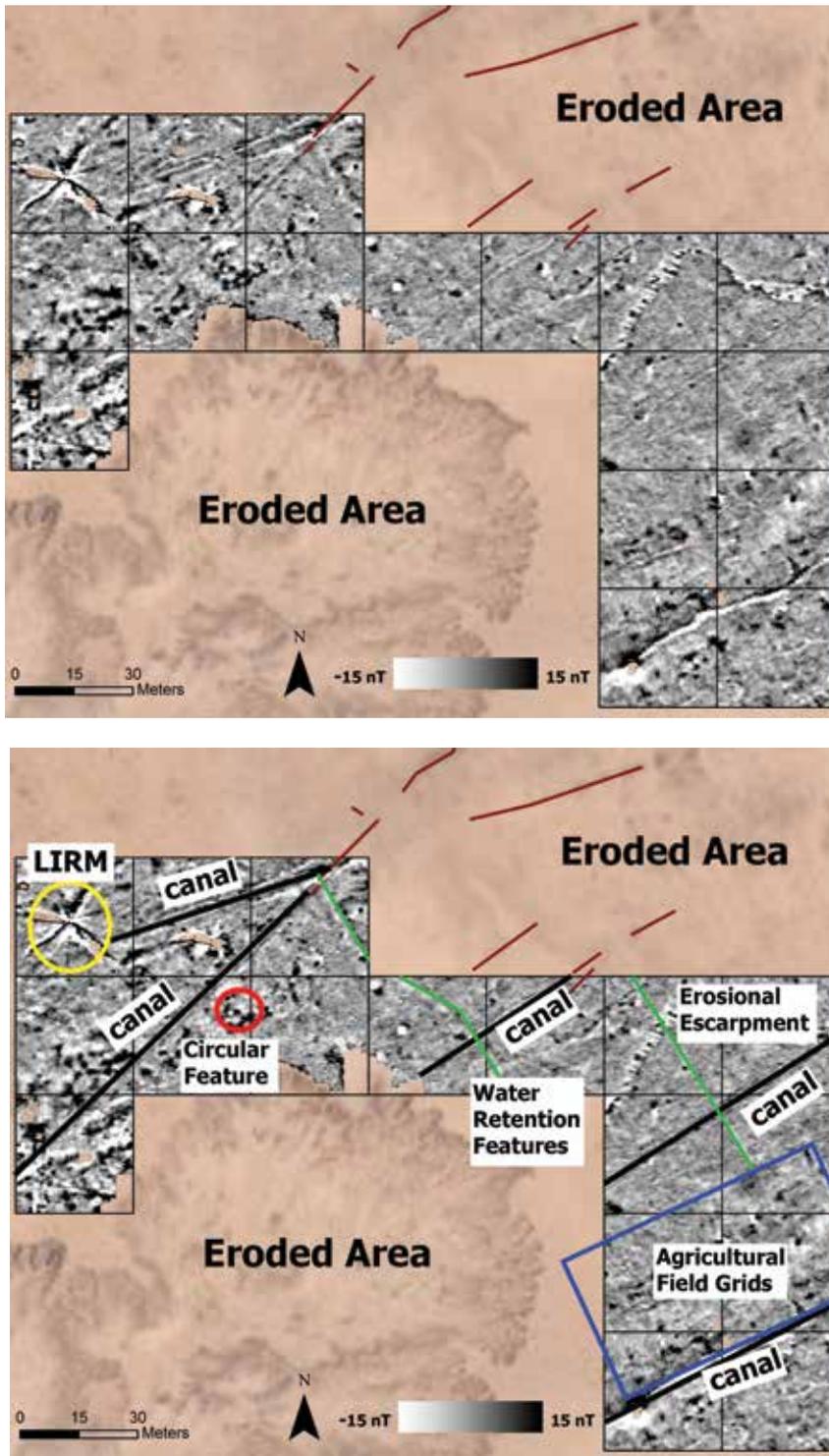


Figure 15. Gradiometry map of prehistoric canals and related features at La Playa, Sonora, Mexico (from Cajigas 2015, c/o Rachel Cajigas).

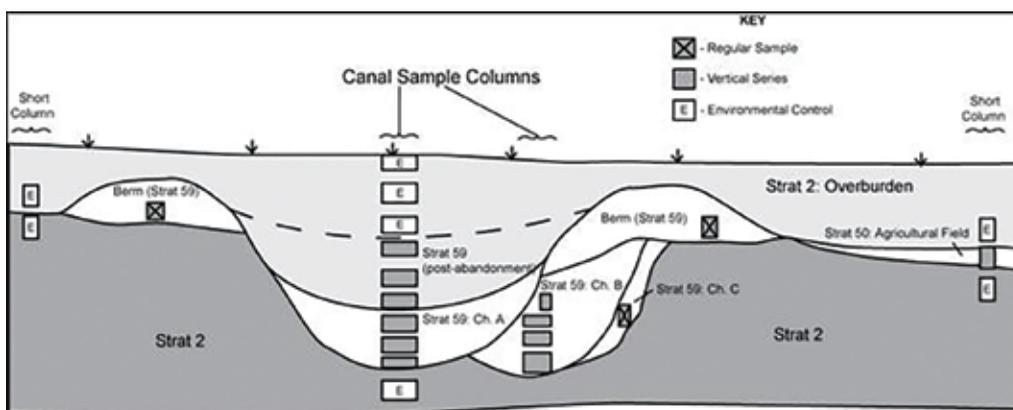


Figure 16. Canal profile and sampling diagram (c/o Cultural Resource Management Program, Gila River Indian Community).

DATA COLLECTION

After a canal or irrigation feature has been located and identified, it must be sufficiently documented and sampled to facilitate an adequate interpretation and provide material for further analysis. Relict canal systems are mostly stratigraphic phenomena and require careful and methodical excavation, mapping, and description in the field (fig. 16). Once canal alignments are identified, they need to be traced as far as possible with multiple cross sections for purposes of mapping and documenting any possible longitudinal (down-stream) changes in channel geometry and stratigraphy. This is accomplished by excavating multiple trenches perpendicular to the axis of the canal alignment. Canal intersections should be investigated to determine the relative ages of the channels and locate water control features. For canal systems or irrigation features visible at ground surface, a great deal of data can be recovered by surface survey, description, and mapping, as well as aerial photography. Canal gradient can be estimated by ground surface slope for both surface and subsurface irrigation features.

DESCRIPTION

Profiles of canal stratigraphy should be drawn of vertical exposures situated perpendicular to the axis of the alignment to better define channel shape and area. Deposits both inside and outside the canal channel need to be described using US Department of Agriculture soil nomenclature⁴⁵ and standard geological terminology for texture and bedforms.⁴⁶ Profile descriptions also should note the presence of unconformities in sediment deposition, which represent either natural or culturally induced modifications to canals or other irrigation features.

45 Schoeneberger et al. 1998.

46 E.g., Boggs 1995.

SAMPLING

Canal deposits can be sampled for various types of laboratory analyses (described in the next section). A sample of canal sediments can be collected for granulometric analyses and characterization of depositional environments. The objective is to sample the stratigraphy that is characteristic of the feature. Sediment samples may also be collected for various ecological analyses, including pollen, microinvertebrate, and malacological (shell) studies. In addition to sediments, datable materials should be collected from canal and related deposits. Absolute dating is most successful with accelerator mass spectrometry (AMS) radiocarbon dating of carbonized plant remains (which can also be recovered by flotation of canal fill sediments) and OSL dating of canal sediments. Some temporal inference of canal age can also be made by the artifactual content of the canal. A screened excavation unit in the canal fill sediments is sufficient for the recovery of temporally diagnostic artifacts.

CANAL ANALYSES

Once field observational data and samples have been collected from an irrigation feature, an investigator may pursue several types of specialized analyses. The decision to proceed with such analyses will depend on the project's research goals and budget.

HYDRAULIC MODELING

Irrigation canals are subject to the same physical laws that govern streamflow and sediment transport and deposition as occur in natural watercourses. Consequently, principles of open channel hydraulics, sedimentology, stratigraphy, and geomorphology can be applied to relict canal systems in an effort to better understand their history.⁴⁷ Hydraulic analysis permits the reconstruction of water velocity and discharge, two important parameters for understanding irrigation capacity and channel stability.⁴⁸ This type of analysis further helps to define the engineering efficiency of canals and allows the estimation of potential irrigable area.

SEDIMENTOLOGY

Sedimentology, the study of the characteristics and formation of deposits,⁴⁹ can be used to help answer questions about the flow history and depositional regimes of canals.⁵⁰ In this approach, laboratory particle-size analysis (cost: \$50 per sample) is used to characterize sediment components (silts, sands, clays) from canal sediment samples. Because alluvial textures record previous flow regimes,⁵¹ there is some correspondence between the reconstructed channel flow characteristics and transported sediments within the channel. Thus,

47 Howard 1993; Huckleberry 1991.

48 Howard and Huckleberry 1991; Ortloff, Feldman, and Moseley 1985.

49 Waters 1992, 4.

50 Huckleberry 1991.

51 Huckleberry 1999a, 8.

for example, massive dark clay deposits in the base of a canal channel indicate stagnant water conditions. Conversely, high-energy, unregulated flood deposits in canals should be coarser than the underlying deposits formed by regulated canal discharge.⁵²

MICROMORPHOLOGY

Micromorphology is a pedostratigraphic analysis technique that can be used to reconstruct paleoenvironmental conditions in a canal or other setting.⁵³ The method (cost: about \$300 per sample) allows for the identification of relict sedimentary features and pedological transformations, whether or not they are linked to human activity. It facilitates recognition of either discrete episodes of use or the precise local paleoecological environment of the canal.

FLORA AND FAUNA

Besides sediments, the water in streams is full of aquatic life (fishes, mollusks, plants, microorganisms) and organic material, and these materials would have been swept into prehistoric canals that diverted stream water. Both during the operation of canal systems and after their abandonment, plants such as pollen and macrofossils (larger plant remains) and microinvertebrates such as ostracodes and mollusks become deposited in sediments within canals and associated features. Analysis of sediment samples for the remains of these organisms provide information on several issues relevant to ancient irrigation agriculture, including hydrological and environmental conditions.⁵⁴ Microinvertebrate analysis (cost: \$330 per sample) provides insight into the evolution of irrigation technology (e.g., transition from opportunistic use of water to functional canal operation) and aspects of climatic change suggested by flood events or temperature changes, as well as salinity. Pollen analysis (cost: \$320 per sample) and macrofossil analysis (cost: \$280–\$300 per sample) offer perspectives on aspects of canal system components (e.g., main, distribution, or lateral canals), distance of canal segments from river headwaters, burning of vegetation as a form of canal maintenance, nature of crops grown in agricultural fields, and wild plants likely encouraged along canals and the edges of nearby fields. Complementing each other, microinvertebrates and pollen/plant remains can reveal episodes of water flow in canals and periods of water stagnation or desiccation, provide insight into the season(s) of canal operation, and help to understand long-term water storage in reservoirs.

DATING CANALS

A fundamental approach to dating canals continues to be relative dating using stratigraphy and temporally diagnostic artifacts found in canal fill (usually ceramics). Absolute dating of canals is also used extensively, and the primary techniques are AMS radiocarbon dating of carbonized plant remains in canal sediments (cost: \$595 per sample) and OSL

52 Huckleberry 1999a, 1999b, 28.

53 Purdue et al. 2010.

54 Adams, Smith, and Palacios-Fest 2002; Woodson and Huckleberry 2002.

dating of sediments in canal fill (cost: \$800 per sample). AMS dating of annual plants is preferred over charcoal to help counteract the problem of determining the precise association of the dated material with canal use events. With improvements in single-grain aliquot OSL dating, Arizona archaeologists have used this technique more extensively and with great success. Investigators also have used archaeomagnetic dating of fine canal sediments (cost: \$300 per sample), carbon-14 dating of shells in canals (cost: \$595 per sample), and thermoluminescence dating of sherds in canal fill (cost: \$400 per sample). A key component in successful dating is the pooling of multiple dates obtained on irrigation features to achieve higher confidence ages.

CANAL EXPLANATION AND INTERPRETATION

Implementing these types of data recovery and analyses on ancient canals enables researchers to better interpret canals and canal systems and to address higher-level anthropological questions about them. An important step is to assess the structure or layout of the canal system and to evaluate the entirety of a system on the landscape. Here, we should strive to understand the environmental and cultural context of the system: what settlements and natural features are located within and adjacent to it? It is also important to establish the chronology of canal system development, because it impacts the diachronic interpretation of system growth, size, and potential productivity (fig. 17).

A benefit of mapping the extent of a canal system is that it allows a critical assessment of the size (or command area) of the irrigated field areas. Modeling irrigated areas requires a solid understanding of the location of main and distribution canals, but it also depends on the lengths of the lateral canals that extend into the fields. By analyzing the lateral lengths of prehistoric and early historic indigenous canals on the middle Gila River, Woodson⁵⁵ was able to calculate an average lateral length to facilitate the estimation of command areas. My work in the middle Gila River valley suggests that prehistoric Hohokam could have irrigated between 30,000 and 50,000 acres (12,000–20,000 ha). The larger canal systems in the lower Salt River valley feasibly could have irrigated twice that amount.⁵⁶

If the command area of a canal system is known, then some estimates can be made for the population size supported by produce from the fields. Along the middle Gila River, ethnographic data on the indigenous, historic Akimel O'odham population indicates that an average family of five farmed 2 ha per year.⁵⁷ If we assume the same held for prehistoric Hohokam, and accept my findings that 12,000–20,000 ha were being farmed, then we can estimate that 6,000–10,000 households—or 30,000–50,000 people—may have been living along the middle Gila River.⁵⁸ In another example, researchers used data from prehistoric agricultural systems, soil, and moisture, with assumptions about land-use practices and per capita demand, to model prehistoric agricultural productivity (crop yields) as a proxy for population scale.⁵⁹

⁵⁵ Woodson 2010.

⁵⁶ Nicholas 1981; Turney 1929; Woodbury 1962.

⁵⁷ Castetter and Bell 1942, 54–56.

⁵⁸ Woodson 2010.

⁵⁹ Van West and Altschul 1998.

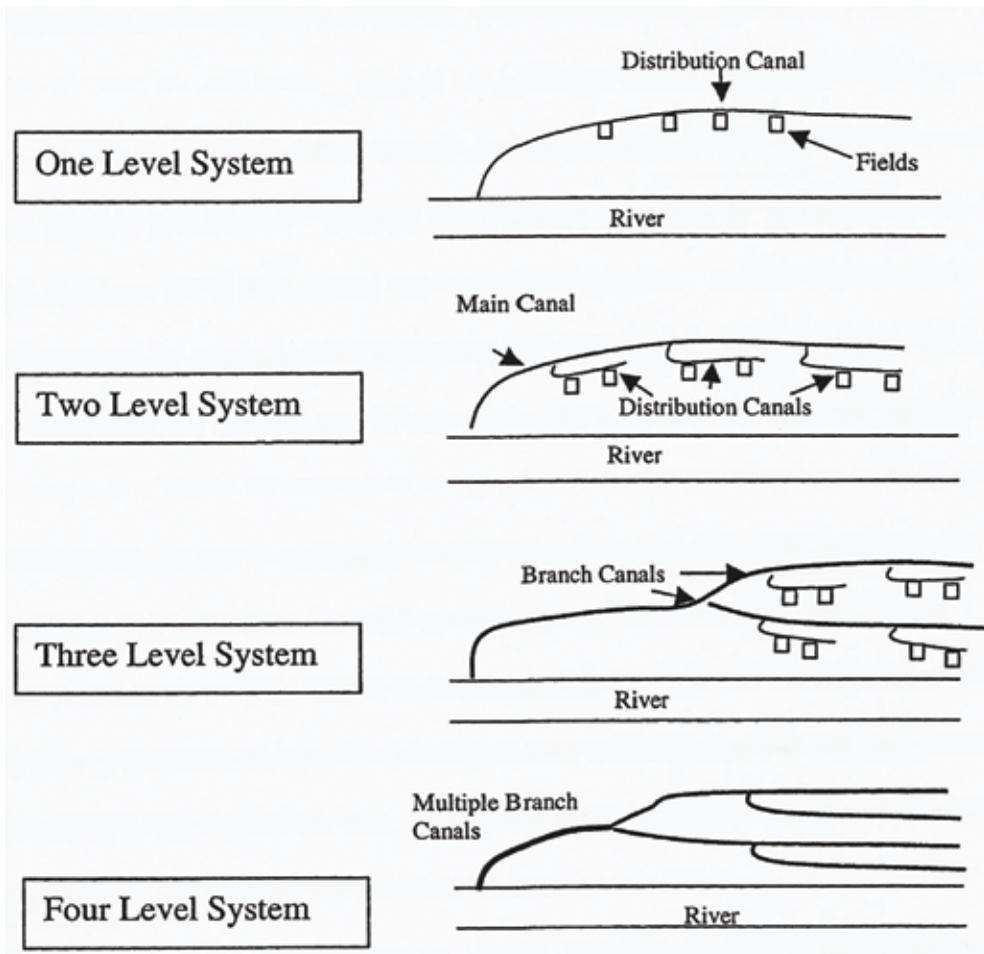


Figure 17. Schematic diagram of organizational levels of a canal irrigation system (from Howard 2006, 22, after Uphoff 1986, 59–66).

Ethnographic and historical research provides the basis for much of what we know about the social organization of irrigation management. Such studies generally address the social, political, and economic aspects of irrigation organization. Often missing from this research are details on the physical elements and structure of a canal system.⁶⁰ Moreover, there are only a few models⁶¹ for how these physical elements may relate to the social organization of irrigation.⁶² Recent archaeological work in the Hohokam area has begun to change this situation by defining task groups that are linked to specific physical elements of an irrigation system.⁶³ Another important factor in understanding the social

60 With notable exceptions in Downing 1974; Lees 1973.

61 E.g., Downing 1974; Uphoff 1986.

62 Howard 2006, 6.

63 Howard 2006; Woodson 2016.

organization of irrigation is the amount of labor invested in building canals.⁶⁴ The volume of soil excavated during canal construction provides a relative measure of labor input. If assumptions are made regarding the amount of soil a worker can move in a day and the duration of the construction project, an estimate can be made of the size of the work crews that would be needed for the project. These measures provide insight into the number of people needed to build and maintain the canals, as well as the size of the population using the canal system.

CONCLUSION

My goal has been to review the techniques that have fruitfully been used to detect, document, analyze, and explain ancient irrigation features. The gains in research and expansion of knowledge of prehistoric irrigation in Arizona that resulted from the passage of the NHPA cannot be overstated. NHPA compliance-driven research on ancient irrigation quickly adopted, tested, and refined new technologies. Our studies of prehistoric irrigation went from only basic information to an explosion of new projects, new methodologies, and new techniques. These studies provided not only basic information on the structure and chronology of irrigation systems but also answers to higher-level questions concerning sociopolitical organization. The advantages of good, fundamental data recovery on ancient canals are manifold. I suggest that these same techniques for detection, documentation, analysis, and explanation can also be productive for the study of irrigation in early states. The selection of techniques must be tailored to each project's scope and budget. However, if more such studies are conducted on early state irrigation systems, they will open up new understandings of the function of irrigation in early states.

64 Howard 1993; Woodson 2014, 2016.

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6 Archaeobotanical Perspectives on Water Supply and Water Management in the Indus Valley Civilization

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TODAY, IN AREAS of the Old World with very low rainfall (<300 mm/year), irrigation is a precondition for the cultivation of certain crops such as winter cereals (i.e., wheat, barley). In regions where rain-fed agriculture can be practiced, irrigation can be employed to raise the yields per unit of area or to improve the reliability of harvest. This chapter focuses on water management systems in the Indus Valley Civilization, an area that has not yet found definitive archaeological evidence either in favor of or against them. We start by presenting a review of the traditional irrigation systems in the area once occupied by this civilization and then discuss some potential archaeological proxies that could be used to provide a definitive answer to the type and amount of water management practices in the past.

The role of irrigation in past agricultural systems has been the focus of extensive debate because of the relationship between agricultural practices at large and socioeconomic change in prehistory. Indeed, the presence of irrigation technology has been regarded as a key feature for the development of civilizations in many parts of the world, especially Asia. Wittfogel's "hydraulic hypothesis" was very influential throughout the twentieth century and was reinterpreted in several ways, which ultimately satiated the archaeological search for the origin of social complexity and state development.¹ According to Wittfogel, the implementation of massive infrastructures to support irrigation (i.e., large-scale irrigation) is a precondition for the presence of "despotic rulers." Management of large-scale irrigation requires a centralized control that then provides the necessary precondition for a ruler to expand his rule to a despotic form. It is also a primary condition for the intensification of agriculture.

The Indus Valley Civilization, in what is today northwest India and Pakistan, is an example of a past society where the application of an efficient and apparently simple small-scale water management technology eventually supported a power similar to state-level political units. This civilization is often idealized as occupying a homogeneous landscape, even more so because it is often thought, erroneously, to represent a homogenous cultural tradition. This image is rather simplistic given that we find evidence of this culture across incredibly diverse ecological zones. Indeed, within the Indus territory, two climatic systems meet—the Indian summer monsoon and the westerly winter rains—and there are deserts, alluvial plains, highlands, and related alluvial fans, lakes, and marshes (see table 1).

¹ Wittfogel 1957; cf. Butzer 1996.

Table 1. Main types of landforms found in the Greater Indus valley (the numbers in parentheses refer to the location of these landforms in the map in figure 7).

Landform	Description	Upper basin/area	Lower basin/area
Sandy deserts (1)	Complex of dunes and terraces	Cholistan, southeast margins of Ghaggar Plain	Upper Thar Desert and parts of southern reaches
Undulating sandy stabilized desert (2)	Complex of dunes and terraces	N/A	North Gujarat former Thar Desert extension
Bajadas (3)	Coalescent aprons and alluvial fans	Along piedmont edge of western relief to margin of Indus	Fans grading directly onto alluvial terrain
Undulating sandy terraces (4)	High escarpment interfluves	Between Jhelum and Indus	N/A
Bar uplands (doabs) (5)	Extensive terraces 2–9 m high	Outwash deposits between Punjab rivers	N/A
Terraces (6)	Low-relief terrain (cultivated today)	Almost continuous bands running parallel to course of Punjab Five Rivers	Along the former meandering Indus trunk stream
Floodplains (7)	Near-level to mildly undulating surfaces	Along outside banks of meandering segments of primary drainage	Along the Indus
Indus delta / estuary (8)	Coastal plains aggradation	N/A	Along the coast

Many of these areas receive far less than 300 mm of rain per year, which is supposed to be the minimum for rain-fed agriculture, but are watered by major perennial or seasonal rivers. Other areas receive abundant winter rain or the full strength of the monsoon with more than 700 mm of rain, mostly in the summer. Thus, the geography of the Indus Valley Civilization includes areas with high rainfall (only in summer or in both summer and winter), areas with abundant and reliable floods, microzones relying on very localized water (e.g., lakes), and extensive areas where dry farming is possible but highly unpredictable. In these regions with distinctive agricultural risks, water management—in the form of irrigation and/or water harvesting—can be employed to ensure the growth of crops that need a certain level of moisture (e.g., winter crops such as wheat and barley, some legumes). On the other hand, species such as millets can survive with much less water, in areas where rainfalls are short lived and temperatures relatively high,² but productivity increases when extra water is supplied.³

2 Seetharam, Riley, and Harinaryana 1989.

3 Kijne et al. 2009.



Figure 1. Image reproduced from Mackay (1938) showing Late Phase III drainage system in “Low Lane” (looking south). On the left of the street, a set of side drains evidently emerges from the houses and connects with the main drain running on the right side.

Archaeology has shown that water was a very important resource for the Indus Valley Civilization.⁴ One specific trait that seems to be widespread in the major cities is an almost obsessive attention to water management and control that led Possehl⁵ to introduce the concept of *Wasserluxus* (water splendor) for the urban phase of the civilization. This concept is well exemplified at Mohenjodaro, where water seems to have played a special role in both private life (with wells, drains, and individual bathing platforms found inside residential structures) and public life (with the great bath structure representing a focal point of water-related public functions).⁶ It is clear from the archaeological evidence that, in the large urban centers, water resources were collected, stored, or accessed and widely distributed within the site and that the management took place, if not at the household level, at least at the neighborhood level. The many wells in Mohenjodaro were associated with houses or more public spaces, and most seem to have been used during the entire life of the settlement by raising the steenings from time to time.⁷ The city also had a capillary drainage system, and many houses had bathrooms and privies, all attesting to the importance of water in the life of urban Indus people (fig. 1).

Small settlements do not usually show this type of evidence, probably because each household could easily obtain water from structures outside the houses or settlement (e.g.,

4 For a general discussion, see, e.g., Kenoyer 1998; Possehl 2002; Wright 2010.

5 Possehl 2002, 57.

6 Mackay 1938; Marshall 1931.

7 Mackay 1938.

basins, small rivers, wells). Indeed, the vast majority of Indus settlement that is not located on, or close to, a watercourse presents an artificial water basin in the vicinity (e.g., the “tanks” located near Kanmer, Loteshwar, and Moti Pipli in Gujarat observed by the authors during the North Gujarat Archaeological Project survey).

The large-scale technical and hydraulic engineering knowledge displayed by the people of the Indus Valley Civilization is possibly best exemplified by the reservoirs of Dholavira or the great artificial basin of Lothal. In the first case, a series of water tanks was constructed, in some cases cutting into the bedrock, and connected to one another through canals to recover and preserve as much water as possible from the rainy season.⁸ In the second case, a large, artificial basin was constructed next to the city that served either as a dockyard for cargo ships or as a water reservoir for field irrigation.⁹

CURRENT TRADITIONAL WATER MANAGEMENT IN THE GREATER INDUS VALLEY

We consider water management a more general and inclusive concept than irrigation to describe the use and control of water resources. This concept includes both the artificial application of water collected from a permanent water source (irrigation proper) and the extension and conservation of surface water when available (water harvesting techniques such as slowing runoff or trapping). In the following sections, we will briefly describe the most common preindustrial water management techniques to be found in the area once occupied by the Indus Valley Civilization. For the current discussion on the Indus civilization, we consider only surface irrigation techniques, since to date there is no archaeological evidence of any major canal network.

IRRIGATION TECHNIQUES

Irrigation techniques depend on the way water is collected and then distributed to the fields. There are two main types of surface irrigation: basin and furrow. Basins are flat areas of land, usually not very large, surrounded by low bunds that prevent water from flowing to the adjacent piece of land. Basin irrigation is applied primarily in paddy fields, where plants are grown waterlogged, but also in systems of adjacent parcels where the water is allowed to overflow from one parcel to another once the soil has been moistened. Trees can also be grown in basins, with one tree usually located in the middle of a small basin. In general, the basin method is suitable for crops that are unaffected by prolonged waterlogging (e.g., twelve to twenty-four hours). In contrast, furrow irrigation relies on small channels that carry water down land slopes between the crop rows (fig. 2). Water infiltrates into the soil as it moves along the slope, with crops usually grown on the ridges between the furrows. This method is suitable for all row crops (e.g., cereals) and for crops that cannot withstand prolonged waterlogging, such as vegetables and spices. Both basin irrigation and furrow irrigation require only low-energy investment for their setup (apart from some paddy fields); both can easily be managed at the family level; and the water

⁸ Bisht 2005.

⁹ Rao 1979; Leshnik 1968.



Figure 2. Furrow irrigation in an eggplant (*Solanum melongena* L.) field in North Gujarat. The water is currently sourced from a tube well, allowing the cultivation of vegetable (cash) crops on the consolidated dunes. Photo by M. Madella.

provisioning can come from floods, permanent bodies of water (including rivers), and/or wells (e.g., *shadoof*). A way to extend the reaches of a flood, and artificially apply water to areas that normally would not be flooded, is to construct a small, temporary canal to route the water (fig. 3) or to take advantage of abandoned river channels by simply breaking the levees of the river and discharging some of the floodwater into side branches. The water can also be directed through basin and furrow irrigation to expand the areas taking advantage of the flood. Furthermore, waters of the rainy or flood season can be stored in simple or elaborate reservoirs and then directed to the fields when needed. Other sources



Figure 3. A temporary canal dug to route irrigation water to fields farther away from the main floodplain. The photo was taken looking east, with the Mirwah Canal, where the water is currently sourced, behind the viewer. The walls are those of the Kot Diji Fort on the Rohri Hills (Sindh, Pakistan). Photo by M. Madella.

of water beyond rain and floods are lakes, tanks, and wells. Perennial lakes and tanks can be an important source of water when it is directed to the fields via small channels or by lifting (e.g., *shadoof*).

WATER-HARVESTING TECHNIQUES

Water harvesting can be achieved through different strategies and provisioning. The simplest setting is the use of the river floods (sheet floods), called *sailabi* cultivation in Pakistan, where the water inundates the plains, then recedes and leaves behind moistened, enriched soils. This approach entails some water management, which may include the slowing down of receding waters to further imbibe the soil by constructing basins and bunds, or directing water to areas beyond the reach of the natural flood by digging small channels. Lakes with a seasonally fluctuating water level can see settings similar to *sailabi*. There, small bunds delimit the fields built in the area between the high and low water levels, perpendicular to the receding water, to slow down the drainage and maintain humidity. The fields are planted while the water of the lake recedes during the post-rain period but preserve the moisture during the crop-growing season (fig. 4).

Another way to implement *sailabi* cultivation by capturing water and, at the same time, facilitating the deposition of silt/clay to produce a cultivable soil is by creating

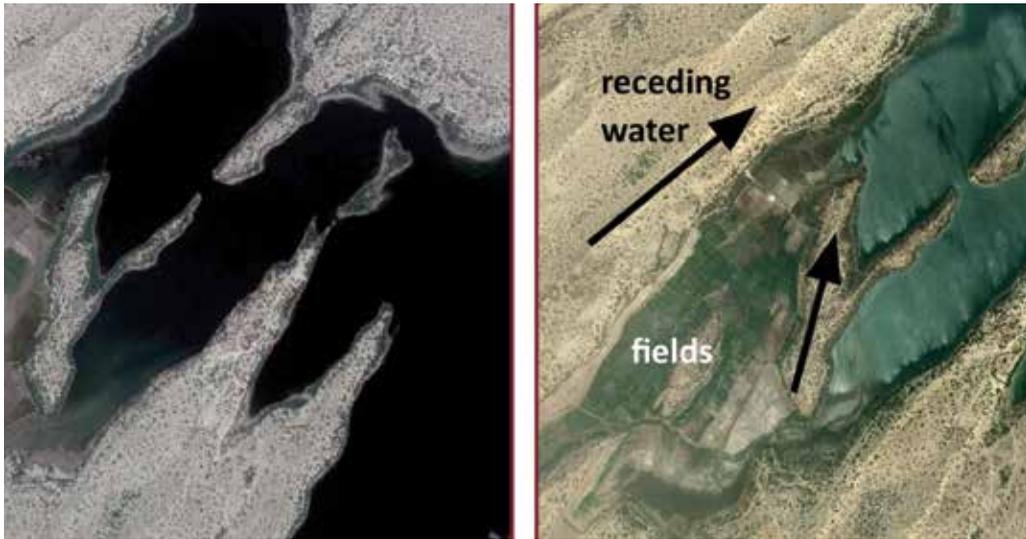


Figure 4. Interdunal lakes on the outskirts of Ghulam Nabi Shah, near Umarmkot (Sindh, Pakistan), with the fields clearly visible at the western edges of the lake, where the slope is gentler and the receding of water is slower and more controllable (copyright Google Maps). The two captures show the lake with the fields in use (end of winter: February 5, 2010) and just when the water is receding (autumn: October 8, 2013).

so-called *gabarbands* and associated fields. *Gabarbands*, which have also been interpreted as dams, are essentially terraces onto which the seasonal flood of nonperennial streams is directed, enabling the silting of the fields constructed behind the *gabarband* and their watering during the seasonal flood (fig. 5).¹⁰ Traditional *sailabi/gabarband* systems in the Zhoab division of contemporary northeastern Baluchistan are constructed and maintained by pooling labor from the village men, and managed through a set of well-defined rules.¹¹ This system allows for the cultivation of both winter (*rabi*) crops, such as wheat (*Triticum* sp.), and summer (*kharif*) crops, such as sorghum (*Sorghum bicolor* [L.] Moenk) and mung bean (*Vigna radiata* [L.] R. Wilczek), in areas with precipitation below the dry farming threshold. The fields are cultivated following three cropping patterns: (1) mixed sorghum/mung bean–wheat; (2) fallow–wheat; (3) mixed sorghum/mung bean–wheat–fallow–fallow.¹² These patterns relate quite strictly to the position of the field with respect to the stream: head, midstream, or tail. The *kharif* sorghum/mung is commonly planted in the head or midstream fields, where more water is available, while the fallow/wheat is more frequently practiced in the tail end of the stream, where there is less water. Though wheat generally requires more water, it has a lower rate of evapotranspiration than sorghum or mung bean and is thus better suited to the less-watered fields down the slope.¹³

¹⁰ Raikes 1965.

¹¹ Ahmad et al. 1998.

¹² Ahmad et al. 1998.

¹³ Ahmad et al. 1998.



Figure 5. Traditional *sailabi* agriculture using *gabarbands* (Baluchistan, Pakistan). The white arrows indicate the seasonal flood courses filling the fields, as estimated from the slope and *gabarbands* construction. The darker color of some of the fields is due to the higher level of silting (copyright Google Maps, September 2013).

WATER MANAGEMENT DURING THE INDUS CIVILIZATION: WHAT WE KNOW

A significant number of Indus sites were located on the banks or in the proximity of perennial and semiperennial rivers. Although new research and recent surveys conducted with precise GPS measurements are correcting settlement distributions in many areas of the Indus civilization,¹⁴ this general trend seems to hold. Indeed, in the past, floodplains constituted some of the most favorable areas for agriculture. Even though notable differences in water regimes characterized the systems of the Upper and Lower Indus, as well as of the Ghaggar-Hakra, all of them most surely provided sufficient water discharge to maintain successful farming systems.¹⁵ At the same time, there is also the presence of major Indus Valley Civilization settlements, such as Banawali,¹⁶ Rakhigarhi, and Farmana,¹⁷ in the plains of Haryana in northwest India, farther away from the main river channels. These sites were almost certainly provided with water from some source, be it a water-course or managed rainfall. However, such a source must have been relatively close to the settlements, since at present there is no evidence of a canal system.

Francfort¹⁸ suggested the presence of canal irrigation for the northern extension of the Ghaggar River. However, subsequent geomorphological studies did not provide any evidence of artificial canals associated with the Indus occupation.¹⁹ Indeed, so far no evidence of irrigation systems has been found, although Wright²⁰ suggests that severe modification of the landscape as a result of modern agricultural works may be responsible for this lack of evidence. In contrast, Miller²¹ believes that the building of irrigation structures was not needed, noting that the water sheet created by river overflow was sufficient for agricultural needs. In addition, the existence of sandbars and slightly raised flood terraces in most of the greater Indus valley river systems may have provided extra natural features for the retaining of floodwater.

Farther away from the floodplains, where water availability was less predictable and mostly associated with seasonal rains, some structures for water retention and storage were undoubtedly built. This is the case for the above-mentioned *gabarbands*, the dam-like structures still common today that are built across river valley floors to divert and trap runoff water, to slow down floodwaters, or to simply store water for longer periods. Ancient *gabarbands* have been widely observed and described in the hills of Baluchistan²² and even in some wadis of the Rohri Hills well within the Thar Desert (M. Madella, personal observation), though their chronological attribution is not completely certain. In other areas, where water was needed not only for the fields but also for the population of major

14 See, e.g., Petrie, Singh, and Singh 2009; Conesa et al. 2014.

15 For an overview of the hydrology of the Indus civilization, see Wright 2010, ch. 2; Giosan et al. 2012; Singh and Petrie 2009.

16 Singh et al. 2008, 79–80.

17 Shinde et al. 2008; Kumar 2009.

18 Francfort 1986.

19 Courty 1995.

20 Wright 2010.

21 Miller 2006.

22 Stein 1937; Dales 1986; Fairservis 1967; Flam 1998 in Wright 2010.

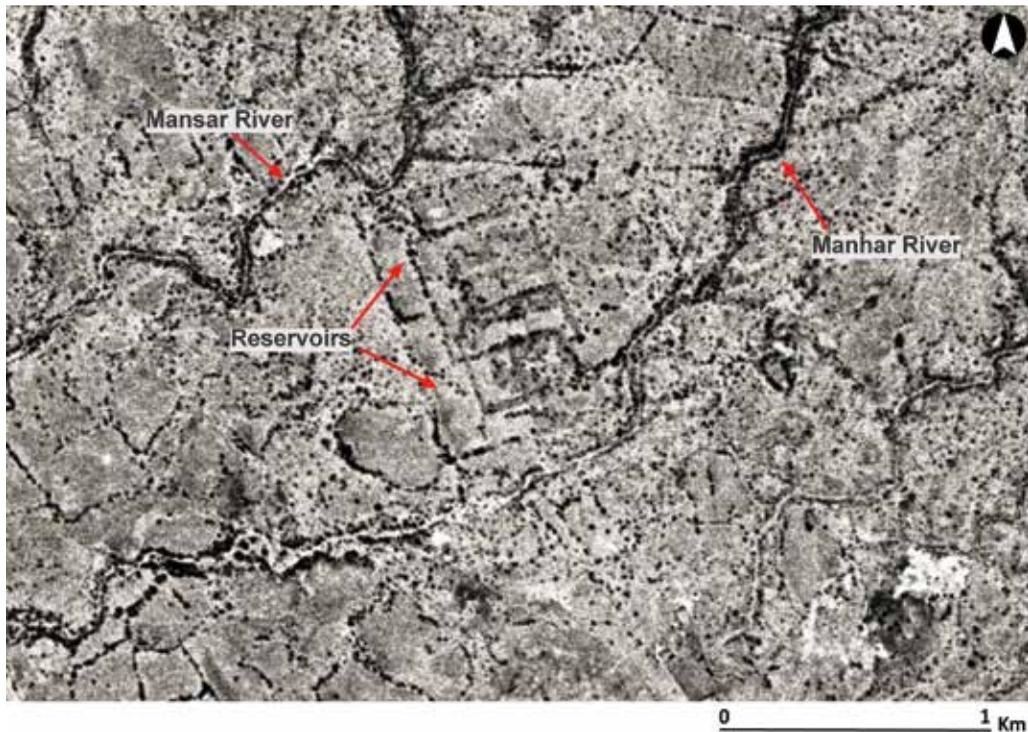


Figure 6. CORONA image (December 10, 1965) of the Indus Valley Civilization town of Dholavira and the surrounding area, with the Mansar and Manhar seasonal rivers from which the water was captured and diverted into rectangular reservoirs surrounding the town. Photo by F. Conesa.

settlements, it was necessary to build structures for water diversion from seasonal rivers, rainwater harvesting, and long-term storage. This is the case in Dholavira, in Kachch (Gujarat), in an area that today receives less than 200 mm of rainfall per year. Here, a series of small dams along the stream slow down the seasonal water, but, more importantly, an impressive system of water reservoirs has been documented into which water was diverted and where it was probably stored for many months after the rains (fig. 6).²³

The data from past and current reconnaissance survey of the Indus civilization territory highlight a mixed settlement pattern, with many sites located along river channels, others at some distance from the modern relict watercourses, and still others placed on the banks of ephemeral nullahs/wadis or lakes/reservoirs.²⁴ The variation in site distribution suggests that the Indus people had an adaptable approach to accessing water and that they used various sources throughout the year, much as it happens today.

²³ Bisht 2005.

²⁴ Conesa et al. 2014; Mughal 1997; Singh et al. 2010.

ARCHAEOBOTANICAL PERSPECTIVES ON DETECTING WATER AVAILABILITY IN PREHISTORIC GREATER INDUS VALLEY

The current agrobiodiversity of South Asia is high by comparative standards,²⁵ especially when cereals and grain legumes are considered. Traditional South Asian agriculture shows the use of countless varieties, including twelve domestic millet crop species as well as rice (*Oryza sativa* L.), wheats (emmer, durum, bread wheat), barley (*Hordeum* sp.), Job's tears (*Coix lacryma-jobi* L.), and a dozen pulse species. The Indus Valley Civilization area, which rests within arid or semiarid climate zones and experiences unreliable rainfall or full aridity, is part of the current "Western Arid" agrobiodiversity region,²⁶ and although current climatic conditions are different from those of the past, archaeobotanical data suggest that most of this agrobiodiversity has been present since the beginning of agriculture.²⁷

The Indian subcontinent has been identified as one of the settings for the emergence of additive, inspired, or pristine origins of cultivation²⁸ in this part of the world. The typical domesticates of the Indus plains seem to have originated beyond the Zagros Mountains in the eastern Fertile Crescent (Iran), which has been identified as the source of most Asian barleys.²⁹ On its way to Baluchistan and then the main Indus valley, though, the Near Eastern package was reshuffled, and while the region can be seen as a secondary center of agricultural origins, it was also the focus of indigenous developments. Among these new domesticates were cotton (*Gossypium* sp.), positively identified as threads in Neolithic Mehrgarh,³⁰ and sesame (*Sesamum* sp.).³¹ The village farming of the early Holocene, as typified by Mehrgarh and other early settlements in the western borderlands of the Indus valley, is quintessentially Near Eastern Neolithic and quite different from the early food-producing communities to the east or south of the subcontinent.

Although the number of Indus Valley Civilization sites where plant remains have been analyzed is still limited (about seventy sites with different levels of recovery and analysis by 2017; see summary in fig. 7), past research at Harappa in Punjab³² and current research in Haryana³³ and Gujarat³⁴ have provided important insights into the diversity of the agricultural systems of the Indus civilization. These studies highlight the distinct ecological areas covered by the Harappan culture and the two main cropping regimes based on the planting season: the winter-sown *rabi* crops and the summer-sown *kharif* crops. A further group of crops is that of fruit trees, perennial vines, vegetables, and spices, for which there is also some evidence.³⁵ All these cropping strategies take advantage of the rainfall from

25 Kumar et al. 2015.

26 <http://plantauthority.gov.in/hotspots.htm> (accessed July 12, 2016).

27 Fuller 2006; Fuller and Madella 2001; Weber, Barela, and Lehman 2010.

28 Fuller 2011.

29 Morrell and Clegg 2007; Saisho and Purugganan 2007.

30 Moulherat et al. 2002.

31 Fuller 2003; García-Granero et al. 2016.

32 Weber 2003.

33 Bates, Petrie, and Singh 2017; Bates, Singh, and Petrie 2017.

34 García-Granero et al. 2016; Pokharia et al. 2011.

35 Fuller 2003; Fuller and Madella 2001; García-Granero et al. 2016; Kashyap and Weber 2010.

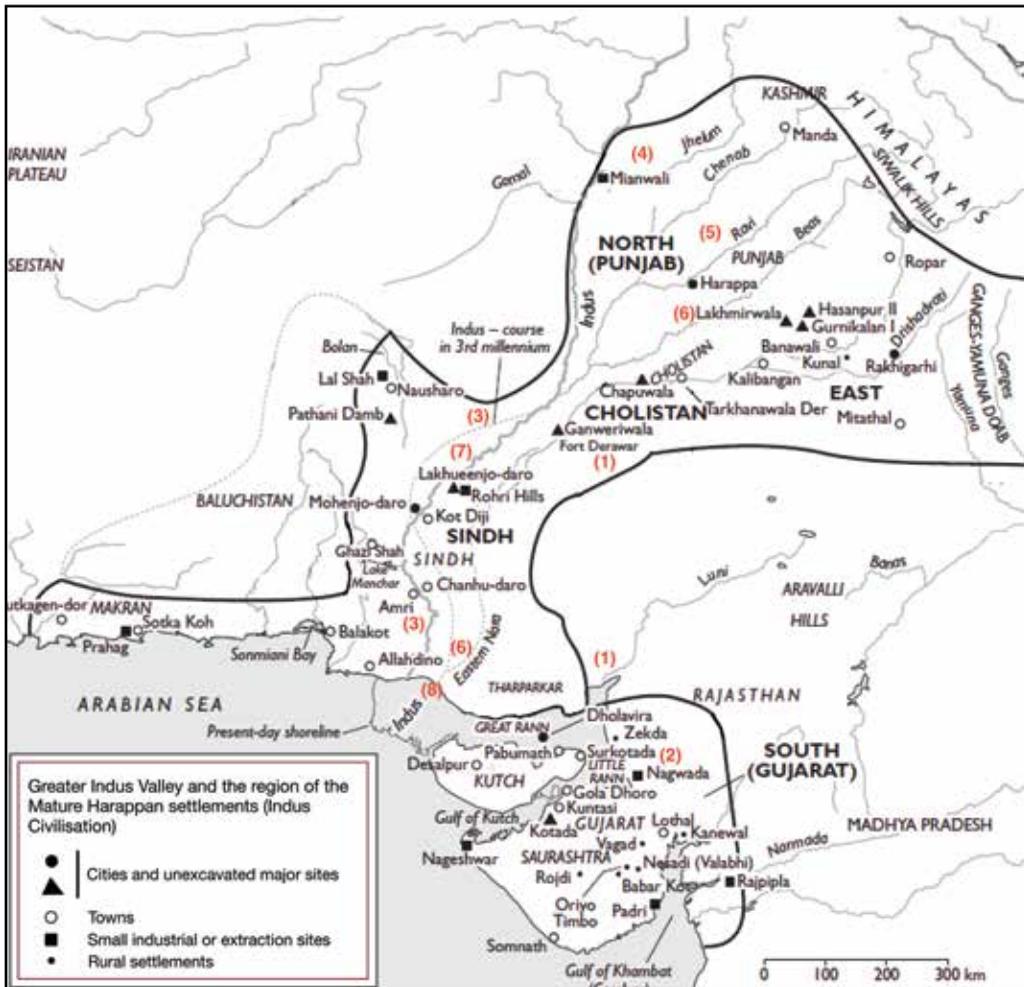


Figure 7. Map of the main Indus Valley Civilization sites showing the diverse area covered during the urban phase (Mature Harappan), from the Arabian Sea to the Himalayas and the Thar Desert (adapted from McIntosh 2008). For the numbers corresponding to types of landforms, see table 1.

two climatic systems—the South Asian summer monsoon and the winter anticyclone—and floodwater from the main and seasonal rivers. However, most of the Indus River plain is located where these two climatic systems meet at their weakest and most irregular, and where rain is less than 250 mm/year. Punjab, being farther north, receives more winter rain, with 250–500 mm of mean annual rainfall. Gujarat, facing the Arabian Sea, receives the summer monsoon with 500–1,000 mm of mean annual rainfall, depending on the area. A striking characteristic of the beginning of cultivation in the Indus region is the lack of evidence for the emergence of sedentary, densely populated hunter-gatherer societies similar to what we see in the Epipalaeolithic Levant³⁶ or parts of East Asia (e.g., the early

36 E.g., Goring-Morris and Belfer-Cohen 2011; Zeder 2011.

to mid-Holocene Lower Yangtze and parts of Jomon Japan³⁷). Plant food production seems to arise among more mobile and sparser populations with some existing form of pastoral economy. These presedentary sites have been harder to identify and are rarely excavated, and currently the most informative examples are the sites in North Gujarat such as Loteshwar and Vaharvo Timbo.³⁸

Once sedentary and densely populated villages emerged, and then urban centers typical of the urban phase, the issues related to water resources and their management become fundamental to understanding the economy and social organization of the Indus Valley Civilization. Miller³⁹ provides a detailed discussion of the possible models of water management for the core Indus valley and the implications for social organization and land ownership. She outlines four possible models of water management, from rain-fed agriculture to well or lift irrigation, according to an increasing level of organizational complexity and labor intensity. However, she admits that most of her discourse is theoretical and speculative, as the archaeological and archaeobotanical evidence for water management practices in these areas is scarce. Most of the models put forward so far rely on scanty ethnographic information and modern-day practices, and their use in the past is inferred from the water requirements of the crops identified in the archaeobotanical assemblages, when these are available. A more proficient approach would be not only the systematic collection of plant materials from excavated sites (charred seeds and wood, phytoliths, starch) but also the direct application of modern analytical techniques on these materials. These approaches have been useful for investigating prehistoric water management in Europe and the Near East, and they can be applied to South Asian plant remains to clarify water management during the Indus civilization, as well as in later periods. The level of applicability of these techniques needs to be clarified, however, depending on the specific taphonomical processes in South Asian deposits.

WEED ECOLOGY

Initial attempts at understanding field management (including water availability to the fields) through weed ecology have been related to phytosociology (groups of species representing ecological conditions)⁴⁰ and autoecology (a single-species ecology).⁴¹ However, the application of phytosociology to archaeological plant data has been criticized,⁴² as it is difficult to establish a direct correlation between past and modern phytosociological groups. Furthermore, to be meaningful, phytosociological studies require a number of species that may not be available in archaeological samples, since only a few weed seeds are often recovered. These problems are less stringent when using autoecology, pioneered in

37 Cohen 2011; Crawford 2011; Crema et al. 2016; Zhao 2011.

38 García-Granero et al. 2016; Patel 2009.

39 Miller 2006.

40 Ellenberg 1974.

41 Ellenberg 1988.

42 van der Veen 1992.

archaeology by Wasylikowa and Willerding,⁴³ but issues of applying modern ecological models to the past are still relevant.

There is currently strong empirical support for a limited set of functional plant trait combinations to be associated with single plant organs, such as leaves, stems, and seeds.⁴⁴ The high evolutionary pressure exerted by farming practices affects plant ecological strategies, and therefore the functional trait variation of the weed flora generally converges around stress-tolerant, ruderal, and competitor strategies.⁴⁵ Several studies in archaeology have shown that a set of functional plant traits or attributes, consistent with the predictions of ecological theory, successfully discriminate between the weed flora of relatively high- and low-intensity cultivation regimes⁴⁶ and dry-farmed and irrigated fields.⁴⁷ The application of this methodology to unprocessed plant harvests or processing by-products will need the development of Functional Interpretation of Botanical Surveys (FIBS) in current traditional fields to create a “library” of weeds for the diverse types of South Asian cultivation strategies and ecology. A first step in this direction, but in East Asia, is related to the application of the FIBS approach to phytolith assemblages to understand rice cultivation strategies in the Neolithic of the Lower Yangtze.⁴⁸

STABLE ISOTOPES

More recently, greater emphasis has been placed on direct means of inferring water conditions from archaeological crop remains themselves, through stable carbon isotope analysis.⁴⁹

The measurement of carbon isotope discrimination (Δ) from seeds of C3 plants, such as wheat or barley, has been used to assess the availability of water during the plant’s growth. The mature grains record the compounded ratio of intercellular to atmospheric partial pressure of CO₂, and thus the water-use efficiency of the plant during the grain filling period.⁵⁰ As this efficiency is in turn affected by the water status during growth, the measurement of ΔC from kernels could be a rapid method for determining whether irrigation (or another form of water management) was practiced in marginal farming areas with relatively low rainfall. In the western Mediterranean, for example, the grain development period (from anthesis to maturity) is between four and six weeks (April/May) for barley and five to six weeks (May/June) for wheat and is characterized by the lowest rainfall and the highest evapotranspiration of the entire plant cycle. As a result, in these ecophysiological conditions, the analysis of ΔC can help in understanding water management. Obviously, a limitation of this approach is the inherent difficulty in distinguishing between low

43 Wasylikowa 1981; Willerding 1978.

44 Diaz et al. 2004, 2016.

45 Grime 2001.

46 Jones et al. 2000; Bogaard et al. 2016.

47 Charles et al. 2003.

48 Weisskopf et al. 2015.

49 E.g., Arous et al. 2007; Ferrio et al. 2005; Fiorentino et al. 2008; Fiorentino et al. 2012; Riehl 2008; Riehl, Bryson, and Pustovoytov 2008.

50 Arous and Buxó 1993.

levels of irrigation and natural conditions, such as the presence of a wetter climate or use of naturally wetter soils. To untangle these different conditions, comparison with climatic proxies⁵¹ or a combined FIBS and carbon isotopes approach⁵² may be necessary.

In specific cases, oxygen isotope composition ($\delta^{18}\text{O}$) may be used as an indicator of crop water status, assuming little variation in the isotope composition of the water source.⁵³ However, carbonization strongly affects the values of $\delta^{18}\text{O}$, making its use possible only on waterlogged or desiccated remains. A possible alternative, though much less explored at present, is the analysis of oxygen and silicon isotopic signal in phytoliths.

PHYTOLITHS

Another direct way of inferring water conditions from archaeological crop remains is through phytoliths.⁵⁴ Phytoliths are opal silica particles deposited mostly within the cell lumen. They are formed by the absorption of monosilicic acid from the soil water solution, and their quantity, morphology, and isotopic composition are conditioned both by genetic and environmental mechanisms.⁵⁵ Morphology—through indices based on morphotype ratios⁵⁶—and isotopic analyses⁵⁷ have been explored to identify different water regimes from archaeobotanical samples. Several researchers⁵⁸ have used phytolith morphology to infer palaeoclimate in East Africa, including variations in water availability. More recently, others⁵⁹ have suggested using the ratio of genetic (fixed) versus environmentally controlled (sensitive) morphotypes to directly assess crop water-management practices (fig. 8). These studies are based on the evidence that in the epidermal tissues of C3 grasses, short cells (e.g., bilobates, cork cells, rondels, trapeziforms) are genetically fixed morphotypes that are always produced, whereas elongate cell (e.g., elongate psilate, elongate echinates, dendritics) and stomata cell silicification is controlled by the availability of water during plant growth. Therefore, the ratio between the two groups can provide information on different water regimes (environmental conditions) in which the plant was cultivated. More recently, isotopic signatures from phytoliths were investigated as a potential avenue for dating purposes,⁶⁰ as well as for inferring palaeoenvironmental conditions.⁶¹ Most of this research has concentrated on carbon stable isotopes, although silicon and oxygen were also

51 E.g., Lancelotti et al. 2013.

52 Bogaard et al. 2016.

53 Fiorentino et al. 2015; Cabrera-Bosquet et al. 2009, 2011.

54 Jenkins, Jamjoun, and Al Nuimat 2011; Madella et al. 2009; Miller Rosen and Weiner 1994; Mithen et al. 2008; Piperno 2006.

55 Miller Rosen and Weiner 1994.

56 Jenkins et al. 2016; Madella et al. 2009; Weisskopf et al. 2015.

57 Leng et al. 2009; Webb and Longstaffe 2003.

58 Alexandre et al. 1997; Barboni et al. 1999, 2007; Bremond et al. 2005.

59 Jenkins et al. 2016; Madella et al. 2009; Weisskopf et al. 2015.

60 Carter 2009; Piperno 2016.

61 Kelly et al. 1991; McClaran and Umlauf 2000.



Figure 8. Wheat (*Triticum* sp.) silica skeleton (phytoliths) from chaff in which sensitive (environmentally determined) and fixed (genetically determined) forms can be observed.

investigated.⁶² While occluded carbon in phytoliths seems to be partly influenced by soil carbon,⁶³ both silicon and oxygen have been found to have potential as proxies for environmental conditions and change. On the one hand, values of $\delta^{18}\text{O}$ appear to be strongly correlated with soil-water and general plant-water isotopic signature,⁶⁴ while on the other hand, $\delta^{30}\text{Si}$ in phytoliths was shown to be a proxy for soil conditions, particularly for weathering and organic matter content.⁶⁵

COMPARING APPROACHES AND FUTURE PERSPECTIVES

What is clear from the discourse developed in this chapter is that there is no single approach to understanding water availability and management during the urban phase (Mature Harappan) of the Indus Valley Civilization.

Plant remains from archaeological sites are the most-direct evidence for cultivation practices of this ancient society. However, recognizing different water management practices directly from archaeological plant remains is not trivial, primarily because of

62 Hodson 2016; Hodson et al. 2008; Leng et al. 2009; Prentice and Webb 2016; Webb and Longstaffe 2000.

63 Alexandre et al. 2016; Reyerson et al. 2016; Santos, Alexandre, and Prior 2016.

64 Webb and Longstaffe 2000, 2002, 2003.

65 Leng et al. 2009.

taphonomy and, in some cases, difficulty in identifying reliable proxies of these practices. Various approaches, especially for sites in the Near and Middle East, have been developed to extract water availability data from archaeobotanical charred material or phytoliths. However, much research is still needed to perfect these avenues of research and to test them in the South Asian context. An advance in this direction may lie in combining data from different proxies and from different analytical approaches. An example of a multi-proxy approach could be the investigation of crop and weed seeds together with isotopes analysis, or the joint analysis of carbon isotopes from charred seeds/fruits and oxygen/silicon isotopes from phytoliths, possibly offering more balanced information on water availability versus water management practices by exploiting the different physiological pathways of isotopes absorption.

Parallel to archaeobotanical research, and as a way to create models of agricultural practices, key ethnoarchaeological work is needed in South Asia that targets quantifiable data on cultivation methods (e.g., tilling, weeding, manuring, ploughing), information on decision making related to where and when cultivation is carried out, and how these processes are affected by climate variability. This methodology will help the interpretation of the archaeobotanical evidence and play a role not as a direct parallel to past practices but as an aid in formulating hypotheses on ancient processes of plant domestication (model making).

On a local and regional scale, remote sensing (including the use of free software such as Google Earth) can help in investigating the Indus basin to produce a more detailed account of water availability in relation to geomorphology and physiography. Infrared and multispectral images can play a role in revealing the presence of subsurface humidity (including past river channels) that can be favorable to agricultural practices, as well as areas of potential water management (e.g., old river branches, interdunal lakes).

All the above data can then be combined at different scale levels to explore resources, use, and management of water along temporal timeframes of Indus prehistory, from the early producing-era villages to fully urbanized cities. Furthermore, the aggregation of these data can make it possible to create models and to simulate scenarios for agricultural productivity, climate change, and social dynamics that can elucidate the processes behind the settings of the Indus Valley Civilization, the major urbanization push, and the subsequent demise of the major cities.

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Written Sources in the Empirical Investigation of Ancient Irrigation: The Operation of the I-sala Irrigation System in the Umma Province in Late Third-Millennium BCE Southern Mesopotamia

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THE ROLE OF IRRIGATION in the formation and functioning of early states is still poorly understood because of a lack of empirical data. Limited archaeological data are available on the ancient irrigation systems of most relevant cases (China, Indus Valley, Egypt), and even less direct evidence exists on how they were managed. This is problematic insofar as the social organization of irrigation is and has been at the center of how the role of irrigation in the development and functioning of early states is conceptualized.¹ New research methods and technologies allow for the collection of a much wider array of data that permit a more nuanced understanding of the role of irrigation in early states (see the chapters by Ur and Woodson in this volume). Computer simulations and agent-based modeling allow considerable insight into the social organization of irrigation even in the absence of direct evidence (i.e., textual records; see Ertsen's chapter in this volume).

Hence, the goal of the section "The Empirical Investigation of Ancient Irrigation" in this volume is to provide an overview of the various empirical data and methods that can be brought to bear in the investigation of ancient irrigation. This chapter will present the case of written records on irrigation management. The sample records presented here pertain to the organization of a single irrigation system; they derive from the oldest, most comprehensive corpus on ancient water management, dating to the late third-millennium BCE, and come from southern Mesopotamia. This subset of texts will function as a case study to describe the kind of information that written records provide on the social organization of irrigation. While texts are the most direct evidence on the social management of ancient irrigation, they served a specific accounting purpose when they were produced. As a result, they omit crucial information, which at times makes it difficult for the modern reader to fully understand their content. As such, these records present an incomplete data set that needs to be supplemented by archaeological and comparative ethnographic data. As will be discussed, adopting an interdisciplinary approach yields extraordinarily detailed insight into how irrigation was managed in this early state society.

1 Childe 1950, 8; Kang 2006, 196; Millon 1954, 178; Sanders and Price 1968, 177–87; Sanders and Marion 1970, 104–6; Steward 1955; Wittfogel 1957.

HISTORICAL BACKGROUND

The written records pertaining to the management of the I-sala irrigation system derive from the governor's archive of the Umma province of the kingdom/state of the Third Dynasty of Ur (2112–2004 BCE), or "Ur III" for short. The Ur III state controlled a core territory that was roughly equivalent to modern-day southern Iraq and was divided into twenty-one provinces (map 1).² The periphery of the state extended all the way to modern-day Iran in the east and Syria in the north.³ The dynasty was founded by King Ur-Namma, who unified the former patchwork of city-states located between ancient Sippar in the north and ancient Ur in the south into a regional state. He was succeeded by four kings: Šulgi, Amar-Suen, Šu-Sin, and Ibbi-Suen (table 1).⁴

Table 1 Regnal year of the Ur III kings⁵

King's name	Abbreviation	No. of regnal years	Dates
Ur-Namma	UN	18	2112–2095 BCE
Šulgi	SH	48	2094–2047 BCE
Amar-Suen	AS	9	2046–2038 BCE
Šu-Sin	SS	9	2037–2029 BCE
Ibbi-Suen	IS	25	2028–2004 BCE

Each province consisted of two sectors: the governor-operated sector, which was run by the governor (*ensi*), and the royal sector, which was run by a hierarchy of military officials headed by a general (*šagina*).⁶ Apparently the land and resources controlled by the governors previously constituted the city-state, and many governors were recruited from the families that had previously ruled those city-states.⁷ In Umma, the agricultural land managed by the governor-run sector amounted to only 13,154.76 ha, equaling 7 percent of the province's entire surface area (map 2). The much larger portion of the province

² Sharlach 2008, 80.

³ Dahl 2007, 1.

⁴ Dahl 2007.

⁵ Dates on the records are given in abbreviated form, e.g., AS01-02-20. The two letters are the abbreviation of the ruler's name and are followed by the number of the regnal year. The other numbers represent the month and the day. Thus, AS01-02-20 translates to Amar-Suen's first regnal year, month 2, day 20. The reader should be aware that the Ur III calendar was different from our Gregorian calendar. For example, April/May (month I) was considered the beginning of the year. Moreover, the Sumerian month consisted of thirty days and therefore shifted annually somewhat within the solar year. Sumerian bureaucrats were aware of this discrepancy and inserted an intercalary month (*iti diri*, or thirteenth month) at a frequency that is so far not well understood, as it was done irregularly and varied from city to city (Cohen 1993, 5; Lehoux 2000, 172–74; Sallaberger and Westenholz 1999, 233–36; Sharlach 2008, 82). Englund (1988, 123) suggests that an intercalary month was added every three years. In Umma, the intercalary month was always inserted after the twelfth month.

⁶ Hallo 1953, 74, 81–82; Sallaberger and Westenholz 1999, 191; Maekawa 1996.

⁷ Steinkeller 2013, 351.



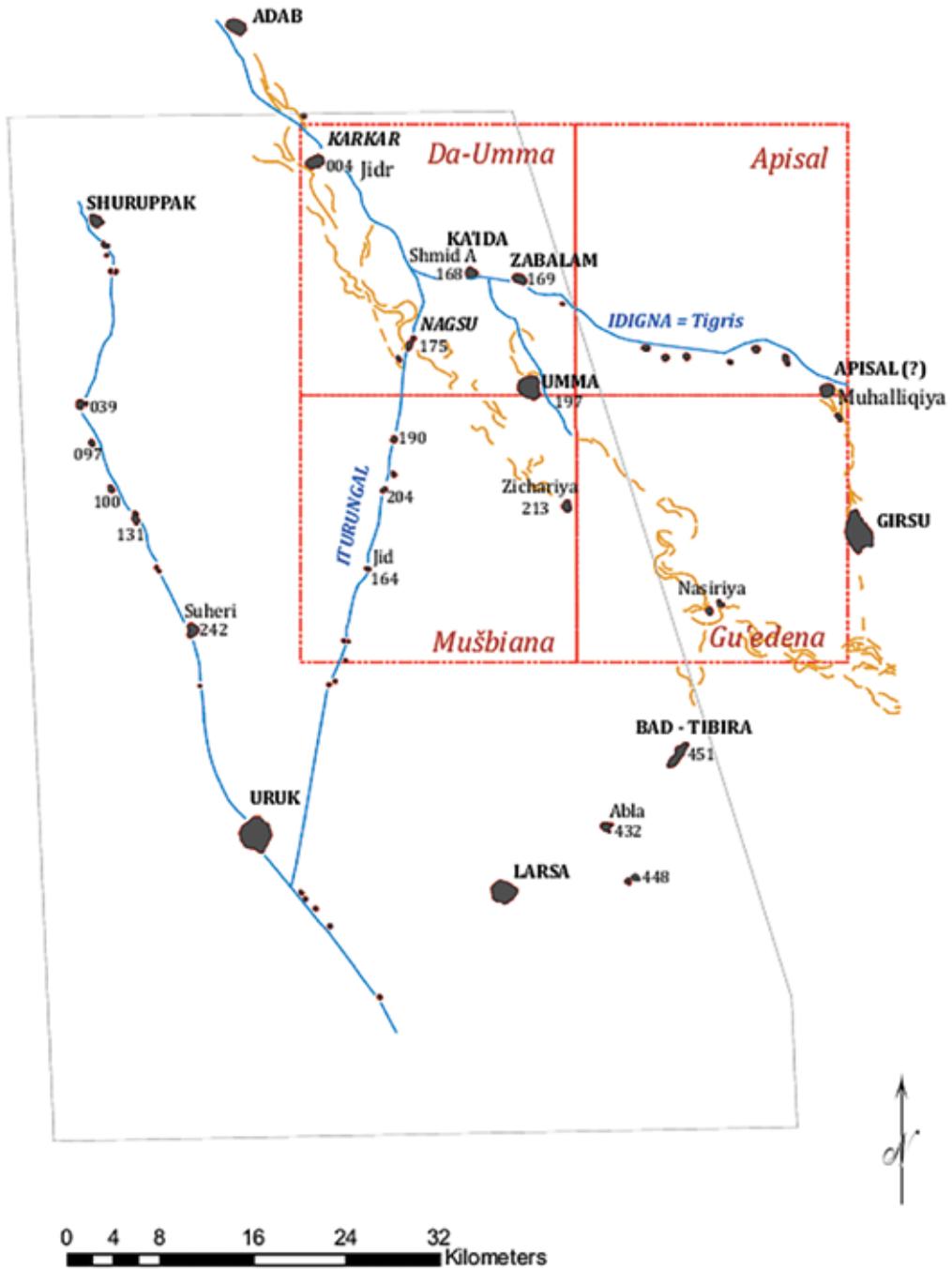
Map 1: The Ur III state (reprinted from Dahl 2007, 6, with the permission of the author).

constituted the royal sector, which consisted of newly established settlements of royal dependents (*eren₂*), many of whom had immigrated to the area and made up two-thirds of Umma's population.⁸ These settlers received land allotments from the crown in return for corvée labor.⁹ While it is difficult to determine the size of all the arable land in the Umma province and the percentages cultivated by the governor-run sector and the royal sector, respectively, it is certain that the portion managed by royal settlers was considerably larger.¹⁰

8 Steinkeller 2013, 360; 2007, 204.

9 Maaijer 1998, 55.

10 Steinkeller 2013, 353–56.



Map 2. Umma province with districts in red (after Adams and Nissen 1972, 36, fig. 17; Steinkeller 2001, 50).

The Ur III period is one of the best-documented eras in antiquity because the state was governed by means of a highly complex administrative apparatus that kept extensive records.¹¹ To date, the corpus of Neo-Sumerian texts housed in museums and private collections all over the world amounts, according to Molina,¹² to 120,000 cuneiform tablets, of which around 75,000 have been published. Despite this abundance of data, the majority of available documents come from the archives of two provincial capitals, Umma and Girsu/Lagaš, and the state administrative center Puzriš-Dagan.¹³ Our understanding of the Ur III state is thus somewhat biased toward the provincial sectors run by governors. In Umma, for example, we have hardly any information on the organization of the royal sector. The governor-run and royal sectors operated as almost entirely separate economic entities, each with its own administrative and accounting system. The recent acquisition and publication of the GARšana archives, which document the management of a royal estate in the Umma province, has provided some insight into the royal sector.¹⁴ In addition, there is very little direct evidence on the interaction between the crown and the governor-run and royal sectors of any given province, making it difficult to fully establish the nature of the power relationship among these three entities beyond the system of taxation.¹⁵

The Umma corpus consists of approximately 30,000 cuneiform tablets, dating primarily to a period of thirty-eight years (2062–2025 BCE).¹⁶ Approximately 3,000–4,000 of the Umma archive tablets pertain generally to irrigation and water management. As can be seen in the sample text below (Princeton 1 502), they provide detailed information on work projects such as (a) the number of workers involved, (b) the duration of the project, (c) the types of activities involved (e.g., cleaning a canal or irrigating a field), (d) the project's location, (e) the supervisor's name and the name of the official who authorized the project's execution, and (f) the date (year and/or month). About 260 records refer to the operation of the I-sala irrigation system alone.

<p>Princeton 1 502 <i>obverse</i></p> <ol style="list-style-type: none"> 1. +6 guruš u₄ 1-še₃ 2. I₇-Sa₄-la^{ki}-ke₄ / šu-luh ak 3. ugula Šeš-kal-la 4. kišib Da-da-ga <p><i>reverse</i></p> <ol style="list-style-type: none"> 1. iti RI 2. 'mu` ma₂ ^dEn-ki ba-ab-du₈ <p><i>seal</i></p> <ol style="list-style-type: none"> 1. Da-da-ga 2. dub-sar 3. dumu Ur-nigar_x ^{gar} šuš₃ 	<p><i>o. 1–2</i> 6+ workdays spent on cleaning the I-sala canal</p> <p><i>o. 3–4</i> supervisor was Šeš-kala tablet was sealed by Dadaga</p> <p><i>r. 1–2</i> <i>month:</i> V (August) <i>year:</i> the boat of Enki was caulked (SS02)</p> <p><i>seal:</i> Dadaga, scribe, son of Ur-Nigar</p>
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11 Garfinkel 2008, 55; Steinkeller 1987a, 20–21.

12 Molina 2008, 20.

13 Molina 2008, 52.

14 Owen, Mayr, and Kleinerman 2007; Heimpel 2009; Steinkeller 2011.

15 Dahl 2007, 56–57; Steinkeller 2003, 41–42.

16 Molina 2008; Steinkeller 2003, 40.

ENVIRONMENTAL BACKGROUND

The irrigation system under question was located in what is now southern Iraq, which belonged since the late fourth millennium BCE to the semiarid zone—with cool, wet winters and hot, virtually dry summers. The annual precipitation rate in most years is less than 100 mm, and most of the rain falls in the winter months, between December and February, while the summer months, May through October, are almost completely dry. Therefore, Iraq's agricultural production is and always has been focused on the cultivation of winter crops—predominantly barley and wheat, which are sown in October/November and harvested in April/May.¹⁷ The water regime of the Euphrates and Tigris system is characterized by strong, seasonal fluctuations opposite to the water demands of barley and wheat—that is, water levels are low during the sowing period in October/November, and they peak just prior to the harvest in April/May. Since the Tigris is considerably shorter, it usually floods a month earlier than the Euphrates (fig. 1).¹⁸ The flooding of the rivers has led, over millennia, to the formation of massive levee systems, which have a triangular-shaped cross-section with a width of 2–5 km and a height 2–4 m above the flood plain, with the river riding elevated at its center (fig. 2). Because of its higher elevation, the soil on the levees' crests and slopes is well drained and constitutes the main agricultural ground in southern Iraq. Further, the levees' topographical relief is well suited to irrigation, as the location of canals along the levees' back slope enables adequate flow velocity within the canals and onto agricultural fields. The river basins constitute the drainage areas for both irrigation and floodwater and, over time, develop into lakes, marshes, and wetlands because of their poor drainage.¹⁹

LAYOUT OF ANCIENT IRRIGATION SYSTEMS

We still have only a vague idea about the layout of ancient irrigation systems because the locations of only major canals are known, and their identification has been done with varying degrees of confidence. We know from cuneiform field plans that the agricultural landscape in southern Iraq was dominated by elongated field strips.²⁰ Their size varied between 32 ha and 49 ha, with an average length of 900–2,700 m and an average width of 100–300 m. The length corresponds well with the average width of the levee system on either side of the river, suggesting that the fields were arranged as narrow strips running down the levee slope (fig. 2). We also know from texts that fields were watered by means of furrow irrigation. The furrow width (measured from furrow ridge to furrow ridge) documented in third-millennium BCE texts from Nippur, Umma, and Girsu/Lagaš ranged from 0.5 m to 0.75 m.²¹ The length of a furrow is limited, since water can travel over a certain distance at only a relatively low gradient (< 0.5 percent). At a furrow depth of 0.75 m, the furrow length can be 400 m, while at 0.5 m depth, the furrow length can be

17 Charles 1988, 2–3; Maekawa 1985, 97–101; Wirth 1962, 47–48.

18 Ionides 1937, 247–59.

19 Pollock 1999, 32; Verhoeven 1998, 171–73; Wilkinson 2003, 76–79; 2013, 35–43; de Vaumas 1965.

20 Liverani 1990, 1996; Maekawa 1992.

21 Pettinato and Waetzoldt 1975, 278–79.

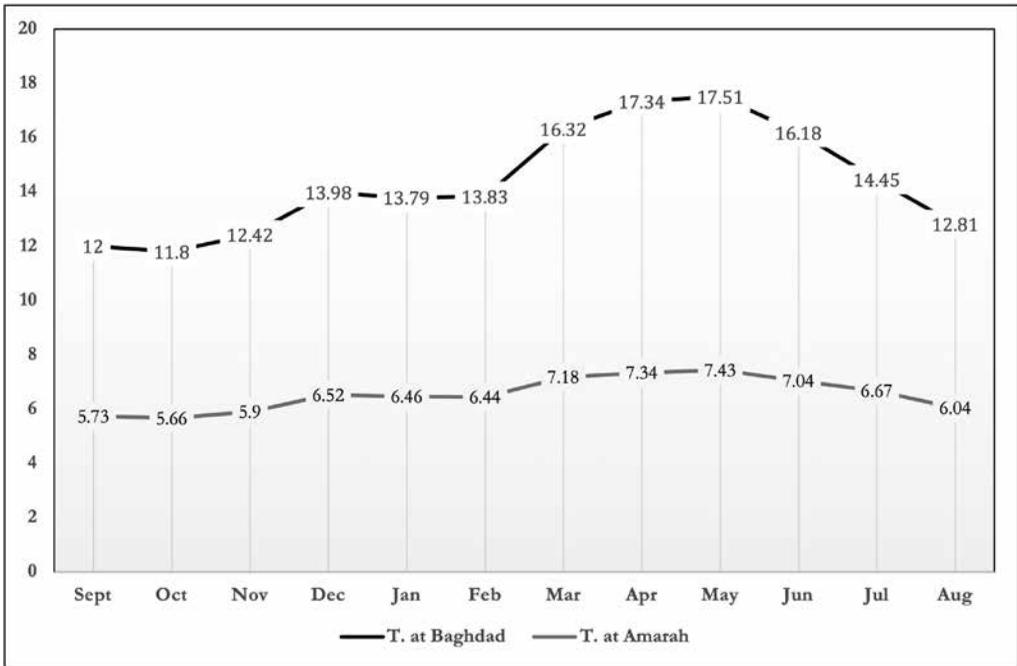


Figure 1. Difference in water levels of the Tigris at Baghdad (1906-32) and of the Tigris at Amarah (1918-32). Source: Ionides 1937, 45; 153; 180, table 96; 191, table 98.

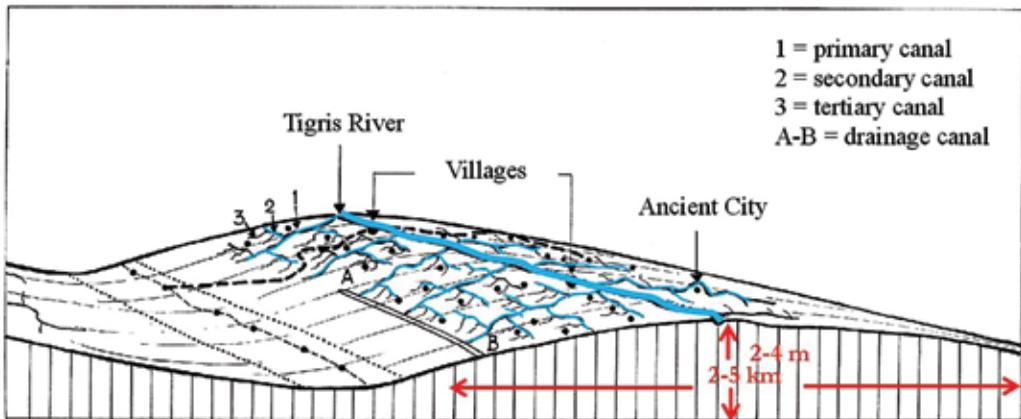


Figure 2. Cross section of a levee system alongside the Baghdad-Nasiriyah Depression (Vaumas 1965, pl. XXII).

only 280 m.²² An elongated field strip of 1–3 km would have had to be further subdivided by secondary canals that supplied water for the irrigation furrows. There is evidence of minor canals (pa₄-a-da-ga) with a length of 300 m, a width of 0.5 m, and a depth of 0.25 m.²³ The length of these minor canals corresponds well to the width of the individual elongated field strips. In addition, the verb a-da-ga is possibly a syllabic spelling of a-du₁₁-ga (watering/irrigating).²⁴ The literal translation of pa₄-a-da-ga would be “watering/irrigation canal,” which corresponds well with the function of these canals supplying water directly to the fields.²⁵

Following this reconstruction, late third-millennium BCE irrigation systems would have been two tiered, with primary and secondary canals. It is, however, conceivable that small feeder canals ran parallel to the secondary canals to provide water for the irrigation furrows (fig. 2). Another possible reconstruction—depending on the width of the primary canal—is that irrigation furrows took off directly from the primary canal.²⁶ Such a system was observed in the central alluvium area just south of Baghdad in satellite imagery by Hritz and Pournelle.²⁷ The system was located on top of an ancient Euphrates levee already observed by Adams.²⁸ The traces of fields were similar to those recorded in texts (1.3–2 km long and 150–300 m wide = 35–39 ha). The sites associated with the system date from the third millennium to the first millennium BCE. Since a ground check is still pending, the result of the satellite imagery analysis has to be regarded as preliminary. Wilkinson²⁹ suggests that this layout—also called “herringbone patterned” because of the river at its center with short primary canals taking off on either side at regular intervals—was characteristic of the early forms of irrigation management in southern Mesopotamia (fig. 2).

22 Brouwer et al. 1985, 3.4.

23 Waetzoldt 1990, 8. Note that the size of lower-order canals (pa₅ sig) documented in Old Babylonian mathematical texts is greater, with a length ranging from 1.8 km to 2.16 km, a width ranging from 1 m to 1.5 m, and a depth ranging from 0.5 m to 0.25 m. This may indicate a difference in either the layout of Ur III versus Old Babylonian irrigation systems or the use of irrigation terminology.

24 It is possible that some of the minor canals ran on top of the low earth walls surrounding a field plot, as has been documented ethnographically by Fernea (1970, 122). According to Abdulmir Hamdani (personal communication, March 23, 2015), such canals are rarely used in modern times because their construction is labor intensive. However, if the fields are located far from the river, such canals may be necessary to achieve the necessary gradient and flow velocity to transport water over a long distance. According to Steinkeller (1988, 73–74), the noun pa₅ could describe such a canal, as the cuneiform sign for pa₅ is a compound of the sign eg₂ “dam” and pa₄ “minor canal/ditch.” This also suggests that in certain instances the noun eg₂, which generally describes “dam/dike,” may describe a canal on top of an earthen wall.

25 Piotr Steinkeller, personal communication, March 23, 2015.

26 Maurits Ertsen, personal communication, January 2016.

27 Hritz and Pournelle 2015, fig. 5.

28 Adams 1981.

29 Wilkinson 2013, 42–45.

THE I-SALA IRRIGATION SYSTEM

It remains unclear whether the I-sala irrigation system had the layout described above. None of the 260 records pertaining to this system provides conclusive information about the size of the system or the length and width of its primary canal, making it difficult to contextualize the labor data recorded in the available sources. In addition, the system's location can be identified only approximately because of the lack of archaeological settlement data for the Umma area. Located in the southeastern part of the Ur III state, and encompassing an area of approximately 2,000 sq km (map 2), the province was covered only partially by the regional site survey efforts of Adams and Adams and Nissen.³⁰ Only nineteen sites were documented at the time, dating to the Ur III Period and the following Isin-Larsa Period.³¹ Textual evidence, however, indicates that there were at least 110, and possibly 158, settlements in the Umma province in the Ur III period.³² The toponym "I-sala" described not only a specific canal but also a settlement ($I_7\text{-sal}_4\text{-la}^{ki}$) with a grain silo (*guru*)³³ and a sanctuary to the goddess Gula³⁴ and possibly Ur-bartab.³⁵ It was also used as a field name ($a\text{-}\check{s}a_3\ i_7\text{-Sal}_4\text{-la}$)³⁶ with a threshing floor ($ki\text{-}su_7\ i_7\text{-Sal}_4\text{-la}$),³⁷ an orchard ($^{e}is\text{-}kiri_6\ i_7\text{-Sal}_4\text{-la}$),³⁸ and a major water control device ($ka_b_2\text{-}ku_5$),³⁹ as well as the location of some serious flood events⁴⁰ that will not be discussed in this article.

30 Adams 1981; Adams and Nissen 1972.

31 Adams 1981, 151.

32 Steinkeller 2007.

33 See, e.g., text Ontario 2 016 or CDLI P424400. Note that there is also a settlement named I-sal-la in the neighboring province Girsu, which appears to have had a grain silo ($i_3\text{-}dub$) (see BAOM 2 25 21 and PPAC 5 0293). It also appears to have been a canal according to a letter (TCS 1 185) in which two individuals ask a person called Nani for permission to draw water at the inlet of the I-sala canal.

34 According to text UTI 5 3493: o.ii 2, 4.32 ha of land were set aside for offerings for her sanctuary.

35 Text Nebraska 37 o. ii 8 (see also UTI 5 3485+3509, which records a sheep for the deity), dating to SH43, lists yield estimates of land in Umma at the time of harvest. Among the areas listed are those that were set aside for providing grain offerings ($sa_2\text{-}du_{11}$) for the various deities who were venerated in the Umma province. Among them was the deity Ur-bartab from I-sala (see Steinkeller 1987b, 87). The amount of land set aside for Ur-bartab was 3.2 ha, for which 660 l of grain were estimated. According to text MVN 21 342: r. i. 24, a 216 ha parcel of land was set aside in the field Egu-RU-agi for Ur-bartab with an estimated yield of 2,400 l of grain.

36 See, e.g., text BPOA 6 1179.

37 See, e.g., text SET 243: o.i 1–o. ii 11.

38 See, e.g., text TIM 6 45: r ii 12'.

39 The function of the water-control device called $ka_b_2\text{-}ku_5$ has been identified as a flow divider, designed to split the water flow of a parent canal into a set of smaller canals for the spatial distribution of water (Steinkeller 1988, 78; Rost 2015, 137–57). However, the $ka_b_2\text{-}ku_5$ of I-sala was clearly of major importance for water control in the Umma province. Of the 590 references pertaining to flow dividers in the Umma province, 75 record work on the one at I-sala. In addition, there is evidence that this flow divider also served as a flood control device through which water could be diverted from the Tigris to lower the water level (Rost 2015, 152–53). It remains unclear whether this device also regulated the water flow of the I-sala canal and has hence been excluded from this discussion. The evidence for this device, as well as the flood events, will be treated in a future article.

40 See, e.g., text Princeton 1 320: o. 1–2.

The approximate location of the I-sala irrigation system can, however, be determined on the basis of the geographic information derived from the texts. According to text AnOr 07 250 (below), we know that the I-sala irrigation system was located in the so-called Da-Umma district—one of the four districts (Da-Umma, Apisal, Gu'edena, and Mušbiana) that subdivided the area of the Umma province (see map 2).

<p>AnOr 07 250 <i>obverse</i> 1. [x]+60+20 guruš ša₃-gu₄ / u₄-1-še₃ 2. 60+50 guruš 3. n[u-b]anda₃ gu₄ Ur-^{gis}gigir 4. nu-banda₃ gu₄ Lugal-ku₃-zu 5. a-ša₃-ge a du₁₁-ga 6. i₇-da šu ur₃-ra <i>reverse</i> 7. kab₂-ku₅ I₇-sal₄-l[a] 8. 'u₃' bar-ba 'sahar' 'si-ga' 9. 'a-ša₃' 'da'-Umma^{ki} 10. giri₃ Lugal-a₂-zi-da 11. ugula Ur-^dŠul-pa-e₃ 12. kišib Ša₃-nin-ga₂ 13. mu 'ma₂-gur₈'-mah ba-/[dim₂] <i>seal</i> 1. Ša₃-nin-ga₂ 2. dub-sar 3. dumu Lugal-ušur₃</p>	<p><i>o. 1-r. 12</i> 80+ workers, ox-drivers, for one day (from) Ur-gigir the inspector of the (plow-) oxen 110 workers (from) Lugal-kuzu, the inspector of the (plow-)oxen irrigated the field, leveled the (spoil bank) of the canal and covered the outer part of the flow divider of I-sala with earth in Da-Umma under the authority of Lugal-azida supervisor (was) Ur-Šulpa'e sealed (by) Šaninga <i>year:</i> SS02-00-00 <i>seal:</i> Šaninga, scribe, son of Lugal-ušur</p>
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Another text indicates that the I-sala canal branched off the Tigris downstream of Ka'ida (see map 2). According to MVN 16 0976: o. 7-r. 4,⁴¹ "11 workers for 5 days cut (a type of) rush at the (riverine) 'forest' of Ka'ida and loaded it onto a boat and floated the boat (downstream) to the inlet of the I-sala canal and (there) unloaded the boat."

The settlement Ka'ida (lit. mouth/inlet of the canal) was located at the inlet of the so-called Umma^{ki} canal that branched off the ancient Tigris and took a course southward to the provincial capital Umma and possibly farther south to Bad Tibira.⁴² As Ka'ida was located at the Tigris, the obvious route taken would have been on the Tigris. Even though text MVN 16 0976 does not specify the travel time between the riverine forest of Ka'ida and I-sala, they must have been fairly close, as other references indicate that travel between I-sala and Umma took only one day (table 2).

41 MVN 16 0976: o. 7-r. 4 '11 guruš u₄ 5-še₃ tir Ka-i₇-da u₂KWU_127.ŠE₃ ziX-a (=SIG₇) ma₂-a ga₂-ra u₃ ka I₇-sal₄-la-še₃ ma₂ diri-ga u₄ 1-še₃ ma₂ ba-al-la'.

42 Steinkeller 2001, 49-50; see map 2.

Table 2. Boat trips between I-sala and Umma (see map 2)

Date	Text	No. of days of travel
Between Umma and the settlement I-sala		
AS09-00-00	MVN 16 0795: r. 2-4	1
SS06-00-00	MVN 21 107: o. 1-r. 1	1
SS09-00-00	SNAT 523: o. 5-r.2	1
Between the threshing floor alongside the I-sala canal to the harbor of Umma		
SS06-00-00	JCS 24, 151 09: o.1-r. 4	1
SS06-00-00	MVN 21 107: o. 1-r. 1	1

HISTORY OF THE I-SALA CANAL

The I-sala canal is the most frequently mentioned irrigation canal in the Umma record. The exceptionally high number of references to this system suggests that it constituted one of the major irrigation systems under the management of the governor, possibly watering a substantial amount of land under his control. The fact that it was located in Da-Umma supports this assumption, as 60 percent of the land managed by the governor and his administration was located in this district.⁴³ The canal was in use for nearly thirty-three years (SH35–SS08) and may already have been in operation prior to the Ur III period. The I-sala canal underwent considerable modifications at least four times, with the most dramatic alteration done around SH46 and SH47, when 4,182 tons of earth were removed (table 3). Three other modifications were undertaken later—two in an interval of four years, and the last-recorded alteration five years later. Right around the time when the documentation on the operation of the I-sala irrigation system ceases, a new water control device called *barla* was added to the canal system, constructed of tree trunks and reed mats. Unfortunately, the function of this device remains unclear.⁴⁴

The term *ba-al* (digging/excavating) usually refers to the initial construction of a canal. However, the I-sala canal was certainly already in operation before the first construction work on this canal is recorded (see table 3). A court document dating to SH44 (YOS 04 001) deals with a water conflict involving water taken illegally from the I-sala canal (see below). The ten texts recording specific amounts of earth excavated from the canal do not specify the purpose of the construction work. It is likely, however, that they record extending the canal's length, width, or both in order to extend the command area that this system could irrigate. This small sample of texts provides detailed insight into the frequency with which

⁴³ Steinkeller 2013, 359; Vanderroost 2008, 137; 2012a, 78–86.

⁴⁴ Rost 2015, 147, n. 125.

canals and irrigation systems were altered, which is something to be considered when interpreting the related archaeological remains. The information provides us, in particular, with an understanding of the magnitude of the anthropogenic impact on a natural landscape that the late Tony Wilkinson and Robert McCormick Adams have cautioned us to consider in historical reconstructions.⁴⁵

Table 3. Construction work (ba-al) at the I-sala canal

Date	Text	Task	Supervisor (ugual)	Authorizing official (kišib)
SH46-06-00	SAT 2 0486: o. 1–3	174 m ³ earth work: excavating the I-sala canal. Lugal-muman-ag excavated it		Erdingir, servant of Šara, son of Lugal-saga
SH47-00-00	Princeton 2 403: o. 1–r. 3	672 m ³ earth work [. . .] digging the I-sala canal [. . .]	Habluge	
SH47-00-00	BRM 3 162: o. 1–3	606 m ³ earth work: digging the I-sala canal	Inim-Šara	Lugalemah(e), scribe, son of Lugal-kugani
SH47-00-00	Princeton 2 466: o. 1–4	1,710 m ³ earth work: digging the I-sala canal [. . .]	Inim-Šara	
AS03-00-00	BIN 5 272: r. iii 17'–20'	915 m ³ of earth, 3 m ³ per worker per day, its job equals 305 workdays—excavating the I-sala canal		Lugalemah(e), the balanced account of Lugal-gu(e), the inspector
AS05-00-00	SAT 2 0866: o. 1	36 m ³ excavating from the I-sala canal	Basa	Dagi, the chief livestock manager Da'agi, scribe
SS01-00-00	MVN 16 1555: o. 1–r. 1	8 workers for one day excavated the I-sala canal	Lugalemah(e)	Ur-Lugal, scribe, son of Da'agi

(continued)

⁴⁵ Wilkinson 2003; Adams 1981.

Table 3. Construction work (ba-al) at the I-sala canal (*continued*)

Date	Text	Task	Supervisor (ugual)	Authorizing official (kišib)
SS07-00-00	AAICAB 1/1, Ashm. 1924-0682: o. 1-11	51 labor days spent on excavating the barla of the I-sala canal, carrying reed from the Šara-field (and) bringing poplar and another type of tree from the riparian forest of Ninildum and the Lamah-field and filling in/piling up earth	Ipa'e	
SS07-00-00	SNAT 516: o. 1-2	86 workers for one day excavated the barla at I-sala—carrying cut reed from the Šara-field (and) bringing poplar and another type of tree from the riparian forest Ninildum and the Lamah field and filling in/piling up a type of reed mat	Šeš-kala dumu Tirgu	Lu-Šulgira, scribe, son of Dadaga
SS07-10-00	BPOA 1 0848: o. 1-2	37.4 m ³ of earth excavated from the barla of I-sala	Lu- ^d Šara	

WORK AT THE I-SALA IRRIGATION SYSTEM

About seventy references pertain to the operation and upkeep of the irrigation system itself (table 4). The work recorded in the texts pertains to maintaining the canal, such as clearing accumulated sediments (šu luh-ak), profiling its embankment (gu₂ šu-ur₃-ra), and filling in earth to repair eroded parts or lining the canal to prevent seepage (sahar si-ga). Other works pertain to maintaining related water control devices, such as the inlet of the canal (ka i₇) and weirs or barrages (kun-zi-da), designed to regulate water intake and the water level in the canal to facilitate water diversion into smaller canals and onto the fields. Work performed at the inlet of the canal was most likely related to maintaining the inlet dam (table 4). As I have discussed in detail elsewhere, the inlets of canals in third-millennium BCE southern Mesopotamia were sealed by inlet dams equipped with clay pipes at the bottom for water intake. This inlet construction is still practiced today, as it allows water intake at fluctuating water levels in the river.⁴⁶ In antiquity, the dams sealing the inlets were constructed primarily of reed and mud.

⁴⁶ Rost 2015, 111–15; 2019, 38; Rost and Hamdani 2011.

Table 4. Maintaining the I-sala irrigation system

English	Sumerian	No. of references
A. Work at the canal itself (I ₇ -sal ₄ -la)		
Modification of the I-sala canal ⁴⁷	ba-al	7
Cleaning the I-sala canal ⁴⁸	šu luh-ak	19
Profiling I-sala canal (?) ⁴⁹	I ₇ -sal ₄ -la šu ur ₃ -ra	1
Profiling the canal levee (?) ⁵⁰	gu ₂ šu-ur ₃ -ra	1
Incising the canal and profiling its levee ⁵¹	I ₇ -sal ₄ -la ^{ki} ku ₃ -a u ₃ gu ₂ -ba šu ur ₃ -ra	3
Lining the canal with earth or repairing an eroded part alongside the canal (?) ⁵²	I ₇ -sal ₄ -la sahar si-ga	2
B. Work at water control devices		
Restoring the barrage/weir of the I-sala canal ⁵³	kun-zi-da I ₇ -sal ₄ -la ^{ki} gi ₄ -a	1
Coating the barrage/weir of the I-sala canal with earth ⁵⁴	kun-zi-da I ₇ -sal ₄ -la sahar si-ga	1
Constructing the barla of the I-sala canal ⁵⁵	bar-la ₂ I ₇ -sal ₄ -la	3
Stationed at the inlet ⁵⁶	ka I ₇ -sal ₄ -la gub-ba	1
Inserting earth into the inlet ⁵⁷	ka I ₇ -sal ₄ -la sahar si-ga	3
Carrying/bringing reed to the inlet ⁵⁸	ka I ₇ -sal ₄ -la gi ga ₆ -ga ₂ / gi de ₆ -a	5
Towing the boat to the inlet ⁵⁹	ka I ₇ -sal ₄ -la ma ₂ diri-ga	3
Cleaning the inlet of the canal ⁶⁰	ka I ₇ -sal ₄ -la šu luh-ak	1

47 See table 3.

48 See table 6.

49 SAT 2 0837: o. 1-4.

50 UTI 4, 2348: o. 1-r. 2.

51 UTI 4, 2562: o. 4; UTI 4, 2884: r. 20; UTI 4 2892: o. 3.

52 BPOA 7 2444: o. 1-2; SACT 2 129: r. 5.

53 BPOA 2 2221: o. 1-4.

54 BPOA 7 2444: o. 5-6.

55 See table 3.

56 Syracuse 115: o. 1-2.

57 UTI 3 1808: o. 1-5; AAICAB 1/1, Ashm. 1924-0682: o. 1-9; BPOA 7 2878: o. 1-6.

58 BPOA 7 1813: o. 1-r. 1; BPOA 2 2091: o. 1-r. 1; BPOA 7 1889: o. 3-r. 1; BPOA 7 1935: o. 1-r. 1; UTI 4 2988: o. 1-r. 1.

59 See texts BPOA 7 1670: o. 4-r. 2; MCS 3 88 BM 111755: o. 2-6; MVN 16 0976: o. 7-r. 4.

60 See text MVN 21 199, r.iv 23.

Table 4. Maintaining the I-sala irrigation system (*continued*)

English	Sumerian	No. of references
C. Other tasks		
Stationed at the water of I-sala canal ⁶¹	a-da gub-ba I ₇ -sal ₄ -la ^(ki)	2
Stationed at I-sala canal ⁶²	I ₇ -sal ₄ -la ^(ki) gub-ba	2
Carrying reed to I-sala canal ⁶³	I ₇ -sal ₄ -la gi ga ₆ -ga ₂	7
Carrying grass to I-sala canal ⁶⁴	I ₇ -sal ₄ -la u ₂ gi ₆ -ga ₂	5

Hence, the numerous records on the transport of reed from the Šara-field to the inlet of I-sala canal (or, more generally, I-sala; see table 4, sections B and C) may have been related to the construction or repair of the inlet dam. As table 5 illustrates, when sorting the records according to date and authorizing official (in this case Dadaga, the later governor of Umma), the size of the workforce engaged in one or two tasks can be reconstructed. Thus, fifty-five workers distributed over six work crews consisting of six to twelve workers spent a day transporting reed from the field to the canal inlet.⁶⁵

Table 5. Work authorized by Dadaga, scribe, son of Ur-nigar, the chief livestock administrator

Date	Publication	Tasks	Supervisor	Conveyor
SS01-00-00	UTI 3 1950: o. 1–r. 6	12 workmen for 6 days irrigated the Muru-field. 10 workmen for 1 day carried reed from the Šara-field to I-sala.	Šeš-kala	Luduga
SS01-00-00	UTI 3 2168: o. 1–r. 6	10.5 workers for 6 days irrigated the Muru-field. 12 workers for 1 day carried reed from the Šara-field to I-sala.	Lugal-nesage	Luduga

(continued)

61 CTMMA 1 33: o. 5–r. 1; MVN 13 363: r. 2–3.

62 Farmer's Instructions 7.09: o. 4–9; Studies Leichty 290 21: o. 4–6.

63 SNAT 295: o. 6–7; Farmer's Instructions 7.09: o. 4–7; UTI 3 1808: o. 1–3; UTI 3 1950: o. 3–r. 1; UTI 3 2168: o. 3–r. 1; ASJ 18 081 16: o. 1–4; OrSP 47-49 395: o. 3–5; Princeton 1 362: o. 1–4.

64 BPOA 2 2444: r. 1–3; UTI 4 2851: o. 5–r. 1; SAT 2 0837: o. 1–4; SAT 2 1028: o. 1–r. 2; UTI 4 2781: o. 6–r. 1.

65 I am aware that the phrase "x number of workers for one day" may record only the number of work-days and not the actual size of the work crew and the real number of days it took to complete the task. However, since all the texts record the irrigation of the Murub field with the actual size of the work crew and the number of days it was deployed, I think it is safe to assume that the recording of the transportation of reed follows the same pattern.

Table 5. Work authorized by Dadaga, scribe, son of Ur-nigar, the chief livestock administrator (*continued*)

Date	Publication	Tasks	Supervisor	Conveyor
SS01-00-00	OrSP 47-49 395: o. 1-5	10 workers for 6 days irrigated the Muru-field. 12 workers for 1 day carried reed to I-sala.	Ur-mes	Luduga
SS01-00-00	BPOA 7 1813: o. 1-r. 2	5 workers for 1 day irrigated the field. 7 workers for 1 day carried reed from the Šara-field to the inlet of the I-sala canal.	Basa	Luduga
SS01-00-00	BPOA 2 2091: o. 1-r. 1	7 workers for 6 days irrigated the Muru-field. 6 workers for 1 day carried reed from the Šara-field to the inlet of the I-sala canal.	Lugal-unkene	Luduga
SS01-00-00	BPOA 7 1935: o. 1-4	8 workmen for 6 days irrigated the Muru-field. 8 workmen for 1 day carried reed from the Šara-field to the inlet of the I-sala canal.	Ur-Enlil	Luduga
SS01-09-00	UTI 5 3343: o. 1-5	13 workers for 1 day carried reed from the Šara-field to I-sala. 10 $\frac{1}{3}$ workers for 6 days performed water duty at the Muru-field.	Ur-sig	Luduga
SS01-09-00	ASJ 18 081 16: o. 1-4	13 workmen for 1 day carried reed from the Šara-field to I-sala. 7 workmen for 1 day performed water duty at the Muru-field.	Akala	Luduga, son of Lugal- nesag
SS01-09-00	BPOA 1 1168: o. 1-2	4 workers for 1 day coated with / filled earth into the flow divider of the I-sala canal.	Ur-sig	
SS01-09-00	BPOA 6 1349: o. 1-2	5 workers coated with / filled earth into the flow divider of the I-sala canal.	Ur-mes	
SS01-09-00	BPOA 1 1593: o. 1-2	4 ox-drivers were stationed at the flow divider of the I-sala canal.	Šeš-kala	

Table 5. Work authorized by Dadaga, scribe, son of Ur-nigar, the chief livestock administrator (*continued*)

Date	Publication	Tasks	Supervisor	Conveyor
SS01-09-00	MCS 3 88 BM 105562: o. 1–2	6 workers for 1 day were stationed at the flow divider of the I-sala canal.	I-pa'e	
SS01-09-00	MVN 16 1463: o. 1–2	5 workers for 1 day coated with / filled earth into the flow divider of the I-sala canal.	Lugal-unkene	
SS01-09-00	SACT 2 001: o. 1–2	240 ½ workers for 1 day covered/coated the flow divider with a type of reed mat (?).	Akala	

CLEANING THE I-SALA CANAL

The most frequent task recorded—as expected—is the cleaning of the main canal (i₇ šu luh-ak) by removing sediments that had accumulated in the canal bed during the previous year to guarantee adequate flow velocity (table 6). The cleaning of irrigation canals in southern Mesopotamia was conducted at the onset of the agricultural cycle, primarily in the month of August (month V),⁶⁶ a pattern that is reflected in this subsample of records. During canal maintenance, accumulated sediment would be piled up on either side of the canal and compressed to form an embankment.⁶⁷ Sediment accumulates in canals unevenly because of frequent changes in water velocity, especially at offtakes. Fernea⁶⁸ observed that within a 1.6 km long and 1–2 m wide secondary canal in the Daghara area, the silt that accumulated in a year amounted to 46 cm at the head of the canal but only 15–18 cm at the tail end.⁶⁹

As table 6 shows, the nineteen records are unevenly distributed chronologically, with most falling into SS02, the fourth of the five Ur III kings. This pattern reflects the overall chronological distribution of the record from the Umma archive, the largest quantities dating to the early years of the reign of King Šu-Sin.⁷⁰ This distribution is most likely the result of a discovery bias of the archive itself. All tablets known from the archive of Umma derive exclusively from illicit excavations; very little is known about the circumstances in which these records were unearthed and sold.⁷¹ It is still not entirely clear whether the

66 Rost 2015, 127–29.

67 Rost 2015, 129–33.

68 Fernea 1970, 132, 159–62.

69 See also Adams 1965, 8.

70 Molina 2008, 48, fig. 3. This is still the case even with the slight increase in records added to the database since 2008 (<http://bdts.filol.csic.es/>; accessed December 12, 2015).

71 According to Steinkeller (2003, 40–41), their interconnectedness seems to indicate that they were found in one location and were the result of a single discovery.

Table 6. Cleaning the I-sala canal

Date	Text	No. of work days	No. of men	No. of days	Volume in m ³	Supervisor (ugula)	Official (kišib)
AS05-04-00	SNAT 358: r. 1-3	8			<u>18</u>	Lugalemah(e)	Lugalemah(e), scribe, son of Lugal-kugani
AS08-00-00	Hirose 372: o. 1-3	<u>400</u>			900	via Ur-[. . .]	Lugalemah(e), scribe, son of Lugal-kugani
SS02-00-00	SACT 2 010: o. 1-3	12			<u>27</u>	Lugal- nesag(e)	
SS02-00-00	BPOA 6 1466: o. 1-5	30	15	2	<u>67.5</u>	Akala	
SS02-00-00	MVN 16 0903: o. 1-5	20	10	2	<u>45</u>	Lugal-kuzu	Ur-Šara, scribe, son of Šeš-kala
SS02-00-00	SACT 2 009: o. 1-4	20	10	2	<u>45</u>	Šeš-kala	
SS02-00-00	BPOA 6 0892: o. 1-4	34	17	2	<u>76.5</u>	Tabšala	
SS02-00-00	UTI 5 3024: o. 1-5	30	15	2	<u>67.5</u>	I-kala	
SS02-05-00	BPOA 7 2110: o. 1-2	8			<u>18</u>	Lugalemah(e)	
SS02-05-00	Princeton 1 502: o. 1-2	6+			<u>13.5</u>	Šeš-kala	Dadaga, scribe, son of Ur-nigar, the chief livestock administrator
SS02-05-00	BPOA 1 1303: o. 1-2	6			<u>13.5</u>	Dadamu	
SS02-05-00	MVN 16 1517: o. 1-2	9			<u>20.25</u>	Išarum	
SS02-05-00	UTI 4 2994: o. 1-2	7			<u>15.75</u>	Basa	

Table 6. Cleaning the I-sala canal (*continued*)

Date	Text	No. of work days	No. of men	No. of days	Volume in m ³	Supervisor (ugula)	Official (kišib)
SS03-00-00	UTI 4 2766: o. 1–2	2,400			5,400 (90?)	Luduga	
SS03-00-00	MVN 16 1158: o. 1–5	40			90	Šeš-kala ⁷²	En-kaš, scribe, son of Ur-Ištaran
SS03-00-00	HUCA 29 087 13: o. 1–2	<u>40</u>			90	Lugalemah(e)	
SS05-08-00	MVN 21 150: o. 1–4	5			15	Ur-lugal	Dadaga, scribe, son of Ur-nigar, the chief livestock administrator
SS06-00-00	Farmer's Instructions 2.10: o. 1–5	3			<u>6.75</u>	via Gugua Lugal-kuzu	
SS06-00-00	JCS 46 023 11: o. 1–5	4			<u>9</u>	via A'akala, son of Lugalemah(e) Abbasiga	Gugua, scribe, son of Mansum

Note: Italic and underlined entries represent reconstructions of the volume of earth or number of workdays (values not explicitly stated in the text). See Rost 2015, 214–15.

archive was unearthed in full or only in part and how many of the illicitly excavated documents are accessible for scientific research. As a result, it is difficult to assess the degree and nature of the discovery bias introduced. In other words, it is often difficult to tell whether an observed pattern reflects past reality or is a result of discovery bias.⁷³ Thus, it remains difficult to say if the chronological distribution of the records reflects the frequency with which the I-sala canal was cleaned—which, as it stands, was done either every three years, biannually, or annually.

⁷² “A well-known member of the group of agricultural overseers” (Dahl 2007, 87). It is not entirely clear to me who Šeš-kala is, but he could be an administrator who was very active in Umma.

⁷³ Rost 2015, 16–17.

THE ORGANIZATION OF CANAL MAINTENANCE

The records do, however, provide important insight into how the work was organized. The labor organization system of the Ur III period was very complex and was realized by a highly sophisticated administrative and accounting system. Each cuneiform tablet that records the labor and material expenditure for a particular work project also provides information about its administration. As seen in text Princeton 1 502 (below), the name of the work crew supervisor is usually given, here Šeš-kala, as is that of the high-level administrator, in this case Dadaga, who was authorized to commission the project in the first place and who deposited his seals on the tablet confirming that the work had been carried out.

<p>Princeton 1 502 <i>obverse</i></p> <ol style="list-style-type: none"> 1. +6 guruš u₄ 1-še₃ 2. I₇-Sa₁-la₄-la^{ki}-ke₄ / šu-luh ak 3. ugula Šeš-kal-la 4. kišib Da-da-ga <p><i>reverse</i></p> <ol style="list-style-type: none"> 1. iti RI 2. 'mu` ma₂ ^dEn-ki ba-ab-du₈ <p><i>seal</i></p> <ol style="list-style-type: none"> 1. Da-da-ga 2. dub-sar 3. dumu Ur-nigar_x ^{gat} šuš₃ 	<p><i>o. 1–2</i> 6+ workdays spent on cleaning the I-sala canal</p> <p><i>o. 3–4</i> supervisor was Šeš-kala tablet was sealed by Dadaga</p> <p><i>r. 1–2</i> <i>month V (August)</i> <i>year: SS02</i></p> <p><i>seal: Dadaga, scribe, son of Ur-Nigar</i></p>
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Employment rosters allow us to reconstruct the administrative hierarchy of officials in charge of managing the various economic sectors. The work related to water control and irrigation was handled by the administration of the agricultural sector of Umma. A highly centralized administrative system was employed for the management of agricultural land and the required irrigation infrastructure, consisting of laborers and mid- and high-level agricultural administrators (fig. 3).

The governor-run sector was in charge of the cultivation of approximately 14,000 ha, which were unevenly distributed among the four districts: Da-Umma (60%), Apisal (19%), Gu'edena (7%), and Mušbiana (14%).⁷⁴ Each district had its own set of administrators in charge of managing the agricultural sector. The administrative hierarchy of agricultural officials rested on the basic unit of a responsible “cultivator” (engar), who was in charge of cultivating one agricultural unit of 6 *bur* (ca. 39 ha, with 1 bur₃ ≈ 6.48 ha) and supervised three “ox-drivers” (ša₃-gu₄). The field size corresponds to one of the elongated field strips discussed above. According to two texts,⁷⁵ as many as 104 plow teams were in operation

74 Steinkeller 2013, 359; Vanderroost 2008, 137; 2012a, 78–86; see map 2. This subdivision existed only in the fourth decade of Šulgi's reign. Earlier, the agricultural land was subdivided into the so-called Menkar (later Gu'edena and Mušbiana) and Lamah (later Da-Umma) fields (Vanderroost 2012a, 119).

75 According to text AAS 83 (SH35-04 to SH36-01), 104 plows were in operation in SH35, and according to MCS 6, 83, BM 105334 (AS 2), 101 plows were in operation in AS02 (Vanderroost 2012a, 85, 94, 103–8, 178).

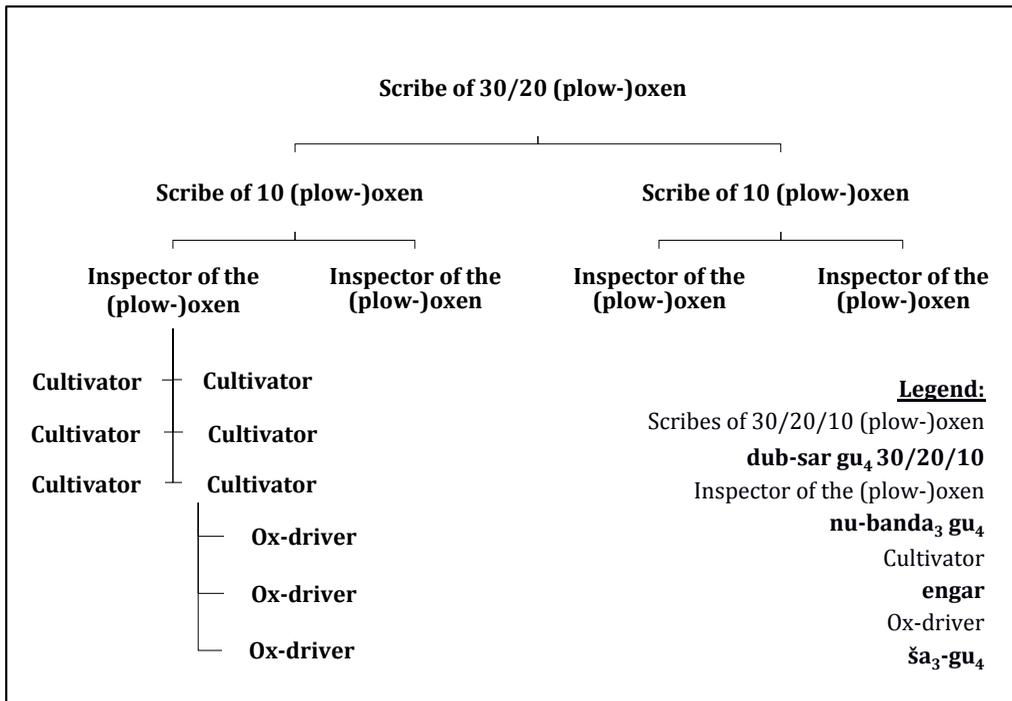


Figure 3. Administrative hierarchy of the management of agricultural land in the Umma province, based on Vanderroost 2012a.

in the governor-run sector of the Umma province in a given year. At the upper end of the administrative hierarchy, usually four to six cultivators, and thus four to six agricultural units, were subsumed under the authority of the “inspector of the (plow-)oxen”⁷⁶ (nu-banda₃ gu₄).⁷⁷ The inspectors of the (plow-)oxen, in turn, answered to a scribe of either ten/twenty or thirty (plow-)oxen, depending on the size of the landholding in the district.

Vanderroost⁷⁸ showed that the various levels of the administrative hierarchy were organized along kinship lines.⁷⁹ Thus, the primary administrative unit of cultivators (engar) and ox-drivers (ša₃-gu₄) consisted almost always of a father and his two or three sons or close kin, such as a nephew. Once the father retired, a younger brother or his oldest son assumed the position of cultivator, and a nephew or grandson took the vacant position of

76 This term is related to a set of tablets documenting the inspection of (plow-)oxen, listed under the responsibility of a certain “inspector of the (plow-)oxen” (nu-banda₃ gu₄), and their subordinated “cultivators” (engar) (Heimpel 1995). The number of plows operating in the Da-Umma district was about 54, 22 for the Apisal district and about 28 for the Gu’edena and Mušbiana districts (Vanderroost 2012a, 85, 94, 103–8, 178).

77 Heimpel 1995; Vanderroost 2012a, 92, 180.

78 Vanderroost 2012a, 2012b.

79 Vanderroost 2008; 2012a, 98–171.

ox-driver.⁸⁰ Similar observations have been made by Steinkeller⁸¹ on the organization of the “foresters of Umma.” Thus, the basic agricultural units were in fact quite stable, and certain cultivators can be attested as having been employed for twenty-two to twenty-six years.⁸² High- and mid-level administrative positions were also frequently passed down from father to son. In addition, as will be discussed below, most of the high-level agricultural administrators of scribes of ten/twenty or thirty (plow-)oxen either were members of the governor’s family of Umma or derived from prominent families that held other key positions in the administration of the Umma province.

The labor related to irrigation and water management was organized into work gangs of twelve to thirty workers who carried out a specific work project under the supervision of a foreman. In the case of cleaning the I-sala canal, the size of the work gang varied between ten and seventeen (see table 6). As with the cleaning of the I-sala canal, a large portion of the work related to the upkeep of the irrigation and water control infrastructure was carried out by the permanently employed workforce of the agricultural sectors of the Umma province. Once the work tasks related to cultivating the fields were completed, it was primarily the ox-drivers (approximately eighteen of them) subsumed under one inspector of the (plow-)oxen who would perform work on the irrigation system as a team. The heads of individual plow teams—the cultivators (*engar*)—were the more senior workers and hence were rarely employed for tasks other than the cultivation of fields. Most records do not specify the affiliation of the employed workforce but simply refer to it as x number of male (*guruš*) or female (*geme₂*) workers. In many cases, however, the affiliation of the work crew supervisor is known, allowing conclusions to be drawn about the employed male or female workforce. Thus, inspectors of the (plow-)oxen appear frequently as work crew supervisors (*ugula*) in texts documenting irrigation works.

Most work crew supervisors who carried out the cleaning of the I-sala canal are known inspectors of the (plow-)oxen (i.e., Akala, Basa, Dadamu, Lugal-kuzu, Šeš-kala, Lugalemah(e), Lugal-kuzu, Lugal-nesag) of the Da-Umma district who operated under the authority of Lugalemah(e), the son of Lugal-kugani. He, together with Egalesi, was in charge of the agricultural sector of the Da-Umma district. Both held the title of scribe of thirty (plow-)oxen and derived from two prominent families of land surveyors—an office that was connected to substantial power and prestige.

As the permanent agricultural workforce was too small to handle all the work related to cultivation and irrigation, the agricultural sector relied heavily on hired laborers (*lu₂-hun-ga₂*) and, more importantly, on seasonal labor drawn from various other economic sectors of the province. The Ur III workforce was composed of distinct working classes of

80 Vanderroost 2012a, 158–67. As could be shown in text Talon-Vanderroost 1 and 2, children are listed as being provided with rations ranging between 10 and 30 sila (1 sila₃ = 1 l) of grain per month. They were included in the plow team as junior males working between one-third and two-thirds of an adult workload, depending on their age. Once a new teammate was needed, they were promoted to full wages and adult workloads (Vanderroost 2012a, 137–38, 143–45).

81 Steinkeller 1987b.

82 Vanderroost 2012a, 169.

different socioeconomic statuses and incomes.⁸³ Eren₂ workers constituted the more privileged working class, possessing subsistence fields allotted to them by the state in return for corvéé services. These workers owed a corvéé duty worth six months of labor days to the state and its various institutions. Most attested “cultivators” (engar) and ox-drivers (ša₃-gu₄) were in fact eren₂-workers who were in possession of sustenance fields.⁸⁴ After the fulfillment of their corvéé duty, many eren₂ workers were hired (lu₂-hun-ga₂) by the state in return for wages.⁸⁵ Studevent-Hickman⁸⁶ notes, however, that the hired labor force consisted of members of a great variety of social groups of Ur III society. While eren₂ workers were recruited, members of their households such as their wives and children were hired as well. In addition, the urban populations of cities and towns appear to have been an additional source of hireable labor. Thus, it is possible that the work crews of those supervisors whose affiliation remains unclear (i.e., Tabšala, I-kala, Luduga, Išarum) may have supervised menials, hired labor, or seasonal labor from other institutions and industries.

The term UN.IL₂/ug₃-ga₆ (“carrier”/“menial”) refers to the class of unskilled laborers who were employed in agriculture or other economic sectors year-round and who received monthly wages consisting mainly of grain and wool but also at times of oil, bread, or flour and occasionally of fish, milk products, fruits, and vegetables.⁸⁷ The size of this working class was relatively small, ranging between three thousand and four thousand individuals with equal numbers of male and female workers. Menials most likely were impoverished natives who were forced by their life circumstances to become full-time employees of the state institutions.⁸⁸ Unskilled labor was not assigned to particular occupations except as part of work teams under specific supervisors (ugula).⁸⁹ The wide range of tasks for which menials were employed suggests they may have formed a permanent reserve pool from which workers could be recruited whenever and wherever a shortage of labor occurred.⁹⁰

The labor organization of the cleaning of the I-sala canal in SS02 indicates that the individual work crews spent a relatively short period of time at the work site—no more than two days. However, the total number of workers amounted to at least 100–150 people who needed to be recruited and organized. We obviously do not know whether all work crews were at the work site simultaneously, but it appears that the underlying organizational strategy was to have a large number of workers employed to accomplish the cleaning in a short period of time.

83 For a detailed discussion of the various working classes, see Englund 1991; Koslova 2008; Nissen, Damerow, and Englund 1993; Steinkeller 1987a; 2003, 45; 2015; Studevent-Hickman 2006.

84 Koslova 2008, 165; Vanderroost 2012a, 68–69, 189–90.

85 Steinkeller 1996, 239–41; 2013, 350–51.

86 Studevent-Hickman 2006, 326.

87 Koslova 2008, 166–67; Steinkeller 2013, 365; Waetzoldt 1987, 119.

88 Steinkeller 2015, 24–26.

89 Englund 1991, 257.

90 Steinkeller 2015, 26; see also Rost 2015, 208.

ORGANIZING THE WORKFLOW: ACCOUNTING

This complex organization of labor was realized with a system of extensive record keeping. The accounting system was based on advanced computational processes that allowed labor inputs and expenditures to be quantified to aid in economic planning. Work volumes are usually expressed in volumes of earth to be moved, either to clean a canal or to reinforce a water control device. In computational terms, however, the most important invention during the Ur III period was the use of standardized work norms.⁹¹ The most common work norm for earth work was 3 m³ (10 gin₂) or 2.25 m³ (7½ gin₂), which is the amount that one worker was expected to move in one day (see, e.g., MVN 21 150).

<p>MVN 21 150 <i>obverse</i> 1. 5/6 sar kin sahar-ra 2. guruš-e 10 gin₂-ta 3. a₂ lu₂ hun-ga₂ 4. i₇-I₇-sal₄-la šu-luh ak 5. ugula Ur-lugal <i>reverse</i> 1. kišib Da-da-ga 2. iti e₂-iti-6 3. mu us₂-sa dŠu-dSuen lugal-e bad₃ mar-tu mu-du₃ <i>seal</i> 1. Da-da-ga 2. dub-sar 3. dumu Ur-nigar_x^{gar} šuš₃</p>	<p><i>o. 1-4</i> 15 m³ earth work, 3 m³ per worker per day—the job of hired laborers—cleaning the I-sala canal <i>o. 5-r. 1</i> supervisor was Ur-Lugal tablet was sealed by Dadaga <i>month:</i> VII (November) <i>year:</i> SS05 <i>seal:</i> Dadaga, scribe, the son of Ur-Nigar</p>
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The use of work norms opened up totally new accounting and administrative possibilities. Human labor could be expressed in numbers, which allowed easy conversion of specific workloads into labor days that could then be divided up and assigned to the responsible personnel. This abstraction of human labor in quantifiable units is extremely significant, as it permits standardized administrative procedures that can be institutionalized. Thus, the texts allow us to reconstruct the individual administrative steps by which the workflow was organized in a highly efficient manner: (1) inspection of the devices in different locations, (2) surveying and measuring out the work that needed to be done, (3) division and assignment to different supervisors, (4) execution of the work by the supervisors and their work crews, and (5) payment of the employed workers and their supervisors.

INSPECTION OF WATER-CONTROL DEVICES

Text YOS 04 235 is a letter instructing Erdingir to inspect all the flow dividers in the Da-Umma district of the Umma province. A flow divider in an irrigation scheme has the

⁹¹ Nissen, Damerow, and Englund 1993, 47–54.

function of subdividing the flow of a parent canal into a set of smaller canals.⁹² The order may have come from a higher official to whom Erdingir was a subordinate. The tablet was sealed by Erdingir to prove that he did the assigned job.

<p>YOS 04 235</p> <p><i>obverse</i></p> <ol style="list-style-type: none"> 1. kab₂-ku₅ da Umma^{ki}-ka a-na gal₂-la 2. Er₂-dingir-e igi kar₂-kar₂-dam <p><i>reverse</i></p> <p>=====</p> <ol style="list-style-type: none"> 1. mu ^dAmar-^dSuen lugal <p><i>seal</i></p> <ol style="list-style-type: none"> 1. Er₂-dingir 2. arad₂^dŠara₂ 3. dumu Lugal-sa₆-ga 	<p><i>o. 1–2</i></p> <p>Flow dividers—as many as they are in the Da-Umma^{ki} district—are to be inspected by Erdingir.</p> <p><i>r. 1</i></p> <p><i>year:</i> ^dAmar-^dSuen is king (AS01)</p> <p><i>seal:</i> Erdingir, servant of god Šara, son of Lugal-saga</p>
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It is conceivable, though not explicitly stated in the text, that the devices were inspected for possible damage that allowed necessary repairs to one or more irrigation systems to be prioritized. Erdingir probably reported back to an office in charge of sending survey personnel to collect linear measurements, based on which the workload could be calculated (see, e.g., text Princeton 2 403).

<p>Princeton 2 403</p> <p><i>obverse</i></p> <ol style="list-style-type: none"> 1. 37 1/3 sar kin sahar 2. a₂ lu₂ hun-ga₂ 3. 6 sila₃ še-ta 4. i₇-I₇-Sal₄-la ba-al-la 5. giri₃ Ha-ba-lu₅-ge₂ 6. A-kal-la u₃ Lugal-e₂-mah-e ib₂-gid₂ <p><i>reverse</i></p> <ol style="list-style-type: none"> 1. 14 guruš u₄ 1-še₃ 2. ki Arad₂-ta zi-ga 3. a₂ lu₂ hun-ga₂ 4. kišib Lugal-e₂-mah-e 5. mu us₂-sa Ki-maš^{ki} ba-hul <p><i>seal</i></p> <ol style="list-style-type: none"> 1. Lugal-e₂-mah-e 2. dub-sar 3. dumu Lugal-ku₃-ga-ni 	<p><i>o. 1–4</i></p> <p>672 m³ earth work—the job of hired labor with a daily wage of 6 liter of grain to dig the I-sala canal</p> <p><i>o. 5–6</i></p> <p>under the authority of Habaluge Akala und Lugalemah(e) measured out the work to be done</p> <p><i>r. 1–3</i></p> <p>14 labor days withdrawn from Arad—hired laborers</p> <p><i>r. 4–5</i></p> <p>tablet was sealed by Lugalemah(e)</p> <p><i>year:</i> SH47-00-00</p> <p><i>seal:</i> Lugalemah(e), scribe, son of Lugal-kugani</p>
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⁹² Laycock 2007, 143.

SURVEYING AND COMPUTATION OF WORKLOADS

Textual evidence indicates that Mesopotamian measuring tools consisted of measuring rods and ropes. None of these measuring tools has been preserved because they were made of perishable materials, such as reed or palm tree fibers.⁹³ The computation of work volumes was done with basic formulas, multiplying the length by the width and depth.⁹⁴ In computational terms, canals have been perceived as a rectangular prism, even though they more likely had a trapezoidal cross section. Workloads are reported in the ancient administrative documents in two ways. In some cases, work volumes are simply listed without providing the dimensions of the device or canal in question (see, e.g., text Princeton 2 403). In other cases, all the dimensions are given, as in text SAT 2 0210: o.i 1–2 “1 nindan gid₂ 2(diš) nindan dagal 4(diš) kuš₃ bur₃ kin-bi 8(diš) sar” = 1 nindan length, 2 nindan width, 4 kuš depth; its volume is 8 sar = 6 m length, 12 m width, 2 m depth; its work volume is 144 m³.” Texts that list all three dimensions are rare. Much more common are texts that list only the volume of a type of cleaning or reinforcement work.

Texts listing all three dimensions may be scarce because surveying land with ropes and rods not only required skilled laborers but also must have been very time-consuming. It is unlikely that a full-fledged survey of canals and/or hydraulic devices was conducted for the computation of the amounts of maintenance work every year. More likely, surveying consisted of simply measuring out one linear dimension, such as the height of accumulated sediments in a canal. The measurements taken in the field may have been recorded on wax-coated wooden boards (li-um), known from the first millennium BCE. Other accounting and recording devices are conceivable, such as stone calculi and counting sticks that would aid in the memorization of the measured dimensions.⁹⁵

ASSIGNMENT OF WORK PROJECTS

The computation of the work volumes was most likely done in an office setting, where tablets recording all three dimensions of the water control device in question were on file and where records for the subdivision of work and assignment to different supervisors and their work crews were also drawn up. The work project documented in text BPOA 2 2547 concerns the annual removal of sediments from the Šara-gugal canal and the subdivision of the workload among various supervisors of work crews. Unfortunately, no comparable text records the assignment of the cleaning work for the I-sala canal. It is safe to assume that a similar record for the division of the workload of the cleaning of the I-sala canal once existed, as it represents a planning stage in organizing the work project.

As has been observed for the records of the cleaning of the I-sala canal (see table 6), most individuals mentioned in text BPOA 2 2547 are also various inspectors of the (plow-) oxen who operated in the Da-Umma district, where the Šara-gugal canal was probably located.⁹⁶ Though the text indicates that the workforce consisted of hired laborers (a₂ lu₂

93 Nissen, Damerow, and Englund 1993, 68; Powell 1987–90; Waetzoldt 1992.

94 For specifics, see Civil 1994, 116; Rost 2020.

95 Steinkeller 2004, 75.

96 Vanderroost 2012a, 99–105, 260–70, table 6; 2012b, 8–14.

BPOA 2 2547 (SS 02)	
<i>obverse</i>	
1. 59 1/3 sar sahar	<i>o. 1-2</i> 1,068 m ³ of (earth assigned to) the inspector of the (plow-)oxen Ipa'e
2. I ₇ -pa-e ₃ nu-banda ₃ -gu ₄	<i>o. 3</i> 1,080 m ³ (of earth assigned to) Abba-saga
3. 60 sar Ab-ba-saga	<i>o. 4</i> 1,080.5 m ³ (of earth assigned to) [Ur]-mes
4. 60 sar 1 2/3(diš) gin ₂ [Ur]-mes	<i>o. 5-6</i> 1,153.5 m ³ (of earth assigned to) Lugal-nesage
5. 64 1/2 sar 5 [gin ₂]	<i>o. 7</i> 1,620 m ³ (of earth assigned to) Abba-[. . .]
6. Lugal-nesag-e	<i>o. 8</i> 360 m ³ (of earth assigned to) Ur-[gigir]
7. 90 sar Ab-ba-[. . .]	<i>o. 9</i> 360 m ³ (of earth assigned to) Ur-am[ma]
8. 20 sar Ur- ^{gis} [gigir]	<i>o. 10</i> 1,080 m ³ (of earth assigned to) Šeš-kala
9. 20 sar Ur-am ₃ -[ma]	<i>o. 11</i> 1,080 m ³ (of earth assigned to) Lugal-itida
10. 60 sar Šeš-kal-la	<i>o. 12</i> 1,099.8 m ³ (of earth assigned to) Basa
11. 60 sar Lugal-iti-da	<i>o. 13</i> 1,083 m ³ (of earth assigned to) Lugal-ema(e)
12. 61 sar 6 gin ₂ Ba-sa ₆	<i>o. 14</i> 540 m ³ (of earth assigned to) Ur-gigir, the inspector of the (plow-)oxen
13. 60 sar 10 gin ₂ Lugal-e ₂ -mah-e	<i>o. 15</i> 1,080 m ³ (of earth assigned to) Ur-mes
14. 30 sar Ur- ^{ges} gigir nu-banda ₃ -gu ₄	<i>r. 1-2</i> 1,246.5 m ³ (of earth assigned to) Lugal-kuzu
15. 60 sar Ur-mes	<i>r. 3-4</i> 1,148 m ³ (of earth assigned to) Ur-Urbartab
<i>reverse</i>	<i>r. 5-6</i> 392.65 m ³ (of earth assigned to) Ur-Lugal
1. 69 sar 15 gin ₂	<i>r. 7</i> 360.5 m ³ (assigned to) Nimgirane
2. Lugal-ku ₃ -zu	<i>r. 8</i> Total is 15,832.45 m ³ (written 15,670.45 m ³ but in error).
3. 63 2/3 sar 6 2/3 gin ₂	<i>r. 9-10</i> earth work—the job of hired laborers with a wage of 6 liters of grain
4. Ur- ^d Ur ₃ -bar-tab	<i>r. 11</i> (the work project concerns): The cleaning of the Šara-gugal–canal
5. 21 2/3(diš) sar 8 5/6 gin ₂	<i>r. 12</i> Dadaga and Gugua surveyed it
6. Ur-lugal	<i>r. 13-14</i> sealed (by) Dadaga
7. 20 sar 1 2/3 gin ₂ Nimgir-an-ne ₂	<i>year:</i> The boat of god Enki was caulked.
8. šu-nigin ₂ 870 1/2 sar 4 5/6(diš) gin ₂	<i>I.e. 1</i> The Engabra-canal
9. kin sahar-ra a ₂ lu ₂ hun-ga ₂	<i>seal:</i> Dadaga, scribe, son of Ur-nigar, the chief livestock administrator
10. a ₂ 6 sila ₃ -ta	
11. i ₇ - ^d Šara ₂ -gu ₂ -gal-e šu luh-ak	
12. Da-da-ga u ₃ Gu-u ₂ - gu-a ib ₂ -gid ₂	
13. kišib ₃ Da-da-ga	
14. mu ma ₂ ^d En-ki ba-ab-du ₈	
<i>left</i>	
1. i ₇ -En-gaba-ra ₂	
<i>seal 1</i>	
1. Da-da-ga	
2. dub-sar	
3. dumu Ur-nigar ^{gar} šuš ₃	

hun-ga₂), we can assume that workers were recruited from among the labor force under the authority of the individual inspectors of the (plow-)oxen (see above). Each of them had approximately eighteen ox-drivers under his jurisdiction, and the workforce amounted to about 252 individuals for the cleaning of this canal. Indicative of the management structure is the fact that the surveying, planning, and assignment of the workload was done by Dadaga, who became the governor of the Umma province in the year SS07. As will be discussed below, Dadaga and his brother Akala appear frequently in documents pertaining to agricultural or water works in the Da-Umma district. Clearly, the gubernatorial family of Umma ultimately retained oversight over the entire agricultural operation of the province. Gugua, the son of Mansun, appears frequently in relation to projects concerning irrigation, flood control, and river management and may have functioned as an assistant to Dadaga in this surveying project.⁹⁷

EXECUTION OF THE PROJECTS

Text Princeton 2 403, discussed above, is a record of a single work project carried out by one work crew. This text contains all the administrative steps described above: Akala and Lugalemah(e) surveyed the work to be done, and the work was then assigned to hired laborers under the supervision of Habaluge who received 6 l of grain per day as their payment. Depending on their employment status, workers received grain allotments (šag₄-gal) when on corvé duty and wages (a₂) when contracted as hired laborers (lu₂-hun-ga₂). Wages are usually listed in daily payments varying between 4 and 6 *sila* (liters).⁹⁸ The wages were usually three times higher than the grain allotments received during corvé duty.⁹⁹ However, depending on the status of the workers, the grain allotment/wage could vary considerably.¹⁰⁰

DISCUSSION AND CONCLUSION

The written documents provide us with a wide array of detailed information on the social organization of work related to irrigation and water control. Probably contrary to our expectations, the texts clearly show that the provincial governments under the authority of the governor managed the entire system, literally down to the individual field level, by relying on a great labor force of dependent and semidependent workers, corvé laborers, and administrators. Many of the tablets were sealed by members of the governor's family, such as Dadaga, who appeared in a number of texts presented in this chapter. At the time, he was the governor's brother and assumed governorship in Umma later on. Many of the male members of the governor's family were intimately involved in the administration of the province—especially in the administration of the agricultural sector. In the Da-Umma district, it appears that Dadaga and his brother Akala—who also assumed the governorship of Umma—held key positions in the agricultural sector and appear regularly as the

97 Vanderroost 2012b, 41.

98 Nissen, Damerow, and Englund 1993; Koslova 2006.

99 Steinkeller 2003, 45.

100 Koslova 2006.

sealing officials on tablets related to the management of agricultural land and associated irrigation infrastructure. This shows that agriculture, and by extension water control, were overseen by the provincial government under the authority of the governor and members of his family.

That being said, we have to keep in mind that this centralized mode of irrigation management may have been specific to the estate run by the governor whose landholding amounted to only 7 percent of the entire area of the Umma province (as it is currently reconstructed, since the exact location of the province border is not clear). Unfortunately, we have no information on how land and water were managed for the rest of the province, let alone for the rest of the Ur III state.

As to the question of the state, there is no indication that the central government, as represented by the crown, was involved in the day-to-day operation of the water control system. This should not give the impression, however, that the crown was totally uninvolved or passive when it came to water management. On the contrary, there is clear evidence that high-profile water disputes were handled by the central government.

The court document YOS 04 001 from the Umma province (see next page) documents a dispute over water that Lu-gina diverted from the I-sala canal. The case was brought by the governor of Umma to the palace, and Lu-gina swore an oath to the king to replace the water he had taken from Lu-kala the cupbearer. The fact that the governor testified suggests that Lu-gina was a member of the royal sector. Three members of the royal sector functioned as witnesses, probably on behalf of Lu-kala the cupbearer (Zuluhu the colonel, Ur-Damu the soldier, and Lu-Suen the fattener).¹⁰¹ Lu-kala the cupbearer (sagi) is attested mainly in records from Puzriš-Dagan, further supporting the assumption that he was a member of the royal sector. Ur-gigir, son of Baran, on the other hand, was an inspector of the (plow-)oxen under the authority of Egalesi.¹⁰² He appears in most administrative documents in the capacity of the sealing and authorizing official and may have occupied a high position in the administration of the agricultural sector in the Da-Umma district. It is possible that he attended this hearing as a representative of Egalesi or Lugalemah(e), but in what capacity remains unclear. The fact that Lu-gina swore an oath by the king indicates that the crown retained some control over local water affairs. Other cases regarding high-profile water conflicts (usually involving entire towns and villages) were attended and judged by a royal envoy.¹⁰³ In addition, Mesopotamian rulers commonly claimed royal patronage over the construction of canals or water-control devices. Ur-Namma, the founder of the Ur III state, was most vocal about his role in water management. The magnitude and frequency of such royal/state intervention remain unclear, with documentation restricted to the rule of Ur-Namma.¹⁰⁴

101 Molina 2013.

102 Vanderroost 2012a, 99.

103 Rost 2015, 232–34.

104 Rost 2015, 246–53.

<p>YOS 04 001 <i>obverse</i></p> <ol style="list-style-type: none"> 1. Lu₂-ge-na a i₇-Sa₄-la i₃-in-e₃ 2. ensi₂-ke₄ e₂-gal-la di-da kab in-na-an-du₁₁ 3. Lu₂-ge-na e₂-gal-še₃ na-an-du-un 4. a-ša₃ Lu₂-kal-la sagi a-e de₆-a 5. a ga-ab-su in-na-an-du₁₁ 6. mu lugal-bi i₃-pa₃ 7. igi Zulu₂ nu-banda₃-še₃ 8. igi Ur-^{giš}gigir dumu Bar-ra-AN-še₃ <p><i>reverse</i></p> <ol style="list-style-type: none"> 1. [igi Ur]-^dDa-mu [aga₃]-us₂-še₃ 2. [igi Ur]-ku₃ aga₃-us₂-še₃ 3. [igi . . .]-banda₃^{da}-še₃ 4. [igi Lu₂?]-‘{d}’ Suen kurušda-[še₃] (=KWU_822) ===== 5. ===== # (and erasure over A [x]) 6. mu us₂-sa en ^dNanna maš-e i₃-pa₃ ===== 	<p><i>o. 1</i> Lu-gina let water out from the I-sala canal.</p> <p><i>o. 2</i> The governor testified against him in the palace.</p> <p><i>o. 3–5</i> Lu-gina said to him: “I will not go to the palace. The water that has been taken away from the field of Lu-kala the cupbearer, I will replace it.”</p> <p><i>o. 6</i> He swore an oath on the king</p> <p><i>o. 7–r. 5</i> in front of (witness) Zulu₂, the colonel in front of (witness) Ur-gigir, son of Baran in front of (witness) Ur-Damu, the soldier in front of (witness) [. . .] the colonel (?) in front of (witness) Lu-Suen, the fattener ===== <i>year: SH44-00-00</i></p>
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Despite the exceptionally detailed insight into ancient irrigation management that these records provide, we should not assume that their formulaic character implies neatly organized, conflict-free, and smoothly managed irrigation systems. The written record represents—like the archaeological record—an end product after all the negotiations, decision making, and face-to-face interaction have taken place. They may mask a messier social reality in which authorities were resisted, compliance was enforced, and competing interests were negotiated. Such tensions may be concealed in the frequent appearance of Dadaga and Akala in records pertaining to the management of agricultural land and irrigation in the Da-Umma district. The agricultural sector of this district was nominally run by two high-level agricultural administrators, Lugalemah(e), son of Lugal-kugani, and Egalesi, son of Lu-^dŠara, the land surveyor, who both came from prominent families of land surveyors (sa₁₂-du₅)—the families of Lugal-kugani and Inim-Šara, the grandfather of Egalesi. Inim-Šara was a royal land surveyor who may have been installed by the crown in Umma to ensure accurate reports on the province’s agricultural potential.

The relationship of the two high-level agricultural administrators and brothers of the governor remains obscure, perhaps reflecting some power struggle between the gubernatorial and other prominent families of the Umma province, some of which were clearly backed by the crown (i.e., royal surveyors)—possibly to keep more independent loci of power (e.g., provincial gubernatorial families) in check. Similarly, the office of the provincial archivist (pisan dub-ba) was in the hands of the family of Lugalušur, who managed the agricultural domain of the temple household of Umma’s main deity, ^dŠara. Apparently, important offices in Umma’s administration went along with exercising control over the management of agricultural land and irrigation.¹⁰⁵ How these potential power tensions

105 Dahl 2007, 70–72, Vanderroost 2012a, 186–87.

may have played out in the day-to-day operation of the irrigation systems remains an open question but must be considered in historical reconstructions based on ancient administrative documents.

While a “thick description” in an ethnographic sense may never be possible for the past, an interdisciplinary approach permits a more nuanced understanding. As this chapter may have made clear, the lack of archaeological data prevents this rich set of administrative documents from being explored to its full potential. Archaeological data (e.g., settlement data, cross sections of canals and water courses, test trenches on water control devices) would allow us to anchor the geographic information in the texts that is key to understanding the natural and anthropogenic landscapes, as well as the size and routes of canal systems of the irrigation infrastructure. As shown above, the 250 records pertaining to the I-sala canal provide no information about its size. This makes it difficult to contextualize the recorded labor and material expenditure to better understand the underlying labor organization system, the complexity of the logistics of material acquisition, and the overall organization of the irrigation system. Moreover, without the archaeological counterpart, translating the water control terminology has been extremely challenging. While ethnographic analogies provide indispensable clues,¹⁰⁶ the kinds of devices that were in use and the functions they fulfilled can be gained only from archaeological investigations.

To conclude, the written documents from third-millennium BCE Umma provide exceptionally rich insights into the social organization of irrigation. They show that irrigation management was organized in a highly centralized fashion at the province level. However, it remains unclear whether this kind of management was restricted to the governor-run sector of the Umma province. The court document over illegal water withdrawal from the I-sala canal indicates some individual water rights—at least for members of the royal sector—and may point to the coexistence of different modes of irrigation management in the province at large. How they coordinated the shared use of certain features of the irrigation infrastructure remains unclear. The document also shows that the central government, as represented by the crown, was not deeply involved in the management of irrigation at the local level, except for conflict resolution. This chapter also showed that despite the abundance of information these texts provide, they are not without problems. The information that is omitted, such as the exact dimensions of canals and water control devices—sometimes makes it difficult to fully understand the recorded information. On a more epistemological level, this chapter also cautions against being deceived by the formal character of these records, which may conceal a much more complex social reality. It is hoped that future research, in particular the collection of archaeological data, will—as McGuire Gibson so well puts it in this volume—allow for paying more attention to “the folks” who dealt with the day-to-day operations of irrigation management and give more insight into how they related to the state.

106 Rost 2015.

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PART III

THE ECONOMIC FUNCTION OF IRRIGATION

8

Irrigation, Food Surplus, and Complexity: A Case from Hohokam, a Prehistoric Neolithic Culture in the American Southwest

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THE PARTICIPANTS IN the Oriental Institute seminar on irrigation and the early state were asked to consider why irrigation was important for early states. It is clear that waterworks, including canal irrigation, provide many services in addition to food production in arid zones.¹ A large and reliable supply of fresh water can be delivered to extensive areas away from the river courses. This fresh water serves domestic, livestock, transport, craft, and production needs. It enables the production of a food surplus. It provides fish, useful plants grown on canal banks, and fodder, all in addition to agriculture. This sometimes vast expansion of the fresh waterscape makes economic and population growth possible in arid riverine environments.

Another feature of irrigation is the possibility of food surplus. Food surplus is a necessary condition for a complex society. The shift in production from subsistence to a food surplus requires intensification. Intensification results in an increase in the productivity of land and/or an increase in the productivity of labor. Irrigation intensifies food production. Irrigation is one means of generating a food surplus.

This case study investigates irrigation and food surplus. The case study is located in Hohokam, an ancient Neolithic culture with large irrigation systems in the Sonoran Desert in southern Arizona. A simulation of maize production, consumption, and food surplus for Snaketown, a large and important Hohokam social system, is constructed.

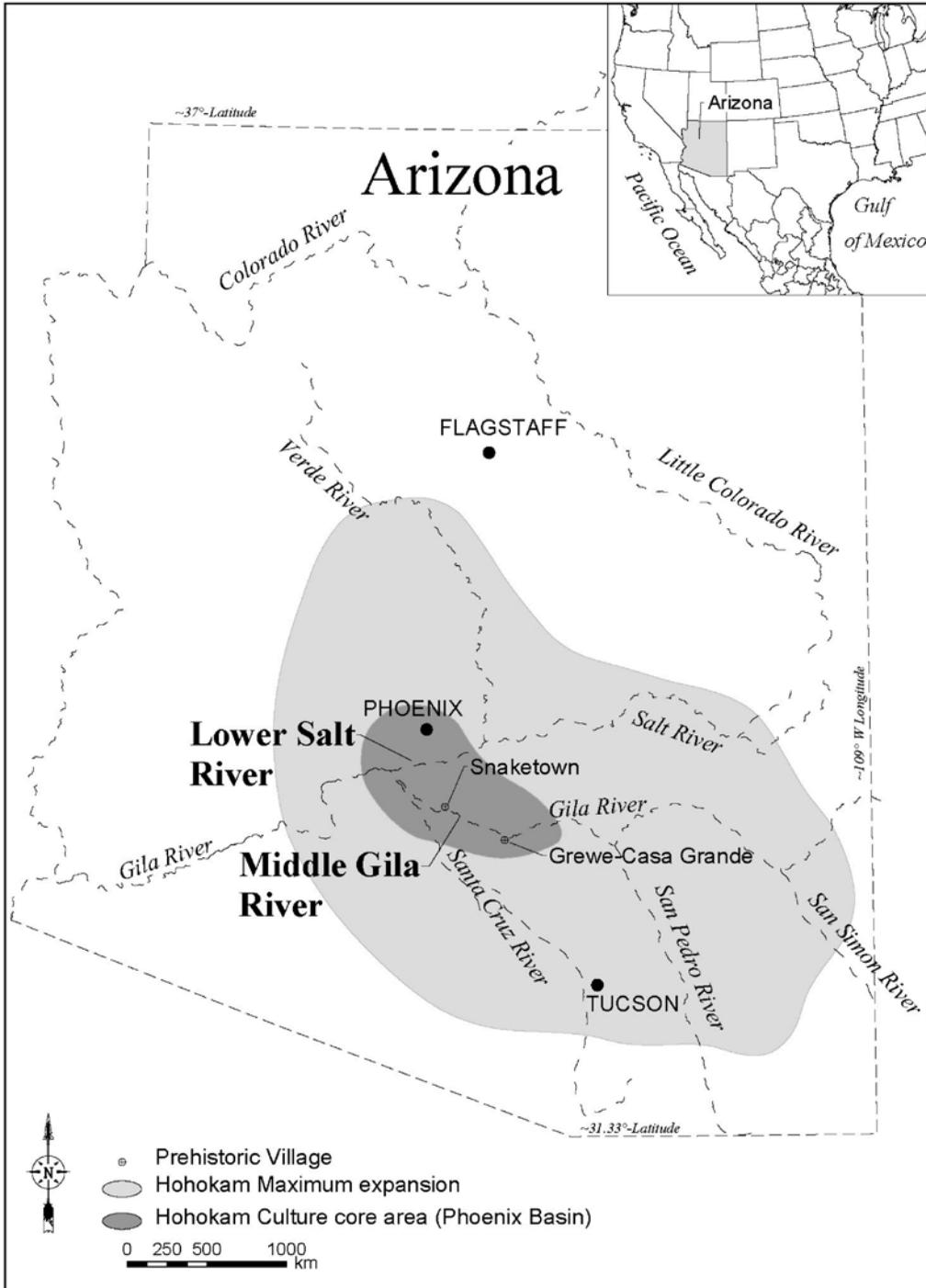
The question asked was whether a food surplus was possible for Snaketown. The results suggest that Snaketown irrigation could not produce a reliable food surplus. One reason is that there was insufficient water. These results suggest some implications for understanding the role of irrigation in early states.

1. HOHOKAM

Hohokam was located in southern Arizona, USA, and existed from 450 to 1450 CE.² It had a number of large irrigation systems (see Woodson, this volume, fig. 11), a substantial

1 Adams 1981; Algaze 2008; Hunt 1988a; Rost 2015. I am not an archaeologist. Rather, I am an economic anthropologist, applying concepts and methods to a data set that includes archaeological information. I am massively indebted to the army of archaeologists and other scholars who have worked on Hohokam, and in the Southwest of the United States, Kyle Woodson is prominent among them.

2 Fish and Fish 2007.



Map 1. Arizona, Hohokam, Phoenix basin, and Salt and Gila Rivers (drafted by and used courtesy of the Cultural Resource Management Program, Gila River Indian Community, Sacaton, Arizona).

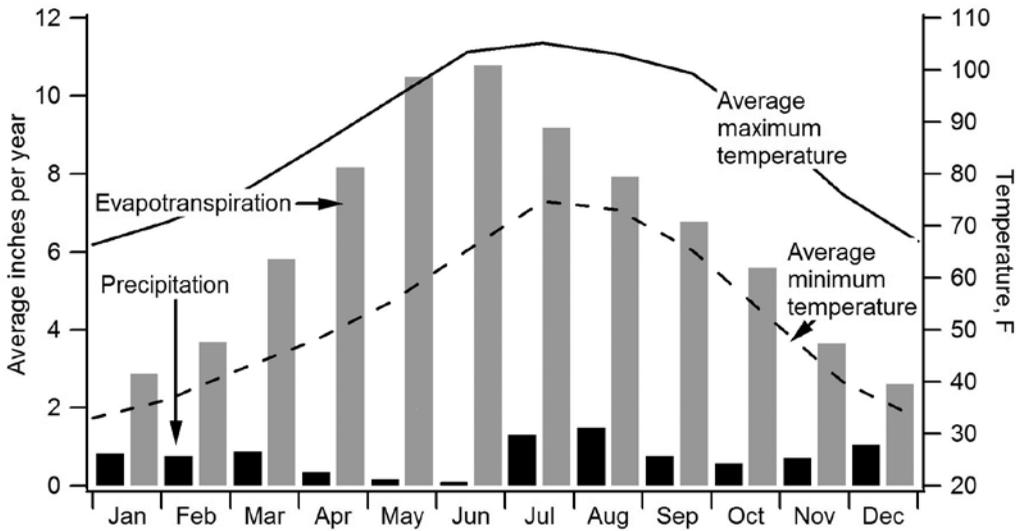


Figure 1. Air temperature, rainfall, and evapotranspiration for Sacaton in the Phoenix basin (from Hunt and Ingram 2014, 257).

population, and extensive trade. Yet, it remained Neolithic in organization, without cities, social stratification, full-time specialists, or a state. Given the Hohokam attributes, one question that arises is why a complex society did not develop. The maize production and consumption simulation that follows suggests that an unreliable water supply constraining production of a food surplus was a factor.

The heartland of Hohokam culture was the Phoenix basin in the Sonoran Desert (see map 1). Two perennial rivers, the Salt and the Gila, course through this area. There are large amounts of alluvial soils. The latitude is around 33 degrees north, and the altitude varies around 1,200 feet (365 m) above sea level.³ The Phoenix basin is a large area. I have chosen the area around Snaketown for the data on location and elevation. Modern data on rainfall, temperature, and their products (evapotranspiration, growing degree days) come from the settlement of Sacaton, 20 km upstream on the Middle Gila River (see fig. 1). It is about 100 feet higher than Snaketown. The differences between Snaketown and Sacaton in rainfall and air condition (temperature, dewpoint, evapotranspiration) are unknown. Differences from other places in the Phoenix basin are, from an agricultural point of view, minor (Hunt 2015b). The frost-free period (at 90% probability) is about 270 days. Mean annual rainfall is 8 inches (20 cm). The summer-season rainfall approximates 4 inches (10 cm), while the evapotranspiration is at least 10 times that amount.⁴ Most of the remainder of precipitation comes via winter storms, which often roll in from the Pacific Ocean. The maximum temperature is at least 121°F (50°C), and there are about 8,000 maize growing degree days, indicating adequate accumulating heat for producing successful maize crops.

³ Haury 1976, 5.

⁴ Hunt and Ingram 2007.

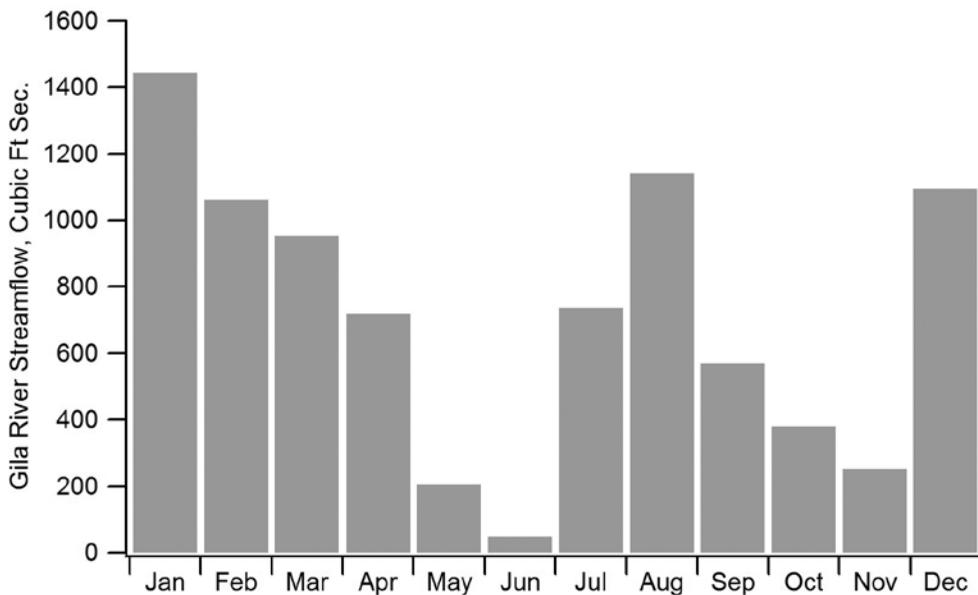


Figure 2. Gila River mean monthly flow, 1912–29.

Although both the Salt and Gila Rivers were perennial, the flow of water in the Gila River cannot be regarded as steady. The mean flow per month is highly variable, with May and June providing very little water (see fig. 2).

When Hohokam blinked into existence around 450 CE, maize, beans, squashes, and cotton—annual tropical crops domesticated in Mesoamerica—were being grown. Because of the arid environment, none of the Mesoamerican crops can be grown without irrigation. Hohokam eventually developed upward of twenty irrigation systems, varying in size from a few hundred hectares to several thousand hectares.

By 1100 CE, the population of the Phoenix basin was at least 50,000.⁵ There was extensive trade in pottery within the Phoenix basin,⁶ and Hohokam traded widely.⁷ There is evidence of trade with Mesoamerica, such as imported macaw feathers (and birds), copper bells, and cacao.⁸

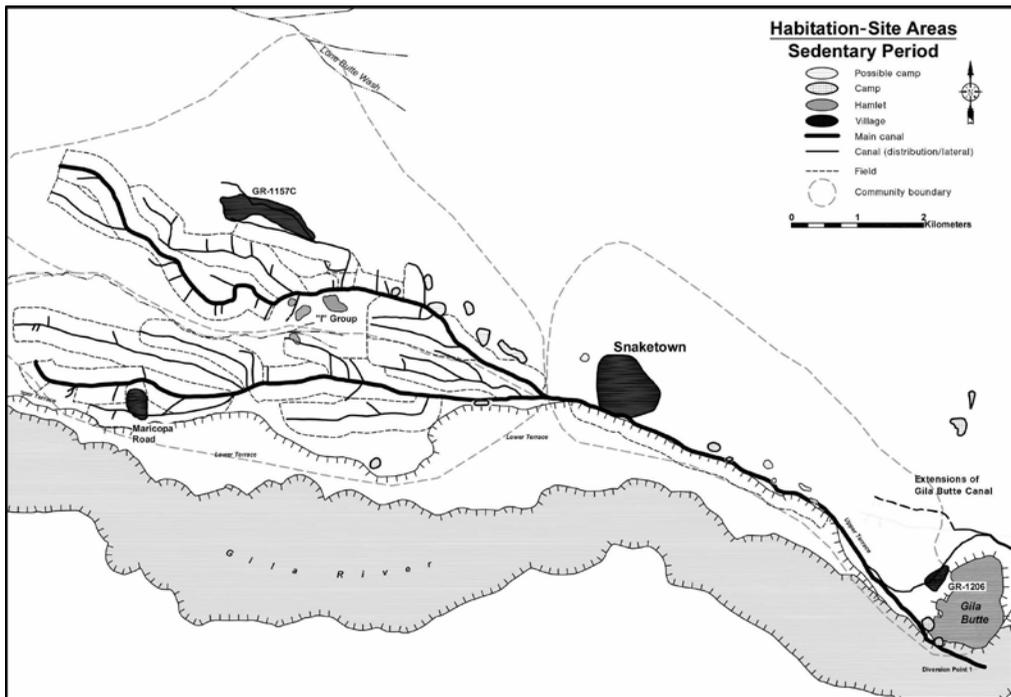
The focus of this study is the settlement and irrigation system known as Snaketown on the Middle Gila River during the Sedentary Period (950–1150 CE). “Snaketown” here refers to both a major settlement and an irrigation system whose main canal bisected the village and whose canals, fields, and hamlets surrounded the settlement (see map 2). There is a large literature on the settlement of Snaketown. The Gladwins and Emil Haury

5 Hunt and Woodson, n.d.

6 Abbott 2009; Abbott, Watts, and Lack 2007.

7 Abbott 2010; Doyel 1991; Hunt 2011; Teague 1997; Vokes and Gregory 2007.

8 Crown and Hurst 2009; Crown et al. 2015; Washburn et al. 2011.



Map 2. Map of the Snaketown irrigation system during the Sedentary Period, showing habitation sites, canals, and fields (from Woodson 2010, 2016).

excavated there,⁹ and Haury produced a massive volume after excavations in the 1960s.¹⁰ Wilcox, McGuire, and Sternberg¹¹ have published a volume examining various aspects of the Snaketown settlement. Ravesloot et al.¹² have presented data on how Snaketown fits into long-term variability of the Gila River. M. Kyle Woodson's dissertation¹³ at Arizona State University summarized and synthesized many years of work at the Cultural Resource Management Program of the Gila River Indian Community on the Middle Gila area with Snaketown at the center. Woodson's dissertation was published as a book in 2016. It includes a detailed examination of both the Snaketown irrigation system and the settlements therein. The Sedentary Period (950–1150 CE)¹⁴ was the time when Snaketown had the most people, the largest amount of pottery trade with the Salt River communities, and two ball courts, and it was arguably the most complex phase of Snaketown's existence.

9 Gladwin et al. 1937.

10 Haury 1976.

11 Wilcox, McGuire, and Sternberg 1981.

12 Ravesloot et al. 2011.

13 Woodson 2010.

14 Woodson 2016, 3.

This article proposes that the primary social system of Snaketown was the irrigation system, not just the main settlement. It is based on an argument presented elsewhere.¹⁵ There was, through centuries, a single main canal. It was of such a size that it must have been unified and managed by a single irrigation community.¹⁶ The Snaketown irrigation system population during the Sedentary Period is estimated at 3,730 people, divided into 746 households (assuming that a household contained five persons).¹⁷ Hunt and Woodson estimated the population of the Snaketown irrigation system, as well as the population of the settlements.¹⁸ The irrigation system population figure for the Sedentary Period is used throughout the simulation of maize production and consumption in this article. This is the first time that an estimate of the population of an irrigation system has been attempted. The effort is based on Woodson's work¹⁹ and would not have been possible otherwise.

The command area of the irrigation system, defined as the area of fields to which a canal system is built to deliver water, is estimated at 1,492 ha.²⁰ Woodson provided two estimates of command area based on the estimated length of lateral canals, a large one and a small one. Originally I chose the small one for simulations, thinking that the conservative choice was more likely to be valid. Once the results of this simulation were available, another reason for choosing the small command area became clear: even the small command area is problematic from the point of view of Snaketown's water supply. The irrigation water supply for Snaketown in the Sedentary Period is so small and unreliable that the large command area becomes improbable.

2. SIMULATION OF MAIZE PRODUCTION

Hohokam farmers raised irrigated maize, beans, squashes, and cotton as their major field crops. Maize is the cynosure of domesticated plants in the prehistoric and historic Southwest. Traditional maize in the Southwest required about 120 days from planting to maturity.²¹ The other crops must have had dietary importance. Unfortunately, however, we know almost nothing of prehistoric and traditional crops other than maize. This simulation is exclusively concerned with irrigated maize.

There is a US Geological Survey river gage at Kelvin, Arizona, just upstream from the Middle Gila Hohokam irrigation systems (USGS 09474000). Daily flow records start in 1912 and continue to the present. However, the flow records for an undammed Middle Gila River cover only the eighteen-year period from 1912 to 1929 because the Coolidge Dam, upstream from the Kelvin gage and with water storage, came online in 1930 (see fig. 2). Still, I know of no other example where daily flow records over a substantial stretch of time come from a location so close to an archaeological site with agriculture, along with many other sets of data.

15 Hunt et al. 2005.

16 Hunt 1988b.

17 Hunt and Woodson, n.d.; Woodson 2016.

18 Hunt and Woodson, n.d.

19 Woodson 2010, 2016.

20 Woodson 2016.

21 Adams et al. 2006.

Graybill and others have published reconstructions of streamflows based on tree-ring analyses.²² I have often been asked why I did not use their estimations of annual flows for this study. The answer is that the annual flows are not relevant for maize agriculture. As Hunt and Ingram have argued,²³ there are two maize crops per year in the Phoenix basin. The first is planted in March and profits from silking water in May. The second is planted in July–August, and the silking water is beneficial in September. The Kelvin gage, with its daily reports, provides data on water supply when it is agriculturally relevant for maize (March, May, July, September). Other field crops have different schedules. For the production simulation offered here, the annual flow estimates are not relevant.

There is another reason for not using the reconstructions of Graybill et al.²⁴ The Gila River basin lies to the south of the Phoenix basin, and the water supply comes largely from the North American monsoon (NAM). Only a handful of tree-ring stations are listed for the Gila River streamflow reconstruction by Graybill et al.,²⁵ and they are located at the northern edge of the Gila River basin. The NAM rainfall occurs primarily to the south, and primarily in the summer. The tree-ring reconstructions of precipitation in the Southwest are derived from a growth signal from the winter rainfall, and that growth occurs in the spring, producing “early wood” rings. The NAM rainfall is primarily in the summer, and any growth signal from the NAM will occur in late summer, producing “late wood” rings. So far, the only published study of a tree-ring summer growth signal is by Stahle et al.,²⁶ for the Malpais in New Mexico. The agriculturally relevant surface water flow in the Gila occurs between March and September, and the summer water is from the NAM. So far, there has been no published attempt to analyze summer growth signals in tree rings in the Gila River basin. Other tree-ring analyses would thus seem to have little to no relevance for understanding the Gila River flows. Huckleberry’s review of what is understood of Southwest climate supports the position taken here.²⁷

Sacaton, Arizona, is 20 km upstream from Snaketown on the Middle Gila River, and it was a location for gathering important environmental data. It was the location of a USDA field station for the first half of the twentieth century (Station 027370). There are publications of environmental data, as well as of the results of agricultural experiments at Sacaton. Daily temperature records (Tmin, Tmax) for Sacaton are available starting in 1908.

2.1. MAIZE PLANTING AND HARVESTING DATES

For nearly a century, it has been argued that two crops of maize were often possible in a solar year.²⁸ The Phoenix basin agricultural calendar is different from that of the higher Colorado plateau, where the last frost occurs in May, rains come in June, and the first frost is in September. Only one maize crop per year is possible on the Colorado plateau. In the

22 Graybill et al. 2006.

23 Hunt and Ingram 2014.

24 Graybill et al. 2006.

25 Graybill et al. 2006.

26 Stahle et al. 2009.

27 Huckleberry 2015.

28 Castetter and Bell 1942; Bohrer 1970; Hunt and Ingram 2007, 2014.

Phoenix basin, the spring crop (cycle 1) was planted in late February/early March and harvested in July. The summer crop (cycle 2) was planted after the harvest of the spring crop, in July/August, and harvested in November.²⁹ The present simulation analysis starts from the results presented by Hunt and Ingram,³⁰ which are based on ethnographic work in the nineteenth and twentieth centuries. An estimated 25 percent (0.5 ha) of irrigated area in each irrigation system was planted in maize in each cycle,³¹ providing about 25 percent of calories. After seeing the results of the simulation, I have come to the conclusion that 25 percent is about right. The reason is that there is not enough water in the river on a reliable basis to plant more land in maize. Occasionally there is, of course. But there is no way to accurately predict the amount of water that will be available. The 25 percent of calories from maize, derived from the ethnographic accounts, was an effective strategy for adapting to the highly variable water supply.

The planting and harvesting dates for maize at Snaketown along the Middle Gila have been articulated with water flow (from the Kelvin gage) and temperature (from Sacaton) from 1912 to 1929. Water supply at Snaketown for each of the thirty-six cycles (eighteen spring plantings, eighteen summer plantings) was estimated in the following way. For the spring planting, the water flow at the Kelvin gage in early March was noted. For each irrigation system down the river (Grewe–Casa Grande, etc.), the command area was estimated, and 25 percent of that command area was allotted to maize (see table 1). A conveyance loss of 50 percent was assumed. Water in the river was subtracted from the total surface flow for the planting needs of each of the systems. Snaketown was the eleventh system (of thirteen) to receive water, and Snaketown was allotted water from the water remaining in the river (see table 1). That water supply could be far greater than needed, just sufficient to supply the need, enough to partially meet the need, or zero. This procedure was repeated for the water for spring silking (May; see table 2), for the summer planting (July–August), and for the summer silking period (September; see table 3). Thus, the water supply of Snaketown for each cycle was estimated based on the supply at Kelvin and subtracting the water taken out of the river by the upstream irrigation systems.³² Only water for maize was calculated. The other field crops (beans, squashes, cotton) would need water as well, but nothing is known of the area planted in those crops, or of the water needs and responses of the traditional Native American landraces.

Tables 2 and 3 show data on the yields of irrigated traditional maizes. The data are from experiment station results in three places in the Southwest (Sacaton, AZ; Albuquerque, NM; and Farmington, NM). The traditional lowland maize landraces have a wide range of responses to water, from 500 kg/ha to 1,900 kg/ha (see table 4).³³

²⁹ Hunt and Ingram 2014.

³⁰ Hunt and Ingram 2007, 2014.

³¹ Hunt and Ingram 2007.

³² As an example, the spring flow in 1912 is presented: 207,932 acre feet passed Kelvin in March, and 4,342 acre feet in May. Between Kelvin and Snaketown, there were ten irrigation systems with a total command area of 4,693 acres (1,899 ha) for maize. By the time the water reached Snaketown, 197,525 acre feet remained in the river, and Snaketown took 2,501 acre feet for its maize lands (922 acres, 373 ha). In May, only 4,342 acre feet were available at the Kelvin gage, and the water was all gone long before it reached Snaketown. Thus, Snaketown in spring 1912 had plenty of water for planting (plus germination and early growth of maize), and no water for the silking period.

³³ See Hunt 2015a for details.

Table 1. Middle Gila Hohokam irrigation systems

Sequence from upstream	Name	Bank	Command area (ha)	Maize area (ha)
1	Grewe–Casa Grande	Left	2,374	594
2	Poston-Escalante	Right	297	74
3	Chee Nee	Right	458	115
4	Blackwater	Left	830	208
5	Sweetwater	Left	457	114
6	Casa Blanca	Left	2,342	586
7	Granite Knob	Right	133	33
8	Santan	Right	1,193	298
9	Sacaton	Left	469	117
10	Gila Butte	Right	660	165
11	Snaketown	Right	1,492	373
12	Riverbend	Left	1,873	468
13	Gila Crossing	Right	203	51
Sum			12,781	3,196

A reasonable question to ask is how many times the maize crop was irrigated. The short answer is that we do not know. What we do know is that in a desert (such as the Phoenix basin), an irrigation at the start of the cycle was crucial.³⁴ It was necessary for germination, as soil moisture was low. We also know that the irrigation at the time of silking had a large effect on maize productivity.³⁵ It would make sense that Snaketown farmers would have irrigated at silking time if there was water. Water supplied to the maize plants at other times may well have been productive. There were probably other irrigations if water was available. It is clear that the first irrigation was sufficient to bring a crop to maturity. It would not yield very much, but it would yield.

³⁴ Castetter and Bell 1942.

³⁵ Hunt 2015a.

Table 2. Water and maize production at Snaketown during spring (cycle 1)

Year	Water leaving Kelvin (acre feet)		Water arriving at Snaketown (acre feet)		Water for Snaketown to use (acre feet)		Maize (ha)	Yield (kg/ha)	Harvest (kg/ha)
	March	May	March	May	March	May			
1912	207,932	4,342	198,425	0	1,540	0	373	1	373
1913	45,805	4,176	36,298	0	1,540	0	373	0	0
1914	9,563	438	56	0	0	0	373	0	0
1915	233,639	72,140	224,132	53,126	1,540	3,080	373	1,900	709
1916	165,804	27,521	156,297	8,507	1,540	3,080	373	1,900	709
1917	44,495	14,963	34,988	0	1,540	0	373	1	373
1918	49,483	2,505	39,976	0	1,540	0	373	1	373
1919	69,618	50,264	60,111	31,250	1,540	3,080	373	1,900	709
1920	84,932	13,524	75,425	12,236	1,540	3,080	373	1,900	709
1921	4,367	953	0	0	0	0	373	0	0
1922	6,827	1,531	0	0	0	0	373	0	0
1923	14,176	427	4,669	0	1,540	0	373	0	0
1924	20,092	15,184	10,585	0	1,540	0	373	1	373
1925	3,364	413	0	0	0	0	373	0	0
1926	31,033	37,484	21,526	18,470	1,540	3,080	373	1,900	709
1927	50,369	3,333	40,862	0	1,540	0	373	1	373
1928	11,660	1,285	2,153	0	1,540	0	373	1	373
1929	2,349	208	0	0	0	0	373	0	0
Sum	1,055,508	250,691	905,503	123,589	20,020	15,400			5,783
Mean	58,639	13,927	50,306	6,866	1,112	856			363

Sources: Kelvin gage; Woodson 2016; hard frost in March 1913, 1923, and 1929.

Table 3. Water and maize production at Snaketown during summer (cycle 2)

Year	Water leaving Kelvin (acre feet)		Water arriving at Snaketown (acre feet)		Water for Snaketown to use (acre feet)		Maize (ha)	Yield (kg/ha)	Harvest (kg/ha)
	July	Sept	July	Sept	July	Sept			
1912	103,999	17,993	94,490	0	1,540	0	373	1	373
1913	11,611	9,895	2,104	0	1,540	0	373	1	373
1914	120,633	53,788	111,126	34,774	1,540	3,080	373	1,900	709
1915	94,095	19,207	84,588	193	1,540	0	373	1	373
1916	14,342	53,003	4,835	33,989	1,540	3,080	373	1,900	709
1917	33,407	10,688	23,900	0	1,540	0	373	1	373
1918	4,533	1,755	0	0	0	0	373	0	0
1919	212,729	31,878	203,282	12,864	1,540	3,080	373	1,900	709
1920	5,664	7,527	0	0	0	0	373	0	0
1921	99,138	23,372	89,631	4,358	1,540	3,080	373	1,900	709
1922	10,000	6,384	493	0	493	0	373	0.5	0.5
1923	47,477	57,304	37,970	38,290	1,540	3,080	373	1,900	709
1924	2,189	421	0	0	0	0	373	0	0
1925	12,251	109,302	3,418	90,288	1,540	3,080	373	1,900	709
1926	5,527	117,096	0	98,082	0	3,080	373	0	0
1927	12,274	54,431	2,767	35,414	1,540	3,080	373	1,900	709
1928	9,871	6,010	364	0	0	0	373	0	0
1929	16,513	30,696	7,006	11,682	1,540	3,080	373	1,900	709
Sum	816,253	610,750	665,974	359,934	18,973	27,720			7,164.5
Mean	45,347	33,931	36,999	19,996	1,054	1,540			

Table 4. Maize yield responses to water

Planting water supply (acre feet)	Flowering water supply (acre feet)	Yield (kg/ha)
0	0	0
0.5	0	500
0.5	0.5	1,000
1.0	0.5	1,200
1.0	1.0	1,400
1.0	2.0	1,900

Source (interpolated): Hunt 2015a, 171, table 5.4.

Hunt's analysis³⁶ presented only the yields derived from experiment stations. No data for Native American traditional irrigated maize farming yields have been found. Given that many experiment station conditions (fertilizer, weed control, water supply) are as close to ideal as possible, it is reasonable to suggest that the experimental yield reports are close to some sort of maximum. Farmers' fields have variable conditions (e.g., wet spots, sandy spots). Farmers' areas planted to field crops are normally much larger than the tiny plots in experiments. It seems reasonable to expect that farmers' yields are variable from field to field, from year to year, and from farmer to farmer and that the farmers' yields are lower than the experimental maxima, but the differences are unknown. Simulation runs at 90, 80, 75, 70, 60, and 50 percent of the experiment station estimated maximum yields are displayed in tables 5 and 6 to illuminate the impact of variable farmer yields.

Estimates of the amount of maize that would be produced given the temperature and water supply conditions for the Snaketown irrigation system were made for each of the thirty-six crop cycles from 1912 to 1929 (eighteen spring cycles, eighteen summer cycles; see tables 5 and 6). There is a total crop failure due to water shortage in fourteen (39%) of the thirty-six cycles over eighteen years.³⁷

³⁶ Hunt 2015.

³⁷ An effort was made to think a way around the shortage of water for planting for the first (spring) cycle. What if there were plenty of water in the Middle Gila in February? Could Snaketown (and other Gila irrigation systems) capture some of that February water at an early date, and store it in the soil? Planting would have to wait for the vegetative signal of the start of the maize-growing season (leafing out of the cottonwood trees). But if water could be stored in the soil, it might be enough to bring in a crop. The question then was the time needed to move water from the Kelvin gage site to Snaketown. Woodson and Arleyn Simon measured the distance from the Kelvin gage to Snaketown's head gate, and the result was 83.6 km. Maurits Ertsen, an irrigation engineer in Delft, The Netherlands, was asked to estimate the amount of time it would take for large February flows to move from the Kelvin gage site to the Snaketown inlet. Ertsen estimates that three days would be sufficient for a flow rate (at Kelvin) of 1 m³/sec or less. My conclusion is that the strategy is plausible but would work only for the first irrigation of the year. I have been unable to think of what kinds of evidence might be available. (Personal communications: Kyle Woodson, Arleyn Simon, and Maurits Ertsen, all in September 2016.)

Table 5. Snaketown maize production, spring (cycle 1) 1912–29 (in metric tons)

Year	100%	90%	80%	75%	70%	60%	50%
1912-1	438	394	350	325	307	263	219
1913-1	0	0	0	0	0	0	0
1914-1	0	0	0	0	0	0	0
1915-1	1,281	1,153	1,025	961	897	769	641
1916-1	1,113	1,002	890	835	779	668	557
1917-1	438	394	350	325	307	263	219
1918-1	438	394	350	325	307	263	219
1919-1	624	562	499	468	437	374	312
1920-1	438	394	350	325	307	263	219
1921-1	0	0	0	0	0	0	0
1922-1	0	0	0	0	0	0	0
1923-1	0	0	0	0	0	0	0
1924-1	438	394	350	325	307	263	219
1925-1	0	0	0	0	0	0	0
1926-1	1,281	1,153	1,025	961	897	769	641
1927-1	438	394	350	325	307	263	219
1928-1	0	0	0	0	0	0	0
1929-1	0	0	0	0	0	0	0
Sum	6,928	6,234	5,539	5,175	4,852	4,158	3,465
Mean	385	346	308	288	270	231	193

2.2. TIME PERIODS FOR ANALYSIS

A number of time periods are available for the analysis.

2.2.1. CYCLE OF FIELD CROPS: 182 DAYS (HALF YEAR)

Daily river-flow records are available for the period 1912–29. There are two cycles of maize production in a year (see tables 5 and 6), and there are temperature and water records for both cycles for eighteen years. The temperature and water conditions vary from cycle to cycle within a year. Because there are data for each cycle, and because maize production is not correlated from one cycle to another, the cycle is used as one time period for estimating maize production.

Table 6. Snaketown maize production, summer (cycle 2) 1912–29 (in metric tons)

Year	100%	90%	80%	75%	70%	60%	50%
1912-2	373	336	298	280	261	224	187
1913-2	373	336	298	280	261	224	187
1914-2	709	638	567	532	496	425	355
1915-2	373	336	298	280	261	224	187
1916-2	709	638	567	532	496	425	355
1917-2	373	336	298	280	261	224	187
1918-2	0	0	0	0	0	0	0
1919-2	709	638	567	532	496	425	355
1920-2	0	0	0	0	0	0	0
1921-2	709	638	567	532	496	425	355
1922-2	0	0	0	0	0	0	0
1923-2	709	638	567	532	496	425	355
1924-2	0	0	0	0	0	0	0
1925-2	709	638	567	532	496	425	355
1926-2	0	0	0	0	0	0	0
1927-2	709	638	567	532	496	425	355
1928-2	0	0	0	0	0	0	0
1929-2	709	638	567	532	496	425	355

2.2.2. SOLAR YEAR: 365 DAYS

Most simulations use the solar year, and most temperate-zone agricultural systems have one seasonal crop per solar year. Hohokam is unusual for the temperate zone and for traditional agriculture in that there are two food crops per solar year. The solar year has therefore been chosen as one of the time periods for analysis. It conforms, in most senses, to other simulations. The maize production from the spring and summer cycles of a calendar year are added to get a yearly sum (see table 7). Likewise, consumption is computed for the same solar year. For the time period of a solar year, maize production, postharvest loss, and maize consumption are calculated.

Postharvest loss can only be estimated. There have been few attempts to measure postharvest loss, either in experimental contexts or in farm contexts. Causes for postharvest loss include fungi, microorganisms, insects, larger animals (mice, birds, deer), and theft.³⁸ For this simulation, the total loss was estimated at 10, 20, 25, 30, 40, and 50 percent (see table 7).

³⁸ See Diehl and Davis 2016 for a recent account.

Table 7. Snaketown maize production by solar year, 1912–29 (in metric tons)

Year	100%	90%	80%	75%	70%	60%	50%
1912	746	671	597	560	522	448	373
1913	373	336	298	280	261	224	187
1914	709	638	567	532	496	425	355
1915	1,082	974	866	812	757	649	541
1916	1,418	1,276	1,374	1,064	993	851	709
1917	746	671	597	560	522	448	373
1918	373	336	298	280	261	224	187
1919	1,418	1276	1374	1064	993	851	709
1920	709	638	567	532	496	425	355
1921	709	638	567	532	496	425	355
1922	0	0	0	0	0	0	0
1923	709	638	567	532	496	425	355
1924	373	336	298	280	261	224	187
1925	709	638	567	532	496	425	355
1926	709	638	567	532	496	425	355
1927	1,082	974	866	812	757	649	541
1928	373	336	298	280	261	224	187
1929	709	638	567	532	496	425	355
Sum	12,947	11,652	10,835	9,716	9,060	7,767	6,479
Mean	719	647	602	540	503	432	360

Postharvest loss in the simulation occurs prior to consumption. There is a possible confusion with regard to the postharvest loss. Given the large number of maize cycles with no production ($N = 14$) and the existence of some consecutive cycles with no production, it is often the case that the maize consumed was produced more than one cycle before. The postharvest loss can be spread over a time period longer than the cycle or year in which it was produced. Therefore, the time period for postharvest loss can be more than a solar year. For the purposes of this simulation, the postharvest loss has been assigned to a single cycle even though that loss can occur over a time period longer than a cycle.

The Snaketown system had sufficient land. There would have been a sufficient population to supply the labor to operate the irrigation system.³⁹ The maize landraces had the potential to give high yields.⁴⁰ However, there were two environmental constraints on maize

³⁹ Woodson 2016.

⁴⁰ Hunt 2015a.

production: water supply and air temperature. Air temperature for the summer maize crop (cycle 2) poses no problem from the point of view of minimum temperature; the spring crop (cycle 1) is another matter. Maize is planted early in March. The twentieth-century temperature records for the Phoenix basin document the occurrence of freezing temperatures sometimes as late as March 27. In the Sacaton data (for 1912–29), three of the eighteen spring cycles saw a hard freeze on March 16 or later (in 1913, 1923, and 1929). I have assumed that the hard freezes would have killed the young maize plants.⁴¹

Water could also be problematic. Both the spring and summer crop cycles had highly variable water supplies, sometimes leading to crop failures. Neither crop cycle was reliable enough to provide maize for the entire Snaketown population. Furthermore, there was not enough water in the Gila River in either the spring or summer to increase the amount of land sown to maize at Snaketown. As a consequence, the double crop cycle was essential for providing maize to the inhabitants.

2.2.3. WET AND DRY YEARS

Upon inspection, it seemed obvious that there were two different sets of years in the eighteen-year run. The time period from 1912 to 1919 had a higher amount of water in the river as compared with the period from 1920 to 1929 (see tables 8 and 9). The wet years had far more water than the dry years in a given month, except for the September dry years. The number of cycles with zero maize production varied substantially (1912–19: $N = 3$; 1920–29: $N = 11$). The estimated maize production in the wet years (eight years, mean 733 mt, 100% yield) is larger than the estimated maize production in the dry years (ten years, mean 608 mt, 100% yield). The number of consecutive periods of zero maize production also varied—for the wet years, there were no sequences of consecutive cycles with no maize production; in contrast, during the dry years, there were two sequences of three consecutive cycles with no maize production (see tables 5 and 6).

Table 8. Gila flows at Kelvin, 1912–29 (in acre feet)

	March	May	July	September
Wet years (1912–19)	826,339	176,349	595,349	198,207
Dry years (1920–29)	229,169	54,342	220,904	412,543

41 Replanting after the last frost would not produce a mature crop, for the germination is delayed and the crop would not mature before the time to plant the summer crop arrived. If this happened, the late spring crop would run over into the planting time of the summer crop. However, not all is necessarily lost. A successful late planting could have resulted in “roasting ears,” immature maize that is cooked and eaten or stored. It is edible, and desired. We have no idea what the timing would be, or what the caloric results would be.

Table 9. Gila flows at Snaketown, 1912–29 (in acre feet)

	March	May	July	September
Wet years (1912–19)	650,283	82,883	524,325	81,820
Dry years (1920–29)	155,220	30,706	141,649	278,114

The pattern of monthly flows is erratic. It is perhaps bimodal, with some months seeing very large flows (>100,000 acre feet) and other months seeing much lower flows (the lowest in these records is 208 acre feet). This is another reason why mean flows are meaningless. The very large flows increase the mean to a meaningless number.

Another question is the agriculturally relevant water that arrives at Snaketown. Here, too, the mean is meaningless, and the law of the minimum is central to understanding.

In general, at Kelvin the wet years provide more water than the dry years by a very large margin. Also, the water supply at Snaketown provides more water in the wet years than in the dry years. If we change focus and ask whether the wet and dry years are different in their supplies of agriculturally relevant water (for maize), the answer is that for three of the months, the wet years are considerably wetter. The exception is September for the dry years (see table 10). September water is useful for raising yields during the silking period. In general, then, the wet years provide more water than the dry years, and sometimes substantially so.

The length of time that cereal grains can be stored in traditional agricultural systems is unknown, but estimates vary from one year to a maximum of three years. For this simulation, I chose three years of storage life. The twentieth-century data display a series of wet years followed by a series of dry years. If this was true in prehistory,⁴² then it would have been impossible for the physical surplus of the wet years to be available for consumption during the entire dry-year period; the population must be provisioned during those dry years in some other way. Thus, the wet and the dry years as time periods are separated for this analysis (see tables 11–13).

Table 10. Gila flows at Snaketown: months with zero water

	March	May	July	September
Wet years (1912–19)		5 (63%)	1 (13%)	4 (50%)
Dry years (1920–29)	4 (40%)	8 (80%)	3 (30%)	4 (40%)

⁴² Suggested by Ravesloot et al. 2011.

Table 11. Snaketown wet years (1912–19): mean maize available per year (in kilograms)

		Postharvest loss percentage, and mean yearly production (N = 8)							
% of maximum yield	Maize total	10%		20%		30%		50%	
		Maize	Mean	Maize	Mean	Maize	Mean	Maize	Mean
100	6,865	6,179	772	5,492	687	4,806	601	3,433	429
90	6,179	5,561	695	4,843	605	4,325	541	3,090	386
80	5,492	4,943	618	4,394	549	3,844	481	2,746	343
75	5,149	4,634	579	4,119	515	3,604	451	2,575	322
70	4,806	4,325	541	3,845	481	3,364	421	2,403	300
60	4,119	3,703	463	3,295	412	2,883	360	2,060	258
50	3,433	3,090	386	2,746	343	2,403	300	1,717	215

Table 12. Snaketown dry years (1920–29): mean maize available per year (in kilograms)

		Postharvest loss percentage and mean yearly production (N = 10)							
% of maximum yield	Maize total	10%		20%		30%		50%	
		Maize	Mean	Maize	Mean	Maize	Mean	Maize	Mean
100	6,082	5,474	547	4,866	487	4,257	426	3,041	304
90	5,474	4,927	493	4,379	438	3,832	383	2,737	274
80	4,868	4,381	438	3,894	389	3,408	341	2,434	243
75	4,562	4,106	411	3,650	365	3,193	319	2,281	228
70	4,257	3,831	383	3,406	341	2,980	298	2,129	213
60	3,649	3,284	328	2,919	292	2,554	255	1,825	183
50	3,041	2,737	274	2,433	243	2,129	213	1,521	152

Table 13. Usable maize in Snaketown: percentage yield and percentage loss, by wet and dry years (in kilograms)

	75% yield	-30% loss	Remainder	Mean	50% yield	-50% loss	Remainder	Mean
Wet years (1912–19)	5,149	1,545	3,604	451 (N = 8 years)	3,434	1,717	1,717	215
Dry years (1920–29)	4,562	1,369	3,193	319 (N = 10 years)	3,041	1,521	1,522	152

3. SIMULATION OF MAIZE CONSUMPTION

The consumption of maize by the Snaketown population is estimated. Maize is needed for food, seed, and ceremonies. Two values of calories per capita per day were run: 2,000 and 2,500 (see tables 14 and 15). The smaller value is supposedly closer to caloric minima. The agricultural year extends from February to November, the work is often arduous, and it is hot from June until September. Men, women, and adolescents work hard most of the year. The higher value of 2,500 cal/cap/day feels more realistic than the lower value. The other variable for consumption is the percentage of calories derived from maize. Our food production calendar analysis reported that maize provided 25 percent of daily calories.⁴³ That was the starting point for the simulation. A total of 25 percent of calories from the staple grain seems very low, so the percentage of calories from maize was varied upward to 50 percent to explore the effect of the variation.

I have no empirical evidence for seed needs for maize for the Phoenix basin. The seed-to-yield ratio for maize runs up to 1:400, far larger than for any other major cereal crop—rice is often estimated at 1:20, for example. The maximum harvest is estimated at 1,900 kg/ha, and each household is operating an estimated 0.5 ha of maize. At a ratio of 1:400, it would require about 5 kg of maize seed per planting. Some seeds would not germinate. An estimate of 10 kg/ha of seed is not unreasonable. I took a guess that 10 kg would be enough seed for two plantings. Even if 20 kg were needed, the difference is trivial.

Ceremonial needs are also guesses, as there are no data. Wolf⁴⁴ thought that a ceremonial fund was necessary for farming households. I agree, though I know of no empirical studies of ceremonial needs spread over years. I guessed 10 kg. Even if that number rose to 20 kg, it would have only a small effect on the results.

⁴³ Hunt and Ingram 2014.

⁴⁴ Wolf 1966.

Table 14. Snaketown maize consumption rates, 2,000 cal/cap/day⁴⁵

	25% of calories	30% of calories	35% of calories	50% of calories
Calories/capita/day of maize	500	600	700	1,000
Household need for kg/day	0.7 kg	0.9 kg	1.0 kg	1.4 kg
Household need for kg/cycle	127 kg	164 kg	182 kg	255 kg
Seed fund	10 kg	10 kg	10 kg	20 kg
Ceremonial fund	10 kg	10 kg	10 kg	10 kg
Total household demand per cycle	147 kg	184 kg	202 kg	285 kg
Total for all households per cycle	110 mt	137 mt	151 mt	213 mt
Total for all households per year	220 mt	274 mt	302 mt	426 mt

Table 15. Snaketown maize consumption rates, 2,500 cal/cap/day

	25% of calories	30% of calories	35% of calories	50% of calories
Calories/capita/day of maize	625	750	875	1,250
Household need for kg/day	0.89 kg	1.07 kg	1.25 kg	1.8 kg
Household need for kg/cycle	162 kg	195 kg	228 kg	328 kg
Seed fund	10 kg	15 kg	20 kg	20 kg
Ceremonial fund	10 kg	10 kg	10 kg	10 kg
Total household demand per cycle	182 kg	220 kg	258 kg	358 kg
Total for all households per cycle	136 mt	164 mt	192 mt	267 mt
Total for all households per year	272 mt	328 mt	384 mt	534 mt

4. SIMULATION OF MAIZE STORAGE

Only minute amounts of maize were consumed immediately after harvest. Most harvested maize was stored for consumption days or years later. Therefore, maize storage is an important part of this account. There is substantial food storage in the Phoenix basin.⁴⁶ Maize

⁴⁵ Population = 3,730; five-person households = 746; command area = 1,492 ha; area planted to maize – 25% of command area (Hunt and Ingram 2007) = 373 ha; household need for kg of maize = five persons × calories, proportion of 3,500 cal/kg; household need for kg of maize per cycle = 182 days. Same quantities used for table 15.

⁴⁶ Hunt 2012.

can be stored in the field (for months) or in storage structures (on the cob or as kernels). It can be processed in a number of ways. As noted above, I have assumed that the upper limit for maize storage is three years. In consequence, maize consumption is affected not only by the maize yield of the previous planting but also by the storage activity of the past three years. Tables 16 and 17 present the results of maize production, consumption, and storage for the years 1912 to 1929.⁴⁷

Table 16. Maize production, consumption, and storage (50% of maximum production, 50% loss, 2,000 cal/cap/day, maize is 25% of calories) (in metric tons)

Year	Old maize in storage	New maize	Year's consumption	End of year	Yearly excess (new maize plus consumption)	Yearly deficit (new maize minus consumption)
1912	220	191	-220	191		-29
1913	191	94	-220	65		-126
1914	65	178	-220	23		-42
1915	23	271	-220	74	51	
1916	74	355	-220	209	135	
1917	209	187	-220	176		-33
1918	176	94	-220	50		-126
1919	50	355	-220	185	135	
1920	185	178	-220	143		-42
1921	143	178	-220	101		-42
1922	101	0	-220	0		-220
1923	0	178	-220	0		-42
1924	0	94	-220	0		-126
1925	0	178	-220	0		-42
1926	0	178	-220	0		-42
1927	0	271	-220	51	51	
1928	51	94	-220	9		-126
1929	9	178	-220	0		-42
Sum		3,252	3,960		372	1,080

Note: Deficit (yearly consumption minus yearly new maize) is 708 mt, or 39 mt/year. 39 mt = 18% of daily consumption (220 mt).

⁴⁷ Storage data under these circumstances are very complicated. Each year contains new maize and maize in three-year classes from the past. Maize in storage that is beyond three years must be discarded. I have chosen not to present those complications, as they do not appear to be germane to the argument.

Table 17. Maize production, consumption, and storage (75% of maximum production, 30% loss, 2,500 cal/cap/day, maize is 25% of calories) (in metric tons)

Year	Old maize in storage	New maize	Year's consumption	Yearly excess (new maize plus consumption)	Yearly deficit (new maize minus consumption)
1912	272	392	272	188	
1913	392	196	272		76
1914	316	372	272	100	
1915	416	568	272	296	
1916	712	745	272	473	
1917	1,185	392	272	100	
1918	1,305	196	272		76
1919	1,229	745	272	473	
1920	1,702	372	272	100	
1921	1,802	372	272	100	
1922	1,902	0	272		272
1923	1,630	372	272	100	
1924	1,730	196	272		76
1925	1,654	372	272	100	
1926	1,754	372	272	100	
1927	1,854	568	272	296	
1928	2,153	196	272		76
1929	2,077	372	272	100	
Sum		6,798	4,896		
Mean		378			

I have presented two scenarios for storage. One is based on 50 percent of yield and 50 percent postharvest loss. It is likely at the low end of maize availability. The wet years provide more than enough maize. The dry years ($N = 10$), on the other hand, show two years without any local maize to eat. When (and if) these assumptions are valid, food supply would have been precarious. The other scenario is based on 75 percent of yield and 30

percent postharvest loss. This condition is optimistic but not unreasonable, and it could have been matched by reality with some frequency. The wet years of this scenario provide a very large amount of maize, up to eight years of consumption in storage at any one time. The dry years are not as prolific but still provide locally grown maize every year.

How much maize was available to feed the Snaketown population? The results of the simulation were unanticipated (see tables 18–20). The consumption rates in tables 14 and 15 were compared with production rates from tables 5 and 6 (the dry years, all in yearly terms). The wet years provide plenty of maize (see table 19). The wet-year production of maize would support the population at a high maize level (50% of calories, at a postharvest loss rate of 30% and a yield of 70% of maximum).

The dry years are less productive than the wet years and are therefore the most important. Table 20 reveals that minimal consumption needs are not met with 50 percent of maximal yield and 50 percent or 30 percent postharvest loss. At the consumption rate of 2,000 cal/cap/day, 60 percent, 70 percent, and 75 percent yield plus 30 percent loss all allow for consumption. If we use the 2,500 cal/cap/day consumption rate, needs are met only if yields are 70 percent or higher. Table 16 shows that at 2,000 cal/cap/day consumption and 50 percent yield with 50 percent loss, the dry years provide only a small proportion of consumption needs. Much higher yields, and lower loss rates, are needed to produce a reliable amount of maize for consumption.

Eventually, solid data on postharvest loss may be produced. Because traditional irrigated maize farming in the Phoenix basin is nearly extinct, it may not be reasonable to hope for data on farmer yields in the future. At least the outlines of the problems facing this kind of analysis are clear.

Table 18. Harvests of maize, consumption, and surplus, all years (1912–29)

Yield	Yield (mt)	Mean (mt)	Consume 2,000 cal (220 mt)	25% surplus (175 mt)	50% surplus (331 mt)	Consume 2,500 cal (275 mt)	25% surplus (344 mt)	50% surplus (413 mt)
75% 30%	6,801	378	Yes	Yes	Yes	Yes	Yes	No
70% 30%	6,342	352	Yes	Yes	Yes	Yes	Yes	No
60% 30%	5,437	302	Yes	Yes	No	Yes	No	No
50% 30%	4,535	252	Yes	Yes	No	No	No	No
60% 50%	3,884	216	No	No	No	No	No	No
50% 50%	3,240	180	No	No	No	No	No	No

Note: In leftmost column, first number is percentage of maximum yield, and second number is percentage postharvest loss.

Table 19. Harvests of maize, consumption, and surplus, wet years (1912–19)

Yield	Yield (mt)	Mean (mt)	Consume 2,000 cal (220 mt)	25% surplus (175 mt)	50% surplus (331 mt)	Consume 2,500 cal (275 mt)	25% surplus (344 mt)	50% surplus (413 mt)
75% 30%	3,604	451	Yes	Yes	Yes	Yes	Yes	Yes
70% 30%	3,364	421	Yes	Yes	Yes	Yes	Yes	Yes
60% 30%	2,883	360	Yes	Yes	Yes	Yes	Yes	No
50% 30%	2,403	300	Yes	Yes	Yes	Yes	No	No
60% 50%	2,060	258	Yes	Yes	No	No	No	No
50% 50%	1,717	215	No	No	No	No	No	No

Note: In leftmost column, first number is percentage of maximum yield, and second number is percentage post-harvest loss.

Table 20. Harvests of maize, consumption, and surplus, dry years (1920–29)

Yield	Yield (mt)	Mean (mt)	Consume 2,000 cal (220 mt)	25% surplus (175 mt)	50% surplus (331 mt)	Consume 2,500 cal (275 mt)	25% surplus (344 mt)	50% surplus (413 mt)
75% 30%	3,193	319	Yes	Yes	No	Yes	No	No
70% 30%	2,980	298	Yes	Yes	No	Yes	No	No
60% 30%	2,554	255	Yes	Yes	No	No	No	No
50% 30%	2,129	213	No	No	No	No	No	No
60% 50%	1,825	183	No	No	No	No	No	No
50% 50%	1,521	152	No	No	No	No	No	No

Note: In leftmost column, first number is percentage of maximum yield; second number is percentage post-harvest loss.

During the Phoenix basin dry years, there should be less mesquite, fewer rabbits, and fewer fish because of less water and increased hunting/gathering pressures. Snaketown may be trading for maize, but then the production and consumption conditions of those who are providing the traded maize have to be accounted for. One way to explore the possibility would be a simulation of maize production, postharvest loss, and consumption for the entirety of the Middle Gila Hohokam during the Sedentary Period. A Middle Gila simulation of maize production is possible. A simulation of maize consumption is less likely because we have far fewer data on population size for the whole of the valley than we do for Snaketown.

Given the level of trade in pottery between Snaketown and the Salt River valley Hohokam, a simulation of maize production and consumption for the Salt River valley would be desirable. That simulation is not possible at this time. We do not have data on three crucial variables: intra-annual water supply variability in the river over time, command area for irrigation systems, and population of irrigation systems.

This simulation started with Hunt and Ingram's statement⁴⁸ that the Pima population consumed 25 percent of its calories from maize. During the nineteenth century CE, they also grew substantial amounts of winter wheat. Dave Abbott raised the question of the impact of wheat on consumption.⁴⁹ Winter wheat was added to the Pima food system after the arrival of the Spaniards. By the 1860 Agricultural Census, it is clearly well established.⁵⁰ Wheat products were consumed by the Pima⁵¹ but made an unmeasured and unknown contribution to the local diet. Doelle⁵² charts the rapid growth of wheat production in the nineteenth century, driven in (large?) part by US military needs (men, horses). Doelle and Rea⁵³ are clear that the Pima's wheat was grown during the winter and on dedicated land. It was sown in November and December, after the other field crops had been harvested. It needed little attention during the winter. Harvesting took place in May, after the summer field crops were sown. Therefore, the production of wheat took no land, no water, and only some labor (the amount is unknown) from the other Mesoamerican field crops being produced. Undomesticated resources were widely used, especially the mesquite tree pods and various cacti, but they are also unmeasured.

A maize consumption rate of 25 percent of calories for the period before the availability of wheat poses a problem: Where are the rest of the calories in the diet to be found? If 25 percent of calories are from maize and 50 percent are from undomesticated species, then 25 percent of the calories are not accounted for. The other Mesoamerican field crops are beans, squashes, and cotton. A substantial number of calories are missing: 625 cal/cap/day if one assumes a daily diet of 2,500 calories. Even at 2,000 cal/cap/day, 500 cal/cap/day are missing. Those missing calories are a puzzle, and a problem. They are not being supplied by maize grown at Snaketown. There is not enough water in the river to increase the area planted to maize, and there is not enough water in the river to increase the production of maize during the dry periods. If it is unreasonable to assume high yields (80% of maximum or higher) or low postharvest loss (less than 30%), then there appears to be a substantial nutrition gap. 25 percent seems a very low number for an upper limit of the grain staple. We are missing a substantial source of nutritionally dense foods for Snaketown. The simulation suggests that maize grown in Snaketown was not that source.

The simulation presented here suggests that in the dry years, the simulated maize production system would provide, on occasion, less than a minimal maize supply for the Snaketown population. Small changes in assumptions could generate an estimation of maize

48 Hunt and Ingram 2014.

49 David Abbott, personal communication.

50 US Census 1864.

51 Rea 1997.

52 Doelle 2002, 65.

53 Doelle 2002; Rea 1997.

supply that is further below assumed needs. The Snaketown maize system, at least during dry years, could well be close to the margin of subsistence, and even below it from time to time.

5. THE QUESTION OF SURPLUS

The question posed at the beginning of this study was food surplus. There are at least two forms of food surplus, physical and institutional.⁵⁴

5.1. PHYSICAL SURPLUS

A physical surplus (of grain) is in addition to that grain needed to provision the producers and their families for a solar year. Grain yield at a particular harvest may be more than, equal to, or less than normal annual consumption. Most of the grain harvested will of necessity be stored, and storage does not mean that the grain is surplus. The stored grain is dedicated to planting in the future (seed) and to provisioning the agricultural population in the (near) future. Postharvest loss is inevitable. Physical surplus is unpredictable and may not be realized in any given year or sequence of years.

5.2. INSTITUTIONAL SURPLUS

Food that is destined for non-food producers (elites, specialists, traders, pilgrims) and that is transferred at some point from the agricultural sector (producers) to the other consumers is institutional surplus. It must be produced and transferred regularly if social complexity is to be sustained. The institutional food surplus must be produced by some agricultural sector and is in addition to the consumption needs of that agricultural sector. Food surplus in a complex society is the institutional surplus, not the physical surplus.⁵⁵

How do we estimate the amount of maize that would be sufficient for an institutional surplus? A surplus of 25 percent and 50 percent of production has been adopted here. Renger suggests a surplus for southern Mesopotamia of 35 percent to 40 percent,⁵⁶ or even 50 percent,⁵⁷ without evidence. A surplus of 50 percent of maize production for Snaketown in the dry years is inconceivably large. It would be illuminating to have real numbers for the surplus production percentage of southern Mesopotamia. The concept of an institutional surplus does not usually suggest amounts that are a bare minimum of subsistence. Rather, we ordinarily assume that a food surplus exists in abundance. Surely 25 percent or even 50 percent is a likely target for institutional surplus? Scholars investigating states, and particularly early states, should take a close look at the amount, and variability, of agricultural surplus.

⁵⁴ Hunt 2012.

⁵⁵ Hunt 2012.

⁵⁶ Renger 2016, 29.

⁵⁷ Renger 2016, 24 n. 12.

5.3. SNAKETOWN INSTITUTIONAL SURPLUS

David Abbott has long analyzed pottery and space in the Phoenix basin. He has found evidence that leads him to conclude that marketplace exchange, focused on ball courts, was present during the Middle Sedentary Period. He argues that three conditions supported the growth of marketplace exchanges in the Phoenix basin during the Middle Sedentary Period: integration through shared beliefs, surplus production of irrigated crops, and an emphasis on specialized production.⁵⁸

Abbott therefore expects to find surplus production of food and cotton in the Sedentary Period. He is of the opinion that surpluses were probably present in the Salt River basin, but not in the Gila River basin. The basis for this claim is the differential results of tree-ring analysis.⁵⁹ Salt River flows showed little variability and few floods for the Sedentary Period. The Gila flows, on the other hand, were more erratic. Abbott states clearly that there are no studies examining surplus production.

This chapter is a study of Snaketown production of maize and food surplus during the Sedentary Period. It claims that, based on flows in the Gila at the Kelvin gage from 1912 to 1929, there was a wet period of eight consecutive years and a dry period of ten consecutive years. During the dry period, little surplus of maize was possible (see table 20). If one assumes that this pattern can be generalized to the Middle Gila River in the Sedentary Period of prehistory, then a reliable institutional surplus of maize was improbable. Abbott's suggestion about the Gila River surplus is supported.

Snaketown was exporting pottery to the Salt River basin during the first half of the Sedentary Period. If it is true that a Snaketown maize surplus was not possible on a regular basis, then it follows that a Snaketown maize surplus relied on an import of maize. The maize imported to Snaketown must have come from somewhere. Given the problems of transporting maize, it probably had to come from within the Phoenix basin. Two plausible sources exist. At the upstream end of the Middle Gila River, there were irrigation systems with a high and regular supply of water (Grewe–Casa Grande is the obvious case). The Salt River basin is also a prime candidate. Support for this supposition about sources of maize must be based on empirical studies of maize production somewhere in the Phoenix basin, and on trade patterns. This chapter argues that Snaketown was not a likely source of surplus maize (see tables 18–20).

Looking at the supply of maize during the dry years of our simulation, it is obvious that no substantial institutional surplus of maize would be possible. For a complex society, an institutional surplus must be present during all (or almost all) years, not just the good ones. And for Snaketown, if it is not possible during all or most of the dry years, it is not possible at all. For Snaketown during the dry period, a maize surplus does not seem to be likely under most of the conditions that have been simulated.

58 Abbott 2010, 80–81.

59 Graybill et al. 2006.

Conclusions from these numbers are heavily reliant on assumptions, particularly on the assumed yield percentage of maximum.⁶⁰ We cannot conclude that a maize surplus at Snaketown would have been impossible. However, optimistic assumptions about yields and postharvest losses are clearly necessary to conclude that a food surplus of maize was likely in the dry years.

6. NEW DIRECTIONS?

These results have implications for irrigation's role in early states. These results raise a number of questions about agricultural economies with irrigation.

6.1. WATER SUPPLY FROM RIVERS

I propose that we normally assume that for complex societies on major perennial rivers, the water supply is at least equal to (the often rising) demand. At issue are the amount of water in the river, the variability of the river's flow regimes, and the demand for river water. The Snaketown case study suggests that this question receive a careful, thorough, and empirical investigation for each river providing irrigation water. The placement along the river of the individual irrigation systems must be taken into account. Although river floods often receive attention,⁶¹ low flows in rivers may be even more important. The Snaketown data on river flows, in the context of demands for food, argue that low flows are of great importance for the economy. This suggests that for riverine societies, one should not assume that a river can supply the water needed to grow and sustain the economy.

The combination of a river and associated alluvial soils may be able to support growth. Many riverine states seem to expand their territories. It would be worth investigating whether this expansion accomplishes an increase in agricultural production by bringing new areas under irrigation. If that increase occurs, it implies a sufficient supply of water from the river(s).

Agricultural production systems are always and everywhere faced with variable water supply. The variant called "floods" is widely acknowledged. The other variant is "drought." Low water supply in the form of low river flow was important for Snaketown and deserves focused attention for other river systems. In addition, intra-annual variability, and the water amounts, need to be understood because they can constrain food production and food surplus.

Let us briefly consider this problem from the other direction. If an agricultural economy in an arid riverine environment is growing over a long time span (centuries), then perhaps it can be assumed that the water supply and the landraces are sufficient to provide for that growth.

⁶⁰ I have kept track of the assumptions used in this analysis. So far, thirty-four have been found.

⁶¹ See Woodson 2015.

6.2. LANDRACE RESPONSES TO WATER

The irrigated maize landraces in the Southwest had a large range of responses to water.⁶² This permits buffering of the impact of variability of river flow. This plant characteristic should be investigated for grain staples (wheat, barley, rice, millet) irrigated in other parts of the world.

6.3. FOOD SURPLUS

By the definition of food surplus proposed here, the simulation of Snaketown maize production and consumption suggests that Snaketown had no reliable institutional food surplus. There were, on some occasions, physical surpluses, but they were far from guaranteed. A complex society has to have a reliable physical surplus of food. How variable can the supply of institutional surplus be? And if the supply of grain is as variable as it apparently was in Snaketown, and if the institutional surplus is set as a constant, where do the calories for the producers come from? Are they able to accumulate a physical surplus that will not be swept up by the elite and still provision them reliably? What is the level of calorie consumption by the producers that, at the low end, is able to sustain production?

These considerations suggest a hypothesis for examining the economic effects of irrigation on early state formation. IF irrigation is to be economically important for an early state, THEN the supply of water must be sufficiently reliable in amount and timing to meet the demand. Water amount and variability are central to the process. IF there is insufficient water, THEN food production is low; food surplus is low or limited; and social, economic, and population growth are constrained. This case study supports the idea that the details of river flow are very important and deserve a careful analysis.

Institutional food surplus is necessary for an early state. Irrigation does not guarantee an institutional food surplus. One needs to understand the supply of water, the water responsiveness of the major landraces, and the demand for water. The details matter.⁶³

7. SUMMARY AND CONCLUSION

Snaketown, a Neolithic culture with a large irrigation system, provides insight into the conditions for early state formation involving canal irrigation. The simulation of maize production for Snaketown suggests that even with irrigation, a maize surplus was not guaranteed. Given sufficient water and responsive landraces, irrigation provides intensification of agriculture by raising the productivity of agricultural land and labor. If there is sufficient land, then the population and the economy can grow. But if water is not sufficient, or if the landraces do not yield enough, then however much the productivity of labor

⁶² See Hunt 2015b for an example.

⁶³ I am fully aware of the amount and quality of data available for Snaketown. Both are very high. The internal validity of this study is consequently rather high. The external validity is uncertain but is probably low. How many other prehistoric (or indeed historic) cases exist, even potentially? My suspicion is that there are very few. River flows at the level of daily observations over years are a main constraint on extending the Snaketown study to other places and times. Another constraint is knowledge about the phenology of traditional grains.

rises, the food surplus will not occur reliably (amount, timing). Early states must have available the necessary and reliable food surplus. Irrigation is one input that can contribute to that food surplus but does not guarantee it.

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9

“Opener of Canals, Provider of Abundance and Plenty”: Royal Investment in Large-Scale Irrigation in Second-Millennium BCE Upper Mesopotamia¹

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“Opener of canals, provider of abundance and plenty for his people”²

THESE WERE TWO of the titles claimed by Yaḥdun-Lîm, king of the Middle Euphratean city-state of Mari (Syria) in the nineteenth century BCE. By using these titles, he set himself within a long-lasting tradition. From mid-third-millennium Sumerian city-rulers to late first-millennium Babylonian emperors, Mesopotamian royal inscriptions celebrated waterworks among the kings’ most notable deeds and pictured rulers as the source of wealth and abundance in their lands through irrigation. In spite of their heavily ideological function, such boasts must be taken seriously; archaeology attests that massive investments in irrigation did create devices able to drastically alter the agrarian potential of entire regions.³ Yet, the scale and nature of these investments varied to a great extent in time and space, depending first and foremost on the king’s capacity to mobilize a taskforce. In Upper Mesopotamia, the massive canals and aqueducts of first-millennium BCE Assyria and later periods (down to Islamic times) dominate the archaeological record, casting a shadow over older, poorly documented waterworks of the third and second millennia.⁴

Cuneiform tablets retrieved from ancient administration centers can, however, help us understand how large-scale irrigation developed in the area. Dealing with daily problems

1 The present essay is an expanded version of my presentation at the twelfth annual Oriental Institute Seminar “Irrigation in Early States: New Directions” in March 2016. It is my pleasure to thank here Stephanie Rost for inviting me to participate in the seminar and for her continuous efforts in making this publication possible. Abbreviations in the footnotes are used for textual references and follow the standard practice in Assyriology, as presented on the website <http://www.archibab.fr> and in the guidelines of the *Reallexikon der Assyriologie und Vorderasiatischen Archäologie* (<http://www.rla.badw.de/Reallexikon/>).

2 RIME4.6.8.2 (inscribed bricks of the Šamaš temple): (17) ¹*ia-aḥ-du-un-li-im* (18) DUMU *ia-gi-id-li-im* (19) LUGAL *ma-ri^{ki} ù ma-at ḥa-na* (20) *pé-ti I₇.DA.ḪIA* (21) *e-pí-iš du-ri* (22) *mu-re-ti na-re-e na-bi šu-mi* (23) *ša-ki-in nu-uḥ-ši-im* (24) ù ḪĒ.GĀL-*lim a-na ni-ši-šu* (25) *mu-ša-ab-ši mi-im-ma šum-šu* (26) *i-na ma-ti-šu* (21) LUGAL *dan-nu-um eṭ-lu-um šu-pu-um*: “Yaḥdun-Lîm, son of Yaggid-Lîm, king of Mari and the land of nomads, opener of canals, builder of walls, erector of steles proclaiming (his) name, provider of abundance and plenty for his people, who makes whatever (is needed) appear in his land, mighty king, magnificent youth” (translation slightly modified from Frayne 1990, 605).

3 Wilkinson 2003, 71–99.

4 Cf. *inter alii* Ergenzinger et al. 1988; Berthier 2001; Ur 2005; Reculeau 2018a.

of water and agrarian management, administrative letters and documents offer an alternative view, less ideologically biased than that of royal inscriptions. They allow for a partial reconstruction of the rulers' actual investments in irrigation, and of their outcome. This essay focuses on two well-documented archives, both recovered in the eastern part of Syria: the first one in the royal palace of the Amorite kingdom of Mari (nineteenth–eighteenth centuries BCE), the other one in the provincial Middle Assyrian administrative center of Dūr-Katlimmu (thirteenth–twelfth centuries BCE), both areas located outside of the zone of dry farming, and even outside of the zone of marginal cultivation where dry farming is possible in good years, albeit risky.⁵ Agriculture was thus only possible in the valleys of perennial rivers, where water was available for irrigation.

In the following pages, I offer a survey of the available evidence and evaluate the inputs and outputs of palace-organized irrigation in the valleys of the Euphrates and Ḥābūr Rivers. Inputs include labor requirements for canal digging and maintenance on the one hand, and for agricultural production on the other hand. Outputs can be estimated on the basis of agricultural yields.

1. LABOR REQUIREMENTS FOR CANAL DIGGING AND MAINTENANCE

1.1. EVIDENCE FOR ROYAL INVESTMENT IN IRRIGATION

Royal investment in irrigation is a commonplace topic in Mesopotamian celebratory inscriptions. In Mari, irrigation works are known from the inscriptions of Yaḥdun-Lîm, at the end of the nineteenth century BCE. Besides the above-mentioned titles, found on the bricks of the Šamaš temple, he celebrates the erection of a new fortress bearing his name, which was accompanied by the digging of a canal that also bore his name. Both are known from his so-called Disc Inscription—located on the head of a massive clay nail:⁶

I opened canals and did away with the drawing of water in my land [follows a mention of the building of the city-walls and of the digging of the moats of the two main cities of the kingdom, Mari and Terqa]. Now in a waste, a land of thirst, in which from days of old no king had built a city, I took pleasure in building a city. I dug its moat and called it Dūr-Yaḥdun-Lîm (“Fort-Yaḥdun-Lîm”). I opened a canal for it and called it Išîm-Yaḥdun-Lîm (“Yaḥdun-Lîm has determined its destiny”).

5 Wilkinson 2004, 13–17, 40–47; Reculeau 2011, 16–17.

6 RIME4.6.8.1 (‘Disc’ Inscription): (26) *na-ra-a-tim* (27) *ú-pé-et-ti* (28) *da-la-a-am* (29) *i-na ma-ti-ia* (30) *ú-ḥa-al-li-iq* [. . .] (35) *ù i-na sa-we-e* (36) *qá-qá-ar* (37) *na-aš-mi-im* (38) *ša iš-tu u₄-um sí-a-tim* (39) LUGAL *šum-šu* (40) *a-lam la i-pu-šu* (41) *a-na-ku la-la-am* (42) *ar-ši-i-ma* (43) *a-lam e-pu-úš* (44) *ḥi-ri-sú aḥ-ri* (45) BĀD-*ia-aḥ-du-li-im* (46) *šum-šu ab-bi* (47) *ù na-ra-am ep-te-šum-ma* (48) I, *i-ši-im-ia-aḥ-du-li-im* (49) *šum-šu ab-bi* (translation by Frayne 1990, 603). The translation of the verb in l. 30 is debated: the traditional reading *uḥalliq* (D-stem of *ḥalāqum*), “I did away,” suggests that the king claims to have replaced well irrigation (drawing water from the water table) with canal irrigation (drawing water from the Euphrates River). However, as J.-M. Durand (1990, 128) points out, well irrigation is still well attested in the area some decades later, on the lands called *dalūwātum*, so in the best of cases, Yaḥdun-Lîm is boasting here—not an unusual practice in celebratory inscriptions. Durand (2002, 566 n5) has suggested an alternative reading of the verb as *‘ulluqum*, meaning “to suspend,” which would in fact imply that the king celebrates both the digging of a canal and the establishment of well irrigation. To my knowledge, however, this verb has no parallel in the Akkadian record.

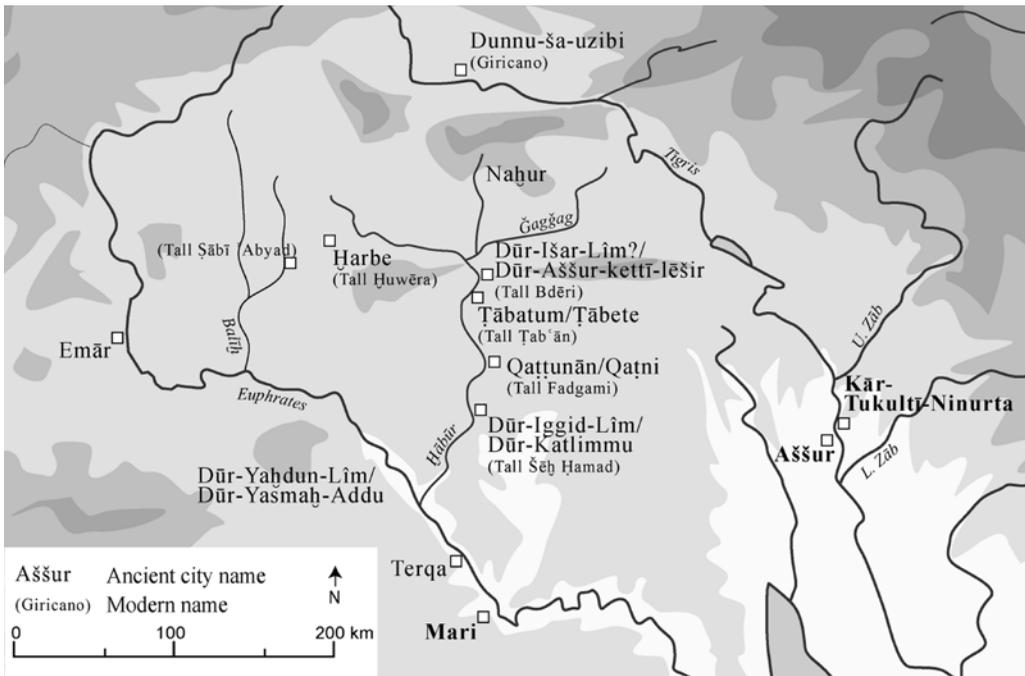


Figure 1. Map of Upper Mesopotamia (nineteenth–twelfth centuries BCE), with places mentioned in the text (based on a map by M. Sauvage).

This inscription is quite unique for the Middle Euphrates region in the early second-millennium BCE. Neither Samsī-Addu, the king of Ekallātum who put an end to the existence of Mari as an independent kingdom in 1792 BCE,⁷ nor his son Yasmaḫ-Addu (1787–1775 BCE), whom he later installed on the Mari throne,⁸ left inscriptions related to irrigation works in the corpus of, respectively, fourteen and four inscriptions that have been preserved from their reigns. The same applies to Yasmaḫ-Addu’s follower on the throne of Mari, Zimri-Līm (1775–1762 BCE), a member of Yaḫdun-Līm’s dynasty for whom we know of only three dedicatory inscriptions.⁹ Even in the third millennium BCE, only one short inscription from Mari (of nine preserved inscriptions)¹⁰ relates to waterworks, that of the city ruler (*šakkanakkum*) Ilum-išar (2084–2072 BCE).¹¹ The situation is comparable in other

7 Charpin and Ziegler 2003, 47–49.

8 Charpin and Ziegler 2003, 79–82.

9 Editions by Grayson 1987, 47–76 for Samsī-Addu, and Frayne 1997, 615–49 for Yasmaḫ-Addu and Zimri-Līm.

10 Original edition by Durand 1985, 151–152; see also Grayson 1987, 439–50.

11 RIME3/2.4.3.1 (bricks inscription of Ilum-išar): (1) DINGIR-*i-ša-ar* (2) ŠAGIN (3) *ma-ri*^{ki} (4) *ù-šu-ri-id* (5) *ḫu-bu-ur* (6) *a-na KĀ-me-er*^{ki}, “Ilum-išar, *šakkanakkum* of Mari, brought the Ḫūbūr (stream) down to Bāb-Mēr” (edition by Durand 1985, 151). The rather elliptic inscription has been misinterpreted by Frayne (1997, 443) as referring to a statue, but the divinized stream Ḫūbūr is a wādi near Mari (and also qualifies the canal that derived its water from it). The inscription must thus be understood as referring to irrigation (Durand 1998, 575–76; Reculeau 2018a, 87–88).

parts of Upper Mesopotamia: of fifty-three inscriptions from rulers of the city-state of Aššur in the third and early second millennia,¹² only one commemorates waterworks, in the time of King Ilušuma (first half of the twentieth century BCE), who channeled the water of two springs in Mount Ebiḫ (probably to be identified with the Jebel Makḫul) down to the city of Aššur.¹³

This scarcity of evidence is partly due to the fact that what would later become Assyria was traditionally a zone of dry farming, even if supplementary irrigation is attested in the area for the eighteenth century BCE and later periods.¹⁴ Yet, irrigation always was a prerequisite on the Middle Euphrates, even if in early days small-scale irrigations that did not require large royal investments may have been predominant. Nevertheless, the pattern is clear, and there seems to have been a difference in discourse between Lower Mesopotamia, where the image of the Irrigator King played a prominent role in royal ideology,¹⁵ and Upper Mesopotamia, where inscriptions almost exclusively relate to religious activities, and only seldom to waterworks. It has been suggested that Yaḥdun-Lîm's emphasis on waterworks was an import on the Middle Euphrates of a traditionally southern ideology, and more precisely that of Ešnunna, in the Diyala valley.¹⁶ Under military pressure, Yaḥdun-Lîm concluded an alliance with the mighty "Prince" (*rubûm*) of Ešnunna, possibly sealed by an interdynastic marriage. Cuneiform tablets record the exchanges of diplomatic gifts and commercial goods between the two cities, and even their material features attest a profound Ešnunnean influence: at that time, the Mari scribes abandoned the traditional formatting, script, and syllabary of their tablets and monumental inscriptions in favor of the ones then in use in Ešnunna.¹⁷ Such a direct influence cannot be suggested for the earlier rulers of Mari and Aššur (even if the ties between the Mari *šakkanakkû* and the Ur III dynasty are well established), but generally speaking one can say that the commemoration of irrigation works in royal inscriptions was not a central aspect of Upper Mesopotamian ideology of kingship.

Things start to change with the rise of the Middle Assyrian kingdom in the fourteenth century BCE. Starting with Aššur-uballiṭ I (1353–1318 BCE), several Middle Assyrian kings celebrate their activities in water management. For about one century, evidence remains

12 The texts are presented by Grayson 1987. This count excludes simple labels, seal impressions, and fragments too small for their object to be determined. It encompasses two dedications of local rulers in charge of the city for foreign powers (the Akkadian and Ur III empires, respectively). To this account could also be added the fourteen inscriptions of Samsī-Addu discussed earlier for Mari, given that both the heartland of what will later become Assyria (especially Aššur and Nineveh) and the Middle Euphrates (centered on Mari and Terqa) were part of his Kingdom of Upper Mesopotamia.

13 RIMA1 A.0.32.2: (30) 2 *e-né-en* (31) *i-na a-bi-iḫ* (32) *ša-du-im* (33) ^d*a-šûr* (34) *ip-ti-a-ma* (35) *i-na e-né-en* (36) *šu-ni-ti* (37) SIG₄ BÂD^{ki} (38) *al-bi-in* (39) 1 *e-nu-um* (40) *ma-ú-ša* (41) *a-na ba-ab* (42) *a-ú-šî-im* (43) *im-qú-tù-nim* (44) 1 *e-nu-um* (45) *ša-ni-tum* (46) *a-na ba-ab* (47) ^d*we-er-tim* (48) *im-qú-tù-nim*; "The god Aššur opened for me two springs in Mount Ebiḫ and I made bricks for the wall by these two springs. The water of one spring flowed down to the Aušum Gate (while) the water of the other spring flowed down to the Wertum Gate" (translation by Grayson 1987, 17). For an analysis of this waterwork and the identification of the mountain, see Bagg 2000, 23–26.

14 Reculeau 2011, 73–78.

15 Charpin 2002.

16 Durand 2002, 565–68.

17 Charpin and Ziegler 2003, 39–40.

limited. Aššur-uballit I mentions the digging of the Patti-ṭuḥdi “Canal of Abundance” and the filling of a well previously dug by one of his predecessors; apparently, the canal was aimed at replacing the nonfunctioning well for the watering of gardens in Aššur.¹⁸

Toward the end of the thirteenth century BCE, Assyrian royal inscriptions celebrate large-scale irrigation programs in the context of the planned *ex nihilo* creation of a new royal city by Tukultī-Ninurta I (1233–1197 BCE).¹⁹ Water was taken from the surrounding mountains and brought first via one and then two canals to the city, designed to irrigate fields, and one of his inscriptions celebrates the digging of the Pattu-mēšari “Canal of Justice,”²⁰ while three others refer to the regular offerings for the main god Aššur and the other great gods, to be taken from the “produce of the water” of the canal.²¹

Later Middle Assyrian kings conducted urban irrigation works aimed at watering gardens in Aššur: this was the case of Tiglath-pileser I, who created an acclimation garden for exotic species,²² and of Aššur-bēl-kala, who rehabilitated a canal previously dug by Aššur-dān I (1168–1133 BCE) in Aššur, which had been abandoned for thirty years, in order to water gardens.²³ No mention, however, is made of irrigation canals for agriculture before the massive works of the Neo-Assyrian period, which are beyond the scope of the present study.²⁴

18 RIMA1 A.0.73.3: (5) *e-nu-ma* ^d*a-šur be-lí* (6) *pa-at-ti-ṭuḥ-di* (7) *a-bi-la-at* 𐎲.𐎲.𐎠 (8) *ù* 𐎲.𐎲.𐎠 (9) *a-na e-pe-ši lu id-ī di-ī-na* (10) PÚ *ša ú-bal-iṭ-<ni>-še-šu šum-ša* (11) *ša ia-a-ar-ḫi ša ku-tal tam-le-e* (12) 10 *i-na am-me-ti* (13) *šu-pu-ul-ša a-di me-e* (14) *ša i-na pa-na* (15) ^{id}*a-šur-na-din-a-ḫi* (16) ÉNSI ^d*a-šur* (17) *iḫ-ru-ši* (18) *i-na pi-li ku-up-r[i]* (19) *a-gúr-ri pi-li* (20) *i-na ti-bi ša PÚ kun-nu* (21) *a-na ši-pár* 𐎲𐎠KIRI₆ (22) *e-pe-ši ul na-ta-a* (23) *e-pe-ra lu ú-me-li-ši*; “When the god Aššur, my lord, allowed me to construct the Patti-ṭuḥdi (‘Canal of Abundance’), bearer of abundant fertility, I filled in with earth the well which was called Uballiṭ-nišēšu (‘He Has Given Life to His People’), (the source) of the pond behind the terrace—(it was) ten cubits down to water(-level)—, which previously Aššur-nādin-ahhē, vice-regent of the god Aššur, had dug (and which) was reinforced with limestone, bitumen, (and) baked bricks—the limestone was below water-level—it was not suitable for the requirements of an orchard” (translation by Grayson 1987, 112; for an analysis of this waterwork, see Bagg 2000, 27–30).

19 See Freydank and Eickhoff 1980; Eickhoff 1985; Gilibert 2008.

20 RIMA1 A.0.78.22: (45) *pa-at-tu me-šá-ri a-na iš-re-ti-šú* (46) *uš-pél-ki ina ḫi-ši-ib* A.MEŠ *pa-at-ti šu-a-ti* (47) *gi-na-a ana* DINGIR.MEŠ GAL.MEŠ EN.MEŠ-*ia ana da-ri-iš* (48) *lu ar-ku-us*; “I made the Pattu-mēšari (‘Canal of Justice’) flow as a wide (stream) to its sanctuaries (and) arranged for regular offerings to the great gods, my lords, in perpetuity from the ‘produce’ of the water of that canal” (translation slightly modified from Grayson 1987, 270; for an analysis of these waterworks, see Bagg 2000, 36–44).

21 A.0.78.23; 24 & 25; see the edition by Grayson 1987, 270; for an analysis of these waterworks, see Bagg 2000, 36–44. The expression “produce of the water” (*ḫiṣib mē*) has been diversely interpreted: Grayson (1987, 270) understands it literally as “fish,” but this is unlikely since the *ginā’u*-offerings are known to consist of agricultural products: barley, honey, fruits, and sesame. It seems preferable to consider (with Bagg 2000, 37) that the inscription refers to the produce of irrigation agriculture permitted by the newly established canals. This is confirmed by a sixteen-column document from Kār-Tukultī-Ninurta, unfortunately only poorly preserved, where acreage of fields is listed (MARV IV 173 = Freydank 2009, 24–29). Among the descriptive terminology in use, several terms relate undoubtedly to irrigation agriculture, such as “irrigation district” (A.GĀR/*uḡāru*), indicating that some of the fields surveyed were currently being watered (*mikru* and *šaḡū*); gardens (*kirū*) are also mentioned, while terms such as “the reed-marsh” (*appāru*) or “the small sea” (*tāmtu šiḫrtu*) refer to wetlands possibly connected with local irrigation devices, or resulting from the outflowing of canals.

22 Bagg 2000, 49.

23 Bagg 2000, 53–55.

24 For which see Bagg 2000, 93–286.

Royal inscriptions were not the only vector of royal ideology in second-millennium BCE Mesopotamia: in the absence of a calendar using a fixed starting point to date years, the computing of time was realized by giving a name to the new year, usually with a reference to a grand royal deed that occurred the preceding year.²⁵ Investments in irrigation were regularly promoted by Lower Mesopotamian kings in their year names,²⁶ but this practice was not unanimously adopted in Upper Mesopotamia. In Mari, Yaḥdun-Lîm and Zimrî-Lîm used such year names, but Samsî-Addu and his son Yasmaḥ-Addu used a system of eponyms also in use throughout Assyrian history, according to which the year was named after a specific official (*limu*) whose charge was annual. Year names were also adopted by small kings of the Middle Euphrates and Ḥābūr region after the fall of Mari, down to the early fourteenth century BCE (and their subsequent incorporation into the Assyrian sphere of influence).

Three of eighteen known year names of Yaḥdun-Lîm celebrate waterworks:²⁷ “Year: Yaḥdun-Lîm opened / caused to be open the Ḥubur-canal;”²⁸ “Year: Yaḥdun-Lîm opened the Iṣîm-Yaḥdun-Lîm-canal;”²⁹ “Year: Yaḥdun-Lîm opened / caused to be open the Puzurrān-canal.”³⁰ In the time of Zimrî-Lîm (1775–1762 BCE), the situation is quite different: for his fourteen years of reign, we know of eighteen well-attested year names (due to the parallel use of alternative year names) and as many as thirty-two when we take poorly attested variants into consideration.³¹ Strikingly, none of the regular year names mentions waterworks, and only two poorly attested ones refer to irrigation: “Year: Zimrî-Lîm (re)dug the Ḥābūr;”³² “Year: Zimrî-Lîm made a headgate (*muballittum*) of stone.”³³ Examples of year names attributed to the local kings following the fall of Mari in 1761 BCE are scanty, but at least one from the late fifteenth-/early fourteenth-century BCE king of “Ḥana,” ‘Ammu-rapi’,

25 Charpin and Ziegler 2013.

26 Charpin 2002, 547–49.

27 Charpin and Ziegler 2003, 57–64. The distribution of year names stresses first and foremost the political and military events of Yaḥdun-Lîm’s reign, with twelve year names commemorating the conquest of cities or the destruction of enemies. Dedicatory year names are evenly balanced between hydraulic works and religious dedications, with three year names each.

28 MU *ia-aḥ-du-li-im* I, DA *ḥu-bu-ur ip-tu-ú / ú-še-ep-tu-ú* (Charpin and Ziegler 2003, 61–62).

29 MU *ia-aḥ-du-li-im* I, DA *i-ši-im-ia-aḥ-du-li-im ip-tu-ú* (Charpin and Ziegler 2003, 62).

30 MU *ia-aḥ-du-li-im* I, *pu-zu-ra-an ip-tu-ú / ú-še-ep-tu* (Charpin and Ziegler 2003, 62).

31 Charpin and Ziegler 2003, 257–60. The distribution of Zimrî-Lîm’s year names is even more oriented toward military activities than that of Yaḥdun-Lîm, with nineteen year names out of thirty-two. A striking difference is that, among the dedicatory year names, only two noncanonical ones refer to hydraulic works, against nine religious dedications (including four canonical year names).

32 MU 1.KAM *zi-im-ri-li-im ḥa-bu-ur iḥ-tú-tú*; this year name is known only from one legal document, in month vi (ARM 8 24) and corresponds to the king’s fifth regnal year (Charpin and Ziegler 2003, 259).

33 MU *zi-im-ri-li-im, mu-ba-li-it-ta-am* (var.: *-tam*), *ša* NA₄ *i-pu-šu*; this year name is mostly attested by approximately fifty administrative texts documenting the king’s meals in months i and ii, and corresponds to the king’s eighth or ninth regnal year (Charpin and Ziegler 2003, 260). A unique text has a variant with a genitive construction and a plural form *ša muballittim* (ARM 23 355 = FM 11 45, 17), but the implications are unclear. For the *muballittum* as a “headgate,” see Durand 1998, 579–80, and Reculeau 2018a, 200–206.

celebrates the digging of a canal: “Year: ‘Ammu-rapi’ the king opened the Ḫābūr-ibāl-bugaš-canal, from Dūr-Išar-Lîm down to Dūr-Iggid-Lîm.”³⁴

Administrative letters and documents discovered in the royal palace of Mari attest that this commitment was not pure propaganda: royal officials regularly report to the king on matters of irrigation and agriculture in the Middle Euphrates valley, and more than one hundred letters deal with canals in the fifty-year span of the documentation from the Mari palace—the vast majority of which actually belong to the final thirteen years covering the reign of Zimri-Lîm. Contrary to year names and royal inscriptions, they do not celebrate outstanding works, such as the (re)digging of an entire canal, but rather document day-to-day interventions, such as regular maintenance or, more often, emergency interventions.³⁵ Later documents are less explicit, and most of the limited Middle Assyrian references rather point to small-scale irrigation.³⁶ Two clear cases, however, suggest planned development of large-scale irrigation under royal impulse in the fourteenth and thirteenth centuries BCE, in contrast to the traditionally rain-fed practices of Assyria.³⁷ In the eastern part of the kingdom, the construction of Kār-Tukulti-Ninurta at the end of the thirteenth century BCE was clearly correlated with a long-distance system of canals.³⁸ In the west, and in spite of contrasted scholarly opinions, it is beyond doubt that the Lower Ḫābūr underwent a regional development after the Assyrian conquest in the fourteenth century BCE, which represents the final stage of a process that started with the kings of Mari in the eighteenth century BCE, was continued by the kings of “Ḫana” (as evidenced by the above-mentioned year name and a few legal documents), and finally expanded by the Assyrians.³⁹ References in letters are limited, but irrigation is clearly mentioned in two Middle Assyrian letters from Tall Šēḫ Ḫamad / Dūr-Katlimmu, even if the details of the activities mentioned there are somewhat obscure.⁴⁰

1.2. ARCHAEOLOGICAL REMAINS OF CANALS: PROBLEMS IN EVIDENCE AND INTERPRETATION

There is ample textual evidence for royal investment in irrigation for the Euphrates and Ḫābūr valleys in the second millennium BCE, but it is not an easy task to link it to archaeological data. In the Middle Euphrates valley between Dayr az-Zūr and Abū Kamāl, field surveys have been conducted by archaeologists and geographers from the Mari excavations, who identified several massive canals:⁴¹

34 LH 13: (30) MU *ḫa-am-mu-ra-pi-iḫ* LUGAL (31) I, *ḫa-bur-i-ba-al-bu-ga-áš* (32) *iš-tu* URU BÂD-*i-šar-li-im*^{ki} (32) *a+na* URU BÂD-*i-gi-id-li-im*^{ki}, *ip-tu-ú* (for the text edition, see most recently Podany 2002, 133–38). For an analysis of this canal and its role in the development of irrigation on the Lower Ḫābūr, see Reculeau 2010, 207–9.

35 Durand 1998, 573–676; Reculeau 2018a.

36 Reculeau 2011, 76–79.

37 Reculeau 2015.

38 Bagg 2000, 36–44; Freydank 2009; Reculeau 2011, 78–79.

39 Reculeau 2010; 2011, 79–91.

40 The two letters, BATSH 4 8 & 17, have been discussed by Cancik-Kirschbaum 1996, 134–36; Bagg 2000, 88–89; and Reculeau 2011, 82.

41 Geyer and Monchambert 2003, 175–231; 2008, see fig. 1.

- The *Mari canal*, close to the site of Tall al-Ḥarīrī / Mari, on the western bank of the Euphrates
- The *Nahr Saʿīd*, upstream on the western bank of the Euphrates
- The *Nahr Semiramis*, upstream of the junction between the Ḥābūr and the Euphrates, on the eastern bank of the Euphrates
- The *Nahr Dawrīn*, downstream of said junction, on the eastern bank of the Euphrates and the left bank of the Ḥābūr, possibly connected there to the easternmost of two canals located upstream on both sides of the Ḥābūr⁴²

In the absence of positive archaeological evidence, the dating of these structures is heavily debated among archaeologists. While the Mari team suggested a highly integrative picture, with all canals being part of a regional system dating back to the founding of Mari in the early third millennium BCE,⁴³ others favor more recent dates, such as the early Neo-Assyrian period for the twin canals of the Ḥābūr and the Nahr Dawrīn,⁴⁴ or even the Islamic (Late Ummayyad) period for both the Nahr Saʿīd and the Nahr Dawrīn.⁴⁵

Philological studies, on the other hand, attest for eighteenth-century BCE Mari the existence of three main canals that formed the backbone of the irrigation system in the kingdom:⁴⁶

- The *Išīm-Yaḥdun-Līm canal*, running on the western bank of the Euphrates, from the vicinity of Dūr-Yaḥdun-Līm (Dayr az-Zūr?) to someplace downstream of Terqa (Tall al-Asharah)
- The *Mari canal*, which ran through the Mari alveolus on the same bank, down to Dēr (Abū Kamāl?)
- The *Ḥābūr canal*, which was supplied with water from the Ḥābūr river, but irrigated fields located in the Euphrates valley on its eastern bank

These canals are known as “riders” (*rākibum*) and must be understood as large-scale canals that fetch water far away upstream and had to “ride” on the Holocene terrace located some 2–3 m above river level.⁴⁷ It has been estimated that, because the water level is located below the level of the fields, such canals need to fetch water at least 8.5 km upstream before the water reaches the level of the fields to be irrigated through gravity flow.⁴⁸ Several attempts have been made to identify the canals mentioned in the Mari texts with the archaeological remains.⁴⁹ J.-M. Durand,⁵⁰ however, has pointed out that the well-documented fragility of the Mari canals does not favor their identification with the massive earthen structures recovered on the field, and my exhaustive study of the technical

42 Ergenzinger and Kühne 1991.

43 Margueron 2004, 68–82; 2014, 13–24; Geyer and Monchambert 2008.

44 Ergenzinger and Kühne 1991; Pucci 2010.

45 Berthier 2001, 29–199; Kennedy 2014.

46 Durand 1998, 577–78; Reculeau 2018a, ch. 1.

47 Durand 1990, 126–27; 1998, 580–81.

48 Geyer and Monchambert 2003, 190.

49 See most recently Lafont 2000; Geyer and Monchambert 2008.

50 Durand 1998, 574–75.

vocabulary of irrigation in Mari⁵¹ confirms his analysis. The evidence at hand rather suggests that the eighteenth-century BCE canals of the kingdom of Mari were earlier, less massive antecedents to the ones visible in the present-day landscape (which most certainly date to the Neo-Assyrian and Islamic periods). Nonetheless, the evidence leaves little doubt that these structures, though smaller, were part of a large-scale network quite remarkable for the technologies of the time. The courses of these canals, which can be reconstructed from textual evidence,⁵² indicate a length of the Mari canal of approximately 35 km, while the Išim-Yahdun-Lîm and Ḫābūr canals neared 75 km.⁵³

Upstream on the Lower Ḫābūr, no evidence exists for large-scale irrigation prior to the mid-second millennium BCE.⁵⁴ Both textual and archaeological data for the Middle Assyrian period suggest that only the upstream portion of the left-bank canal was in operation. It ran from the Ġağğag (the main eastern affluent of the Ḫābūr), where it fed, down to the provincial administrative center of Dūr-Katlimmu, shortly after which it ended.⁵⁵ Yet, given the coherence in shape, technology, and caliber of the twin canals now visible on both sides of the river, one must assume that the archaeological vestiges are those of the early Neo-Assyrian period, in the first centuries of the first millennium BCE, when a whole regional system replaced (and destroyed) the second-millennium one. This is confirmed by an abandoned urban portion of the left-bank canal sealed by occupation layers from the eighth century BCE, suggesting a first phase for the canals whose remains have been preserved dating to the ninth century BCE.⁵⁶

1.3. THE MOBILIZATION OF TASKFORCE FOR CANAL DIGGING AND MAINTENANCE

The above-mentioned discrepancy between archaeological and textual data results in an important caveat with regard to the estimation of the taskforce required for the digging and maintenance of second-millennium BCE large-scale irrigation systems in the Middle Euphrates and Lower Ḫābūr valleys. Insofar as the archaeological remains reflect much later realities (one to two millennia after the time of the kingdom of Mari!), and since no canals datable to the period under study have been recovered so far, one can only rely on textual evidence, which is quite limited as far as canal diggings are concerned. Royal inscriptions always picture the king as a unique actor in the founding act, and no mention is made of the workmen who were actually in charge of (re)digging the canal. Administrative letters and documents are more eloquent, but none can be securely tied to the initial digging of any of the above-mentioned canals; rather, they reflect the day-to-day activities linked to breaches occurring during irrigation season, urgent measures against flood protection, and the annual cleaning of canals.⁵⁷ As far as we can see, the initial dig-

51 Reculeau 2018a, ch. 1.

52 Reculeau 2009, 315–16.

53 Reculeau 2018a, ch. 1.

54 Reculeau 2010.

55 Ergenzinger and Kühne 1991.

56 Pucci 2010.

57 Durand 1998, 582–638; Reculeau 2018a, ch. 2.

ging and seasonal maintenance of canals was organized according to a system of *corvée* (*tupšikkum*): the king's subjects could be summoned by the royal administration for public works that also included public buildings and, every year, the harvest of the crown fields.⁵⁸

The Mari archives contain numerous complaints of administrators regarding the lack of available taskforce (*šābum ēpištum*), which appears to have been a recurring problem. Several letters show that work assignments (*adūm*) were drawn by administrative scribes (*mārū bīt tuppi*), based on what number of workmen required for a given work (*isiktum*) was calculated.⁵⁹ This practice (which applied to all sorts of works) echoes administrative calculations known for Ur III-period irrigation works in southern Mesopotamia (see S. Rost's chapter in this volume) and appears to have been commonplace. Unfortunately, none of these documents could be identified in the preserved records so far.⁶⁰

Only a handful of these complaints offer numerical estimates of the men available and/or required for one given task, and none of them appears to be a systematic census of the whole taskforce required for cleaning the whole course of a canal. The textual evidence is as follows:

- LAPO 17 794 (= ARM 6 5)⁶¹ mentions the mobilization of forty workmen from two villages near Mari (Appān and Ḫumsān), to clear a boulder that had fallen into a channeled wādī.⁶²
- LAPO 17 796 (= ARM 6 7),⁶³ a letter about work on a canal drawing water from a wādī near Mari, mentions two thousand workmen divided between “the district, the palace, and Mari.” It attests the mobilization of palace dependents and free citizens alike. It is, however, not certain whether this encompasses all the taskforce available in the Mari district (one of three districts forming the heartland of the kingdom), or only part of it.⁶⁴

58 Stol 1995; Durand 1998, 658–59.

59 Durand 1998, 540.

60 In addition to LAPO 17 796 (= ARM 6 7) and 798 (= ARM 3 3) quoted below, see LAPO 17 799 (= ARM 3 5): (24) [i-na] ṽu¹-mi-im ša a-na pi-i I₇.DA (25) [ak-šu]-[du] (26) [er-še-tu]m ki-ru-um i-[na-d]i (27) ṽI₇.¹.DA a-na ga-am-ri-im ṽe₄-re-e-[e]t (28) a-du-ú-um ša ša-bi-im ma-di-im (29) it-ta-ab-ši-ma aš-šum ki-a-am (30) a-na ter-qa^{ki} ú-ul ak-šu-dam (31) ši-ip-rum ša ša-ab-ta-ku ma-di-iš da-an (32) i-ba-aš-ši a-šar ka-la-[k]a-am ni-ka-ás (33) a-na-as-sà-ḫu [i]-ba-aš-ši a-[š]a-ar 2 i-na am-ma-tim (34) a-na-as-sà-ḫu ú-wa-a[r-ka-a]t ša-bi-im (35) ša ḫa-al-ši-im ṽša¹-[a-tu] {x x x x} (36) be-lí pa-ri-is ša-bu-um [i-iš]; “The day I reached the intake of the canal, (I realized that) the garden plot is lying waste: the canal is completely silted up! This has become a work estimate of an important group (of workmen), and for this reason I did not come to Terqa. The work that I have taken on is very important! There is a place where I will have to remove a half-reed (50–75 cm) of earth, there is a place where I will have to remove two cubits (33–50 cm)! Moreover, my lord can investigate the taskforce of this district [*the district of Saggarātum*]: (This) taskforce is too small!”

61 Durand 1998, 596–98.

62 LAPO 17 794 (= ARM 6 5): (5) NA₄ i-na ṽIGI.KUR me-eḫ-re-et (6) ap-pí la-bé-ru-tim a-na ša-di-tim (7) im-qú-ut-ma ú-uṽ ú-pu-ur-ra-am (8) ú-ma-aṽ-ṽi eš-me-e-ma (9) 40 ša-ba-am i-na ap-pa-an^{ki} (10) ú ḫu-um-sà-an^{ki} al-pu-ut; “The stone at Ḫubur [wādī Suwab] on the opposite side of the old ‘noses’ has fallen into the wādī, and it has reduced the feeding (of the canal) by half a cubit (8–12.5 cm). I heard (about it) and levied a group of 40 (workmen) in Appān and Ḫumsān.”

63 Durand 1998, 599–600.

64 LAPO 17 796 (= ARM 6 7): (5) aš-šum na-aḫ-lim ša di-ir^{ki} (6) e-li ši-ip-ri-im SUMUN (7) ú ták-ki-ri-im ni-zi-iz-ma (8) DUMU.MEŠ É ṽup-pí a-da-a-am (9) ú-pí-šu-ma (10) e-li ši-ip-ri-im SUMUN (11) a-du-ú-um

- LAPO 17 798 (= ARM 3 3)⁶⁵ mentions “four hundred inhabitants of Terqa,” of whom two hundred have already been assigned a task and two hundred are available for canal cleaning (*ḥaṭāṭum*). The governor then requires additional support from the Mari district, otherwise he will not be able to perform the assigned work.⁶⁶
- In FM 16 16, the governor of Saggarātum explains that the usual taskforce of his district has been assigned to the cleaning (*ḥaṭāṭum*) of the Išim-Yaḥdun-Lîm canal, together with the taskforce of the two other main districts (Terqa and Mari). Confronted with emergency repairs at the headgate of the Ḥābūr canal, he must resort to mobilizing three hundred workmen from the district of Terqa (outside his own jurisdiction), one hundred palatial dependents from the palaces of Saggarātum and Dūr-Yaḥdun-Lîm (who apparently were not summoned for canal maintenance under normal circumstances), and two hundred “strong men” (*awîlû dannūtum*) of unclear status, from an unspecified district (presumably the one where the headgate is situated, as a form of corvée).⁶⁷
- In FM 16 20,⁶⁸ the work estimate (*adûm*) for the digging of a new irrigation canal (*atappum*) aimed at watering a 400 *ikûm* (64–144 ha) field is “3,000 to 4,000 men

ša *ták-ki-ri-i[m]* (12) 2 *li-im ṣa-bu-um qa-al* (13) *ni-iš-ta-al-ma* (14) *ták-ki-ra-am-ma ni-iš-ba-at* (15) *ši-ip-ru-um ṣa ṣniṣ-iš-ba-tu* (16) *ma-di-iš da-mi-iq* (17) *aš-šum a-di i-na-an-na* (18) *a-na ṣe-er be-lí-ia* (19) *la aš-pu-ra-am* (20) *a-di ḥa-al-šú-um é-kál-lum* (21) *ù ma-ri^{ki} zi-ta-šu-ṣnu* (22) *la iṣ-ba-tu* (23) *a-na ṣe-er be-lí-ia* (24) *ú-ul aš-pu-ra-am*; “As regards the wādi of Dēr, we had started working on the ‘old work’ and on the diversion, and the administrative scribes had calculated the work assignment; in addition to the ‘old work,’ (there is) the work assignment for the diversion! A group of 2,000 (workmen), that’s (too) few! We have considered (the matter), and have taken on working on the diversion. The work that we have taken on is very good. Regarding the fact that, until now, I hadn’t written to my lord: I didn’t (want to) write to my lord until the district, the palace, and Mari had taken their share.”

65 Durand 1998, 601–2.

66 LAPO 17 798 (= ARM 3 3): (4) *aš-šum ši-pí-ir I, {x} [ḥa¹-ṭa-ti-im* (5) *ša be-lí iṣ-pu-ra-am* (6) *ši-ip-rum šu-ú ú-ul i-iš* (7) *a-du-ú-um ṣa ṣa-bi-im ma-di-im* (8) *i-ba-aš-ši* (9) *ù aš-sú-ur-ṣe*] (10) *a-na be-lí-ia ki-a-am* (11) *i-qa-ab-bu-ú* (12) *um-ma-a-mi ṣa-bu-um ma-d[u-um]* (13) *i-na li-ib-bi ter-qa^{ki}* (14) *i-ba-aš-ši* (15) *i-na 4 ME DUMU.MEŠ ter-qa^{ki}* (16) 2 ME LÚ *ṣa-bu-um ZI.GA* (17) *ù 2 ME ba-ši-tum* (18) *šum-ma a-na ši-ip-ri-im ṣa-a-tu* (19) *qa-tam a-ša-ak-ka-an* (20) LÚ *ṣa-ba-am e-pí-iš-tam* (21) *ša ḥa-la-aš ma-r[i]^{ki}* (22) *li-ka-am-mi-su-nim*; “As regards the work of cleaning the canal about which my lord wrote to me, this work is not small! This is the work assignment of an important group (of workmen), and on no account should one say to my lord: ‘There is an important taskforce in Terqa.’ Among the four hundred ‘sons’ of Terqa, two hundreds are ‘out’ (i.e., employed elsewhere), and two hundreds are available. If I am to begin that work, one should gather for me a taskforce from the Mari district!” For the administrative meaning of ZI.GA (*wāšitum*) and *bāšitum*, see Durand 1998, 602, n. c).

67 FM 16 16: (21) *e-pí-iš-tum ṣa ḥa-al-ší-ia ṣa I, DA* (22) *e-pé-šum-ma i-ip-pé-eš₅* 3 ME *ṣa-ba-am ter-qa^{ki}* (23) *ù a-pil-i-lí-šu it-ti-ia at-ru-ma* (24) *a-na iḥ-zi-im ak-šu-ud-ma ši-ip-ra-am a-mu-ur-ma ma-di-iš ma-ri-iq* (25) *i-na É.GAL ṣa-ga-ra-tim^{ki}* *ù É.GAL BĀD^{ki}-ia-aḥ-du-li-im* (26) 1 ME *ṣa-ba-am al-pu-ut* *ù i-na ḥa-al-ší-im* (27) *ša LÚ.MEŠ dan-nu-tim* 2 ME *ṣa-ba-am ú-še-et-bi*; “The taskforce of my district [*the district of Saggarātum*] (that works) at the canal (Išim-Yaḥdun-Lîm) does what is to be done. I have taken away with me Apil-ilīšu [*a specialist in waterworks*] and three hundred workmen from Terqa, went to the *facing* (of the headgate) and saw the work (to be done): It’s completely falling into pieces! (Seeing this,) I levied one hundred workmen in the palace of Saggarātum and in the palace of Dūr-Yaḥdun-Lîm, and mobilized a workforce of two hundred strong men in the district.” See the discussion of this passage in Reculeau 2018a, 251–68.

68 Reculeau 2018a.

in one single day.”⁶⁹ This, however, reflects primarily the calculation methods of the administration, according to which the total number of “workers’ days” was established, but it does not mean that three to four thousand workers were actually summoned for the task. In real-life procedures, the whole amount of work would more probably have been carried out by a few hundred men, working over several days.

Middle Assyrian cuneiform records, on the other hand, have not revealed any evidence so far on the number of workmen required for the digging or cleaning of large-scale canals, but the expansion of the regional canal on the Lower Ḫābūr, and more importantly the *ex nihilo* creation of a water management system able to sustain the new royal city of Kār-Tukultī-Ninurta, must have required a huge amount of labor. Like the erection of the city itself, the digging of the canals must have been performed through a system of corvée in which the forced labor of Hurrian and Kassite prisoners of war played a major role. Such deportees are mentioned in royal inscriptions, but the numbers given there (e.g., the 28,800 “Hittite people from Syria” of RIMA.0.78.23 and 24) are problematic and unreliable.⁷⁰ They must, however, have represented a fairly important group of newcomers, amounting to thousands at least, because several administrative texts⁷¹ attest their presence both as builders and as settlers of the new royal city.⁷²

The overall picture remains rather impressionistic, but it is striking that the Mari texts mention an available labor pool from a few dozen to two thousand, which may represent the available taskforce of the whole capital district. A text like FM 16 16 indicates that the levy of several hundred men was not an easy task, and extra taskforces needed to be summoned in case of emergency, if the usual taskforce was already dealing with normal seasonal activities. The early second-millennium BCE Middle Euphrates, as opposed to what is known for example in Neo-Sumerian Lower Mesopotamia, was a region of few men, and their mobilization appears to have been a source of constant stress for the authorities. This, along with mere ideological preferences, probably explains the above-mentioned limited use of the canal-digging motive in Zimri-Līm’s inscriptions and year names, and it is striking that texts from this period mostly relate to emergency works on existing canals, fragile constructions always in need of repair and often unable to support water pressure—especially during the spring flood, but also frequently during normal use for irrigation or transportation.⁷³ In the thirteenth century BCE, Middle Assyrian kings were able to profit from their military successes to bring additional taskforces to their homeland and sustain massive construction works, but the actual numbers remain unknown.

69 FM 16 20: (11) *i-na-an-na* ṚA.ŠĀ¹ (12) *i-na ḫa-am-qí-im ša me-eh-re-et da-m[é-qí]^{Ṛki1} (13) *a-na pu-ut-ti-im iq-bu-nim-ma* (14) [ḫ] *a-zi-ir-^dUTU aṭ-ru-ud-ma* (15) [A.ŠĀ *ša-a-ti*] *ù a-ta-ap-Ṛpa-šu¹* (16) [uš]-*ta-ab-ba-lam-ma* (17) Ṛ4⁷¹ ME GĀN A.ŠĀ *šu-ú* (18) *ù a-de-e a-ta-ap-pí-im* (19) 3 *li-mi ú-lu* 4 *li-mi ša-bu-um* (20) *ú-ma-ak-ka-lu-ú*; “Now, people talked to me about opening to cultivation a field on the valley floor, opposite Damēqum [a city]; so, I sent Ḫāzir-Šamaš, and he made the estimates for this field and his irrigation canal: This field (would amount to) four hundred *ikūm*, and the work estimate for the irrigation canal (is) three to four thousand workmen for one day.”*

70 Grayson 1972, 117–18.

71 Freydank 1974, 1980.

72 Freydank and Eickhoff 1980, 455; Eickhoff 1985, 49.

73 Durand 1998, 594–638; Reculeau 2018a, ch. 2.

2. LABOR AND FOOD REQUIREMENTS FOR INSTITUTIONAL IRRIGATION AGRICULTURE

In addition to labor investments in irrigation and waterworks maintenance, institutional agriculture had to invest in labor for farming and to provide farmers with their means of production and livelihood. Mesopotamian institutional domains (whether of palaces or temples) were organized through a threefold division of land use, among (1) land directly cultivated by the institution, (2) land given out for rent, and (3) land given out in exchange for service to the institution.⁷⁴ This system is attested from the end of the fourth millennium BCE⁷⁵ to the mid-first millennium BCE.⁷⁶ In the second millennium BCE, this system is best known for royal domains, in both southern⁷⁷ and northern Mesopotamia.⁷⁸

The second category (rented land) is only poorly documented in Upper Mesopotamia,⁷⁹ even if it seems to have been the predominant mode of cultivation in contemporary Babylonia (which, however, remains a debated issue⁸⁰). The third category, service land, has received much attention from scholars, but analyses still diverge quite drastically. A quick overview for the Old Babylonian period, with references to earlier literature, is offered by M. Stol,⁸¹ while the classic studies for the Middle Assyrian period are those of N. Postgate.⁸² Due to space limitations, I am not able to discuss here the nature and evolution of service land over the course of the second millennium BCE. This topic will be fully discussed in another article.⁸³ For the present study, however, one should keep in mind that part of the royal investment in personnel, draught animals, and other means of cultivation (e.g., seed) did not go into the direct cultivation of crown land, but was allocated to servicemen. For instance, Middle Assyrian administrative records from Dūr-Katlimmu attest the delivery of barley for seed and fodder to tenants known as “servants of the king” (*urdū šarre*)—that is, people who received land and the means of cultivation in exchange for a service (*ilku*) performed for the king.⁸⁴ On the other hand, they were not provided with rations throughout the year, as was the case for dependent workers who engaged (among other duties) in institutional agriculture.⁸⁵ This is one of the few cases when we actually get a glimpse into what these expenditures meant for the royal administration. Based on three texts dated to a single day (BATSH 18 28–30), at least 122 such servicemen operated at Dūr-Katlimmu,⁸⁶ receiving a total of 150 *emāru* and 1 *sūtu* of barley as seed and fodder—which amounts to 15,010 *qū* (12,008–15,760 l; see below). Servicemen received land and barley as “wages” but

74 [Démare-]Lafont 1998.

75 Steinkeller 1988, 13–14; Englund 1998, 208–13.

76 van Driel 1998, 34–36.

77 Charpin 1987.

78 Durand 1998, 524–35; Lafont 2000, 139–40; van Koppen 2001, 461; Postgate 1971, 1982.

79 But see Durand 1998, 534–35.

80 See Charpin 1987, 116–17.

81 Stol 2004, 732–38.

82 Postgate 1971, 1982.

83 Reculeau, in press.

84 Jakob 2003, 34–38.

85 Jakob 2003, 339–48.

86 Salah 2014, 2.

did not contribute to the agrarian production of the royal household, since their service was of a different nature (often military, though not exclusively). Thus, the grain they received had to be taken from the surpluses extracted from institutional agriculture and taxes. What percentage of the total royal resources was actually devoted to such investments remains unknown. Only in a few cases is the other end of the transaction documented, and almost exclusively for high-ranking dignitaries⁸⁷—with complex issues regarding what part of the documented activities belong to the “public” sphere of interest of these notables and what part to their “private” sphere.⁸⁸

The following pages will focus exclusively on the first category (land in direct exploitation), which is well documented both for Mari and for the provincial Middle Assyrian administrative center of Dūr-Katlimmu, on the Lower Ḫābūr.

2.1. ESTIMATIONS OF THE ACREAGE OF CULTIVATED LAND

An important issue for comparative and quantitative studies in Mesopotamian economic history is our still relatively poor understanding of the value of measure units in use at different times and places. The ubiquitous use of cuneiform writing over more than three millennia led to the adoption of a limited repertoire of signs and terms to denote units of weight, length, surface, and so on. This has traditionally been understood as implying that the actual measures of third-millennium southern Mesopotamia (the “center”) had been adopted by other regions (the “periphery”) without substantial changes during the course of the following millennia.⁸⁹ Recent studies, however, insist that the adoption of the signifier (the grapheme and/or the unit’s name) did not necessarily imply the adoption of the signified (the actual measure, and at times even its name, which is often masked by the use of logograms⁹⁰). These questions are too complex to be addressed here, and the reader is invited to refer to my parallel study on metrological issues affecting yield estimates,⁹¹ where one will find the explanations for the equivalences used in this study for both the surface unit, the *ikû(m)*, and the smallest capacity unit, the *qû(m)*.⁹² Even if they used partially similar terms for surface and capacity units, the Mari and Middle Assyrian administrations in charge of institutional agriculture actually employed measurement systems that referred to very different realities “on the ground,” as summarized in table 1.

87 An exception, but outside of the scope of the present study, is the famous case (among Assyriologists!) of the soldier Ubārum, in the time of Abī-eṣuḫ of Babylon (1711–1684 BCE); see Stol 2004, 813–17, with references to earlier literature.

88 See, for Mari, van Koppen 2002; and for the Middle Assyrian period, Postgate 2013, 327–42, with references to earlier literature.

89 Chambon 2011, 25–28.

90 Chambon 2011, 28–38, 40–43, 173–79.

91 Reculeau 2018b.

92 The presence or absence of a final *-m* (mimation) reflects linguistic evolutions in Akkadian during the course of the second millennium BCE. For the sake of coherence and to facilitate the identification of the two main corpora under study, I use *ikûm*, *sûtum*, *qûm*, for the first half of the millennium (Mari) and *ikû*, *sûtu*, *qû*, for the second half (Middle Assyrian), as is customary among specialists of the respective periods. I do not differentiate between singular and plural forms of the units, and I use the singular in an absolute way.

Table 1. Suggested equivalences for surface and capacity units in the Mari and Middle Assyrian periods (based on Reculeau 2018b; when several options are possible, the most probable values are boldfaced)

Unit		Mari <i>ugārum</i> - system	Middle Assyrian ' <i>sūtu</i> of the Ḫiburnu-house' (= 'old <i>sūtu</i> '?)	Nuzi	
				with 1 <i>emāru</i> = 80 <i>qū</i>	with 1 <i>emāru</i> = 100 <i>qū</i>
Surface	<i>ikū(m)</i>	0.16 ha, 0.23 ha, or 0.36 ha	0.42 ha	0.42 ha	
Capacity	<i>qū(m)</i>	0.6 l 0.37 kg	0.8 l or 1.05 l 0.5 kg or 0.65 kg	0.8 l or 1.05 l 0.5 kg or 0.65 kg	0.8 l or 1.05 l 0.5 kg or 0.65 kg
	<i>sūtu(m)</i>	6 l 3.7 kg	8 l or 10.5 l 5 kg or 6.5 kg	8 l or 10.5 l 5 kg or 6.5 kg	8 l or 10.5 l 5 kg or 6.5 kg
	<i>pānum</i>	36 l 22.2 kg	–	1 l or 1.31 l 0.62 kg or 0.81 kg	–
	<i>paršiktum</i>	–	48 l or 63 l 30 kg or 39 kg	–	–
	<i>kurrum</i>	72 l 44.4 kg	–	–	–
	<i>emāru(m)</i>	–	80 l or 105 l 50 kg or 65 kg	64 l or 84 l 40 kg or 52 kg	80 l or 105 l 50 kg or 65 kg
	<i>ugārum</i>	720 l 444 kg	–	80 l or 105 l 50 kg or 65 kg	–

Unfortunately, there is no systematic record of the total acreage under direct cultivation by the palace, either in Mari or for the Middle Assyrian kingdom. For Mari (table 2), the highest-known acreage for institutional agriculture are the 2,750 *ikūm* (440–990 ha) mentioned in FM 2 12, 8-9. According to F. van Koppen,⁹³ this represents the whole area under institutional cultivation in the town of Guru-Addu, located on the right bank of the Euphrates near Mari.⁹⁴ Yet, the tablet is badly damaged, and the whole situation is far from

93 van Koppen 2001, 463.

94 Durand 1998, 647.

Table 2. Acreage of institutional land in the kingdom of Mari (not exhaustive; the most probable values are boldfaced)

Reference	Date ZL	Date BCE	Locality	Acreage in <i>ikûm</i>	Acreage in ha, with 1 <i>ikûm</i> =		
					0.16 ha	0.23 ha	0.36 ha
FM 2 12			Guru-Addu	2,750	440	632.5	990
FM 2 50	ZL 1–4	1774– 1771	Qaṭṭunān	100	16	23	36
ARM 27 100	ZL 6	1769	Qaṭṭunān	450	72	103.5	162
ARM 27 100	ZL 7	1768	Qaṭṭunān	600	96	138	216
ARM 27 100	ZL 8	1767	Qaṭṭunān	900	144	207	324
ARM 27 37 & 38	ZL 9	1766	Qaṭṭunān	1,000	160	230	360
Ziegler 2011 B (A.2992)			Ṭabātum	100	16	23	36
Ziegler 2011 B (A.2992)			Ṭabātum	125	20	28.75	45

clear: another field of 2,000 *ikûm* is mentioned in line 10, but it is unclear whether this was part of the previous one or an additional surface. A relative exception to this lack of information is the region of the Lower Ḥābūr, which fortunately is well documented for both the Mari and Middle Assyrian periods. During Zimri-Lîm's reign, the land directly exploited by the palace around the city of Qaṭṭunān was increased tenfold in less than a decade, from 100 *ikûm* (16–36 ha) to 1,000 *ikûm* (160–360 ha).⁹⁵ At nearby Ṭabātum, a smaller progression from 100 to 125 *ikûm* (20–45 ha) can be evidenced, but the chronology and further developments are unclear.⁹⁶

For the Middle Assyrian Lower Ḥābūr (table 3 and fig. 2), the evolution of crown land in Dūr-Katlimmu and the nearby satellite town of Duāra can be reconstructed for twenty-six of fifty-four years during the reigns of Shalmaneser I and Tukulti-Ninurta I.⁹⁷ If the acreage at Duāra remained constant at 100 *ikû* (42 ha), there are signs of an increased investment at the provincial capital, Dūr-Katlimmu, in the second quarter of the thirteenth century BCE (ca. 1273–1250 BCE). Starting around 520 *ikû* (218 ha), the total acreage then reaches some 600 *ikû* (252 ha), with the single exception of 1266 BCE, when the acreage in Dūr-Katlimmu is significantly reduced to 302 *ikû* (126 ha), implying a potential total acreage of 402 *ikû* (168 ha). The reason for this decrease is unknown, and one cannot exclude that other years with limited cultivation occurred in the undocumented parts of that chronological sequence. The third quarter of the century attests a progressive diminution

95 van Koppen 2001; Reculeau 2010.

96 Ziegler 2011, 27–32.

97 Reculeau 2011, 163–69, 188–91.

of the total acreage, starting at 510 *ikû* (214 ha) around 1245 BCE before stabilizing at 450 *ikû* (189 ha) between 1238 BCE and at least 1228 BCE. The final years were hindered by military troubles, which explains the lower amounts of 0 *ikûm* and 350 *ikûm* (147 ha) in 1230–1229 BCE, when the presence of an enemy in the countryside prevented the cultivation of part or all of the acreage. A similar situation may also explain the 300 *ikû* (126 ha) for Dūr-Katlimmu in 1220 BCE.⁹⁸

Table 3. Acreage of institutional land at Middle Assyrian Dūr-Katlimmu and Duāra, with 1 *ikû* = 0.42 ha (a dash indicates lack of information; chronology based on Salah 2014, 62).

Reference (BATSH 9 no.)	Eponym	Date BCE	Duāra		Dūr-Katlimmu		Total	
			<i>ikû</i>	ha	<i>ikû</i>	ha	<i>ikû</i>	ha
82	–	[1273- 1270]	100	42	420	176.4	520	218.4
96 ⁹⁹	Aššur-mušabši, s. Anu-mušallim	1269	–	–	52	21.84	–	–
67	Aššur-nādi-šumē, s. Aššur-le'i	1267	100	42	484	203.28	584	245.28
95	[Abī-ilī, s. Aššūr- šumu-lēšir] ¹⁰⁰	1266	–	–	302	126.84	–	–
69	Mušallim-Aššur	1264	–	–	500	210	–	–

(continued)

98 Reculeau 2011, 166. This presentation differs slightly in both absolute and relative chronologies from the ones I offered in Reculeau 2011, 188–91, and 2015, 205–6. The chronology of the reigns of Shalmaneser I (1274/3–1245/4 BCE) and Tukulti-Ninurta I (1244/3–1209/7 BCE) is still a matter of debate among specialists: due to the absence of a preserved list of the eponyms used to name years in the Middle Assyrian period, their chronological sequence must be reconstructed on the basis of partial and often uncertain evidence, resulting in competing propositions. The chronology I used in earlier studies, based on a slightly revised version of the ones proposed by H. Freydank (1991, 2005) and W. Röllig (2004, 2008, 4; see Reculeau 2011, 155–72) has been challenged by Y. Bloch (2008, 2010) and most recently by S. Salah (2014, 57–62), who had access to previously unavailable material and was able to offer a more convincing sequence. This is not the place to discuss the remaining debatable points, and I adopt his chronology for the current essay. Accordingly, I follow him in using the High Middle Assyrian chronology and the absolute dates last supported by A. Fuchs (2011, 308–11) for the reigns of both kings, which seem to have occurred ten years earlier than what the traditional Lower Middle Assyrian chronology assumes. The reader should be aware that these very complex issues are far from having reached a consensus among scholars, even if the High Middle Assyrian chronology seems to have gained more support lately; see esp. Janssen 2014, *contra* Janssen 2012a, 2012b (where the respective reigns are assigned the dates [1264–1235 BCE] and [1234–1199 BCE]), 2013a, 2013b. Such short-term chronological discrepancies are, in any case, of little relevance to the present study.

99 For that year, only the acreage of wheat fields is preserved. These were always sensibly smaller than the predominant barley fields, when they existed at all.

100 This text is dated from Aššur-nādi-šumē, s. Aššur-le'i (1267 BCE), but since it is a delivery of seed, it represents the acreage cultivated and harvested in the following year.

Table 3. Acreage of institutional land at Middle Assyrian Dūr-Katlimmu and Duāra, with 1 *ikū* = 0.42 ha (a dash indicates lack of information; chronology based on Salah 2014, 62).
(*continued*)

Reference (BATSH 9 no.)	Eponym	Date BCE	Duāra		Dūr-Katlimmu		Total	
			<i>ikū</i>	ha	<i>ikū</i>	ha	<i>ikū</i>	ha
70; 71	Ina-pî-Aššur- lišlim, s. Bābu-aḥa-iddina	1261	100	42	500	210	600	252
63	Aššur-dammeq, s. Abī-ilī	1258	100	42	492	206.64	592	248.64
62+100	Ištar-(t)ēriš	1257	[. . .]	[. . .]	[. . .]	[. . .]	[. . .]	[. . .]
60	Aššur-kettī-ide, s. Abī-ilī	1251	100	42	500	210	600	252
64	[Ittabši-dēn- Aššur] ¹⁰¹	1245	100	42	410	172.2	510	214.2
65	Tukultī-Ninurta I	1243	100	42	–	–	–	–
66	Mušallim-Adad, s. Salmānu-qarrād	1241	–	–	410	172.2	–	–
81	Adad-bēl-gabbe	1240	100	42	410	172.2	510	214.2
68	Šunu-qardū	1239	100	42	410	172.2	510	214.2
73	Libūr-zānin-Aššur	1238	100	42	350	147	450	189
74	Aššur-nādin-apli, <i>mar šarre</i>	1237	100	42	350	147	450	189
75	Urad-ilāne	1236	100	42	350	147	450	189
88	Adad-uma ² i	1235	100	42	350	147	450	189
76	Abattu, s. Adad-šamšī	1234	100	42	350	147	450	189
77	Abattu, s. Adad-šumu-lēšir	1233	100	42	350	147	450	189
78	Aššur-da ² ān	1232	100	42	350	147	450	189
79	[Etel-pî-Aššur, s. Kurbānu] ¹⁰²	1231	100	42	350	147	450	189

101 This text is dated from the second month of Ubru (1244 BCE) but records the harvest of the previous year.

102 The acreage of Etel-pî-Aššur, s. Kurbānu (1231 BCE) is referred to in BATSH 9 79, dated from the following year.

Table 3. Acreage of institutional land at Middle Assyrian Dūr-Katlimmu and Duāra, with 1 *ikū* = 0.42 ha (a dash indicates lack of information; chronology based on Salah 2014, 62). (continued)

Reference (BATSH 9 no.)	Eponym	Date BCE	Duāra		Dūr-Katlimmu		Total	
			<i>ikū</i>	ha	<i>ikū</i>	ha	<i>ikū</i>	ha
79	Uṣur-namkur- šarre ¹⁰³	1230	0	0	0	0	0	0
79	Ellil-nādin-apli(?)	1229	0	0	350	147	350	147
80	[Aššur-bēl-ilāne] ¹⁰⁴	1228	100	42	350	147	450	189
72	Bēr-nādin-apli	1220	–	–	300	126	–	–

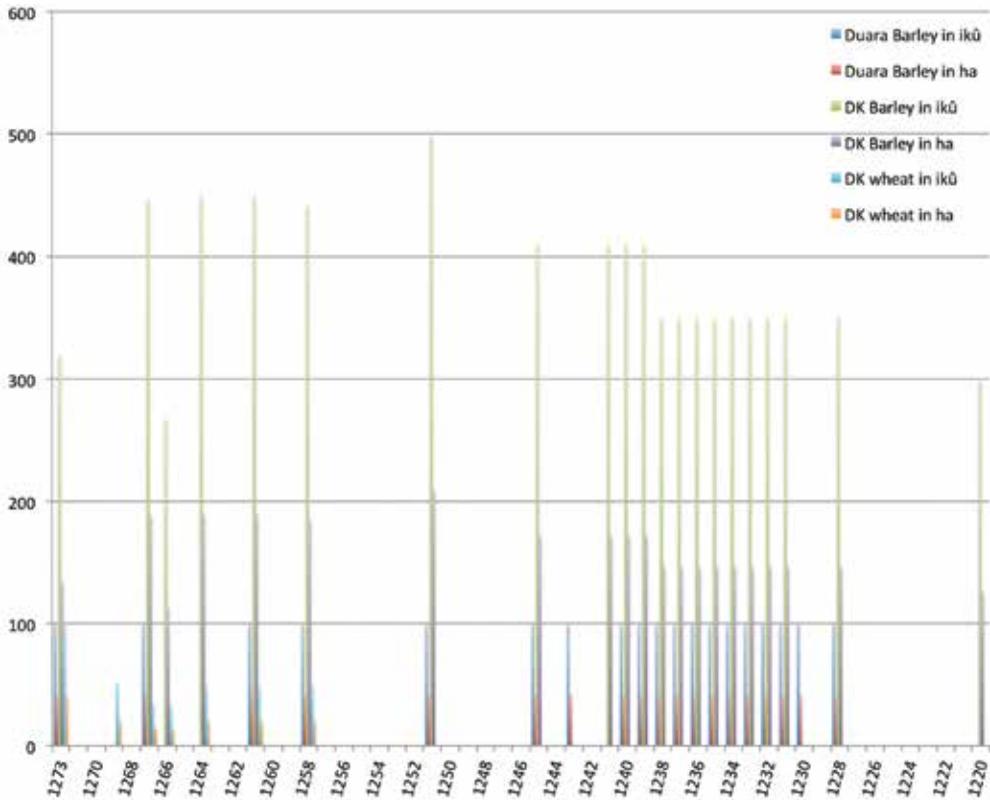


Figure 2. Acreage of cultivated land at Middle Assyrian Dūr-Katlimmu and Duāra, in *ikū* and ha, using the equivalences proposed in table 1 (chronology based on Salah 2014, 62).

103 The acreage of the year after Uṣur-namkur-šarre (1229 BCE) is referred to in BATSH 9 79. It is usually identified with Aššur-bēl-ilāne (for which the same amount of land can be deduced from BATSH 9 80), but according to S. Salah (2014, 62), Ellil-nādin-apli might have been intercalated between these two eponyms.

104 The acreage of Aššur-bēl-ilāne (1228 BCE) is referred to in BATSH 9 80, dated from the following year.

2.2. THE PERSONNEL AND DRAUGHT ANIMALS OF INSTITUTIONAL IRRIGATION AGRICULTURE

An assessment of the economic aspects of second millennium BCE Upper Mesopotamian institutional agriculture requires an estimate, partial as it may be, of the cost–benefit ratio. The data are, as always, limited, and we can only offer a few quantitative hints on these investments. They can at least give an indication of the nature and scale of long-term investments (as opposed to the more punctual ones represented by the annual cleaning of canals, and even more by their initial digging, which resorted to *corvée* work, as discussed above). Textual evidence from both Mari and Dūr-Katlimmu offers insights into the taskforce employed by institutional agriculture and attests some differences in terms of personnel management.

The Mari plough team is the object of a comprehensive study by F. van Koppen,¹⁰⁵ whose results need only be summarized briefly here. The main operator of institutional agriculture at Mari was the “ploughman” (LÚ.ENGAR; LÚ.^{GIS}APIN/*ikkarum*), an agrarian manager who did not till the land himself. Under his supervision was a taskforce that was actually performing land cultivation, called “those who perform labor on the fields” (*ālikūt eqlim*). According to F. van Koppen,¹⁰⁶ they were unfree workers, not tenants as their name (based on the same root as *ilkum*, “service”) may imply.¹⁰⁷ The plough team was divided according to a hierarchy that mirrored its organization during the sowing season: based on the place at which they occur in personnel lists, the “holder” (*mukilum*, short for *mukil epinnim*, “holder of the plough”) ranked first, followed by the “seeder” (*zārûm*) who dropped the seeds in the seeder funnel. In most plough teams, two “irrigators” (*mušaqqûm*) are mentioned, along with three or four ox-drivers (*kullizum*) and weeders (*kāsimum*), whose number varies between zero and five. Less frequent was the “lubricator” (*mupaššišum*), in charge of applying animal fat to tools and implements. Last came the “groats grinder” (*sāmidum*), sometimes “female groats grinder” (*sāmittum*) or “female flour miller” (*ṭē’ittum*), engaged in food preparation for the team. During the rest of the agricultural cycle, it is likely that all workmen performed unskilled labor, such as harvesting, transport, and threshing, whereas independent subjects of the king (*muškēnum*) were summoned, as part of their *corvée* duties, to help harvest crown land, and sometimes they sent their oxen for threshing.

Middle Assyrian management of institutional agrarian personnel is documented primarily by administrative texts from Dūr-Katlimmu. The status of ploughman (LÚ.ENGAR; LÚ.^{GIS}APIN/*ikkaru*) at that time differed from his counterpart in Mari. In the Middle Assyrian period, it refers to persons who actually tilled the land, whereas their superior in charge of agricultural management was known as an “overseer of ploughmen” (GAL LÚ.ENGAR; GAL LÚ.^{GIS}APIN/*rāb ikkarāte*). Both functions have been studied in detail by S. Jakob¹⁰⁸ and are briefly presented here. The “overseers of ploughmen” were the men in charge of

105 van Koppen 2001, 468–82.

106 van Koppen 2001, 473–77.

107 This question may need to be addressed anew, but this is far beyond the scope of the present essay, so for now I follow F. van Koppen’s conclusions.

108 Jakob 2003, 328–41.

cultivating a given acreage of fields. They received personnel and draught animals from the palace, as well as grain for their rations.¹⁰⁹ Agricultural laborers (“ploughmen”) represent the lower ranks, supervised by the “overseers of ploughmen,” and belonged to the *šiluḥlu*-class of “dependent workers.”¹¹⁰ They appear in lists together with the adult women of their household, usually depicted as “workers” (*ša šipre*, sometimes more precisely as “in charge of n *mašḥuru*-textiles,” *ša n mašḥurē*), and their children, who were ranked according to gender and/or age.¹¹¹ They were palatial dependents, sometimes depicted as “servants/maids of the palace” (*urdē/amāt ekalle*),¹¹² and operated under the administrative supervision of the “gang leaders” (*zāriqu*),¹¹³ themselves members of the *šiluḥlu*-class, as evidenced by the rations they received for themselves and their family, if they had one.¹¹⁴ As far as institutional agriculture is concerned, the *zāriqu* were responsible for the allocation of palatial personnel to the “overseers of ploughmen” in charge of agricultural management.¹¹⁵

2.3. ASSESSMENT OF PERSONNEL AND ANIMAL REQUIREMENTS OF INSTITUTIONAL AGRICULTURE

Most evidence on the Mari “plough teams” remains unpublished, but we can build on the remarks of F. van Koppen, who had access to this unpublished material for his 2001 study. He estimates that the average number of permanent workers lay between fourteen and sixteen per plough team (nine or ten in charge of agriculture proper, if one deducts those assigned to the preparation of food), as well as usually seven oxen to draw the plough, pull the carts, and thresh crops, even if their number varies.¹¹⁶ The grand total of attested dependent workers in the Mari plough teams is 828 persons (648 male adults, 150 female adults, 11 boys, and 19 girls)¹¹⁷ and an estimated 385 oxen, but these numbers are biased by the state of preservation of cuneiform tablets and in no way represent the total number of agricultural workers operating at any given time in the kingdom of Mari. The highest-preserved number, that of the (whole?) district of Terqa, suggests that the palace employed 263 male adults, 78 female adults, 6 boys, and 7 girls for its institutional agriculture in one of the three main districts of the kingdom. Unfortunately, none of the preserved lists of personnel can be directly related to any of the above-mentioned fields whose acreage is known. F. van Koppen¹¹⁸ advocates for “a normative field assignment of 150 iku field per plough team” at Mari, so around 10 *ikûm* (1.6–3.6 ha) per team member, or 15 *ikûm*

109 Röllig 2008, 19.

110 Jakob 2003, 39–43; Salah 2014, 1–36.

111 Salah 2014, 1–36.

112 Salah 2014, 24.

113 I borrow this translation from German *Kolonnenführer* proposed by Röllig 2002, 583 n. 4, and followed by Salah 2014.

114 Salah 2014, 21, table 20; 33, table 40.

115 Jakob 2003, 78–82; Salah 2014, 49.

116 van Koppen 2001, 470–78.

117 van Koppen 2001, table 2.

118 van Koppen 2001, 462.

(2.4–5.4 ha) without the food makers. My own reading of the evidence, however, indicates that the documented quota of work (*iškarum*) varied between 112.5 *ikûm* (18–40.5 ha) and 166 *ikûm* (26.5–60 ha) per plough team.¹¹⁹ This was clearly perceived by the administrator in charge at Qatṭunān as being too much work, and the whole dossier points to a voluntary, yet somewhat forced, policy of development, so it is doubtful whether even the lower amount of 112.5 *ikûm* per plough team should be regarded as a standard. In ARM 24 4+5, the work assignment (*iškarum*) of a plough team is estimated at 1,500 *kurru* of barley (108,000 l); using the average yields per hectare defined below, this would represent 39.8 ha, hence 166 *ikûm* with an *ikûm* worth 0.24 ha, or 62.3 ha, hence 173 *ikûm* with an *ikûm* worth 0.36 ha. But yields vary greatly, and nothing indicates that what we can reconstruct based on those documents that have been preserved actually represents the standards that the administration had in mind—not to mention the uncertainties we face for conversions of ancient units into modern ones.

The recent publication of the personnel lists of Dūr-Katlimmu,¹²⁰ many of which are grain distributions to the *šiluḥlu*-workers, offers some decisive information on the personnel of Middle Assyrian institutional agriculture. One important aspect in terms of economic analysis is that the “staff costs” are not directly proportional to the amount of work performed. *Šiluḥlu*-workers were organized by families, and the rations they received depended on the structure of the family, not on the amount of work they were able to perform. With the exception of aged men and women unable to work, who apparently received no ration, all members of the family were allocated a certain amount of grain based on gender and age: adult men received 540 *qû* (442 or 567 l) of barley annually, adult women 240 *qû* (192 / 252 l), male and female young adults (lit. “apprentices,” *talmīdu/talmittu*) respectively 240 *qû* (192 / 252 l) and 180 *qû* (144 / 189 l), and children of both genders respectively 150 *qû* (120 / 157.5 l) for adolescents (*tari’u/tārītu*), 120 *qû* (96 / 126 l) for small children (*pirsu/pirsatu*), and 90 *qû* (72 / 94.5 l) for infants (*ša irte*).¹²¹ So, for instance, for the year Bēr-šumu-lēšir (1259 BCE) in Duāra, the family of Adallulu,¹²² comprising one adult ploughman, his wife, three adult sons, two adult daughters (one with a small child and an infant), and one adolescent son, would have received 3,780 *qû* (3,024 / 3,969 l) of barley in exchange for the agricultural work of four adult ploughmen and the work of three adult women involved in at least weaving (the mother is specifically marked as in charge of five *mašḥuru*-textiles) and probably also in unspecified agricultural activities—as would have been the case for the adolescent son. The same year in Dūr-Katlimmu, the family of Amat-ili,¹²³ a woman with two adult sons, two adult daughters, and an apprentice daughter, would have received 1,980 *qû* (1,584/2,079 l) of barley in exchange for the agricultural work of two ploughmen and the activities (mostly in textile weaving?) of the women of the household. Besides grain, the *šiluḥlu*-workers could also be fed with chickpeas that were deducted from their rations, but the practice is documented by only one text (BATSH 18 46) and must have been exceptional. More common were deliveries of wool and/or textiles

119 Reculeau 2015, 213.

120 Salah 2014.

121 Cf. Jakob 2003, 49; Röllig 2008, 27; Salah 2014, 37–39.

122 Salah 2014, 11–12, tables 1 and 3.

123 Salah 2014, 14, table 6.

for their clothing. Since the women of *šiluhlu* households were in charge of the weaving of textiles for the palace,¹²⁴ wool deliveries as they appear in texts could encompass both the part intended for production for the administration (i.e., raw material for their duties) and that intended for the clothing of their family (i.e., part of their rations), as is apparent in the expression “x mines of wool, as work-quota (*iškarum*) and for clothing” (x *manā* SÍG.MEŠ *ana* GIŠ.GĀR *u lubulte*; cf. BATSH 18 15, 2^o-3^o; 47, 24–25). In other occurrences, the texts make it clear that either wool was delivered as raw material for work (BATSH 18 48) or wool or textiles were delivered as rations (BATSH 18 7; 10; 11; 24–26). A quantitative estimate of these textile rations is not possible in the present state of the documentation. It is, however, clear that because the socioeconomic nature of the palace institution as a productive household itself encompassed the households of its dependents and aimed to perpetuate itself by allowing them to perpetuate over generations, we cannot define the royal investment in “staff costs” or “wages” at any given time in the same terms as we might do for a modern company. These costs covered not only the actual workers (adults and adolescents) but also the costs, so to say, of maintaining future workers (babies and children, even if they may well have started to work at an early age)—while, most notably, persons who were considered not able to produce anymore became the responsibility of their respective families.

Except for the three known “gang leaders” (*zāriqu*),¹²⁵ all but one¹²⁶ adult *šiluhlu*-men in the Dūr-Katlimmu personnel lists are depicted as ploughmen (*ikkaru*)¹²⁷ and were thus engaged in institutional agriculture. Unfortunately, we have only very limited information as to how these men were allocated to the “overseers of ploughmen” (*rāb ikkarāte*). Only one text (BATSH 18 23 = DeZ 3399)¹²⁸ lists the ploughmen not as members of their families, but as part of work teams assigned to the four “overseers of ploughmen” who were in charge of institutional agriculture in Dūr-Katlimmu at the end of Shalmaneser I’s reign, and more precisely here in the year Ištar-(t)ēris (1257 BCE): Sîn-ašarēd (field 1 = *šar[ra]’u*¹²⁹), Ilī-ma-abī (field 2), Sîn-mušēzib (field 3), and Ittabši-lēšir (field 4).¹³⁰ When comparing these work teams with the families reconstructed by S. Salah¹³¹ (the depiction of families by head and numbers are his), it appears clear that their work was not organized on a family-based structure but brought together men from different families (even if they may have been kin-related to a higher degree, which now escapes us).¹³² A comparison with a delivery

124 Jakob 2003, 50, 421–25; Salah 2014, 41–43.

125 Salah 2014, 49.

126 The only exception is Piradi, the “bow-maker” (*sasinnu*), for whom see Salah 2014, 22–23, table 23. He is not to be confused with his homonym (no known family relations) who was a ploughman.

127 Salah 2014, 11–34.

128 Cf. Jakob 2003, 339.

129 This field is always smaller and more productive than the others, and reflects some sort of more intensive agriculture on a small part of the acreage; its precise nature is debated (see Röllig 2008, 22–24; Reculeau 2011, 191; Postgate 2013, 314).

130 See the details in Reculeau 2011, 167–69.

131 Salah 2014, 6–34.

132 Field 1 was tilled that year by one brother of Šilli-Bēl (fam. 27) and two sons of Amat-ili (fam. 6); field 2 by two sons of Uma’itu (fam. 36), one brother of Šamaš-mušēzib (fam. 29), and one son of Ištarēni (fam. 18); field 3 by another son of Uma’itu (fam. 36), another son of Ištarēni (fam. 18), a son of Uballiṭu

of *mašḥuru*-textiles for the same year (BATSH 18 24) shows that the number of active ploughmen in Dūr-Katlimmu in 1257 BCE must not have been much higher than fifteen,¹³³ so BATSH 18 23 can safely be understood as listing all the ploughmen allocated to the “overseers of ploughmen” that given year.

How these numbers relate to the known acreage of fields under cultivation that given year is a delicate matter. Unfortunately, for the only year for which such a document exists (Ištar-[t]ēriš = 1257 BCE), the tablet recording the acreage and annual yields (BATSH 9 62+100)¹³⁴ is so badly broken that no numbers are preserved. Hence, we cannot say how much land these men were supposed to till. S. Jakob¹³⁵ had suggested using the numbers of another tablet (DeZ 2494 = BATSH 9 69) to define an allocation of 50 *ikû* per ploughman, but this text dates to Mušallim-Aššur, s. of Aššur-mušabši (1264 BCE), a date when only three overseers were in charge of the whole acreage of Dūr-Katlimmu.¹³⁶ One must assume that in years when the acreage was divided among four overseers, the teams they supervised were responsible for a smaller acreage (and conversely, that in 1264 BCE, these overseers were allocated a greater number of ploughmen). The closest parallels in date and structure, presented in table 4, rather suggest a much lower attribution when assuming that the number of workers allocated to each overseer remained the same (which cannot be proven in the present state of documentation): 25–37.5 *ikû* (10.5–15.75 ha) per ploughman on fields 2–4, and a constant 16.66 *ikû* (7 ha) per ploughman on the more intensively cultivated field 1. These numbers can be refined for the year Libūr-zānin-Aššur (1238 BCE), since the total number of ploughmen is known from BATSH 18 50, a list of annual barley distribution in which twelve ploughmen are mentioned. Given that 350 *ikû* (147 ha) were put under cultivation that year (and for the next decades), and assuming that field 1 was still tilled by three ploughmen, there remain three ploughmen for each of the 100 *ikû* (42 ha) fields, hence a work quota of 33.33 *ikû* (14 ha) per ploughman, or double that required on the more intensively cultivated field 1. The perfect ratio of 1:2 depending on the type of cultivation, and the fact that these numbers became standard during the reign of Tukulti-Ninurta I, suggests that these were the actual “normative” quota—which does not exclude the possibility of a higher workload in the early days of the archive, reflecting some voluntary policies not dissimilar to the ones we have seen at play in Mari.

(fam. 35), and Piradi (no known family); and field 4 by Alluzu (head of fam. 5, who later moved to Duāra but was still in Dūr-Katlimmu at that time; see Salah 2014, 72), Urdu, another son of Ištarēni (fam. 18), the head of fam. 37, Taḥāka, and a man named Šilliya, of dubious family association (the diminutive used in the text being applicable to a number of persons in the archive).

133 This text actually lists fifteen ploughmen, fourteen of whom are the same persons as the ones in BATSH 18 23. The only difference is the presence in BATSH 18 23 of a man named Pilta-adur, where BATSH 18 24 lists a man named Panba instead. Given that the latter is mentioned only here, he may actually be the same person as Pilta-Adur, but his name was written differently or he went by two different names. I can see no philological way of explaining how one may have been rendered by the other, though (for variant spellings in onomastics, see Salah 2014, 5).

134 Cf. Reculeau 2011, 234–35.

135 Jakob 2003, 339.

136 Reculeau 2011, 167.

Table 4. The institutional fields of Middle Assyrian Dūr-Katlimmu compared to the number of ploughmen assigned to them (with 1 *ikû* = 0.42 ha; chronology based on Salah 2014, 62)

Reference (BATSH 9 no.)	Eponym	Year BCE	Field 1 (Sîn-ašarēd)		Field 2 (Ilī-ma-abī)		Field 3 (Sîn-mušēzib)		Field 4 (Ittabši-lēšir)	
			<i>ikû</i>	ha	<i>ikû</i>	ha	<i>ikû</i>	ha	<i>ikû</i>	ha
63 ¹³⁷	Aššur-dammeq, s. Abī-ilī	1258	50	21	131+17 = 148	62.16	130+17 = 147	61.74	130+17 = 147	61.74
62+100	Ištar- (t)ēriš	1257	[. . .]	[. . .]	[. . .]	[. . .]	[. . .]	[. . .]	[. . .]	[. . .]
60	Aššur-kettī-ide, s. Abī-ilī	1251	50	21	150	63	150	63	150	63
64 ¹³⁸	[Ittabši- dēn- Aššur] ¹³⁹	1245	50	21	120	50.4	120	50.4	120	50.4
73	Libūr- zānin- Aššur	1238	50	21	100	42	100	42	100	42
No. of ploughmen in BATSH 18 23	Ištar- (t)ēriš	1257	3		4		4		4	
Acreage/ ploughman			16.66	7	25– 37.5	10.5– 15.75	25– 37.5	10.5– 15.75	25– 37.5	10.5– 15.75
Acreage/ ploughman (based on BATSH 9 73 & BATSH 18 50)	Libūr- zānin- Aššur	1238	16.66	7	33.33	14	33.33	14	33.33	14

Together with workmen, oxen were also allocated to the “overseers of ploughmen” to till the fields, with numbers varying based on the size of the field. They vary between five and thirty (maybe once thirty-eight), with the number of oxen usually five or six per 100

137 For this year, fields 2–4 were divided into a greater acreage sowed in barley, and a smaller one sowed in wheat. Afterward, only barley was sown on the whole acreage.

138 These values become standard until 1239 BCE and are afterward replaced by the ones presented for 1238 BCE, until the end of the archive around 1220 BCE.

139 This text is dated from the second month of Ubru (1244 BCE) but records the harvest of the previous year.

ikû (42 ha) of field.¹⁴⁰ Under normal circumstances, the operational requirements for institutional agriculture in Dūr-Katlimmu would thus have been roughly three ploughmen and the double of oxen per 100 *ikû* (42 ha) of land, except for the more intensively cultivated *šar(ra)ʷu*-field (field 1), where these costs were applied to a field half the size.

2.4. EXPENDITURES FOR CULTIVATION: THE SEEDING RATES

Besides the cereals that were required to feed families of dependent workers and oxen, the managers of institutional agriculture needed to secure seeding grain for the next agricultural cycle. Mari seeding rates are poorly documented, but the numbers of 35(?), 45, and 50 *qûm/ikûm* can be suggested.¹⁴¹ The situation of Middle Assyrian agriculture is clearer, with seeding rates at 30 *qû/ikû* (Dūr-Katlimmu and Duāra), 31.5 *qû/ikû* (Ḥarbe), 35 *qû/ikû* (Tarbašhe), and 40 *qû/ikû* (Ḥarbe).¹⁴² Based on the equivalences of table 1, the seeding rates in table 5 can be reconstructed.

Mari seeding rates appear rather high, even if how high depends on the actual size of the *ikûm*: in the range of 81–115 kg/ha (131–187 l/ha) for an *ikûm* worth 0.16 ha, 56–80 kg/ha (91–130 l/ha) for an *ikûm* of 0.23 ha, or 36–51 kg/ha (58–83 l/ha) for an *ikûm* of 0.36 ha. Only the last hypothesis would be in the range of the seeding rates of Middle Assyrian Dūr-Katlimmu and Duāra: at 30 *qû/ikû*, these were either 36 or 46 kg/ha (57 or 75 l/ha), depending on the size of the *qû* in that period. Other Middle Assyrian rates are slightly higher than the Dūr-Katlimmu ones. At Ḥarbe, the lowest rates were 38 or 46 kg/ha (60 or 78 l/ha), and the highest ones 48 or 62 kg/ha (76 or 100 l/ha); at Tarbašhe, rates would have been either 42 or 54 kg/ha (77 or 87 l/ha). These cities were located in the better-watered areas of the northern Ġazira and the Lower Zāb, where predominant dry farming could have been supplemented with irrigation.¹⁴³ For Mari, even the lowest seeding rates (implying an *ikûm* of ca. 0.36 ha) are much higher than the ones reconstructed by A. Dornauer, who estimated them at 48.6 l/ha (ca. 30.16 kg/ha), albeit with a different methodology using a 35 *qûm/ikûm* seeding rate, a standard Babylonian value for the *qûm*, and a double-sized *ikûm*.¹⁴⁴ This is, however, highly improbable, on all three accounts.¹⁴⁵ For

140 Röllig 2008, 27 and table 9.

141 Reculeau 2015, 207.

142 Reculeau 2011, 129–33.

143 Reculeau 2011, 73–76.

144 Dornauer 2017, 212.

145 The first hypothesis (standard seed/yield rates of 35 *qûm/ikûm*) assumes as a standard the lowest value mentioned in ARM 23 466: 6, following the copy of the tablet (Michel 1990, 458), but this is problematic. First, the text edition has a value of 45 *qûm/ikûm* for this line (Soubeyran 1984, 270), in contradiction to the copy. Unfortunately, no photograph of the tablet (currently in Dayr az-Zūr, Syria) exists in the archives of the Mari Epigraphic Mission in Paris, so there is at present no way to decide which reading is the proper one (my thanks go to Dominique Charpin for having researched the Paris archives on my behalf). Moreover, the same text undoubtedly indicates another value of 50 *qûm/ikûm* (l. 9), so a uniform seeding rate of 35 *qûm/ikûm* cannot be assumed for all the documented Mari fields. The second hypothesis (a standard Babylonian value for the Mari *qûm*) is not substantiated by the rest of the evidence, and it can be suggested that it was probably worth about 60 percent of its southern counterpart (Reculeau 2018b). Finally, the third hypothesis (a Mari *ikûm* twice the size of a Babylonian *ikûm*) is purely speculative and is no longer required with a lower value for the *qûm* (Reculeau 2018b).

Table 5. The seeding rates of Mari and Middle Assyrian institutional agriculture (the most probable values are boldfaced)

	Mari (<i>ikûm</i> =)												Middle Assyrian (<i>ikû</i> = 0.42 ha)			
	0.16 ha				0.23 ha				0.36 ha							
in <i>qû(m)/ikû(m)</i>	35	45	50	55	35	45	50	55	35	45	50	55	30	31.5	35	40
in l/ha	131.25	168.75	187.50	191.30	117.39	130.43	130.43	130.43	58.33	75.00	83.33	83.33	-	-	-	-
(w/ 1 <i>qûm</i> =)	0.81	-	-	-	-	-	-	-	-	-	-	-	57.14	60.00	66.67	76.19
	1.051	-	-	-	-	-	-	-	-	-	-	-	75.00	78.75	87.50	100.00
in kg/ ha	80.94	104.06	115.63	56.30	72.39	80.43	80.43	80.43	35.97	46.25	51.39	51.39	-	-	-	-
(w/ 1 <i>qûm</i> =)	0.5 kg	-	-	-	-	-	-	-	-	-	-	-	35.71	37.50	41.67	47.62
	0.65 kg	-	-	-	-	-	-	-	-	-	-	-	46.43	48.75	54.17	61.90

Middle Assyrian rates, my reconstructions appear much lower than the ones he posits for Dūr-Katlimmu, at 90.3 l/ha (ca. 56 kg/ha), but he again uses Babylonian units that do not apply to Upper Mesopotamia,¹⁴⁶ and his assumed seeding rate of 32.5 *qû/ikû* is not compatible with the textual record.¹⁴⁷ It is also unclear to me why he chose to retain a high seeding rate (90.3 l/ha) for the Middle Assyrian period that is at odds with the ones he reconstructs for both Mari (48.6 l/ha) and Nuzi (44.5 l/ha), instead of the second hypothesis he proposed (using an Assyrian *ikû* the size of the Mari one), which would have fallen into similar ranges (45 l/ha). Anyway, if my reconstructions for the size of the Mari and Middle Assyrian *qû(m)* and *ikû(m)* are accepted, none of these values are relevant for the present study.

Ancient comparative evidence can be found in the documents from the early Late Bronze Age city of Nuzi (Yorgan Tepe), shortly before the Middle Assyrian period. According to A. Dornauer,¹⁴⁸ the seeding rate in Nuzi was “0.8 ANŠE/ANŠE = 80 *qû*/5 *ikû* ≈ 44.5 l/ha,” hence 16 *qû/ikû* (the *emāru*/ANŠE being used as both a capacity and surface unit). This is much lower than the rates attested for both Mari and the Middle Assyrian period and is quite puzzling. If the surface *emāru* used in Nuzi and other northern Mesopotamian areas can safely be reconstructed as worth 5 *ikû*, the situation of the capacity *emāru* is less clear. Both an *emāru* containing 80 *qû* and one containing 100 *qû* are known to have been in use at Nuzi, but it is unclear whether the two *emāru* were of identical value (but differed at the level of the *qû*) or whether the value of *qû* remained unchanged, but the two *emāru* differed in value (one being worth 80 percent of the other).¹⁴⁹ The value of the Nuzi *qû* in modern units is also an open question. Studies of the Nuzi yields adopt either one of the commonly assumed values, that is, 1 *qû(m)* = 1 l¹⁵⁰ or 1 *qû(m)* = 0.842 l,¹⁵¹ but do not justify these choices. Given the strong relations of the Nuzi system with the Assyrian system for surfaces, I prefer adopting the values proposed for the Middle Assyrian capacity units as well, but I admit that this choice remains highly hypothetical.

The assumed number of *qû* in the *emāru* used for seeding rates also varies, depending on the study. In his initial article on Nuzi yields, C. Zaccagnini¹⁵² chose the value of 100 *qû* per *emāru*, in which he is followed by M. Powell;¹⁵³ however, he later¹⁵⁴ chose the smaller value of 80 *qû* per *emāru*, in order to obtain similar seeding rates for Yorgan Tepe in the third millennium BCE (when it was called Gasur) and in the second millennium BCE (when it was known as Nuzi). He has been followed by A. Dornauer,¹⁵⁵ but given that this hy-

146 Reculeau 2018b.

147 The “average seeding rate of 32.5 *qû/ikû*” used by A. Dornauer (2017) for the Dūr-Katlimmu texts is unnecessary: if indeed “there are different seeding rates of 30 *qû/ikû* and 35 *qû/ikû*” (and even higher) attested in Middle Assyrian documents, this is not the case in the archives from Tall Šeḥ Ḥamad, where the expenses recorded in the texts show that the sowing rate was uniformly of 30 *qû/ikû* (Röllig 2008, 27; Reculeau 2011, 110).

148 Dornauer 2017.

149 Reculeau 2018b.

150 Dornauer 2017.

151 Zaccagnini 1979, 856; 1990, 201.

152 Zaccagnini 1975, 182–84, 217–18.

153 Powell 1990, 488.

154 Zaccagnini 1979, 1990.

155 Dornauer 2017.

pothesis would require the use, in the third millennium BCE, of a unit not attested until the late second millennium BCE,¹⁵⁶ this equivalence need not be accepted without hesitation. Moreover, these are only *theoretical* values, and the *actual* seeding rates reported by Zaccagnini¹⁵⁷ vary greatly. Depending on the numbers of *qû* per *emāru* (table 6), they can be as low as 12.8 *qû/ikû* (with an 80-*qû emāru*) or 16 *qû/ikû* (with a 100-*qû emāru*), and as high as 20.85 or 26.06 *qû/ikû*, respectively. In modern units, the highest values would be reached with a 100-*qû emāru* and a value for the *qû* of 1.05 l, the value considered most plausible for the Middle Assyrian period. The lowest attested seeding rate would be 24.76 kg/ha (40 l/ha), the highest 40.33 kg/ha (65.15 l/ha), and the “standard” rate of 1 *emāru* of grain per *emāru* of field would amount to 30.95 kg/ha (50 l/ha).¹⁵⁸ This is lower than the Mari and Middle Assyrian seeding rates but remains in a similar order of magnitude, except for the very low rate of HSS 13 267. In any case, one should not assume that “Dūr-Katlimmu seeding rates are double the size of the seeding rates from Nuzi and Mari”.¹⁵⁹ using the most probable values in tables 5 and 6, the Mari and Dūr-Katlimmu rates appear strikingly similar (around 45–50 kg/ha, or 75–80 l/ha), which shows continuity in agrarian practices for two similar environments relying on river irrigation. The situation in the east is less clear, with low seeding rates at Nuzi, but higher ones in the eastern Middle Assyrian kingdom (even at Tarbašhe, which was close to Nuzi).

Modern comparative evidence is offered by data from Middle Euphrates Iraq in the 1950s, where irrigated land was sown in barley at rates ranging between 54 and 128 kg/ha; another study¹⁶⁰ points to seeding rates of 100 kg/ha for barley in the area of Abu Ghraib. An interesting feature of the first study is that twentieth-century CE Iraqi farmers had a tendency to adapt their seeding rates to the nature of the soil: the better the soil, the higher the seeding rate (up to 160 or even 200 kg/ha on the best fields, apparently for wheat though not barley).¹⁶¹ Modernized dry farming in Syria also attests variations in seeding rates based on the availability of water: around 100 kg/ha in well-watered areas, but down to 25–50 kg/ha in drier areas.¹⁶² If ancient farmers behaved like their modern counterparts (which, of course, should not be taken for granted), one would expect high seeding rates in the highly efficient irrigation agriculture of Mari, which would favor a smaller size for the *ikûm*. Yet, the use of the Mesopotamian seeder-plough in Mari is implied by the very name of its team-workers (see above), which rather calls for low seeding rates,¹⁶³ so the highest value (0.36 ha) cannot be ruled out and would actually fit the yields per hectare better (see below). For the Middle Assyrian period, the lowest seeding rates (based on a 0.8 l *qû*) are possible, but range into the very lowest values of modern dry farming. Values based on

156 See the details in Reculeau 2018b.

157 Zaccagnini 1975, 184.

158 Nuzi is not at the heart of the present research; I have used the evidence gathered by Zaccagnini in his 1975 and 1990 articles, but have not sought additional material that might have been published since. Similar documents are known from nearby Tell Fakhar/Kurruḫānī (Müller 1995, 37 and n. 32), but to my knowledge they still remain unpublished (Koliński 2001, 201).

159 Dornauer 2017, 224.

160 Quoted by Butz and Schröder 1985, 184 n. 72.

161 Poyck 1962, 50, with Butz and Schröder 1985, 178 n. 60.

162 Wirth *apud* Pettinato and Waetzoldt 1975, 290.

163 Hruška 1995, 61–62.

Table 6. The seeding rates in Nuzi (based on evidence from Zaccagnini 1975 and 1990), using the equivalences for the *ikû* and the *qû* presented in table 1: (1) with 1 *emāru* = 100 *qû*; (2) with 1 *emāru* = 80 *qû* and a stable value for the *qû*; and (3) with 1 *emāru* = 80 *qû* and a stable value for the *emāru* (the most probable values are boldfaced)

	Reference	Crop	<i>emāru</i>	<i>ikû</i>	<i>emāru</i>	<i>qû</i>	<i>qû/</i> <i>emāru</i>	<i>qû/</i> <i>ikû</i>	l/ha (0.8 l)	kg/ha (0.5 kg)	l/ha (1.05 l)	kg/ha (0.65 kg)
(1)	HSS 15 233	Barley	20	100	26	2,600	130	26	49.52	30.95	65.00	40.24
	HSS 15 233	Barley	66	330	86	8,600	130.30	26.06	49.64	31.02	65.15	40.33
	AASOR 16 87	Barley	5	25	5	500	100	20	38.10	23.81	50.00	30.95
	HSS 13 267	Barley	5	25	4	400	80	16	30.48	19.05	40.00	24.76
	JAOS 55, III/2	Barley	6	30	6	600	100	20	38.10	23.81	50.00	30.95
	HSS 16 114	Emmer	16	80	16	1,600	100	20	38.10	23.81	50.00	30.95
	Reference	Crop	<i>emāru</i>	<i>ikû</i>	<i>emāru</i>	<i>qû</i>	<i>qû/</i> <i>emāru</i>	<i>qû/</i> <i>ikû</i>	l/ha (0.8 l)	kg/ha (0.5 kg)	l/ha (1.05 l)	kg/ha (0.65 kg)
(2)	HSS 15 233	Barley	20	100	26	2,080	104	20.8	39.62	24.76	52.00	32.19
	HSS 15 233	Barley	66	330	86	6,880	104.24	20.85	39.71	24.82	52.12	32.27
	AASOR 16 87	Barley	5	25	5	400	80	16	30.48	19.05	40.00	24.76
	HSS 13 267	Barley	5	25	4	320	64	12.8	24.38	15.24	32.00	19.81
	JAOS 55, III/2	Barley	6	30	6	480	80.00	16	30.48	19.05	40.00	24.76
	HSS 16 114	Emmer	16	80	16	1,280	80	16	30.48	19.05	40.00	24.76
	Reference	Crop	<i>emāru</i>	<i>ikû</i>	<i>emāru</i>	<i>qû</i>	<i>qû/</i> <i>emāru</i>	<i>qû/</i> <i>ikû</i>	l/ha (1 l)	kg/ha (0.62 kg)	l/ha (1.3 l)	kg/ha (0.81 kg)
(3)	HSS 15 233	Barley	20	100	26	2,080	104	20.8	39.62	24.76	52.00	32.19
	HSS 15 233	Barley	66	330	86	6,880	104.24	20.85	49.64	30.78	64.53	40.21
	AASOR 16 87	Barley	5	25	5	400	80	16	38.10	23.62	49.52	30.86
	HSS 13 267	Barley	5	25	4	320	64	12.8	30.48	18.90	39.62	24.69
	JAOS 55, III/2	Barley	6	30	6	480	80	16	38.10	23.62	49.52	30.86
	HSS 16 114	Emmer	16	80	16	1,280	80	16	38.10	23.62	49.52	30.86

a 1.05 l *qû* seem more realistic and would offer a very close parallel to the Mari ones at 45 and 50 *qûm/ikûm*. In both periods, seeding rates would have fallen into the range of 46–51 kg/ha in the Middle Euphrates and Lower Ḥābūr areas, while dry-farming areas of higher rainfall like the Upper Ġazīra and the Lower Zāb would attest slightly higher rates, between 49 and 62 kg/ha (Nuzi being here an apparent exception).

3. AGRICULTURAL ACHIEVEMENTS OF INSTITUTIONAL IRRIGATION AGRICULTURE

The aforementioned investments in labor and cereals by the royal administrations of the Mari and Middle Assyrian kingdoms were part of a production system that aimed, first and foremost, at extracting surpluses in grain that could be spent to sustain the king, his court, and his servicemen (including his army). To reach a better picture of these investments, it is necessary to evaluate the results of institutional agriculture in both places and periods, by confronting seed/yield rates, yields per hectare, and, for the Middle Assyrian period, the ratio between production costs and revenue (this research can unfortunately not be offered for Mari in the present state of the documentation).

3.1. PRODUCTIVITY OF IRRIGATED LAND IN MARI AND DŪR-KATLIMMU: THE SEED/YIELD RATES

Because of the aforementioned difficulties in establishing firm connections between ancient and modern surface and capacity units, I have advocated elsewhere¹⁶⁴ that the soundest basis for comparing yields are *relative* values (namely, seed/yield rates on one given area of field), while any attempt at defining *absolute* values (grain yields per surface of field) can only be tentative. I shall refer to my comparative study of Mari and Middle Assyrian seed/yield rates¹⁶⁵ for the justification of the results presented in tables 7 and 8 and apologize for the redundancy of the presentation, which I renew here for the sake of completeness (most of the Mari data actually refer to estimates of harvests for tax purposes, which can be used as a proxy for the productivity of institutional land; Middle Assyrian data also include fields from other parts of the kingdom than Dūr-Katlimmu, part of which may have been partially cultivated in dry farming).¹⁶⁶

With average seed/yield rates ranging between 1:21 and 1:30 (depending on the seeding rate), the Mari data are quite astonishing (table 7). This is even more so if one leaves aside the low yields of ARM 23 426, which were caused by the destruction of the harvest by the flood,¹⁶⁷ and considers only the lowest results (those obtained with a sowing rate of 50 *qûm* per *ikûm*). One-third (twelve of thirty-six) of the rates would have ranged among the best estimates made for southern Mesopotamia (between 1:10 and 1:20 for good to exceptional years) or

164 Reculeau 2011, 121–27.

165 Reculeau 2015, 207–12.

166 See the discussion in Reculeau 2011, 73–91.

167 ARM 23 426: (18') A.ŠĀ.Ī.LA [šī-ib-šī-im(?)], (19') ša a-ḥa-ra-tim, (20') ra-aḥ-šu, (21') ù ša me-e BA.UG; "(tax?)-fields from the right bank, flooded, and killed by water."

Table 7. Estimated seed/yield rates of some institutional, service, and tax fields in Mari (in ascending order; the most probable values are boldfaced)

Reference	Location/ landlord	Yield per <i>ikûm</i> (in <i>kurrum</i>)	Seed/yield rate (1:x)		
			at 35 <i>qûm</i> / <i>ikûm</i>	at 45 <i>qûm</i> / <i>ikûm</i>	at 50 <i>qûm</i> / <i>ikûm</i>
ARM 23 426:8–9	. . .-AN	0.71	2.42	1.89	1.70
ARM 23 426:1–4	Mišlân and Zarrum	1.11	3.82	2.97	2.67
ARM 23 426:5–7	Ša-iššûrâtîm	1.74	5.98	4.65	4.19
ARM 23 591:1–3	Suqâqum	4.96	17.01	13.23	11.91
ARM 23 591:13–15	Našer district (total)	5.16	17.67	13.75	12.37
ARM 23 591:4–6	Našer	5.29	18.15	14.12	12.71
ARM 23 591:7–9	Amâtum	5.87	20.11	15.64	14.08
ARM 24 003:16'–17'	. . .-AN ^{ki}	5.96	20.43	15.89	14.30
FM 16 55+:9–10	Ša-ḥaddi	6.49	22.27	17.32	15.59
M.12017:1–2	Inib-šîna	7.50	25.71	20.00	18.00
ARM 24 002:35–37	Damêqum	7.52	25.79	20.06	18.05
ARM 23 591:10–12	Atamrum	7.55	25.89	20.14	18.12
M.12017:7–8	Yatar-Aya	8.00	27.43	21.33	19.20
ARM 24 003:14'–15'	Dêr	8.14	27.91	21.71	19.54
FM 16 53:6	. . . ^{ki} (total?)	8.27	28.35	22.05	19.85
M.12017:9–10	Total	8.36	28.66	22.29	20.06
FM 16 53:11–13	Aḥu-waqar	8.45	28.95	22.52	20.27
M.12017:5–6	Belessunu	8.50	29.14	22.67	20.40
FM 16 53:8–10	Belšunu	8.67	29.72	23.11	20.80
FM 16 55:8'–11'	. . . ^{ki} (total)	8.72	29.89	23.25	20.92
FM 16 53:5–7	Left bank	8.90	30.52	23.74	21.37
ARM 24 003:12'–13'	Bâb-Naḥlim	9.03	30.96	24.08	21.67
ARM 24 002:13–15	. . .im ^{ki}	9.26	31.75	24.69	22.22
FM 16 63:2–4	šîbšum of the Rabbeans	9.30	31.88	24.80	22.32

Table 7. Estimated seed/yield rates of some institutional, service, and tax fields in Mari (in ascending order; the most probable values are boldfaced) (*continued*)

Reference	Location/ landlord	Yield per <i>ikûm</i> (in <i>kurru</i> m)	Seed/yield rate (1:x)		
			at 35 <i>qûm</i> / <i>ikûm</i>	at 45 <i>qûm</i> / <i>ikûm</i>	at 50 <i>qûm</i> / <i>ikûm</i>
M.12017:3–4	Ḥaliatum	9.34	32.03	24.91	22.42
ARM 23 464:1–2	From Ziniyan Yaḥpilum to Amâtum	9.43	32.33	25.14	22.63
FM 16 57:6	Nagum	9.44	32.38	25.19	22.67
FM 16 55:3–4	Mišlân	9.53	32.66	25.40	22.86
A.2157. 5–7	Ṭābatum	9.60	32.91	25.60	23.04
FM 16 55:11–12	Ša-paḥuri	9.61	32.93	25.61	23.05
FM 16 57:7	Šubātum	10.10	34.64	26.94	24.24
ARM 24 002:38–41	Terqa district (total)	11.92	40.88	31.80	28.62
FM 16 57:5	... ^{ki}	11.97	41.02	31.91	28.72
ARM 24 002:7–9	... ^{ki}	12.28	42.10	32.75	29.47
FM 16 55:1–2	Zurmaḥum	12.29	42.13	32.77	29.49
ARM 24 002:32–34	Dumtên	13.33	45.70	35.55	31.99
ARM 24 002:10–12	... ^{ki}	13.71	47.01	36.56	32.91
ARM 24 002:4–6	... ^{xki}	14.45	49.54	38.53	34.68
ARM 24 002:1–3	ḤA-... ^{ki}	17.60	60.33	46.93	42.23
Average		8.67	29.72	23.11	20.80

other ancient societies.¹⁶⁸ The other two-thirds would correspond to exceptionally high results (sixteen between 1:20 and 1:25) or even to suspiciously high ones (eight between 1:28 and 1:42). Even if we consider that these documents reflect primarily the bureaucratic expectations of the administration, they must have been somehow connected to reality. Moreover, letter A.2157 leaves little doubt for Ṭābatum: there, “125 *ikûm* of field

168 See Reculeau 2011, 127–28 for an overview of available data, with Dornauer 2013, 249 for a correction on the Nuzi yields; see also Dornauer 2017, 212 for additional evidence from modern experimental agriculture.

(20–45 ha), bearing (*našūm*) 120 *ugārum* of grain (86,400 l), have been harvested.”¹⁶⁹ I see no reason not to take this sentence at face value and understand it as depicting the actual harvest obtained, in one given year, on said field. With a seed/yield rate of 1:23, productivity on that part of the Ḫābūr would have been among the highest levels known—which suggests that the other figures mentioned should also be trusted, even as rough estimates (except, perhaps, for the values above 1:30 of ARM 24 2). This would place Mari in the range of the highest yields reconstructed by K. Maekawa for Sumerian agriculture, especially Ur III Girsu (1:24),¹⁷⁰ and among the best-performing agricultural systems of Mesopotamian history, which contrasts sharply with the numerous complaints about the lack of grain and bad harvests found in the Mari letters. Such a discrepancy remains difficult to explain. If indeed our understanding of the seed/yield rates is valid, why were there such repeated shortages? One possible explanation would be that the land under cultivation was highly productive, but not enough land was being farmed overall. This would point to taskforce shortages rather than a lack of agricultural productivity. Another suggestion could be that too many of the crops were destroyed by natural and anthropogenic calamities, such as destructive floods, locust swarms, and military activities in the countryside. Locust invasions are the best-documented calamity, and we see them indeed occurring at a high pace over several consecutive years, causing great concern in the country.¹⁷¹ In the present state of research, however, one must remain cautious and acknowledge the fact that we are probably seeing only part of the global picture.

By contrast, Middle Assyrian yields (table 8) are much lower, and the overall picture is that of (very) low productivity, with maximal seed/yield rates at circa 1:10, and two-thirds of the results (twenty-four of thirty-six) below 1:5.5.¹⁷² According to the highest known seed/yield rates, the fields of Dūr-Katlimmu and Duāra were among the most efficient, with maximum rates between 1:5.6 and 1:8.75 for fields 2–4 in Dūr-Katlimmu, 1:6.67 for Duāra, and 1:9.87 for the more intensive field 1 in Dūr-Katlimmu. Yet, we are facing a documentation bias here, since these fields are documented over more than twenty years, whereas other Middle Assyrian fields are known only for a single year. Average results are much lower (between 1:2.6 and 1:5.63) and closer to the values known from other fields in the kingdom.

If we look once again to the Nuzi material for comparison, we find a situation that seems somewhat intermediary between Mari’s high-efficiency agriculture and the Middle Assyrian low-productivity one. The relevant documentation has been assembled by G. Müller¹⁷³ and need not be repeated here. Assuming a standard seeding rate of 1 *emāru* of grain per *emāru* of field¹⁷⁴ (but see above), he calculated the seed/yield rates for some 190 fields located in 33 cities and villages of the kingdom of Arrapha, to which Nuzi belonged.

169 A.2157 (Ziegler 2011): (5) 1 ME 25 GĀN A.ŠĀ ŠE.NUMUN, (6) *ša* 1 M[E] 20 A.GĀR ŠE *na-šu-ú*, (7) *i-na e-še-di-im š[u-u]l-lum*.

170 Maekawa 1984; Koliński 2003, 88–89.

171 Lion and Michel 1997; Heimpel 1996; Reculeau 2010, 196–201.

172 Reculeau 2011, 129–50.

173 Müller 1994, 229–32, table 1.

174 The actual number of *qū* per *emāru* used in Nuzi agriculture does not affect the seed-to-yield rates, since we can safely assume that whatever the *emāru* used to calculate seeding rates was, the same unit was also used when measuring the harvest.

Table 8. Minimal, maximal, and average yield per *ikû* (in *qû*) and seed/yield rate of Middle Assyrian fields, with the hypothesis that 1 old *sûtu* = 1 *sûtu ša ħiburni*, in ascending order of maximal seed/yield rate (based on data from Reculeau 2011; DK = Dür-Katlimmu; KTN = Kār-Tukulti-Ninurta)

Field	% of misharvests	Yield per <i>ikû</i> (in <i>qû</i>)			Seed/yield rate (1:x)		
		Min.	Max.	Average	Min.	Max.	Average
KTN 14	41.66 (10/24)			8	0.23	0.27	
KTN 29	58.33			22.40	0.64	0.75	
KTN 27	41.67			23.57	0.67	0.79	
KTN 28	75.00			40.00	1.14	1.33	
KTN 30	70.00			43.33	1.24	1.44	
KTN 13	41.66 (10/24)			56	1.60	1.87	
KTN 12	41.66 (10/24)			62.5	1.79	2.08	
KTN 11	41.66 (10/24)			69	1.97	2.30	
DK 5	–	–	–	72.58	–	–	2.42
KTN 10	41.66 (10/24)			85	2.43	2.83	
KTN 9	41.66 (10/24)			86	2.46	2.87	
Tarbašĥe 3	–	–	–	102.5	–	–	2.93
Tarbašĥe 2	–	–	–	105.25	–	–	3.01
KTN 26	60.00			90.75	2.59	3.03	
KTN 7	41.66 (10/24)			100	2.86	3.33	
KTN 8	41.66 (10/24)			100	2.86	3.33	
KTN 25	86.67			107.00	3.06	3.57	
Tarbašĥe 1	–	–	–	134	–	–	3.83
KTN 6	41.66 (10/24)			120	3.43	4.00	
Hiššutu 3	–	–	–	128.75	3.68	4.29	–
KTN 5	41.66 (10/24)			136	3.89	4.53	
KTN 4	41.66 (10/24)			155	4.43	5.17	
KTN 3	10/24			156	4.46	5.20	
Hiššutu 4	–	–	–	163.33	4.67	5.44	–
DK 3	10 (2/20)	34	168.13	78.03	1.13	5.6	2.6

(continued)

Table 8. Minimal, maximal, and average yield per *ikû* (in *qû*) and seed/yield rate of Middle Assyrian fields, with the hypothesis that 1 old *sûtu* = 1 *sûtu ša ħiburni*, in ascending order of maximal seed/yield rate (based on data from Reculeau 2011; DK = Dür-Katlimmu; KTN = Kâr-Tukulti-Ninurta) (*continued*)

Field	% of misharvests	Yield per <i>ikû</i> (in <i>qû</i>)			Seed/yield rate (1:x)		
		Min.	Max.	Average	Min.	Max.	Average
Hiššutu 2	–	–	–	190.00	5.43	6.33	–
Hiššutu 1	–	–	–	192.50	5.50	6.42	–
KTN 2	41.66 (10/24)			200	5.71	6.67	
Duāra	21.05 (4/19)	46	200	84.12	1.53	6.67	2.8
KTN 31	63.64			203.00	5.80	6.77	
Nēmad-Eštar 2	–			216.67	6.19	7.22	–
KTN 1	41.66 (10/24)			250	7.14	8.33	
DK 2	9.53 (2/21)	45.83	255.75	104.13	1.53	8.53	3.47
DK 4	10.53 (2/19)	33.33	262.5	87.06	1.11	8.75	2.9
Nēmad-Eštar 1	–			270.00	7.71	9.00	–
DK 1 šar(ra)ʿu	22.22 (4/18)	85	296	168.99	2.83	9.87	5.63

They appear to have varied to a great extent, with the lowest value at 1:0.8 and the highest at 1:50. Fields explicitly indicated as irrigated or located along a canal also exhibit great variability, with rates as low as 1:1.50 and as high as 1:13.30, and almost all intermediary values attested at least once. These values could, of course, have varied extensively, depending on the actual seeding rates: on the basis of available evidence, these could be as much as 20 percent lower and 30 percent higher than the assumed “standard” of 1 *emāru* of grain per *emāru* of land (table 6), affecting the seed/yield rates accordingly. Focusing on the cities and villages for which a good number of fields are documented,¹⁷⁵ he calculated average rates ranging between 1:3 and 1:17.5, depending on the location of the field. Using the whole documentation, A. Dornauer¹⁷⁶ estimated an average seed/yield rate for the Nuzi documentation of 1:7, but this number must be taken with caution given that the extreme variation between the actual rates clearly attests to the impact of local conditions (e.g., the nature of soil, water availability) on the yields attained on each field. A final element to be considered is the possibility, as suggested by M. Müller,¹⁷⁷ that these texts record only

175 Müller 1994, 233, table 2.

176 Dornauer 2017.

177 Müller 1995, 38.

part of the actual harvest, and that the seed/yield rates should be increased consequently. Following Müller's suggestion, A. Dornauer¹⁷⁸ applied a doubling factor to the values mentioned in the documents (hence suggesting an average yield for the total documentation of 1:14), but this is very speculative.

3.2. PRODUCTIVITY OF IRRIGATED LAND IN MARI AND DŪR-KATLIMMU: THE YIELDS PER HECTARE

Yields per hectare, as they can be estimated on the basis of modern equivalences of ancient units proposed in table 1, allow us to refine the analysis of yields based only on seed/yield rates. As regards Mari (table 9), average yields of 2,405 kg/ha or even 1,673 kg/ha (3,900 and 2,713 l/ha), as reconstructed on the basis of an *ikûm* worth 0.16 or 0.23 ha, seem too high to be realistic. Even when evidence suggesting seed/yield rates above 1:25 is discarded, most evidence points to yields per hectare ranging between 1,377 kg/ha and 2,803 kg/ha (2,232–4,546 l/ha) with an *ikûm* of 0.16 ha, and between 958 kg/ha and 1,950 kg/ha (1,553–3162 l/ha) with an *ikûm* worth 0.23 ha. This is even higher than the 1,153 kg/ha average yield reported by G. Johnson¹⁷⁹ for modern Khuzestan and used as a comparative basis by R. Adams.¹⁸⁰ Yet, these were achieved by using chemical fertilizers.¹⁸¹ Even without fertilizer, very high yields above 2,000 kg/ha are not impossible, and some reports exist of average barley yields of 2,240 kg/ha (and maximum yields of 3,952 kg/ha) on newly claimed fields in the area of Twairij (ca. 20 km east of Karbalā', in Iraq).¹⁸² Yet, such yields remain exceptional and require optimal conditions that cannot define the norm even for a highly efficient agriculture.¹⁸³

It seems to me that a more conservative approach, using the value of 0.36 ha (or close to it) for the Mari *ikûm*, would be more plausible, despite the problems it raises for the size of the Mari cubit.¹⁸⁴ Even then, Mari agriculture appears to have been very successful, with average yields of 1,069 kg/ha (1,734 l/ha) and recorded yields routinely in the range of 611–1,246 kg/ha (992–2,385 l/ha). These would, however, not be too far a fetch from estimates at ca. 700 kg/ha for Ur III Lagaš.¹⁸⁵ It would still be higher than the wheat yields of intensive agriculture in medieval Italy and southern France (700–800 kg/ha)¹⁸⁶ and would be in the higher range of productivity of Iraqi agriculture between 1934 and 1959, when the national yield per hectare of barley (including both irrigation agriculture and dry farming) oscillated between 670 and 1,050 kg/ha.¹⁸⁷ Based on the Twairij data mentioned above,

178 Dornauer 2017, 212.

179 Johnson 1973, 98.

180 Adams 1981, 86.

181 Butz and Schröder 1985, 188 n. 86.

182 Hulsbos 1977, 60.

183 Butz and Schröder 1985, 194.

184 Reculeau 2018b.

185 Butz and Schröder 1985, 180–81.

186 Butz and Schröder 1985, 167.

187 Butz and Schröder 1985, 178.

Table 9. Yield per hectare of the Mari fields, in ascending order (the most probable values are boldfaced)

Reference	Location/ landlord	Yield per <i>ikûm</i> (in <i>qûm</i>)		w/ 1 <i>ikûm</i> = 0.16 ha		w/ 1 <i>ikûm</i> = 0.23 ha		w/ 1 <i>ikûm</i> = 0.36 ha	
		Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha
ARM 23 426:8-9	...-AN	84.86	196.23	318.22	196.23	221.37	136.51	141.43	87.21
ARM 23 426:1-4	Mišlān and Zarrum	133.62	308.99	501.06	308.99	348.56	214.95	222.69	137.33
ARM 23 426:5-7	Ša-iššurātīm	209.35	484.12	785.06	484.12	546.13	336.78	348.92	215.17
ARM 23 591:1-3	Suqāqum	595.32	1,376.68	2,232.46	1,376.68	1,553.02	957.69	992.20	611.86
ARM 23 591:13-15	Našer district (total)	618.62	1,430.56	2,319.83	1,430.56	1,613.79	995.17	1,031.03	635.80
ARM 23 591:4-6	Našer	635.28	1,469.08	2,382.29	1,469.08	1,657.25	1,021.97	1,058.80	652.93
ARM 23 591:7-9	Amātum	703.85	1,627.64	2,639.42	1,627.64	1,836.12	1,132.27	1,173.08	723.40
ARM 24 003:16'-17'	...-AN ^{ki}	714.95	1,653.32	2,681.05	1,653.32	1,865.08	1,150.13	1,191.58	734.81
FM 16 55:9-10	Ša-ḥaddi	779.34	1,802.23	2,922.53	1,802.23	2,033.07	1,253.72	1,298.90	800.99
M.12017:1-2	Inib-šina	900.00	2,081.25	3,375.00	2,081.25	2,347.83	1,447.83	1,500.00	925.00
ARM 24 002:35-37	Damequm	902.52	2,087.09	3,384.46	2,087.09	2,354.41	1,451.89	1,504.21	927.59
ARM 23 591:10-12	Atamrum	906.18	2,095.53	3,398.16	2,095.53	2,363.94	1,457.76	1,510.29	931.35
M.12017:7-8	Yatar-Aya	960.00	2,220.00	3,600.00	2,220.00	2,504.35	1,544.35	1,600.00	986.67
ARM 24 003:14'-15'	Dēr	976.83	2,258.92	3,663.12	2,258.92	2,548.26	1,571.42	1,628.05	1,003.97
FM 16 53:6	... ^{ki} (total?)	992.38	2,294.87	3,721.42	2,294.87	2,588.81	1,596.43	1,653.96	1,019.94
M.12017:9-10	Total	1,002.99	2,319.40	3,761.19	2,319.40	2,616.48	1,613.50	1,671.64	1,030.85
FM 16 53:11-13	Aḥu-waqar	1,013.41	2,343.52	3,800.30	2,343.52	2,643.69	1,630.28	1,689.02	1,041.56
M.12017:5-6	Belessunu	1,020.00	2,358.75	3,825.00	2,358.75	2,660.87	1,640.87	1,700.00	1,048.33

FM 16 53:8-10	Belşumu	1,040.11	3,900.40	2,405.25	2,713.32	1,673.22	1,733.51	1,069.00
FM 16 55:8'-11'	... ^{ki} (total)	1,046.11	3,922.91	2,419.13	2,728.98	1,682.87	1,743.51	1,075.17
FM 16 53:5-7	Left bank	1,068.25	4,005.94	2,470.33	2,786.74	1,718.49	1,780.42	1,097.92
ARM 24 003:12'-13'	Bāb-Naḥlim	1,083.69	4,063.82	2,506.02	2,827.01	1,743.32	1,806.14	1,113.79
ARM 24 002:13-15	... ^{im} ^{ki}	1,111.11	4,166.67	2,569.45	2,898.56	1,787.44	1,851.85	1,141.98
FM 16 63:2-4	šibsum of the Rabbeans	1,115.78	4,184.16	2,580.23	2,910.72	1,794.94	1,859.63	1,146.77
M.12017:3-4	Ḥaliatum	1,121.05	4,203.95	2,592.43	2,924.49	1,803.43	1,868.42	1,152.19
ARM 23 464:1-2	From Ziniyan Yaḥpulum to Amātum	1,131.40	4,242.76	2,616.37	2,951.49	1,820.08	1,885.67	1,162.83
FM 16 57:6	Nagum	1,133.36	4,250.11	2,620.90	2,956.60	1,823.23	1,888.94	1,164.84
FM 16 55:3-4	Mišlan	1,143.08	4,286.55	2,643.37	2,981.95	1,838.87	1,905.13	1,174.83
A.2157. 5-7	Ṭābatum	1,152.00	4,320.00	2,664.00	3,005.22	1,853.22	1,920.00	1,184.00
FM 16 55:11-12	Ša-paḥuri	1,152.64	4,322.39	2,665.48	3,006.88	1,854.24	1,921.06	1,184.66
FM 16 57:7	Šubātum	1,212.25	4,545.93	2,803.32	3,162.38	1,950.14	2,020.41	1,245.92
ARM 24 002:38-41	Terqa district (total)	1,430.87	5,365.76	3,308.89	3,732.71	2,301.84	2,384.78	1,470.62
FM 16 57:5	... ^{ki}	1,435.83	5,384.38	3,320.36	3,745.65	2,309.82	2,393.06	1,475.72
ARM 24 002:7-9	... ^{ki}	1,473.64	5,526.17	3,407.80	3,844.29	2,370.65	2,456.07	1,514.58
FM 16 55:1-2	Zurmaḥum	1,474.70	5,530.14	3,410.25	3,847.06	2,372.35	2,457.84	1,515.67
ARM 24 002:32-34	Dumtēn	1,599.62	5,998.57	3,699.12	4,172.92	2,573.30	2,666.03	1,644.05
ARM 24 002:10-12	... ^{ki}	1,645.28	6,169.81	3,804.72	4,292.04	2,646.76	2,742.14	1,690.99
ARM 24 002:4-6	... ^x ^{ki}	1,733.76	6,501.60	4,009.32	4,522.85	2,789.09	2,889.60	1,781.92
ARM 24 002:1-3	ḤA-... ^{ki}	2,111.68	7,918.79	4,883.26	5,508.73	3,397.05	3,519.46	2,170.34
Average		1,040.15	3,900.55	2,405.34	2,713.43	1,673.28	1,733.58	1,069.04

even the highest yields recorded in Mari (up to 2,170 kg/ha, or 3,519 l/ha), could be deemed acceptable—but as the exception rather than the norm.

Looking at Middle Assyrian yields on the Lower Ḫābūr, the results are, unsurprisingly, much lower than the ones obtained in Mari (tables 10–14 and figs. 3–7). As for the seeding rates discussed above, using the traditional equivalence of 0.8 l (or 0.5 kg) for the Middle Assyrian *qû* results in numbers that are too low. Even on the more intensively cultivated field 1 at Dūr-Katlimmu, the average yield (excluding years of complete crop failure) would be 201 kg/ha (322 l/ha), while the less intensively cultivated fields 2–4 and the field of Duāra would range between 93 and 124 kg/ha (149–198 l/ha). Such numbers would be much lower than any recorded yields in modern Iraq, and even lower than the average results obtained for wheat in dry-farming areas like eighteenth-century CE Macedonia (320 kg/ha) and early nineteenth-century CE France (601 kg/ha)¹⁸⁸—and this, despite wheat yields being sensibly lower than barley ones.¹⁸⁹ Even if there are good reasons to believe that Middle Assyrian agriculture was not very productive, it seems preferable to use here the results obtained when assuming a value of 1.05 l (or 0.65 kg) per *qû*, which is also more satisfying for seeding rates (see above) and for the value of the “assload” (*emārum*, or 100 *qûm*) with regard to the carrying capacities of a donkey.¹⁹⁰

Using the higher value for the *qûm* (1.05 l, or 0.65 kg), results are still quite low, but less catastrophic than one may at first think when assuming that *qû(m)* and *ikû(m)* did not change over time and space. Generally speaking, the average yield on field 1 would be 261 kg/ha (422 l/ha), range between 121 and 161 kg/ha (195–260 l/ha) on the other fields of Dūr-Katlimmu, and reach 130 kg/ha (210 l/ha) in Duāra. These are still extremely low yields, and the situation is even harsher when one considers interannual variability. The best year ever recorded in Dūr-Katlimmu was a year whose eponym is lost but that should be located in the early days of the archive (and attributed here the range [1273–1270 BCE]). At that time, the more intensively cultivated parcel later known as *šar(ra)ʿu*-field is not attested, perhaps because it was not deemed necessary to invest twice as much work in a time of relatively higher harvests. That year, fields 2 and 4 reached yields of, respectively, 396 and 406 kg/ha (639 and 656 l/ha; the data for field 3 is lost), and even the field of Duāra (which usually had lower results) peaked at 226 kg/ha (365 l/ha). Later in the thirteenth century BCE, the second best year is 1251 BCE, when the (now well-established) more intensively cultivated field 1 in Dūr-Katlimmu reached yields of 458 kg/ha (740 l/ha), the more extensively tilled fields 2–4 ranged between 207 and 260 kg/ha (334 and 420 l/ha), and the Duāra field reached 180 kg/ha (290 l/ha). The latter had an all-time record in 1261 BCE, peaking at 310 kg/ha and outperforming all the fields of Dūr-Katlimmu—even field 1, whose harvest was destroyed. This points to local differences possibly caused by a flood

188 Butz and Schröder 1985, 168.

189 Butz and Schröder 1985, 178–79.

190 Reculeau 2018b.

Table 10: Yield per hectare of field 1 (*šar[ra]’u*) at Middle Assyrian Dūr-Katlimmu (the most probable values are boldfaced; chronology based on Salah 2014, 62)

Reference (BATSH 9 no.)	Year BCE	Yield in <i>qû</i>	Acreage in <i>ikû</i>	Yield in <i>qû/ikû</i>	w/ 1 <i>qû</i> = 0.8 l = 0.5 kg		w/ 1 <i>qû</i> = 1.05 l = 0.65 kg	
					Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha
67	1267	0	50	0.00	0.00	0.00	0.00	0.00
69	1264	7,140	50	142.80	272.00	170.00	357.00	221.00
70	1261	0	50	0.00	0.00	0.00	0.00	0.00
63	1258	8,460	50	169.20	322.29	201.43	423.00	261.86
60	1251	14,800	50	296.00	563.81	352.38	740.00	458.10
64	1245	10,550	50	211.00	401.90	251.19	527.50	326.55
66	1241	6,000	50	120.00	228.57	142.86	300.00	185.71
81	1240	10,000	50	200.00	380.95	238.10	500.00	309.52
68	1239	10,000	50	200.00	380.95	238.10	500.00	309.52
73	1238	5,120	50	102.40	195.05	121.90	256.00	158.48
74	1237	8,800	50	176.00	335.24	209.52	440.00	272.38
75	1236	11,400	50	228.00	434.29	271.43	570.00	352.86
88	1235	9,625	50	192.50	366.67	229.17	481.25	297.92
76	1234	8,100	50	162.00	308.57	192.86	405.00	250.71
77	1233	6,000	50	120.00	228.57	142.86	300.00	185.71
78	1232	6,500	50	130.00	247.62	154.76	325.00	201.19
79	1231	0	50	0.00	0.00	0.00	0.00	0.00
79	1230	0	0	0.00	0.00	0.00	0.00	0.00
80	1228	4,250	50	85.00	161.90	101.19	212.50	131.55
Average (years of total crop failure excluded)		8,450	50	168.99	321.89	201.18	422.48	261.54
Average		6,671	50	133.42	254.13	158.83	333.54	206.48

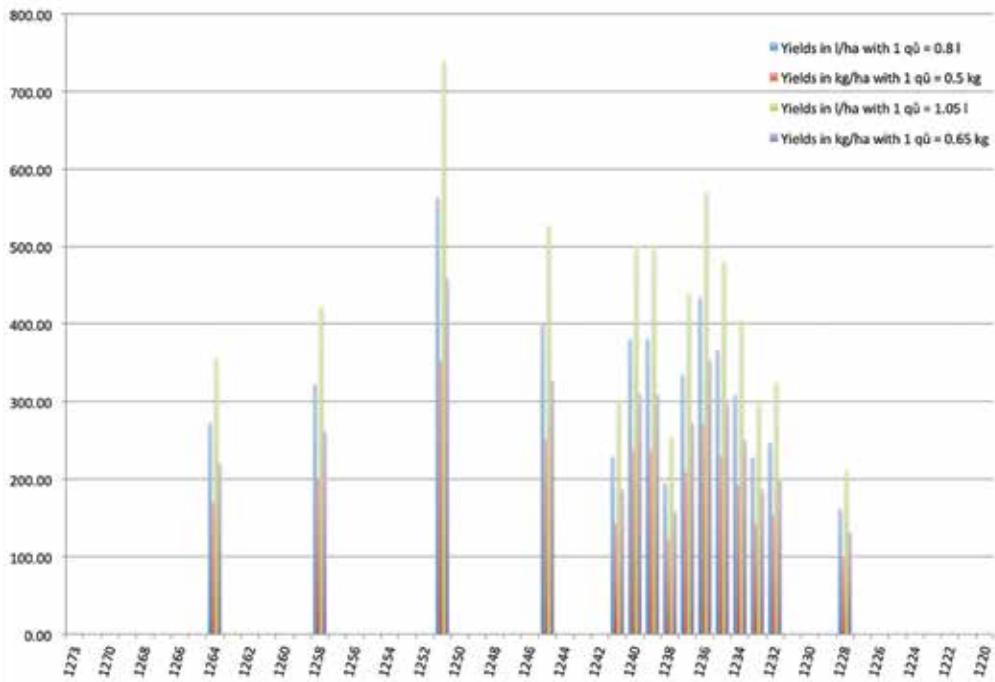


Figure 3. Yields in kg/ha and l/ha of field 1 at Middle Assyrian Dür-Katlimmu, using the equivalences proposed in table 1 (chronology based on Salah 2014, 62).

Table 11. Yield per hectare of field 2 at Middle Assyrian Dūr-Katlimmu (the most probable values are boldfaced; chronology based on Salah 2014, 62)

Reference (BATSH 9 no.)	Year BCE	Yield in <i>qû</i>	Acreage in <i>ikû</i>	Yield in <i>qû/ikû</i>	w/ 1 <i>qû</i> = 0.8 l = 0.5 kg		w/ 1 <i>qû</i> = 1.05 l = 0.65 kg	
					Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha
82	[1273– 1270]	20,460	80	255.75	487.14	304.46	639.38	395.80
67	1267	8,500	112	75.89	144.56	90.35	189.73	117.45
69	1264	25,800	200	129.00	245.71	153.57	322.50	199.64
70	1261	26,200	200	131.00	249.52	155.95	327.50	202.74
63	1258	14,890	131	113.66	216.50	135.31	284.16	175.91
60	1251	24,040	150	160.27	305.27	190.79	400.67	248.03
64	1245	6,710	120	55.92	106.51	66.57	139.79	86.54
66	1241	8,420	120	70.17	133.65	83.53	175.42	108.59
81	1240	8,450	120	70.42	134.13	83.83	176.04	108.98
68	1239	5,500	120	45.83	87.30	54.56	114.58	70.93
73	1238	10,900	100	109.00	207.62	129.76	272.50	168.69
74	1237	8,050	100	80.50	153.33	95.83	201.25	124.58
75	1236	15,000	100	150.00	285.71	178.57	375.00	232.14
88	1235	9,400	100	94.00	179.05	111.90	235.00	145.48
76	1234	7,350	100	73.50	140.00	87.50	183.75	113.75
77	1233	8,100	100	81.00	154.29	96.43	202.50	125.36
78	1232	12,500	100	125.00	238.10	148.81	312.50	193.45
79	1231	0	100	0.00	0.00	0.00	0.00	0.00
79	1230	0	0	0.00	0.00	0.00	0.00	0.00
80	1228	6,450	100	64.50	122.86	76.79	161.25	99.82
72	1220	9,300	100	93.00	177.14	110.71	232.50	143.93
Average (years of total crop failure excluded)		12,422	129	104.13	198.34	123.96	260.32	161.15
Average		11,239	117	94.21	179.45	112.15	235.52	145.80

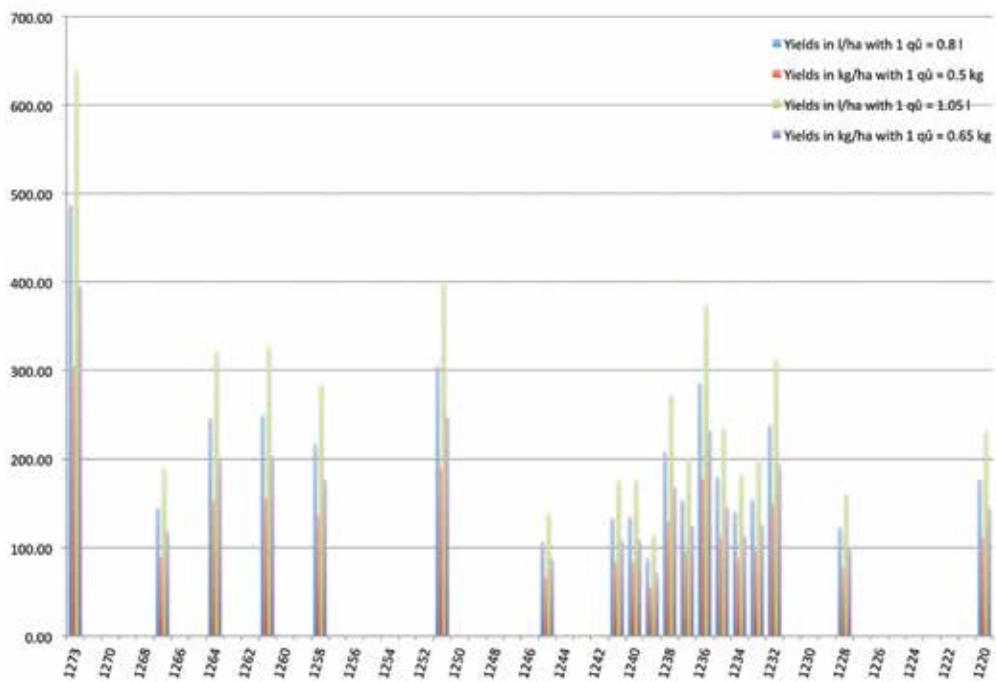


Figure 4. Yields in kg/ha and l/ha of field 2 at Middle Assyrian Dür-Katlimmu, using the equivalences proposed in table 1 (chronology based on Salah 2014, 62).

Table 12. Yield per hectare of field 3 at Middle Assyrian Dūr-Katlimmu (the most probable values are boldfaced; chronology based on Salah 2014, 62)

Reference (BATSH 9 no.)	Year BCE	Yield in <i>qû</i>	Acreage in <i>ikû</i>	Yield in <i>qû/ikû</i>	with 1 <i>qû</i> = 0.8 l = 0.5 kg		with 1 <i>qû</i> = 1.05 l = 0.65 kg	
					Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha
82	[1273– 1270]	...+10	80?	–	–	–	–	–
67	1267	7,400	112	66.07	125.85	78.66	165.18	102.25
69	1264	20,800	200	104.00	198.10	123.81	260.00	160.95
70	1261	26,400	200	132.00	251.43	157.14	330.00	204.29
63	1258	10,000	130	76.92	146.52	91.58	192.31	119.05
60	1251	25,220	150	168.13	320.25	200.16	420.33	260.21
64	1245	4,335	120	36.13	68.81	43.01	90.31	55.91
66	1241	6,500	120	54.17	103.17	64.48	135.42	83.83
81	1240	10,340	120	86.17	164.13	102.58	215.42	133.35
68	1239	6,000	120	50.00	95.24	59.52	125.00	77.38
73	1238	5,000	50	100.00	190.48	119.05	250.00	154.76
74	1237	3,400	100	34.00	64.76	40.48	85.00	52.62
75	1236	8,000	100	80.00	152.38	95.24	200.00	123.81
88	1235	7,000	100	70.00	133.33	83.33	175.00	108.33
76	1234	6,300	100	63.00	120.00	75.00	157.50	97.50
77	1233	5,400	100	54.00	102.86	64.29	135.00	83.57
78	1232	9,200	100	92.00	175.24	109.52	230.00	142.38
79	1231	0	100	0.00	0.00	0.00	0.00	0.00
79	1230	0	0	0.00	0.00	0.00	0.00	0.00
80	1228	4,650	100	46.50	88.57	55.36	116.25	71.96
72	1220	9,140	100	91.40	174.10	108.81	228.50	141.45
Average (years of total crop failure excluded)		9,727	129	78.03	148.62	92.89	195.07	120.76
Average		8,754	116	70.22	133.76	83.60	175.56	108.68

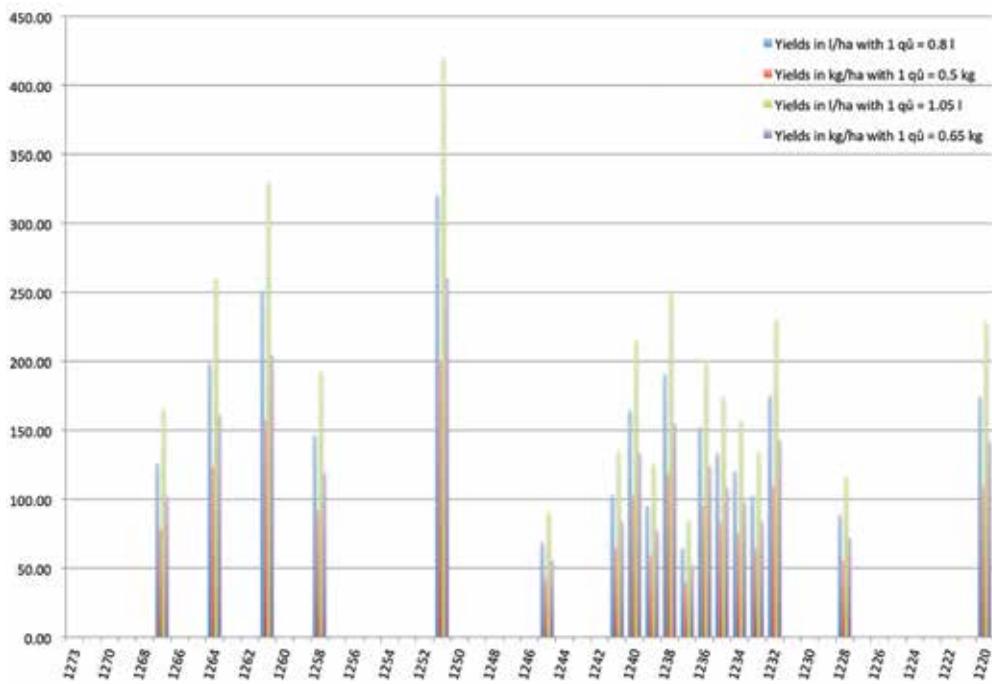


Fig. 5. Yields in kg/ha and l/ha of field 3 at Middle Assyrian Dür-Katlimmu, using the equivalences proposed in table 1 (chronology based on Salah 2014, 62).

Table 13. Yield per hectare of field 4 at Middle Assyrian Dūr-Katlimmu (the most probable values are boldfaced; chronology based on Salah 2014, 62)

Reference (BATSH 9 no.)	Year BCE	Yield in <i>qû</i>	Acreage in <i>ikû</i>	Yield in <i>qû/ikû</i>	w/ 1 <i>qû</i> = 0.8 l = 0.5 kg		w/ 1 <i>qû</i> = 1.05 l = 0.65 kg	
					Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha
82	[1273– 1270]	21,000	80	262.50	500.00	312.50	656.25	406.25
67	1267	7,600	112	67.86	129.25	80.78	169.64	105.02
63	1258	11,140	130	85.69	163.22	102.01	214.23	132.62
60	1251	20,030	150	133.53	254.35	158.97	333.83	206.66
64	1245	5,320	120	44.33	84.44	52.78	110.83	68.61
66	1241	6,280	120	52.33	99.68	62.30	130.83	80.99
81	1240	10,500	120	87.50	166.67	104.17	218.75	135.42
68	1239	4,000	120	33.33	63.49	39.68	83.33	51.59
73	1238	4,550	100	45.50	86.67	54.17	113.75	70.42
74	1237	3,600	100	36.00	68.57	42.86	90.00	55.71
75	1236	13,300	100	133.00	253.33	158.33	332.50	205.83
88	1235	6,700	100	67.00	127.62	79.76	167.50	103.69
76	1234	6,300	100	63.00	120.00	75.00	157.50	97.50
77	1233	9,900	100	99.00	188.57	117.86	247.50	153.21
78	1232	10,500	100	105.00	200.00	125.00	262.50	162.50
79	1231	0	100	0.00	0.00	0.00	0.00	0.00
79	1230	0	0	0.00	0.00	0.00	0.00	0.00
80	1228	7,150	100	71.50	136.19	85.12	178.75	110.65
72	1220	9,300	100	93.00	177.14	110.71	232.50	143.93
Average (years of total crop failure excluded)		9,245	121	87.06	165.84	103.65	217.66	134.74
Average		8,272	108	77.90	148.38	92.74	194.75	120.56

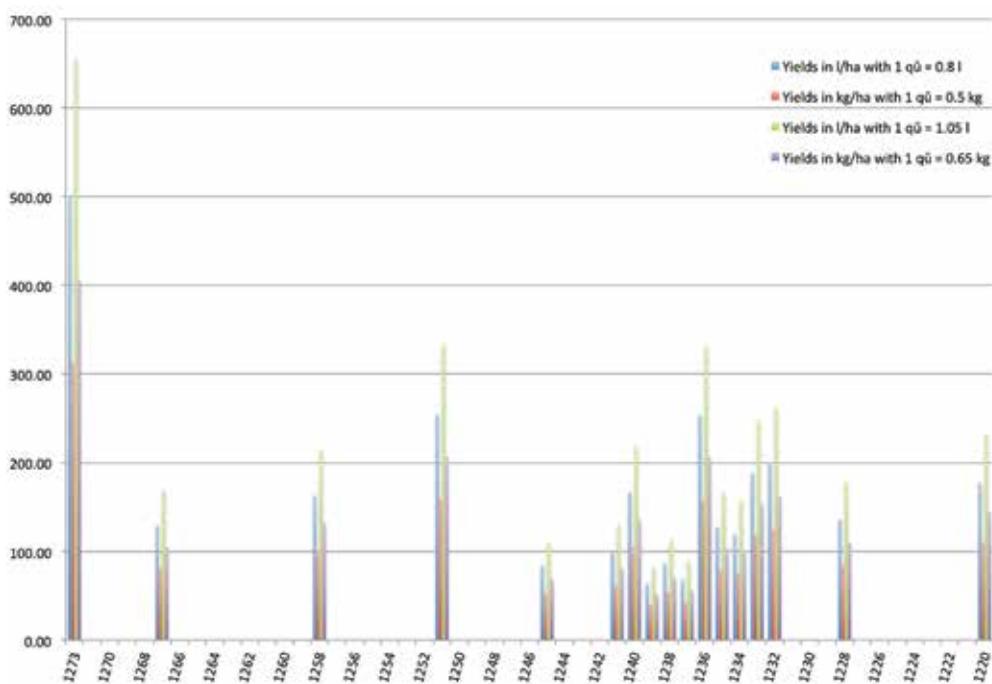


Figure 6. Yields in kg/ha and l/ha of field 4 at Middle Assyrian Dür-Katlimmu, using the equivalences proposed in table 1 (chronology based on Salah 2014, 62).

Table 14. Yield per hectare of the field at Middle Assyrian Duāra (the most probable values are boldfaced; chronology based on Salah 2014, 62)

Reference (BATSH 9 no.)	Year BCE	Yield in <i>qû</i>	Acreage in <i>ikû</i>	Yield in <i>qû/ikû</i>	w/ 1 <i>qû</i> = 0.8 l = 0.5 kg		w/ 1 <i>qû</i> = 1.05 l = 0.65 kg	
					Yields in l/ha	Yields in kg/ha	Yields in l/ha	Yields in kg/ha
82	[1273– 1270]	14,620	100	146.20	278.48	174.05	365.50	226.26
67	1267	4,600	100	46.00	87.62	54.76	115.00	71.19
71	1261	20,000	100	200.00	380.95	238.10	500.00	309.52
63	1258	5,200	100	52.00	99.05	61.90	130.00	80.48
60	1251	11,600	100	116.00	220.95	138.10	290.00	179.52
64	1245	8,180	100	81.80	155.81	97.38	204.50	126.60
65	1243	6,000	100	60.00	114.29	71.43	150.00	92.86
81	1240	6,330	100	63.30	120.57	75.36	158.25	97.96
68	1239	8,000	100	80.00	152.38	95.24	200.00	123.81
73	1238	4,600	100	46.00	87.62	54.76	115.00	71.19
74	1237	0	100	0.00	0.00	0.00	0.00	0.00
75	1236	6,650	100	66.50	126.67	79.17	166.25	102.92
88	1235	6,400	100	64.00	121.90	76.19	160.00	99.05
76	1234	6,200	100	62.00	118.10	73.81	155.00	95.95
77	1233	6,000	100	60.00	114.29	71.43	150.00	92.86
78	1232	11,800	100	118.00	224.76	140.48	295.00	182.62
79	1231	0	100	0.00	0.00	0.00	0.00	0.00
79	1230	0	0	0.00	0.00	0.00	0.00	0.00
80	1228	0	0	0.00	0.00	0.00	0.00	0.00
Average (years of total crop failure excluded)		8,412	100	84.12	160.23	100.14	210.30	130.19
Average		6,641	100	66.41	126.50	79.06	166.03	102.78

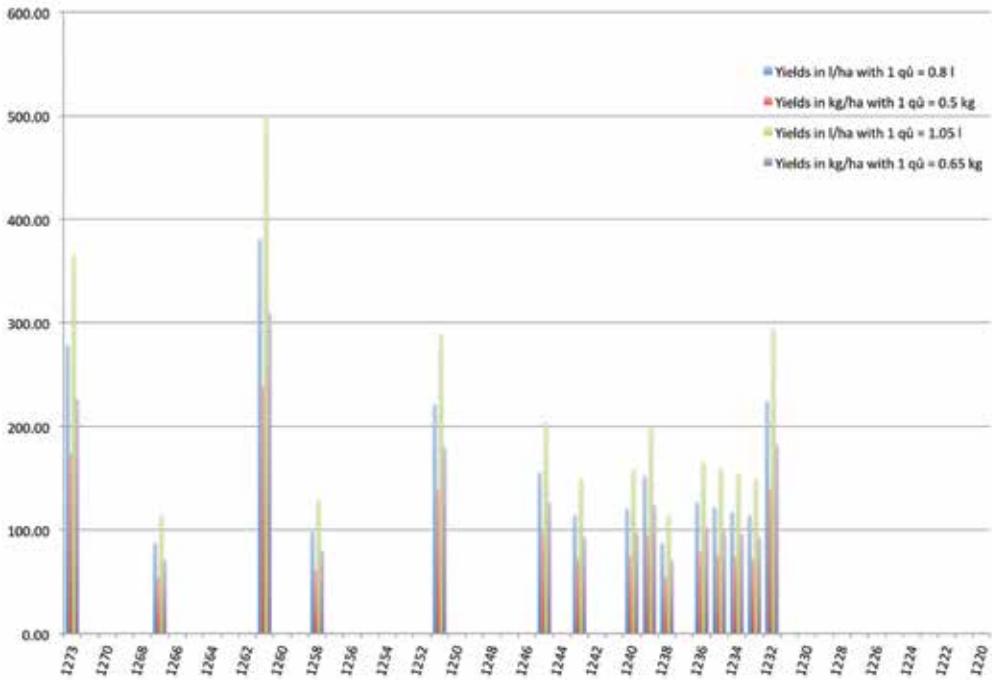


Figure 7. Yields in kg/ha and l/ha of the field at Middle Assyrian Duāra, using the equivalences proposed in table 1 (chronology based on Salah 2014, 62).

or another natural catastrophe in Dūr-Katlimmu.¹⁹¹ Not even mentioning the disastrous war years of 1231–1228 BCE, there are several occurrences of very bad years: in 1238 BCE, even field 1 did not do better than 158 kg/ha (256 l/ha) and was challenged by fields 2 and 3 (155 and 159 kg/ha, respectively), while field 4 and that of Duāra reached poor results in the range of 70 kg/ha. Generally speaking, the area was hindered by a marked interannual variability in yields that attests the fragility of Middle Assyrian agrarian investments on the Lower Ḫābūr and points to low-efficiency irrigation agriculture in the broader context of a long-lasting climatic trend toward aridity.¹⁹²

3.3. REVENUE AND EXPLOITATION COSTS

Given the costs that royal administrations had to support to maintain institutional agriculture, it is tempting to compare those costs with the benefits they obtained in compensation for their investments. Based on the yields discussed above, it would appear that the Mari administration obtained better results than the Middle Assyrian one, even if we cannot get into greater detail as regards the former. Unfortunately, the Mari documents do not allow for any estimate of the exploitation costs of institutional agriculture.

This, fortunately, is not the case for the Middle Assyrian texts, and more particularly those recording the administrative operation known as the “clearance of the grain-heap” (*pišerti karu’ē*),¹⁹³ which have been the basis for the study so far. Besides data on cultivation (acreage, seeding rates) and annual yields, they record operational costs for the following year (including seed, but also food rations for draft animals and *šiluḫlū*-workers), which were deducted from the harvest before it entered the granaries.¹⁹⁴ Ideally, the exploitation costs of a given year should be deducted from the harvest of the following year, but due to the nature of our evidence, we seldom have continuous years that would permit such an analysis. I have thus chosen to report the costs mentioned on a given tablet to the harvest registered on that same tablet (the costs of which had actually been deducted from the previous harvest, or from the stocks). I am aware that this introduces a little bias, given that one good year could trigger higher investments in hope for a second chance, or the other way around. My excuse, at least, is that this yearly “balance sheet” actually reflects the practices of the Middle Assyrian administrators, who settled their accounts according to calendar years. Comparison of costs and revenues (fig. 8 and table 15) confirms the poor profitability of Middle Assyrian agriculture on the Lower Ḫābūr.

Of seventeen years for which sufficient data are preserved, seven years (1267, 1245, 1243, 1241, 1238, 1237, and 1233 BCE) have a cost-to-revenue ratio of over 100 percent, meaning that they actually present a negative balance, with costs exceeding revenues—sometimes heavily, like in 1237 BCE, when costs exceeded revenue by almost one-third. This number could even reach eight or nine years of nineteen when taking into account the crisis years around 1230 BCE, when enemy presence in the countryside prevented

191 Reculeau 2011, 187–98.

192 Reculeau 2011, 182–83, 207–9.

193 See most recently Röllig 2008, 20; Reculeau 2011, 95–97.

194 Röllig 2008, 27–28.

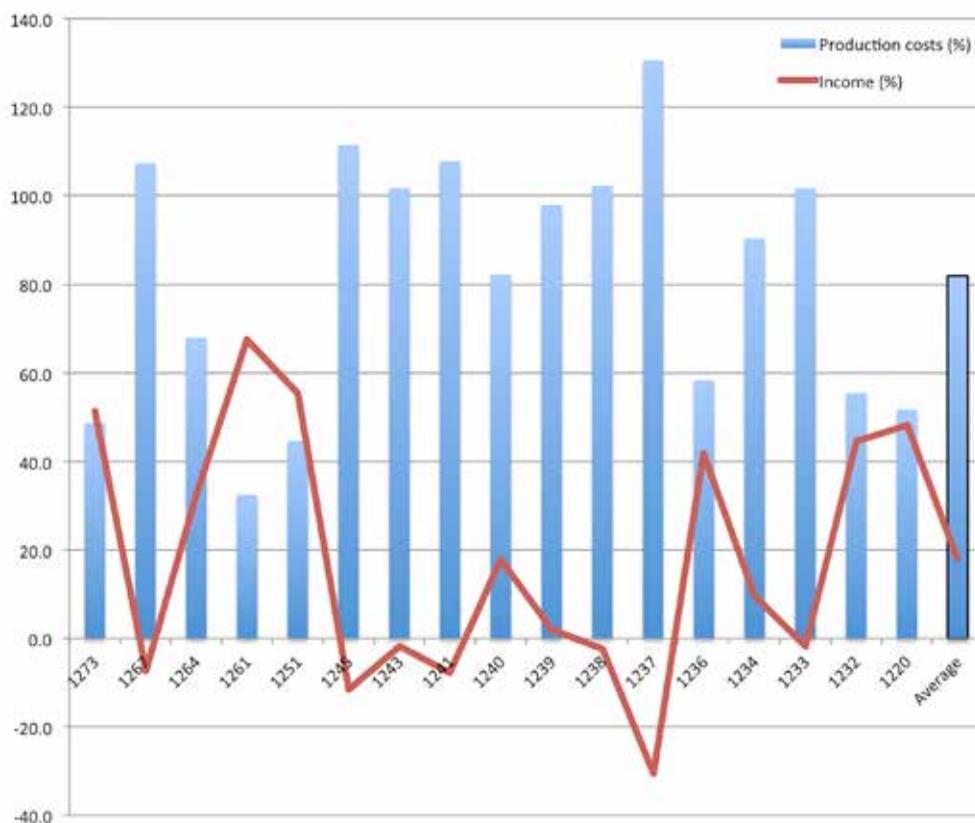


Figure 8. Production costs (blue) and final income (red), as a percentage of the annual harvest (years of total crop failure excluded), for the fields at Middle Assyrian Dür-Katlimmu and Duāra (chronology based on Salah 2014, 62).

agriculture.¹⁹⁵ As a whole, the first decade of Tukultī-Ninurta I's reign (which started in 1244 BCE) appears as a time of low incomes, with only two years when consequent agricultural surplus was extracted on the Lower Ḥābūr: in 1240 BCE, with a 17 percent benefit, and 1236 BCE, when it reached a good 41 percent. One-third of the harvest could be stored in 1264 BCE, while four years ([1273–70], 1251, 1232, and 1220 BCE) allowed for benefits in the range of 50 percent of the harvest. Finally, the best recorded year, 1261 BCE, stands out with a net surplus of two-thirds of the harvest entering the royal granaries.

195 According to BATSH 9 79, the harvest of Etel-pī-Aššur was prepared, but lost to the enemy, meaning an incalculable cost-to-revenue ratio. For Aššur-bēl-ilāne, the ratio could be calculated on the basis of BATSH 9 79 (which registers exploitation costs for the next year) and BATSH 9 80 (which registers the harvest of Aššur-bēl-ilāne, but no exploitation costs). Linking the two would imply sticking to the traditional chronology according to which these two eponyms were consecutive, and the year 1229 BCE would have offered a negative cost-to-revenue ratio of 109 percent (calculated, for once, over two administrative years and one single agricultural cycle). The new chronology proposed by S. Salah (2014, 62), however, intercalates (with hesitation) Ellil-nādin-apli between the two, shifting Aššur-bēl-ilāne to 1228 BCE. This is far from certain, but since I chose not to discuss these matters here and to stick to his chronology, I did not integrate these data in table 15.

Table 15. Harvest yields and exploitation costs at Middle Assyrian Dūr-Katlimmu and Duāra, as a percentage of the harvest (DK = Dūr-Katlimmu, D = Duāra, T = total; chronology based on Salah 2014, 62)

BATSH 9 no.	Year BCE	Harvest (<i>qū</i>)			Seeds (<i>qū</i>)			Fodder (<i>qū</i>)			Rations (<i>qū</i>)			Cost/ revenue (%)	Income (%)
		DK	D	T	DK	D	T	DK	D	T	DK	D	T		
82	[1273- 1270]		14,620	14,620	3,000	3,000	3,000	1,620	1,620	1,620	2,500	2,500	2,500	48.7	51.3
67	1267	28,000	28,000	28,000	13,500	13,500	13,500	8,640	8,640	8,640	7,900	7,900	7,900	107.3	-7.3
69	1264	53,740	53,740	53,740	13,500	13,500	13,500	8,640	8,640	8,640	14,350	14,350	14,350	67.9	32.1
71	1261		20,000	20,000	3,000	3,000	3,000	1,350	1,350	1,350	2,140	2,140	2,140	32.5	67.6
60	1251	84,140	11,600	95,740	15,000	3,000	18,000	8,100	1,350	9,450	13,340	1,944	15,284	44.6	55.4
64	1245	26,850	8,180	35,030	12,300	3,000	15,300	7,090	1,350	8,440	12,505	2,800	15,305	111.5	-11.5
65	1243		6,000	6,000	3,000	3,000	3,000	1,350	1,350	1,350	1,752	1,752	1,752	101.7	-1.7
66	1241	27,200	27,200	27,200	12,300	12,300	12,300	7,030	7,030	7,030	10,000	10,000	10,000	107.8	-7.8
81	1240	39,290	6,330	45,620	12,300	3,000	15,300	7,060	1,350	8,410	12,480	1,320	13,800	82.2	17.8
68	1239		33,500	33,500	14,800	14,800	14,800	8,000	8,000	8,000	10,000	10,000	10,000	97.9	2.1
73	1238	25,570	4,600	30,170	10,500	3,000	13,500	6,480	1,620	8,100	9,064	192	9,256	102.3	-2.3
74	1237	23,850	23,850	23,850	10,500	3,000	13,500	6,480	1,620	8,100	7,522.5	2,021	9,543.5	130.6	-30.6
75	1236	47,700	6,650	54,350	10,500	3,000	13,500	7,000	1,620	8,620	9,564	9,564	9,564	58.3	41.7
76	1234	28,050	6,200	34,250	10,500	3,000	13,500	7,020	1,620	8,640	7,520	1,307	8,827	90.4	9.6
77	1233		6,000	6,000	3,000	3,000	3,000	1,620	1,620	1,620	1,480	1,480	1,480	101.7	-1.7
78	1232	38,700	11,800	50,500	10,500	3,000	13,500	6,480	1,620	8,100	5,102	1,286	6,388	55.4	44.6
72	1220	25,700	25,700	25,700	10,200	10,200	10,200	1,440	1,440	1,440	1,664	1,664	1,664	51.8	48.2
Average		37,399	9,271	34,369	11,800	3,000	11,318	6,788	1,508	6,326	9,251	1,704	8,221	81.91	18.1

CONCLUSION

This overview of some economic aspects of institutional agriculture in the Middle Euphratean Amorite kingdom of Mari, and on the Lower Ḥābūr in the Middle Assyrian period, allows for a few conclusions regarding the nature and scope of royal investments in agriculture in second millennium BCE Upper Mesopotamia—even if it cannot pretend to be fully representative due to the incomplete nature of the evidence at hand.

A first aspect regards the taskforce requirements for canal digging and maintenance. This task, which played an important role in Mesopotamian royal ideology (if to a lesser extent in the north than in Babylonia) was supported by the mobilization of the king's subjects, on the basis of *corvée* work. Even so, the numbers attested in the textual record point to rather limited crews compared to what was known, for instance, in third-millennium BCE Sumer. This reflects the well-known scarcity of men in Upper Mesopotamia during the Middle and Late Bronze Age. Even so, the large scale of the canals mentioned in the texts attests a long-lasting investment in irrigation and waterworks, probably reflecting cumulative efforts over several generations rather than massive *ex nihilo* creations of new systems.

The scarcity of men is also quite clear in the acreage of land under cultivation, and in the number of workers who were required to perform institutional agriculture in both periods. The Mari data are incomplete, but the acreage under direct exploitation seems to have been limited, in the range of a few thousand acres. This is coherent with the attested numbers of adult male workers employed in agriculture, which amounted to several hundred, grouped into plough teams. The scale of institutional agriculture was even more modest at Middle Assyrian Dūr-Katlimmu and Duāra, where fifteen to twenty adult men apparently were enough to cultivate the 200–250 ha of land tilled by the palace.

Seeding rates, in the range of 45–50 kg/ha, did not differ much between the two periods, but the yields obtained did, and to a great extent. With average seed/yield rates around 1:20 and average yields above 1,000 kg/ha, Mari agriculture was extremely productive. Middle Assyrian agriculture, on the other hand, did rather poorly: with average seed/yield rates below 1:5 and average yields between 100 and 200 kg/ha, it barely covered its own exploitation costs, and defaulted almost every other year. Clearly, the Lower Ḥābūr cannot have been the breadbasket of Assyria, despite rather heavy investments in irrigation and control of the Western Ḡazīra—maybe because it failed to perform as was initially expected, as did Kār-Tukultī-Ninurta. If the global trend toward aridity that affected the second millennium BCE played a role,¹⁹⁶ as it surely did, there could be many reasons for such differences in productivity, from the type of barley grown to the agricultural techniques used.¹⁹⁷ One should also not forget that territorial expansion, the development of large-scale irrigation, and the reclaiming of new land not only pursued an economic goal but was also instrumental in shaping the Assyrian ideology of an ever-expanding kingdom headed by a king who controlled nature and shaped the wild landscape into a domesticated one. This ideology, born during the harsh times of the Late Bronze Age, was to be revived, a few centuries later, to the greatest glory of the Neo-Assyrian kings—and in this respect, the efforts of the Middle Assyrian kings can be seen as a sort of very long-term investment, even if it probably is not quite what they had in mind.

196 Reculeau 2011; Dornauer 2017.

197 Reculeau 2015, 207–12.

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10 Role and Characteristics of Irrigation in the Kingdom of Urartu

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IN THE NINTH to seventh centuries BCE, portions of present-day eastern Turkey, northwestern Iran, Naxçivan (Azerbaijan), and Armenia belonged to the kingdom of Urartu (*Biainili*), one of the world's earliest highland-based empires and the earliest historically attested polity in the South Caucasus. Stone fortresses on hills and royal inscriptions carved into architectural blocks or living bedrock mark Urartian control throughout this mountainous region, which consists of mostly small, sometimes irrigable plains separated from each other by large tracts of agriculturally marginal land. Urartian inscriptions frequently mention kings' roles in constructing various types of water management features, including irrigation canals, reservoirs, fountains, and cisterns. Historians and archaeologists have long left Urartu on the sidelines of debates about the relationship between irrigation and state development, in part because Urartu is located on the highland fringes of "core" areas of early political complexity in the Near East and in part because the study of material remains of Urartian irrigation through landscape archaeology has lagged far behind that of other major Near Eastern empires. Some scholars have referred to Urartu as a "hydraulic society" exemplifying cross-culturally observed historical relationships between centralized bureaucracies and large, state-sponsored irrigation structures that enabled the production of agricultural surplus.¹ The arid alluvial plains under surveillance by Urartian fortresses are environments in which agricultural intensification often requires irrigation, and royal inscriptions have long been taken at face value in support of a view that irrigation systems were constructed by the state in order to increase agricultural surplus. However, others have questioned the general idea that Urartu was a centralized state for at least part of its history.² A recent review offers an alternative hypothesis that Urartian-era irrigation systems could have been constructed independently by local rulers and in some cases would have provided water for increasing the production of animal fodder rather than crops for human consumption.³

This chapter reviews and reassesses conflicting views about the political and economic role of irrigation in Urartu and offers two preliminary landscape archaeology studies of Urartian-era irrigation structures. The first examines textually described irrigation

1 Belli 1997; Garbrecht 1988.

2 Bernbeck 2003–4.

3 Çifci and Greaves 2013.

structures from the heart of Urartu—the Lake Van basin—using historical satellite imagery and hydrological modeling. The second draws on recent fieldwork in Naxçıvan, Azerbaijan, to discuss the characteristics of Urartian-contemporary irrigation along the Araxes River, at the kingdom’s eastern fringes. These two studies provide insight into the debate about whether Urartian irrigation systems were designed to benefit agricultural or pastoral food production systems and also provide the basis for scale comparisons to better-known, roughly contemporary irrigation features of the Neo-Assyrians, the Urartians’ enemies to the south. Specifically, this chapter argues that irrigation played a minor political role in Urartu and that securely dated Urartian irrigation systems were used for agricultural production and especially urban water supply. Any state involvement in irrigation for the purposes of increasing pastoral production would most likely have focused on the production of fodder for military horses rather than mobile pastoralists’ sheep, goat, and cattle. Several lines of evidence indirectly suggest indigenous (rather than Assyrian) inspiration for Urartian irrigation systems and the involvement of local rulers rather than the king in the construction of water features.

URARTU: INSCRIPTIONS, FORTRESSES, ENVIRONMENT

Any discussion of irrigation structures in Urartu must rely on the nature and distribution of Urartian inscriptions and fortresses, arguments about the degree of centralization within the kingdom, and a consideration of the varied highland environments within the area controlled by the state. Urartu (*Biainili*) was a kingdom centered in eastern Turkey for around two centuries in the early first millennium BCE (fig. 1). The capital, Tuşpa, is located on the eastern shore of Lake Van, at the edge of the modern city of Van. The Urartians were neighbors and adversaries of the Assyrian Empire, based in Mesopotamia, in what is now northern Iraq. Assyrian cuneiform inscriptions name the Urartians among their enemies from the thirteenth to seventh centuries BCE, but the earliest Urartian written document referring to the state dates to the mid-ninth century.⁴ Sometime in the second half of the seventh century BCE, most Urartian sites known from excavations were destroyed. Both the date of this widespread destruction and the identity of the aggressors remain debated, though nomadic Scythians and Medes have been put forward as possibilities.⁵ Various scholars have suggested mid-seventh-century and early- to mid-sixth-century dates for the fall of Urartu.⁶

The distribution of Urartian inscriptions and Urartian-style fortresses allows for detailed diachronic reconstruction of the territorial growth of the state through time, as the Urartians expanded in all directions out of their core area in eastern Anatolia. About five hundred rock-cut inscriptions of two types have been found spread throughout eastern Turkey, Armenia, Naxçıvan (Azerbaijan), and northwestern Iran. Building inscriptions were carved into architectural features at Urartian fortresses and frequently record construction activities of the king. Campaign inscriptions were often carved into living bedrock and record military campaigns and conquests. The propagandistic nature of these inscriptions indicates that they were frequently erected at the endpoints of campaigns,

4 Kroll et al. 2012, 10; Zimansky 1985, 4.

5 Hellwag 2012.

6 See Hellwag 2012, 238–41, for a chart of different proposed dates.



Figure 1. Distribution of Urartian sites and inscriptions in comparison to topography, with the two landscape study areas labeled. Topographic data from GTOPO30. Site locations and types after Koroğlu 2011; Kroll 2011; Kroll et al. 2012.

far beyond the actual limits of the empire's control.⁷ The second landscape study in this chapter focuses on an area to the north and east of Van that was conquered beginning in the late ninth century BCE.

A significant number of Urartian inscriptions mention water management both within the core area near Van and in conquered territories. Many of the inscriptions are highly formulaic. They typically commemorate the construction of canals that enabled the creation of new fields, vineyards, and orchards within lands identified as previously uncultivated. Canal construction often occurred as part of larger building programs associated with the foundation of new cities.⁸ Additional textual evidence for Urartian irrigation comes from the Neo-Assyrian sources on Sargon II's eighth campaign, which describe canals in the area of a walled Urartian city called Ulhu.⁹ Different interpretations of this Assyrian text have led scholars to identify Ulhu with various archaeological sites in the Urmia area of northwestern Iran¹⁰ and to argue that the canal the Assyrians saw was either an underground qanat¹¹ or an open surface channel.¹²

7 See Kroll et al. 2012, 13–18, for maps showing the location of these two types of inscriptions by king.

8 Çifci and Greaves 2013, 199.

9 Çifci and Greaves 2013, 199–200; Zimansky 1985, 42.

10 Summarized in Çifci and Greaves 2013, 199 n. 59.

11 Laessøe 1951.

12 Dalley 2002, 446–48; Salvini 2001.

Urartu covered areas with highly uneven topography and rainfall and therefore with variable agricultural and irrigation potential. Rain-fed agriculture is possible today within some areas of the Urartian realm, but irrigation is required for broad-scale summer grain and vegetable farming even in some areas that have higher annual rainfall because precipitation is concentrated in the cooler seasons of the year when cultivation is not possible due to low temperatures and/or heavy rains. Water storage and irrigation help mitigate the effects of variation in rainfall patterns, which can easily result in crop failure. Paleobotanical analyses from Urartian contexts excavated at Bastam, Karmir Blur, Ayanis, Yukarı Anzaf, Yoncatepe, and other sites indicate that barley, free-threshing wheat, and emmer wheat were the dominant grain species and likely formed the major source of carbohydrates in the Urartian diet. A variety of legumes (chickpeas, bitter vetch, beans, lentils), other grains (millet, rye), fruits (plum, apricot, pomegranate), and sesame have been identified from Urartian contexts as well.¹³ A number of these crops would have required irrigation in all but the wettest parts of Urartu.

The spatial distribution of texts mentioning irrigation shows that most recorded water management projects occurred in the Van area and in the Araxes River valley (fig. 2) and were limited in other parts of the Urartian realm. Urartian territory centered around three lakes that might at first seem to be important sources of water. However, two of these lakes, Van and Urmia, are too saline for irrigation, while the third, Sevan, is in a highland area with more rain and cool summers where irrigation is less necessary for increasing agricultural yield and where there is no textual or archaeological evidence for Urartian irrigation.¹⁴ Many streams in highland areas of the region are seasonal. These ecological factors restricted the Urartians to the use of groundwater, snowmelt, and a few perennial rivers, like the Araxes, for irrigation. The distribution of texts mentioning canals matches ethnographic and environmental arguments suggesting that irrigation would have been most useful in the Araxes valley, the Van basin, the Urmia basin, and the Malazgirt and Elazığ plains and would not have been necessary in other parts of the Urartian realm, including the Kars, Van-Tunceli, Van-Urmia, and Erzurum areas.¹⁵ Using geographic information system (GIS) analyses to isolate areas that have less than 5 percent slope,¹⁶ cover more than 20 sq km,¹⁷ and are located within 10 km of known Urartian sites, we can estimate that Urartu would have had approximately 20,000 sq km of agriculturally productive land, only some of which would have been irrigable.

13 Çifci 2017, 60–64.

14 Çifci and Greaves 2013, 193; Zimansky 1985, 24.

15 Kroll et al. 2012, 23; Zimansky 1985, 17–27.

16 This 5 percent figure is an estimate, subjectively chosen on the basis of the Food and Agriculture Organization of the United Nations (1993) guidelines for land-use planning. The land suitability classification specifies that land with less than 1 degree (1.75%) of slope is highly suitable for sustaining land use (including agriculture) over long periods, land with 1–2 degrees (1.75%–3.49%) of slope is moderately suitable, and land with 2–6 degrees of slope (3.49%–10.51%) is marginally suitable. These classifications are defined using other variables as well (water, temperature, soil quality, rock cover) that are not known for eastern Anatolia 2,800 years ago, so the calculations here are merely meant to give a general idea of the maximum area that would have been suitable for agriculture at the time of the Urartians.

17 This lower size limit was arbitrarily defined to exclude small areas of land that would not have been worth cultivating on a large scale.

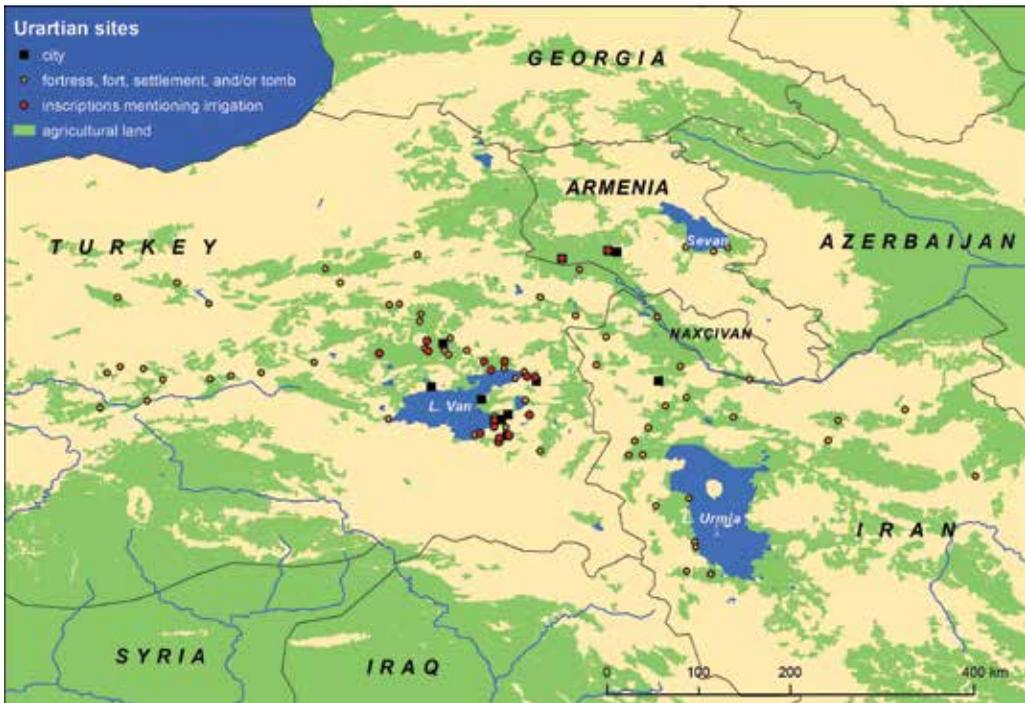


Figure 2. Locations of agriculturally productive areas determined from topographic slope and the distribution of inscriptions mentioning canal construction (or the places mentioned in those inscriptions). The inscription of Menua mentioning irrigation found on Akdamar Island in Lake Van is not included because it was not discovered in situ. “Agriculturally productive areas” are those that have less than 5 percent slope (determined using the GTOPO30 DEM), are larger than 20 sq km, and fall outside a natural water body. The natural water body data come from DIVA-GIS. Note that Lake Urmia was larger in the past. The estimation of the amount of agriculturally productive land in the text was calculated by summing the areas of all (undissolved) polygons within 10 km of a known Urartian site.

The most visible evidence of Urartian control comes from large fortresses, some of which may have guarded and benefited from irrigation systems. Thirty-four fortresses of substantial size, as well as many more smaller military outposts, are known from survey and excavation in Turkey, Armenia, and Iran (figs. 1 and 2).¹⁸ Many of these structures, especially the large fortresses, were built in a distinctively Urartian style that includes architectural characteristics such as ashlar masonry, buttressed walls, and towers.¹⁹ The fortresses appear to have functioned as administrative and storage centers to collect taxes and as military centers for controlling and protecting the local area. Many excavated fortresses, such as Bastam in Iran, Cavuştepe in Turkey, and Karmir Blur in Armenia, were filled with pithoi for storing wine and oil and storage facilities for grain. The Assyrian king Shalmaneser III reports carrying off Urartian goods in these vessels as booty, providing

¹⁸ Köroğlu 2011; Kroll 2011; Kroll et al. 2012.

¹⁹ Smith 2003, 169–80; Zimansky 1995, 106–7.



Figure 3. Gürpınar plain viewed from the Urartian fortress of Çavuştepe, June 2010.

additional evidence that fortresses served as storage centers.²⁰ Some scholars have argued that many fortresses were placed to enable the surveillance of irrigation systems²¹ and further that areas that lacked irrigation structures did not have Urartian centers.²²

Highly uneven topography and variable agricultural and irrigation potential within Urartu were important factors shaping the polity's political and territorial integration. Most of the land in Urartian territories consists of small agricultural plains separated by deep valleys and expansive highland zones (see, for example, the Gürpınar plain in fig. 3). An area of such fragmented territory would be difficult to control, and indeed there is some evidence that the Urartians did not control areas outside of river valleys, such as surveyed Iron Age sites that do not have Urartian pottery.²³ Urartu has frequently been described as a "network empire," a "terrestrial archipelago," and an "imperial archipelago" partly in reference to its environmental setting and resulting distribution of territorial control.²⁴

Urartu's fragmented environmental setting and its distribution of fortresses have been starting points for debates about the degree to which the Urartian state was centralized.

20 Kroll 2011, 23–24.

21 Kleiss 2012.

22 Zimansky 1985, 28.

23 Sagona and Sagona 2004.

24 Smith 2003, 78–79; Smith 1996; Zimansky 1985, 9.

On the one hand, several pieces of historical and archaeological evidence suggest a degree of centralization in the Urartian state: the Urartian texts' narrow focus on the actions of the king, the massive scale of Urartian building programs (including irrigation canals), and the fact that the Urartians produced very characteristic objects and architecture. Unlike many other ancient polities, the Urartians had a fairly uniform and distinct material signature that is visible archaeologically. This material signature consists of architectural characteristics (e.g., ashlar masonry, buttressed walls, towers), red-polished pottery, inscriptions in Urartian using cuneiform script borrowed from Mesopotamia, and luxury goods such as metalwork and ivory.²⁵ All this evidence speaks to the ability of the Urartian ruler and his administration to control large amounts of resources and labor. On the other hand, several other lines of evidence, including its mountainous environmental setting, suggest that Urartu was not a centralized empire but instead a somewhat decentralized tribal confederation. Assyrian documents refer to different tribes in the Urmia region controlled by Urartu²⁶ and indicate the important role of regional governors rather than the king.²⁷ However, it should be noted that the Assyrians often campaigned in border areas and their descriptions of the Urartian administration might not apply to other, more central parts of Urartu.²⁸ While many scholars have seen the large number of fortresses as evidence for a centralized polity, another interpretation argues that the distribution of fortresses suggests a significant amount of internal conflict among smaller political units within a weakly integrated kingdom where the king had limited powers in the ninth and eighth centuries BCE.²⁹

The degree of centralization within Urartu could have changed through time, and what was initially a decentralized polity appears to have become much more tightly integrated in the seventh century, especially under Rusa, son of Argišti (r. 680–639 BCE). Assyrian annals record campaigns against increasingly united opponents, suggesting unification of different tribes or political units.³⁰ Perhaps significantly, seventh-century texts rarely discuss Urartian governors.³¹ While archaeological analysis has frequently remarked on the uniformity of the "Urartian state assemblage," it is increasingly clear that many distinctive Urartian materials and constructions date to the reign of Rusa, son of Argišti, and may not be representative of assemblages at other points in Urartian history.³² Recent work has emphasized the variability in earlier Urartian assemblages and architectural styles.³³

Agricultural intensification through irrigation and food storage in fortresses has long been considered an important goal and outcome of Urartian control of certain regions, but animal husbandry was another important component of the Urartian economy that has

25 Zimansky 1995.

26 Kroll 2011, 151–52.

27 Kroll et al. 2012, 21; Zimansky 2011, 108.

28 Zimansky 2012, 101.

29 Bernbeck 2003–4.

30 Zimansky 2011, 108.

31 Zimansky 2012, 104.

32 Zimansky 2006.

33 Biscione 2012; Earley-Spadoni 2015; Smith and Kafadarian 1996.

been less discussed.³⁴ Livestock and their secondary products appear in many inscriptions, including sheep, cattle, horses, and camels.³⁵ Faunal analysis from Urartian lower towns, such as Ayanis, demonstrates the importance of sheep/goat and especially cattle herding, as well as cheese making.³⁶ The storerooms at Bastam contained the burnt bones of more than 1,500 animals.³⁷ Interpretations that argue for the importance of mobile pastoralists in Urartu are more likely to emphasize evidence for decentralization and limited territorial integration in the polity.³⁸

EXISTING DEBATES ABOUT THE POLITICAL AND ECONOMIC ROLE OF URARTIAN IRRIGATION

The existing literature contains contradictory statements on the political and economic role of irrigation in the kingdom of Urartu. Specifically, these statements concern whether irrigation was integral to Urartian control of territory; whether climatic, demographic, or ideological factors were reasons for Urartian focus on irrigation; and whether water management was geared toward increasing agricultural or pastoral production. Such disagreements are frequently implicit in the way that Urartian water management and its regional historical significance are described using textual or archaeological evidence, and they have rarely reached the level of open debate.

POLITICAL ROLE

Scholars who draw on the Urartian textual record frequently argue that irrigation played an important political role and was integral to state control. Twenty-seven texts out of a corpus of several hundred unique texts mention canal construction.³⁹ The inscriptions typically stress the role of the king, and thus the state, in constructing canals and other water systems that supply fields, orchards, vineyards, and cities. The largest number of these inscriptions belongs to the reign of King Menua (r. 810–786 BCE), who was also the first Urartian ruler to mention irrigation projects. Other kings known for irrigation works mentioned in the texts include Argišti I, son of Menua (r. 786–764 BCE); Sarduri II, son of Argišti (r. 764–735 BCE); Rusa, son of Argišti; Rusa, son of Erimena;⁴⁰ and Argišti II, son of Rusa (r. 714–680 BCE). Royal inscriptions and early archaeological work near Van have long been cited as evidence that irrigation systems were constructed by the state to increase agricultural surplus. Even further, some scholars have labeled Urartu as a Wittfogelian “hydraulic society” on par with various Mesopotamian civilizations⁴¹ and have, moreover, depicted Urartians as innovators who transformed eastern Anatolia from a largely mobile, pastoral

34 Çifci 2015.

35 Burney 2012, 56.

36 Stone 2012, 93, 97.

37 Kroll 2011, 164.

38 E.g., Çifci and Greaves 2013.

39 Çifci and Greaves 2013, 205; Zimansky 1985, 67–68.

40 Seventh-century reigns of debated date; see Kroll et al. 2012, 12.

41 Garbrecht 1988, 186.

zone to an agricultural one.⁴² These inscriptions and archaeological data have been used to further argue that state-constructed irrigation systems, and the systematic cultivation of the countryside that they enabled, were one of multiple ways that the Urartian state (and pre-Urartian fortress polities of the Early Iron Age) extended the “tentacles” of its control from fortresses into the rural countryside as society transformed from a more mobile to a more settled existence—that the increased agricultural production enabled by irrigation “required a concomitant intensification of the control of political subjects.”⁴³

Those who put greater weight on archaeological evidence or who emphasize some nuances of the textual record interpret irrigation as playing a much more limited political role in the Urartian state. There is very little concrete archaeological evidence for irrigation features that demonstrably date to the Urartian period (a point reviewed in greater detail below). Most existing fieldwork has unsystematically identified water management features on the ground that are merely assumed to date to the Urartian period but may in reality be chronologically earlier or later. The first datable irrigation projects from both archaeology and inscriptions are those of Menua, roughly half a century after Urartu had consolidated.⁴⁴ Thus, irrigation cannot be clearly associated with the founding of the Urartian state. A close reading of the inscriptions concerning irrigation shows that these texts mention only the initial construction of water features, not their further maintenance and use. This has led to the conclusion that “if control and regulation of the water supply was one of the roots of the state’s power, it was not exercised in a way that is detectable by archaeologists or historians.”⁴⁵

Another aspect of the different interpretations of the political role of irrigation concerns the reasons why the Urartians invested effort in building irrigation systems. An early argument considered the possible role of population growth, royal policy, imitation of the Neo-Assyrians, and climate. It concluded that decreased rainfall must have been the primary motivation for Urartian kings to construct irrigation systems, as modest reductions in winter or summer precipitation could result in significant changes in the amount of water available during the region’s short growing season.⁴⁶ However, this same scholar later revised his view to argue that irrigation constructions were necessitated by population increase and concentration due to the highland pastoralists and prisoners of war who were resettled in Urartian cities, noting that the first irrigation structures built under Menua coincide chronologically with the first evidence for significant numbers of resettled prisoners.⁴⁷ Others have shared this demographic-driven interpretation.⁴⁸ Still other discussions of Urartian irrigation emphasize the ideological rather than practical role of water management, as it displayed the “power of the king to control the elements and to alter the landscape.”⁴⁹

42 Belli 1997, 36; Çifci 2017.

43 Smith 1996, 380.

44 Zimansky 1985, 68.

45 Zimansky 1985, 68.

46 Burney 1972, 184–86.

47 Burney 2012, 58.

48 Zimansky 1985, 68.

49 Kroll et al. 2012, 23.

ECONOMIC ROLE

Typically, scholars have argued that the economic role of Urartian irrigation lay in increasing agricultural surplus.⁵⁰ Royal inscriptions focus on the king's role in the generation of agricultural abundance through the development of previously "uncultivated" lands. Both the position of fortresses within or on the edges of agricultural plains and the archaeologically demonstrated role of fortresses in storing agricultural products constitute indirect evidence that the state used irrigation systems to increase surplus. The distribution of major Urartian fortresses appears to be tied to places where water management was necessary.⁵¹

A recent review article puts forth an alternative explanation of the economic role of Urartian irrigation, arguing that local rulers could have constructed irrigation systems, rather than the Urartian state, and further that some of these irrigation systems would have provided water for increasing the production of hay as animal fodder rather than crops for human consumption. In this way, Urartian-period irrigation could have supported the intensification of pastoral rather than (or in addition to) agricultural systems.⁵² As evidence supporting this view, the authors highlight the relatively small size of some water installations that are believed to be Urartian, the proximity of some dams to high-elevation pasture areas and large stone structures that have been interpreted as animal pens, and ethnographic examples of water systems in the Van area that irrigated hay meadows. Additionally, they argue that Urartian inscriptions may actually commemorate the repair of earlier water systems that had been constructed by local tribes rather than the construction of new systems by the state. Although not cited by the authors, other scholars have previously hinted at the benefits that irrigation would have had for pastoralists in Urartu, mentioning that highland dams in the area were used for hay cultivation in the twentieth century⁵³ and that the state's cavalry and chariot horses needed summer pasture and winter fodder.⁵⁴

To evaluate some aspects of these different viewpoints concerning the political and economic role of irrigation, I present the preliminary results of two landscape archaeology studies on Urartian-era irrigation on the Van plain, Turkey, and on the Şərur plain of Naxçıvan, Azerbaijan.

LANDSCAPE STUDY 1: IRRIGATION AT THE HEART OF URARTU ON THE VAN PLAIN, EASTERN TURKEY

The clearest evidence for Urartian irrigation and water management systems comes from the heart of the kingdom: the plains that border the eastern shores of Lake Van. These systems have been known since the nineteenth century from chance finds of building and bedrock inscriptions by European travelers. Archaeologists have pursued the more systematic study of these systems only in the past three decades.

50 Burney 1972; Kleiss 2012; Smith 1996, 380; Zimansky 1985.

51 Zimansky 1985, 28.

52 Çifci and Greaves 2013.

53 Belli 1994, 103.

54 Burney 2005, 18; 2012, 58.

The widest ranging of these studies are those of Günther Garbrecht⁵⁵ and especially Oktay Belli.⁵⁶ Belli's studies are difficult to build on given that he assumed that a lot of features across the Van area and other parts of eastern Turkey, many of which were still in use in the 1990s for irrigation and water management, must date back to the Urartian period on the basis of old appearance; Ottoman or early Turkish Republic records of repairs to older water structures; loose spatial association with Urartian fortresses, forts, or settlements; and occasional pottery scatters. Sometimes these features were assumed to be Urartian without any dating evidence at all (see table 1 for a chart of the dating criteria for each identified feature).⁵⁷ This approach is extremely problematic,⁵⁸ especially because other (non-Urartian) periods of occupation have not been systematically documented by Belli for the associated sites and fortresses. Both survey and excavation have established that the plains east of Lake Van were intensely inhabited in both pre- and post-Urartian periods⁵⁹ and that Urartian-period fortresses sometimes had earlier and later phases of occupation. There is no reason to assume that the Urartians were the first or the last to manage water in this region on a large scale. Garbrecht's analysis focuses more narrowly on the supply of water to the area near the city of Van (and the Urartian fortresses at Tuşpa and Toprakkale). Garbrecht is much more conservative in his dating and only labels as Urartian the two water features that are associated with inscriptions, the Menua Canal and Lake Rusa (modern Keşiş Göl).

I have used declassified historical CORONA and HEXAGON imagery to examine these two features in greater detail with hydrological modeling and to search for the remains of canals and dams in the vicinity of Urartian sites. Unlike lowland areas of the Middle East, where imagery captured in the winter is typically the most useful for spotting archaeological features due to increased soil moisture, summer images are the most useful for the Van region because heavy snow cover during the winter months obscures the ground's surface. The images came from CORONA mission 1110, captured on June 4, 1970, and HEXAGON mission 1204, captured on July 13, 1972 (see Ur's chapter in this volume for an introduction to historical imagery sources for the archaeology of irrigation).

In terms of canals, only the well-known Menua Canal is visible in the imagery (figs. 4 and 5). This canal is well known because portions of it were carved into bedrock and are still in use today and because fifteen inscriptions of King Menua were built into its walls or carved into nearby bedrock surfaces. The Menua Canal takes its flow from a spring on the south side of the largest valley to the immediate south of Van (the valley of the Hoşap Çay) and carries this flow at least 50 km to the Van plain and the lower town of the Urartian citadel at Van Kalesi/Tuşpa.⁶⁰ An inscription removed from the spring itself proclaims that King Menua constructed a canal from this location. The other known fourteen inscriptions along the canal's length are largely formulaic in identifying Menua as the person responsible for the canal and were placed at locations where the builders had particular challenges

55 Garbrecht 2004.

56 Belli 1997.

57 Belli 1994, 1997, 1999.

58 Çifci and Greaves 2013, 201.

59 E.g., Marro and Özfirat 2005.

60 Garbrecht 1980.

Table 1. Chart of dating criteria used by Belli (1994, 1997, 1999) in his study of Urartian irrigation features, mostly in the Van region

Name of surveyed irrigation feature	Location of feature	Citation	Dating criteria used by Belli	Notes
Süphan Dam	S of Muradiye plain, 105 km NE of Van	Belli 1994	No specific dating evidence, date unknown	Style of sluice differs from other Urartian dams
Upper Anzaf Dam	600–700 m E of Upper Anzaf fortress, 11 km NE of Van	Belli 1994	Proximity to an Urartian fortress (600–700 m)	
Çavuştepe Reservoir	Cavuştepe fortress, to the NW of entrance	Belli 1994	Part of an Urartian fortress	Unclear if this was used as part of an irrigation system; also has been interpreted as a stable
Arpayatağı Artificial Lake	97 km S of Van, 2 km SE of Pirhılan	Belli 1994	Proximity to Pirhılan (2 km), a settlement the author dates to the 8th century BCE	Locally known as Milla Göleti, unclear if Urartian pottery present at Pirhılan
Arç Dam	103 km S of Van	Belli 1994	8th century BCE pottery and cyclopean walls in vicinity	Locally known as Dest Barajı, unclear if Urartian pottery present at Pirhılan
Kırmızı Düzlük Dam	1 km E of Arç Dam	Belli 1994	Cyclopean walls 1 km away, those walls assumed to be Urartian	Locally known as Deste Sor. Today hay is cultivated in the vicinity
Upper Argıt Dam	120 km N of Van, 23 km N of Muradiye	Belli 1994	Large stone structures in vicinity of uncertain date, assumed to be Urartian; lack of medieval or modern sherds; structural similarities to Gelincik Dam	Today hay is cultivated in the vicinity

Table 1. Chart of dating criteria used by Belli (1994, 1997, 1999) in his study of Urartian irrigation features, mostly in the Van region (*continued*)

Name of surveyed irrigation feature	Location of feature	Citation	Dating criteria used by Belli	Notes
Gelincik Dam	140 km SE of Van, 500 m E of Gelincik Kalesi	Belli 1994	Proximity to an Urartian fortress (500 m) with 7th century BCE pottery and a settlement with medieval pottery	Style of sluice known from medieval dams but not from other Urartian dams. Today hay is cultivated in the vicinity
Lake Aygır	8–9 km from Kef Kalesi Adilcevaz	Belli 1994	Work by the Turkish government in the 1980s revealed terracotta water pipes. It is unclear why the author dates these to the Urartian period, especially as he notes no other evidence exists for such pipes in Urartu	
Kırcagöl Dam	1.5–2 km NE of Adilcevaz	Belli 1994	Settlement on SW side of lake has sherds that the author dates to the reign of Rusa II	
Lake Sihke	NE of modern Van and Toprakkale	Belli 1994	Proximity to Urartian capital (2.5 km), ability to control water flowing out of Keşiş Göl	
Harabe Dam	9 km SE of Van	Belli 1999	Existence of a premodern dam that was destroyed in the mid-twentieth century. More likely to be Early Iron Age than Urartian	Construction style is different from other Urartian dams. Instead the construction style is similar to a nearby Early Iron Age site, Yonca Tepe Kale, located 1 km to the S

(*continued*)

Table 1. Chart of dating criteria used by Belli (1994, 1997, 1999) in his study of Urartian irrigation features, mostly in the Van region (*continued*)

Name of surveyed irrigation feature	Location of feature	Citation	Dating criteria used by Belli	Notes
Azab Reservoir	14 km SW of Van, 1 km E of Zivistan fortress	Belli 1999	Proximity to an Urartian fortress (1 km)	
Menua Canal	Gürpınar plain and Hoşap valley, 50 km S of Van	Belli 1999, 1997	15 inscriptions of Menua	
Kadim Dam	7 km from Van, 2 km SW of Kevenli (Şuşanis) Kale	Belli 1999	Proximity to an Urartian fortress (2 km) that had looted inscriptions of Menua	
Yukarı Ömer Lake Dam	11 km NE of Van	Belli 1999	No dating evidence given, assumed to date to Menua's reign on basis of proximity to Kilise Lake Dam	
Aşağı Ömer Kale Dam	11 km NE of Van	Belli 1999	No dating evidence given, assumed to date to Menua's reign on basis of proximity to Kilise Lake Dam	
Kilise Lake Dam	11 km NE of Van	Belli 1999	Proximity to Aşağı Kevenli Kale and "impossibility" of irrigating the area otherwise	
Kevenli Dam	9.5 km E of Van, 150 m NW of Yukarı Kevenli Kale	Belli 1999	Proximity to an Urartian fortress (150 m)	
Rusa Dam (Keşiş Göl)	23 km E of Van	Belli 1999	Inscription of Rusa, son of Erimena (Salvini 2002) found nearby	

Table 1. Chart of dating criteria used by Belli (1994, 1997, 1999) in his study of Urartian irrigation features, mostly in the Van region (*continued*)

Name of surveyed irrigation feature	Location of feature	Citation	Dating criteria used by Belli	Notes
Doni Reservoir	18 km SE of Van	Belli 1999	No dating evidence given; takes water from the Keşiş Göl	
Köşebaşı Dam	6 km E of Lake Sihke	Belli 1999	No dating evidence given; takes water from the Keşiş Göl	
Ferhat Canal	54 km NW of Doğubeyazıt	Belli 1997	Cut into bedrock and has supporting walls built of large stone blocks like the Menua Canal. Similar incline to the Menua Canal. No inscriptions or other dating evidence. Some seventh century forts and second millennium BCE kurgan burials are known in the region, but their chronology is not described further	The nearest first millennium BCE forts in the region are 1 km to the SW of the canal's beginning point (Balık Göl Kale), 5 km E of the canal's beginning point (Gürgüre Kale), and 17 km E of the canal's beginning point (Ardıç Kale)

to overcome during the course of construction.⁶¹ These include a bedrock inscription 200 m north of where the canal would have needed to cross the seasonal Hoşap Çay via a no-longer-extant aqueduct and inscriptions built into the highest-standing parts of the canal's walls at Gülo Boğazı and Kadem Bastı.⁶²

The parts of the Menua Canal that are still in use are 3.5–4 m wide and 1.5–2 m deep. Given the altitudes of the spring and of the Van plain, approximately 1,760 m and 1,700 m above sea level (ASL), respectively, and the 51 km length of the channel, the canal has an incline of 3 to 10/10,000.⁶³ Using the path of the canal and a digital elevation model, we can estimate that the Menua Canal could have irrigated an area as large as about 6,000 ha/60 sq km (fig. 6). Curiously, no clearly premodern offtakes to feed the vineyards, orchards, and fields mentioned in the inscriptions are visible in the historical imagery, and those who have followed the canal on the ground mention no offtakes either, even though

61 Garbrecht 1980, 1988.

62 Belli 1997, 40–41.

63 Belli 1997, 41–42.



Figure 4. 3D view of the path of the Menua Canal in relationship to Çavuştepe, Tuşpa (Van citadel), and Toprakkale. Imagery and terrain from Google Earth Pro.

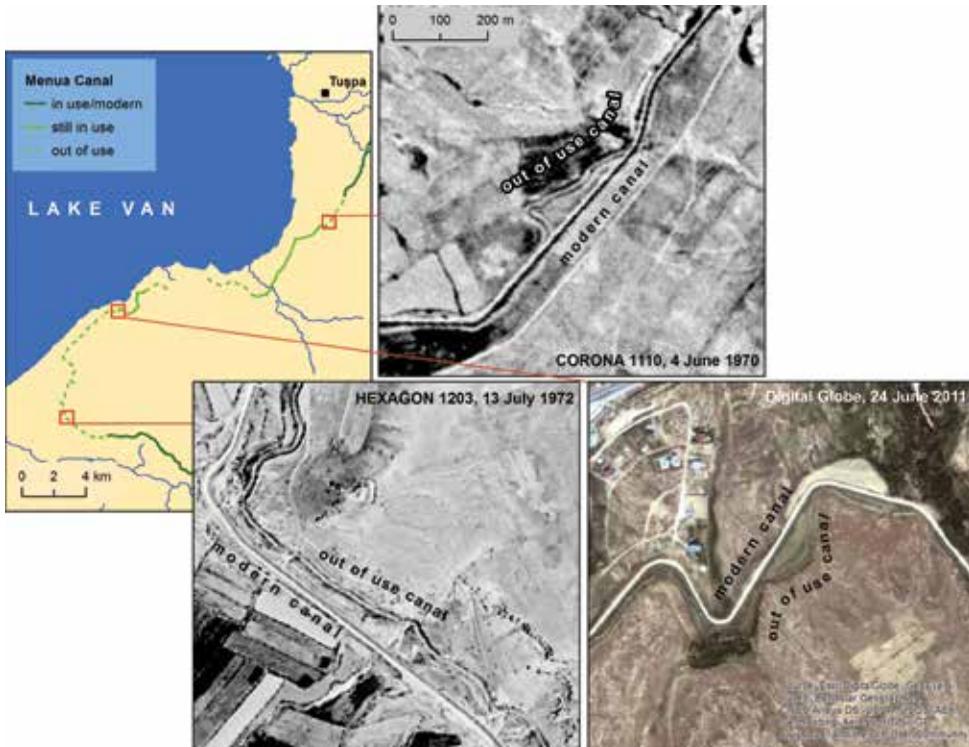


Figure 5. Sections of the Menua Canal as visible in CORONA, HEXAGON, and DigitalGlobe imagery.



Figure 6. Path of the Menua Canal and estimation of irrigable area on the basis of topographic data from SRTM30.

parts of the channel were carved from rock and should therefore preserve evidence of offtakes. The lack of evidence for other premodern canals around the spring and the lack of evidence for offtakes might be due to issues of preservation, or they could indicate that the Menua Canal's flow was largely conserved for transportation to the Van plain and the vicinity of the capital at Tuşpa.

The Van area is littered with dams and high-altitude reservoirs designed to store snow-melt for use throughout the irrigation season, but the date of most of these features remains entirely unclear. The only dams that can be convincingly argued to date to the Urartian period are two at the Keşiş Göl Reservoir. No inscriptions have been found at these dams, and no archaeological evidence dates them to the Urartian period. However, in 1891, a German scholar named Waldemar Belck found a bedrock inscription of the Urartian king Rusa in the nearby mountains that describes Rusa's creation of a reservoir ("Lake Rusa") and a canal leading from here to Rusahinili (Toprakkale).⁶⁴ The king claims to have transformed the area from desert to a landscape of fields and vineyards with the mighty

64 Belck and Lehmann[-Haupt] 1892; Kleiss 2012, 3.

waters of the canal.⁶⁵ A recently discovered fragment of the same inscription lists the gods to whom animal sacrifices were performed when the water was released or conversely when the reservoir water dried up, and it additionally clarifies that the inscription dates to the reign of Rusa, son of Erimena, rather than Rusa, son of Argišti.⁶⁶ The construction of Toprakkale, another fortress 6 km to the east of Tuşpa across the plain, would have motivated the construction of the dams and the creation of the Keşiş Göl Reservoir. Toprakkale, unlike Tuşpa, could not be supplied with year-round water from the Menua Canal.⁶⁷

The Keşiş Göl, situated at an altitude of 2,548 m ASL, was created by damming two wadi systems, one that leads down to the Van plain and another that leads down to the Hoşap valley, exiting near the major Urartian fortress of Çavuştepe (figs. 7 and 8). No artificial channels are visible in the mountains on historical satellite imagery, so the water must have flown via the natural wadis 30 km and 20 km down to these valleys, where diversion features and canals could have carried the water to different parts of the plain. However, relict features for irrigation are not visible in the imagery on the plains either. It certainly makes sense that the Keşiş Göl dams were storage dams designed to allow for irrigation throughout the growing season, and the mention of fields in the bedrock inscription in the mountains suggests this. However, we have no direct evidence that this water system was part of a branching irrigation network nor that artificial channels were dug to carry water from Lake Rusa, as the inscriptions claim. Like the Menua Canal offtakes, this lack of evidence could be due to preservation issues, or it could indicate that Urartian water management systems were primarily constructed for urban water supply to the fortresses of the Van plain at Tuşpa and Toprakkale.

LANDSCAPE STUDY 2: IRON AGE IRRIGATION AT URARTU'S EASTERN BORDER ON THE ŞƏRUR PLAIN

A second landscape study provides evidence for Iron Age irrigation at Urartu's eastern fringes on the Şərur plain of Naxçıvan, Azerbaijan. The Iron Age of the Şərur plain, an alluvial plain formed by the Araxes and Arpa Rivers, has recently been investigated via survey and excavation.⁶⁸ Survey revealed three Middle Iron Age fortresses, Verahram (on the Iranian side of the Araxes River), Oğlanqala, and Sədərəkqala, positioned such that they form a triangle that roughly follows the edges of the plain (fig. 9).

None of these fortresses has Urartian inscriptions, and thus their cultural affiliation must be assessed materially. Since the time of its initial study in the 1970s, Verahram has been considered an Urartian site of the eighth century BCE on the basis of ceramics, plan, and construction style.⁶⁹ Oğlanqala was a large, walled administrative center initially constructed in the eighth century BCE, coincident with textually documented Urartian expansion into the region. However, differences between the material at Oğlanqala and

65 Salvini 2008, vol. 1, 623 CTU 14-1 Ro.

66 Salvini 2002; 2012, 127–31.

67 Garbrecht 1980, 301.

68 Baxşəliyev 2008; Hammer 2014; Herrmann and Hammer 2019; Ristvet, Baxşəliyev, and Aşurov 2011; Ristvet et al. 2012.

69 Kleiss 1973, 82–93.

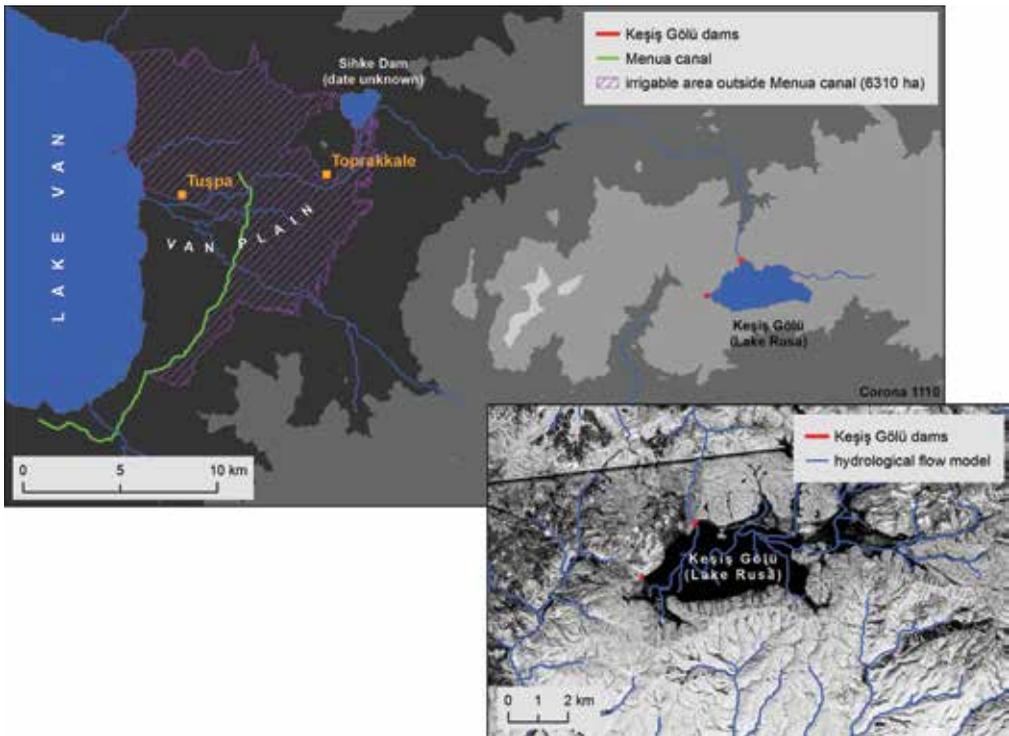


Figure 7. Map of Keşiş Göl north dam flow and estimation of irrigable area. Topographic data for elevation and for hydrological flow model from SRTM30.



Figure 8. Keşiş Göl south dam flow.

other Urartian centers has led the excavators to conclude that Oğlanqala was a center of a local independent polity or tribe on the edge of the Urartian realm. The key pieces of evidence are some local examples of Urartian writing, small amounts of Urartian pottery, and architectural characteristics that differ from known Urartian fortresses.⁷⁰ The excavators' interpretation has been both challenged⁷¹ and defended⁷² on the basis of comparison with nearby Early Iron Age and Urartian fortresses in Armenia.

The third fortress, Sədərəkqala (fig. 10), is unexcavated, and its dating and association remain uncertain. Survey recovered Early Iron Age, Middle Iron Age, and medieval surface pottery, and the survey team's sondages recovered sherds of Early and Middle Iron Age fabric. The fortress lies only about 45 km downstream from important Urartian sites along the Araxes River in Armenia. Given the lack of Urartian pottery at the site and the similarities with construction techniques and pottery at Oğlanqala, Sədərəkqala was arguably another local (non-Urartian) center inhabited just before and possibly also during Urartian control of the region.

Given the distribution and characteristics of the three fortresses, it seems likely that the eastern border of Urartu in the area of Naxçıvan lay at the Araxes River. Like many Urartian centers, the local fortresses of Oğlanqala and Sədərəkqala overlook a fertile, irrigable agricultural plain but also have easy access to pastoral highlands outside the plain. This is especially true of Oğlanqala, which guards the entrance to a mountain pass.⁷³ The Araxes River separates Verahram from the majority of the Şərur plain. Verahram is the only fortress of the three that was definitely Urartian, and it is surrounded by land better suited for pastoralism, the undulating basaltic terrain of the slopes of Mount Ararat (Ağrı Dağı).

The area around Sədərəkqala has revealed some evidence for Iron Age irrigation. Sədərəkqala's rock outcrop is surrounded on three sides by a massive stone wall that archaeologists suggested was an irrigation canal (without mentioning the fortress 100 m above on the same mountainside or other evidence; fig. 11).⁷⁴ The standing segments of this wall had a cumulative length of 512 m when surveyed in 2013. Other segments are visible in declassified HEXAGON imagery from mission 1204, captured on November 13, 1972. The historical imagery suggests that the original wall was at least 1520 m in length. HEXAGON imagery also shows a linear feature in the plain to the east-southeast of Sədərəkqala that appears to be a canal (fig. 12). This canal could have been up to 7 m wide, though it was likely narrower because the feature in the satellite imagery probably includes the width of upcast heaps on either side of the canal. The canal stretches roughly 3.5 km from a colluvial fan to the southeastern edge of Sədərəkqala's mountain, following the topography of the hills bordering the plain at roughly the 815 m ASL contour. The alignment and height of this canal are such that it could have connected with the wall/canal surrounding Sədərəkqala. The canal as preserved in the HEXAGON imagery ends approximately 400 m from the closest standing segment of the surrounding wall. The altitude of the canal's

70 Ristvet et al. 2012.

71 Dan 2014.

72 Hammer, in preparation.

73 Hammer 2014, 769.

74 Belli and Sevin 1999, 58–61.



Figure 9. Iron Age fortresses on the Şərur plain, Naxçıvan. Imagery from Google Earth Pro.



Figure 10. Plan of Sədərəkqala. Base imagery is from HEXAGON mission 1204, captured November 13, 1972.



Figure 11. Photograph of the lower wall/canal at Sədərəkqala, June 2014.

western end is approximately 815 m ASL on a modern elevation model, and the altitude of the surrounding wall's eastern end is approximately 809 m ASL. The canal would have had to cross a gully on the side of Sədərəkqala's mountain in order to feed into a channel associated with the surrounding wall.

The linear feature in the HEXAGON imagery lends considerable support to the hypothesis that the lower wall was part of a former canal but suggests that this canal was of a very different nature than previously described. Belli and Sevin hypothesized that the Sədərəkqala surrounding wall might be part of an irrigation canal that extended 25–30 km from the Arpa River (ca. 16 km away) to the modern village of Sədərək.⁷⁵ If the lower wall was part of a canal, the HEXAGON imagery suggests that the source of this canal was groundwater from the nearby colluvial fan, only 3.5 km away, rather than the faraway Arpa or from the other nearby perennial river, the Araxes. This colluvial fan in recent decades has been a source of water through underground tunnels (qanats or karez, also visible on HEXAGON and DigitalGlobe satellite imagery but currently out of use), and several springs still flow in the area today. Given the topography and the distance, it would have been a much more significant engineering feat to irrigate using the Arpa or the Araxes than groundwater.

The date of the possible canal is unknown. A sondage against the face of the surrounding wall in 2015 cut through fill with Iron Age pottery and was therefore inconclusive. No trace of the linear feature in the imagery remains on the surface. Today, two main canals

⁷⁵ Belli and Sevin 1999, 58–59.

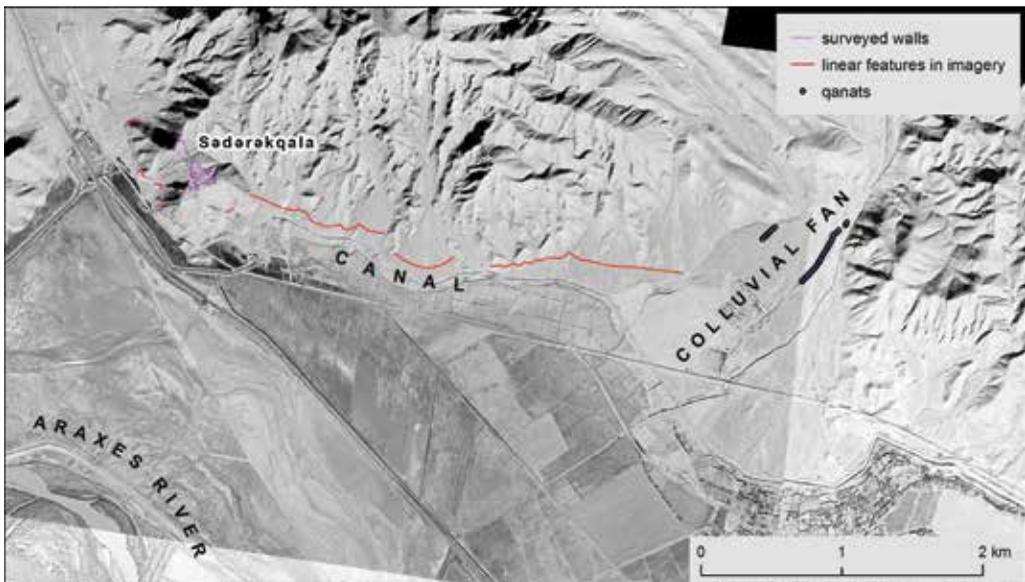


Figure 12. HEXAGON image (mission 1204, November 13, 1972) of the canal to the southeast of Səderəkqala.

feed this corner of the plain, and the construction of the second, sometime after 1980, involved intensive leveling of the area. Further, the construction of a cement factory at the east end of Səderəkqala's mountain sometime before 1972 resulted in major changes to the topography at the foot of Səderəkqala, including leveling of the plain and deepening of the gully on Səderəkqala's eastern slope.

The presence of this canal at the base of an Early and Middle Iron Age fortress of apparently local construction does, however, raise the strong possibility of irrigation by local tribes or polities in the pre-Urartian or Urartian periods at the fringes of this empire. Local irrigation associated with pre-Urartian fortress polities of the Late Bronze Age has been attested on the slopes of Mount Aragats and the Gegham range in Armenia.⁷⁶

CRITICAL DISCUSSION OF URARTIAN IRRIGATION

On the basis of the two landscape studies presented here and other critically reviewed details, we can draw several conclusions about the characteristics and the political and economic role of irrigation within Urartu. Due to the environment of the areas they controlled, the Urartian and also pre-Urartian societies of the Late Bronze/Early Iron Ages often drew on groundwater, spring flows, and snowmelt rather than perennially flowing surface water. Irrigation of the highland plains did not begin with the Urartians. Local polities centered on fortresses in the Late Bronze Age and Early Iron Age of Armenia and possibly also Naxçıvan intensified agricultural production through the construction and use of irrigation canals. These local polities also intensified settlement near their fortresses through transportation of water to lower towns. The Urartians may have increased the

⁷⁶ Kalantar 1994.

scale of irrigation in the Van plain, and they certainly constructed a highly visible and long-enduring canal, but they were not the first to transform parts of the region from pastoralist to agricultural areas.⁷⁷ Earlier arguments suggesting that less rain or more people in the region must have necessitated Urartian irrigation efforts since agriculture is possible without irrigation and that “there is no evidence that earlier settled populations in the area employed it”⁷⁸ cannot be upheld with new evidence concerning the pre-Urartian societies of the South Caucasus.

The current picture from a critical reading of the inscriptions and from archaeology suggests that irrigation played a minor political role in Urartu. A significant number of inscriptions do mention canals, but the information in these inscriptions is rather one-dimensional. Most merely serve to claim that a particular king should receive credit for agricultural abundance and building activities, including canals. Thus, canals are associated with the ideology and legitimacy of the king but not necessarily with state administration. The distinction between irrigation’s administrative/bureaucratic and ideological roles in early polities has been clearly articulated in the case of ancient Yemen.⁷⁹ Outside of the Menua Canal and the Keşiş Göl dams, there is a general lack of material evidence for large-scale irrigation structures in the central part of the empire that would have required continual investment from a centralized polity for construction and maintenance. The state’s direct involvement in water engineering may thus have been limited to structures that supplied the capital, Tuşpa, and another city, Toprakkale, in the Van plain, and may not have extended to other fortresses in the Van area. Elsewhere, in provincial settings, the excavators of two major fortresses, Bastam in Iran⁸⁰ and Armavir in Armenia,⁸¹ claim to have mapped canals mentioned in the Urartian inscriptions from these places. However, the canal at Bastam and the four canals at Armavir are in fact modern features that the excavators argue must also have been used in the past. Historical satellite imagery of these two sites shows some trace features that could correspond to ancient canals (figs. 13 and 14). Without the inscriptions or field survey, it is not yet possible to argue that canals were present at these fortresses during Urartian occupation, nor how large or complex these canals may have been in the past.

Pre-Urartian local-scale polities centered on fortresses had the ability to construct irrigation systems, and there is no reason to assume that this local level of water management did not continue into Urartian times. In the case of Sədərəkqala, what was initially interpreted as a canal of significant length (25–30 km) drawing water from distant perennial rivers appears on closer inspection to have been a much more modest construction (around 3.5 km) drawing from nearby groundwater resources. Such a construction is much more likely to be within the labor capacity of a local-scale polity. Although Sədərəkqala was arguably a local rather than an Urartian fortress, these observations about the organizational capacities of local Early and Middle Iron Age rulers on the fringes of Urartu support the recent suggestion that local leaders, rather than the Urartian state, could have

77 *Contra Belli* 1997.

78 Zimansky 1985, 68; Zimansky 1990, 8.

79 Harrower 2009.

80 Kleiss 1980, 299; Kleiss 2012, 62.

81 Martirosyan 1974.

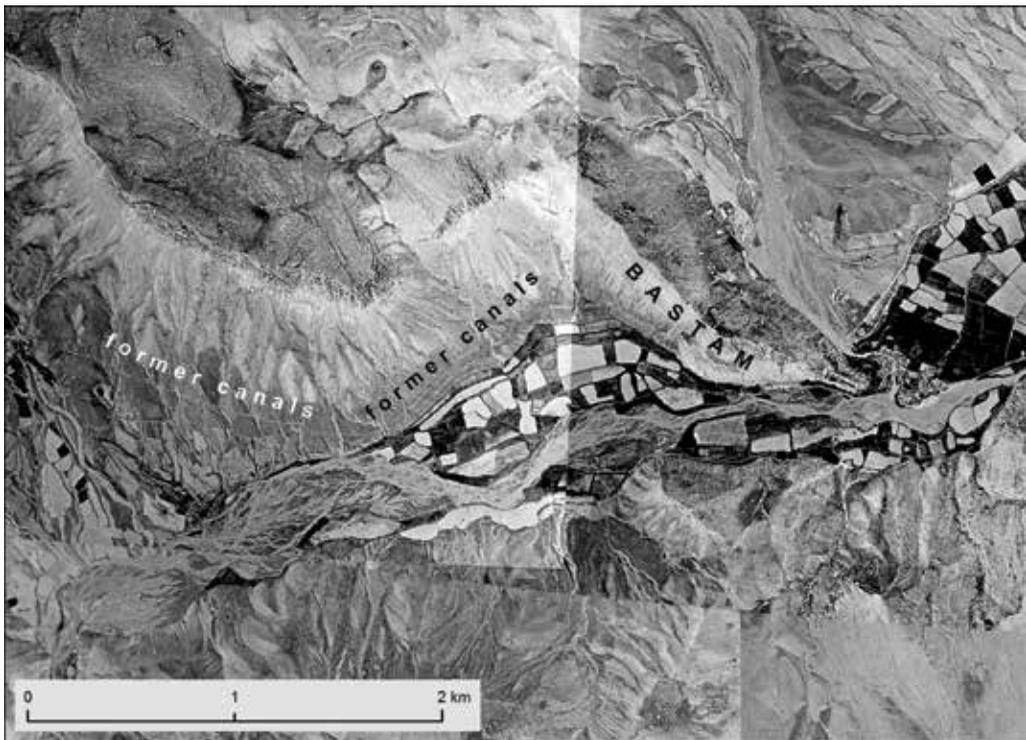


Figure 13. Historical image of the area around the Urartian fortress of Bastam in Iran (HEXAGON mission 1205, May 8, 1973) with possible canal features labeled.

undertaken the construction of Urartian-era irrigation features.⁸² The aforementioned Assyrian documents attesting to the independent activities of some Urartian governors in the Urmia region⁸³ and architecturally based arguments that local rulers constructed some Urartian citadels⁸⁴ provide additional, though indirect, support for ideas about the possible local-led construction of some Urartian-era irrigation systems.

The question of irrigation's economic role in Urartu, and more specifically evaluation of the irrigation-for-crops versus the irrigation-for-fodder hypotheses, cannot be entirely resolved with current evidence. Çifçi and Greaves (2013) are right to highlight the ethnographic evidence for irrigation of hay meadows and for the use of drinking reservoirs by pastoralists. These could have been practices in Urartian times and are important alternative hypotheses to consider through future faunal, botanical, and landscape studies. River valleys and highland plains were not merely domains of agricultural production. Some large Urartian centers, such as Verahram, were located in pastoral zones and were probably not involved in the surveillance of irrigation works or agricultural areas. Bastam was located in an area with very limited fertile soils, surrounded by mountains that could have

82 Çifçi and Greaves 2013, 202–3.

83 Kroll et al. 2012, 21; Zimansky 2011, 108.

84 Koroğlu 2009.

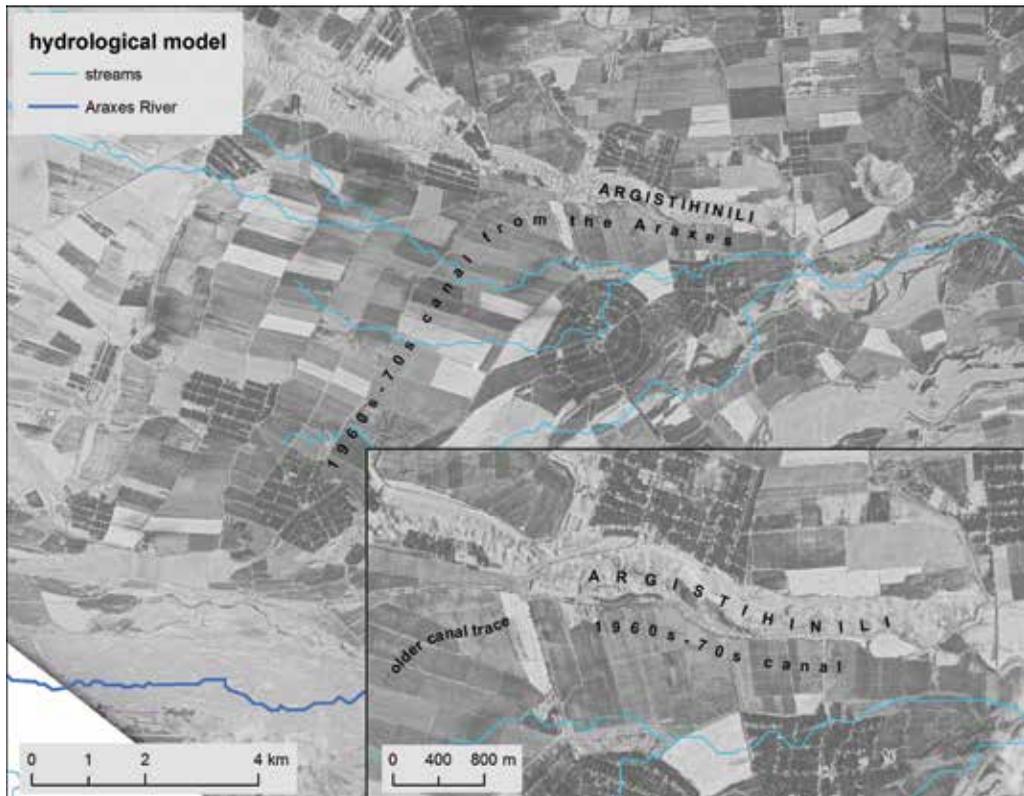


Figure 14. Historical images of the area around the Urartian fortress of Armavir in Armenia (CORONA mission 1111, July 28, 1970) with possible canal features labeled.

been used as pasture areas.⁸⁵ However, the idea that Urartian irrigation systems were designed to produce fodder for livestock currently lacks empirical evidence. Although Çifçi and Greaves criticize Belli for his lack of firm dating evidence,⁸⁶ they ultimately accept without evidence that many small, undated features surveyed in the Van region must be Urartian. To support the hypotheses of Çifçi and Greaves beyond ethnographic analogy, we would need much more detailed fieldwork on small-scale water features in highland pasture areas. The importance of mobile pastoral groups in Urartu has been assumed by many scholars on the basis of ethnographic analogy and ideas that eastern Anatolia would have been home to mobile pastoralists in all periods.⁸⁷ However, no direct evidence exists for these groups.⁸⁸ In fact, recent zooarchaeological work provides evidence for sedentary, settlement-based herding in the Iron Age in parts of northeastern Anatolia where twentieth-century mobile pastoral tribes were active, and researchers have frequently assumed that ancient populations must have practiced mobile pastoralism.⁸⁹

85 Burney 2012, 54.

86 Çifçi and Greaves 2013, 201.

87 Burney 2012; Yakar 2011.

88 Kroll et al. 2012, 21.

89 Howell-Meurs 2001.

If intensified fodder production was an important motivation for Urartian irrigation systems, the beneficiaries of these systems would have been not only the mobile sheep/goat/cattle pastoralists hypothesized by Çifçi and Greaves but also, and perhaps more significantly, horse breeders supplying animals for chariots and cavalry. Middle Assyrian documents of the Early Iron Age and Neo-Assyrian documents of the Urartian period suggest that horse breeding was important in the Urmia region. The Assyrian kings Aššurnasirpal I and Shalmaneser III record receiving horses as tribute when campaigning in this area.⁹⁰ The texts recounting Sargon II's eighth campaign in the Urmia region emphasize the importance of horse breeding and training in the area and recount the existence of an irrigation canal at the Urartian city of Ulhu.⁹¹ Horses were essential for a powerful army, and therefore the state would be highly motivated to irrigate for the purpose of ensuring rich pastures and fodder for these animals.⁹² No securely dated Iron Age irrigation features are yet known from the Urmia region, though traces of a possibly Urartian-era canal have been noted at the southwestern edge of the plain.⁹³

URARTIANS VERSUS ASSYRIANS IN THE CONTEXT OF IRRIGATION

The Urartians were contemporaries, neighbors, and major adversaries of the Neo-Assyrians, with whom they shared a script and some gods and artistic styles, as well as a royal interest in irrigation. Assyria undoubtedly provided a “cultural model” for the Urartian state: the earliest Urartian inscriptions were written in Akkadian, copied from Assyrian texts, and both polities engaged in annual military campaigns led by the king.⁹⁴ Archaeologists have extensively studied Neo-Assyrian irrigation systems,⁹⁵ including from a landscape and satellite imagery perspective.⁹⁶

The landscape study of the Van plain presented here and critical discussion of previous literature offer the opportunity for comparison between the Urartian and Neo-Assyrian empires in the context of irrigation. The textual evidence for irrigation systems is similar for both empires. Inscriptions associated with particular water management features connect the construction of these features specifically with the king and highlight his role in ensuring agricultural abundance. The formulaic emphasis seen in Urartian irrigation inscriptions on the king's role in bringing fertility to previously “uncultivated” areas parallels common themes in the royal inscriptions of the Assyrians and other Mesopotamian societies, where the king frequently claims to have transformed wilderness into garden.⁹⁷ This parallel shows that both the Urartians and the Assyrians saw the creation of irrigation systems as an important part of the king's identity, which could perhaps suggest that the Urartians were influenced by broader Mesopotamian ideas about who the king should be.

90 Kroll 2011, 153–54.

91 Zimansky 1990, 18–19.

92 Burney 2005, 17–18.

93 Kleiss 2012, 62.

94 Zimansky 2011, 109.

95 Bagg 2000; Jacobsen and Lloyd 1935; Oates 1968; Reade 1978; Reade 2002.

96 Altaweel 2008; Morandi Bonacossi 2014; Ur 2005.

97 Dalley 2005; Winter 2007.

Landscape scenes carved into Neo-Assyrian palace reliefs, including depictions of irrigated gardens and bands of decoration with agricultural items produced through irrigation, provide a source of data not available for Urartu.⁹⁸ While archaeology has been able to add considerably to the knowledge that the inscriptions provide for Assyrian irrigation, Urartian irrigation is thus far better attested from a textual point of view.

The Urartians and the Assyrians managed water in different environmental contexts with different technologies.⁹⁹ The Urartians irrigated plains of moderate to high elevation using groundwater and snowmelt. Their main challenge was the storage of seasonally abundant water in the form of snowmelt for distribution throughout the summer dry season using dams and reservoirs. The Assyrians irrigated dry steppe using rivers and other surface flows. Their main challenge was to distribute small amounts of water over a large area using canals, aqueducts, and sometimes underground channels that have shafts like qanats but carry surface flow rather than tapping groundwater. The Menua Canal was cut from limestone for part of its length, and in other places where the canal was excavated from the soil, limestone walls constructed into hillsides supported the canal.¹⁰⁰ By contrast, most Assyrian canals known from survey and satellite imagery analysis appear to have been mostly earthen structures, though rock-cut water tunnels are also known.¹⁰¹

Both the Assyrians and the Urartians devoted major irrigation efforts toward directly supplying their capitals with water (Tuşpa and the nearby fortress of Toprakkale for the Urartians; Nineveh, Khorsabad, and Nimrud for the Assyrians). The focus of their irrigation systems was not just on food production but also on urban water supply. The major urban water supply projects of both the Urartians and the Neo-Assyrians all took place in the ninth to seventh centuries BCE, during the reigns of Urartian kings Menua (r. 810–786 BCE), Rusa, son of Argišti, and Rusa, son of Erimeña (exact reign years debated) and during the reigns of Assyrian kings Aššurnasirpal II (r. 883–859 BCE), Sennacherib (r. 705–681 BCE), and Esarhaddon (r. 680–669 BCE).

Assyrian and Urartian urban water supply projects were broadly similar in scale. The largest archaeologically documented Assyrian irrigation system, the Khinis-Jerwan canal constructed by Sennacherib, carried water 90 km from the Zagros foothills to Nineveh and could have irrigated up to 100 sq km on the Navkur plain. Another well-documented canal constructed by Sennacherib above Nineveh, the Kisiri canal, was much smaller at 15.8 km in length with a possible irrigation area of around 12 sq km (see also Ur's chapter in this volume).¹⁰² The canal supplying Nimrud with water, constructed by Aššurnasirpal II, was at least 21.6 km long but could have been up to 40 km long, and could have irrigated an area of up to 48 sq km.¹⁰³ The Menua Canal supplying Tuşpa with water began approximately 50 km from the fortress's lower town and could have irrigated an area of up to 60 sq km. The wadi flow from the Keşiş Göl north dam began approximately 36 km from

98 Dalley 2005; Winter 2007.

99 Zimansky 1985, 67.

100 Belli 1997, 41.

101 Dalley 2005, 40.

102 Ur 2005.

103 Ur and Reade 2015.

Toprakkale and, if offtakes were constructed, could have irrigated an area up to 63 sq km in the Van plain.

The urban supply system for Assyrian capitals included canals wide enough to have been used for transportation during high-flow periods. Canal placement near quarries suggests that heavy items such as building materials could have been transported,¹⁰⁴ as well as surplus agricultural products.¹⁰⁵ By contrast, the preserved limestone-cut portions of the Menua Canal indicate it was only 3–4 m wide and 1.5–2 m deep, and therefore probably too small to have served any serious transportation function.

The general contemporaneity of Urartian and Assyrian urban water supply projects and similarities between Urartian and Assyrian textual accounts of irrigation systems have led various scholars to argue that innovations in and attitudes toward royal irrigation projects spread either from Urartu to Assyria¹⁰⁶ or from Assyria to Urartu.¹⁰⁷ The greater range of information available for Assyrian irrigation systems¹⁰⁸ and older ideas about the cultural dominance of Assyria over Urartu¹⁰⁹ have frequently influenced the latter arguments. However, there is no reason to look to the external influence of the Assyrians on the basis of chronology or on the basis of construction style. It is important to note that the ninth-century BCE date of the largest known Urartian irrigation feature, the Menua Canal, precedes the huge, very late eighth- to early seventh-century irrigation structures of the Assyrian kings Sennacherib, Esarhaddon, and Aššurbanipal. Further, the groundwater-fed canals and snowmelt-capture water management features of the Urartians have earlier indigenous parallels in the irrigation systems of Late Bronze and Early Iron Age fortress-polities of eastern Anatolia and the South Caucasus. The Urartian use of irrigation systems and royal involvement in the construction of water management features should be seen as an outgrowth of earlier political and agropastoral economic systems in the region, not as an innovative political or economic strategy or as an imitation of the practices of their southern neighbors in Assyria.

CONCLUSION

As a highland empire, Urartu adds environmental diversity to perspectives on the connection between ancient irrigation and state power, a relationship that archaeologists have typically explored through case studies within lowland river plains. A critical review of existing literature on Urartian irrigation and two landscape studies of Urartian-era irrigation at the center and at the eastern fringes of the empire provide insight into irrigation's characteristics and political and economic role within Urartu.

Both at the core and the fringes of Urartu, the Urartians and local Early and Middle Iron Age societies constructed groundwater- and snowmelt-fed irrigation systems designed to increase productivity in the face of long winters and a short growing season. So

104 Morandi Bonacossi 2014.

105 Ur and Reade 2015, 21–23.

106 Boehmer 1997; Radner 2011, 743.

107 Bagg 2000, reviewed in Dalley 2005; Belli 1997, 35.

108 Dalley 2005.

109 Burney 2005, 18.

far, archaeology has uncovered very little empirical evidence for canals and other water management features that can be securely dated to the Urartian period. The increasing availability of higher-resolution historical imagery from the HEXAGON spy satellite program and from Soviet aerial photography should significantly improve archaeologists' ability to detect landscape-scale traces of ancient irrigation networks in the vicinity of Urartian and Early and Middle Iron Age sites such as Sədərəkqala in Naxçıvan, Azerbaijan.

Irrigation appears to have played a minor political role in Urartu, as major irrigation projects significantly postdate the consolidation of the polity and texts mention only the construction but never the maintenance of irrigation systems. Both textual and archaeological analyses point to significant political decentralization within Urartu before the seventh century BCE, as well as the important role played by local governors in military campaigns and local building programs. Despite the texts' emphasis on royal agency in the construction of some water management features, there is a strong possibility that local leaders were involved in the construction and certainly the maintenance of Urartian-era irrigation systems, as local rulers had been in the pre-Urartian period. Belli's claim that Urartu was the "greatest hydraulic civilization of the ancient Near East"¹¹⁰ is clearly hyperbolic both in terms of the scale of Urartian irrigation systems and in terms of the lack of evidence for connections among Urartian irrigation maintenance, bureaucracy, and centralization—connections that Wittfogel used to define "hydraulic civilizations" in the first place.¹¹¹

The economic roles of irrigation within Urartu remain a topic for debate and future research. Irrigation systems certainly would have played a role in creating the agricultural surplus evidenced through excavation of storage areas in Urartian fortresses. The only water features that are certainly Urartian (the Menua Canal and the Keşiş Göl Dam) were used for agriculture and for urban water supply, in accordance with the statements of the inscriptions that accompany them. The lack of visible oftakes in satellite imagery suggests that urban water supply could have been their primary function. However, the ethnographically based hypothesis that Urartian irrigation systems could also have supported the pastoral economy through enriching pastures and intensifying fodder production deserves future investigation. Archaeology has, in general, neglected studying how pastoralists use water.¹¹² Further evidence in support of this hypothesis could in the future come from zooarchaeological and paleobotanical studies of storage areas and houses in the lower towns surrounding Urartian fortresses, such as the studies conducted at Ayaniş,¹¹³ as well as systematic surveys of highland areas. We currently have no direct evidence for sheep/goat/cattle pastoralist-motivated irrigation of hay meadows as described by the authors of the foddering hypothesis. It is important to note that pastoral benefits can also come as a by-product of irrigation systems designed for agriculture, as irrigation canals

110 Belli 1997, 35.

111 Wittfogel 1957.

112 Hammer 2018.

113 Stone 2012; Stone and Zimansky 2003.

and dams provide convenient places for pastured animals to drink and also support denser vegetation at the edges of fields and reservoirs that can be cut for use as fodder.¹¹⁴

On the basis of Neo-Assyrian textual evidence and considerations of the importance of horses in Iron Age warfare, it seems likely that any state-sponsored efforts to support animal husbandry through irrigation would have targeted horse breeders supplying mounts to the Urartian army rather than sheep/goat/cattle pastoralists supplying meat, milk, and wool. Archaeologists have typically drawn a connection between irrigation and state power on the basis of agricultural surplus. The potential significance of horse needs for Urartian water management provides an animal- and military-driven connection between irrigation and state power. Such a connection among qanat irrigation, alfalfa production for fodder, horse breeding, and military power has been drawn for Achaemenid highland Iran.¹¹⁵

The Urartians shared a focus on irrigation and urban water supply with their southern neighbors, the Assyrians. The texts of both empires emphasize the personal role of the king in guaranteeing this supply. Further, these water management projects were of broadly similar scale and were undertaken in the same two-hundred-year period. However, Urartian and Assyrian irrigation systems differed in their technologies and water-engineering aims largely due to differences in environment but also due to differences in function, specifically a transportation function for Assyrian but not Urartian canals.

Archaeological evidence increasingly indicates that Urartu represents continuity rather than a break with earlier Late Bronze and Early Iron Age societies in the region, and pre-Urartian irrigation patterns in Armenia and Naxçivan (Azerbaijan) provide evidence for this continuity. Various scholars have hypothesized that Urartian focus on irrigation was born of external factors or fluctuating environmental conditions: population increase, climate change, and/or imitation of the Neo-Assyrians. However, a much more satisfactory answer might lie in indigenous processes and military needs: the Urartians irrigated because it was part of a suite of political and economic strategies that were innovated and employed by their predecessors in hilltop forts across eastern Anatolia and the South Caucasus and because of the fodder requirements for horses that the state needed for its army.

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114 Tapper 1997, 300–1.

115 de Planhol 2010.

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PART IV

THE SOCIOPOLITICAL FUNCTION
OF IRRIGATION

11

A New Interpretation of Irrigation and Ancient State Formation: Political Rhetoric, Social Logic, and Spatial Heterogeneity

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ARCHAEOLOGISTS RECOGNIZED MORE than seventy years ago, even with the relatively sparse evidence then available, that the rise of many of the world's earliest states appeared to be associated with water control. Julian Steward, who is perhaps best known for his multilineal theory of cultural evolution, considered irrigation the most promising potential cross-cultural parallel worthy of further investigation.¹ Karl Wittfogel, however, was by far the most vocal proponent of the hydraulic hypothesis—that organizational requirements of large-scale irrigation spawned administrative bureaucracies and complex political hierarchies.² Wittfogel eventually discarded the rigid, binary distinction he drew between Western and Eastern types of societies, but he remained insistent that large-scale hydraulic works were key to the rise of ancient states.³ These scholarly precedents have long structured scholars' thinking about irrigation, and the multitude of studies debunking the hydraulic hypothesis have continually focused and refocused attention on managerial requirements of irrigation to the detriment of innovation in considering other less conspicuous ideological dimensions of water and its influences among ancient societies. It is now abundantly clear and widely agreed that large-scale irrigation does not necessarily require state management and that large, state-managed irrigation systems rarely appeared neatly in tandem with state-level political complexity.⁴ However, the hydraulic hypothesis continues to dominate scholarly thinking on the issue, as Karl Butzer⁵ put it:

The Wittfogel model, like Elvis, refuses to die. And like the impersonators of Elvis Presley who earn their keep by rocking around the clock, Karl Wittfogel's (1938; 1957) "hydraulic hypothesis" continues to be repackaged in a variety of guises that assign a unique causal role to irrigation in the development of socio-political complexity.

How, then, do we move forward in examining water's role in ancient political complexity in a manner that acknowledges both the importance of historical particularities

1 Steward 1949, 1955.

2 Wittfogel 1957.

3 Wittfogel 1972.

4 E.g., Adams 2006; Mabry 2000; Wilkinson 2013.

5 Butzer 1996, 200.

and contingencies—that is, the unique nature of different societies and cultures—and the fact that there do seem to be some broad, cross-cultural similarities in water’s influences among ancient societies?

This chapter summarizes a new interpretation of irrigation’s influences in the rise of states in arid regions, one that emphasizes the interactive dynamics of political rhetoric, social logic, and spatial heterogeneity of water.⁶ While generalizations about cultures and histories necessarily conceal underlying diversity—such as the widely divergent range of contexts reflected in the other chapters of this volume—I argue that a new framework is needed to revitalize research on irrigation and state formation. I present a new spatial-political interpretation and use evidence of state formation in ancient Southwest Arabia (fig. 1) to discuss both particularities and general patterns that helpfully inform studies of other arid contexts, particularly in the ancient Near East. I use the term “interpretation,” rather than “model” or “explanation,” because given the importance of historical contingencies, it is highly unlikely that a one-size-fits-all model or explanation can accommodate all the vast diversity apparent even in a single macroregion such as the Near East. Even so, some measure of similarity is apparent in the ways in which early complex polities interjected themselves in the spatiotemporally variable availability of water across landscapes and regions.

A combination of political rhetoric, social logic, and spatial heterogeneity draws together the findings and arguments of previous scholarship on water and emergent political complexity. Two key scholars in particular—Robert McC. Adams and Tony Wilkinson—broke substantial new ground collecting, analyzing, and synthesizing data on water, settlement patterns, and political complexity in the ancient Near East. Both scholars contributed an extraordinary range of insights on irrigation, and both strongly rejected Wittfogel’s hydraulic hypothesis, but neither proposed a fully formulated model, explanation, or interpretation of water’s role among early states.⁷ The closest perhaps was historical narrative description of water’s long-term role and the assertion, which they both made, that state-coordinated irrigation led to the expansion and spread of empires across the Near East but not the initial origins of states. This conclusion was based on the observation that large-scale, state-managed irrigation systems quite simply do not appear to have arisen in tandem with the earliest complex polities. Indeed, this does seem to be the case. Even in southern Mesopotamia, where irrigation was a requirement of crop production, organization and management of water is a complex matter that sometimes, but not always, involves bureaucratic intervention.⁸ This notably contradicts the hydraulic hypothesis, which emphasizes the managerial necessity of state bureaucracies in water management, but it does not override the importance of water and irrigation as one of the key prime movers responsible for the appearance of states. That is, even without directly constructing irrigation systems (or directly managing them), political authorities can and still do claim and exert dominion over water and food production.

The spatial-political interpretation that I propose involves three main aspects: spatial heterogeneity, political rhetoric, and social logic. The interface of these three aspects

6 Harrower 2016.

7 Adams 1960, 1981, 2006; Wilkinson 2003, 2013; Wilkinson and Rayne 2010.

8 Rost 2017.

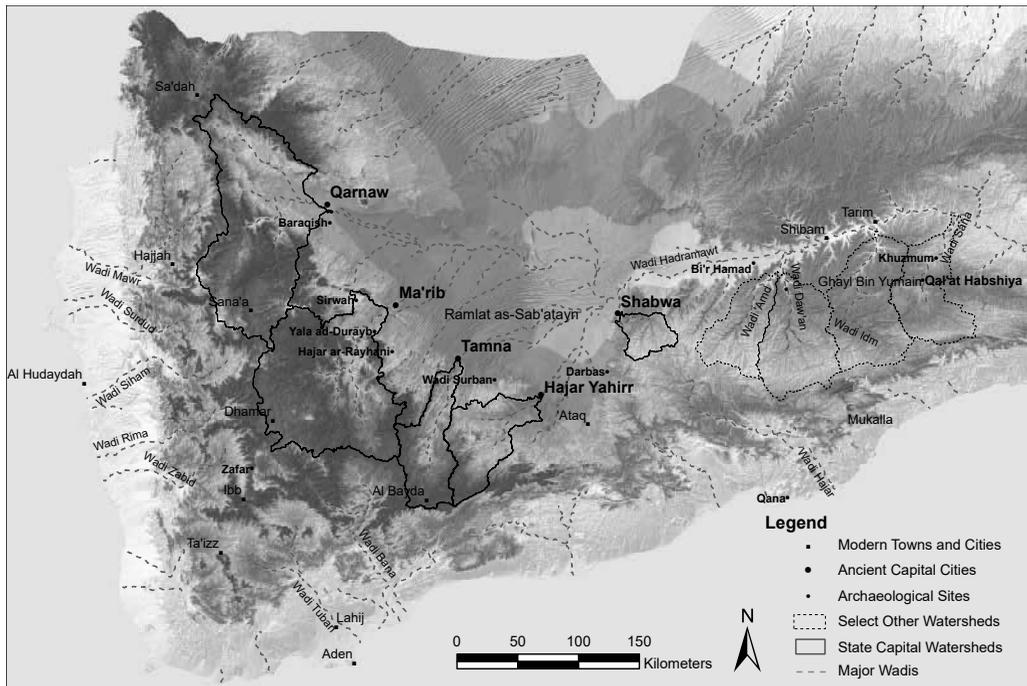


Figure 1. Map of Yemen showing capital cities of major ancient states and associated watersheds, along with a selection of archaeological sites and major drainages. Topography and hydrology derived from NASA Shuttle Radar Topography Mission (SRTM) data.

assists in understanding the combined forces, including environmental, economic, and ideological, related to water and state formation. I argue that it was not the state's supposedly inescapable role in management but rather the ideological and rhetorical exploitation of spatial heterogeneity—patchiness, granularity, and gradients of water availability—that contributed to differential political power and complexity.

SPATIAL HETEROGENEITY

Spatial heterogeneity of water can help explain why complex polities preferentially form in particular areas. A prominent topic of landscape ecology, spatial heterogeneity refers to the uneven, patchy, discontinuous spatial distribution of environmental characteristics across landscapes.⁹ Of the resources required for human adaptation and survival, water is one of the most spatially variable yet readily quantifiable. Archaeologists have long recognized the importance of climatic and environmental changes over time (including drought) as important to societies of the ancient past, but far less attention has been paid to spatial differences in water availability. Just as the invention of radiocarbon dating in the late 1940s transformed archaeologists' ability to build chronologies and understand changes over time, the rise of spatial tools since the 1990s, including satellite imagery,

⁹ Pickett and Cadenasso 1995; Turner 2005.

global positioning system (GPS), and geographic information system (GIS) technologies, has transformed archaeologists' ability to analyze spatial patterning across regions. Julian Steward¹⁰ and Karl Wittfogel¹¹ long ago recognized that many of the world's earliest civilizations appeared along major water courses, such as the Nile, Tigris/Euphrates, Indus, and Yangtze and Yellow Rivers, but far more attention to the subtleties of water geographies is warranted. Indeed, many regions of early state formation are characterized by extreme gradients of water availability with major water sources flowing through otherwise arid regions. These gradients, along with patchiness and granularity at a range of spatial scales, offer a complex spatial mosaic that promotes adaptive creativity, population aggregation, and inequality and comes to inhibit the autonomy of food producers who, given more homogeneous conditions, might chose to splinter off from larger political entities.

Mesopotamia has long been central to debates about the role of water in state formation and exemplifies the importance of spatial heterogeneity. Although the earliest states were traditionally thought to have emerged in southern Mesopotamia, recent evidence from northern Mesopotamia has led scholars to question the primacy of the south.¹² Nevertheless, even in the south, centralized coordination or management of irrigation by state authorities was not required to sustain the food supply among the earliest states.¹³ The anastomosing and marshy fluvial environments played a key role in the patterning of human activity and agriculture.¹⁴ Wilkinson and colleagues¹⁵ helpfully describe the herringbone pattern in which crevasse splays could easily be cut through the levees of the Tigris and Euphrates to irrigate surrounding plains that are naturally situated lower than the rivers' channels. The earliest states did not demonstrably manage or coordinate these efforts, but they certainly did set the political context in which sovereignty over water and territory enabled food production capable of sustaining large urban populations. Moreover, as Algaze¹⁶ argued, channels and canals in these estuary environments contributed to state formation in southern Mesopotamia not only vis-à-vis irrigation but because these waterways facilitated interaction, movement, and trade. These trade networks, facilitated by spatial heterogeneity, helped make southern Mesopotamia, a land largely devoid of valuable natural resources, a hub of ancient trade, interaction, and political complexity.

Spatial heterogeneity was at play not only in southern but also in northern Mesopotamia. As Wilkinson has emphasized, the "zone of uncertainty" where rain-fed agriculture could be practiced but was vulnerable to periodic water shortfalls was an important interface and crucible of complexity.¹⁷ Even where irrigation was not a key component of early crop rearing, water was not homogeneously available, and targeting of low-lying, water-rich areas was a demonstrable tactic of ancient farming in northern Mesopotamia.¹⁸

10 Steward 1949.

11 Wittfogel 1957.

12 Ur 2010.

13 Adams 2006; Wilkinson 2013.

14 Hritz 2010; Pournelle 2007; Wilkinson 2012.

15 Wilkinson, Rayne, and Jotheri 2015.

16 Algaze 2008.

17 Cf. Flannery 1969 for related discussion of marginal environments.

18 Yukich 2013.

In sum, capture of a major water source by the state was not a precondition of political complexity, and many early states did not rely on large, state-coordinated irrigation works. Rather than state management of water from major rivers, exploitation of spatial heterogeneity is a more plausible descriptor of hydrological conditions that have contributed to sociopolitical complexity.

POLITICAL RHETORIC AND SOCIAL LOGIC

Interpretations of irrigation's role in state formation have long inclined toward managerial challenges of large-scale irrigation, while the social, political, and ideological dynamics of water have received far less attention. As a concept describing enactment of social relations and reiteration of culture, habitus has had vast influence on interpretations in anthropology;¹⁹ and similarly, structuration theory established agency as a center point of social analysis.²⁰ The diverse scholarly progeny of these lines of thinking in social theory holds considerable significance for new understandings of water and civilization—particularly, I argue, in terms of social logic and political rhetoric, which can help reframe understandings of water's role in social, political, and religious life.

Investigations of water in state formation have frequently centered on early states' direct role in construction and management of irrigation systems, but numerous studies have demonstrated that food production among early states does not require direct state management of irrigation.²¹ However, this certainly does not mean water was inconsequential to state formation. As Robert Hunt²² has noted, charter authority can be claimed even if state authorities only rarely or intermittently intervene in orchestration of irrigation. Essentially, an irrigation system does not actually need to be designed, constructed, managed, or maintained by the state for elites to claim credit for the success and proceeds of water control.

The role of water in state formation can be helpfully interpreted through the lens of political rhetoric and social logic as related to food and control of water resources. Marx and Engels²³ argued that false consciousness facilitated repression of the proletariat, and Durkheim²⁴ claimed that in primitive societies, collective consciousness, formed through shared beliefs about the world, generated solidarity. The role of the state, however, need not be viewed as conspiratorial, nor as solely marked by collective consensus. Zuckerman²⁵ reviews literature in political science and sociology related to the social logic of contemporary politics and voting behavior in the introduction to his edited volume on the topic. He argues that scholars and pollsters have erroneously come to focus on voters as autonomous, when political choices are made in complex, aggregate social milieus. Although his appraisal certainly does not yield a comprehensive assessment of current American

19 Bourdieu 1977.

20 Giddens 1984.

21 E.g., Downing and Gibson 1974; Hunt 1988; Mabry 2000; Millon 1962; Scarborough 2003.

22 Hunt 2007, 117–22.

23 Marx and Engels 1848.

24 Durkheim 1893.

25 Zuckerman 2005.

politics, it does begin to convey the significance of social logic. More precisely, the social logic of politics is concerned with the social contexts in which people make and experience discussions and arguments that they in turn use to act and make choices. In consideration of the ancient past, Flannery and Marcus²⁶ similarly use the term “social logic” to describe the unique underlying rationale that people use to understand and act in the world around them. Social logic is indubitably shaped by political rhetoric, and together the two are neither the master plan of a nefarious elite nor the collective sentiments of a benevolent populous. Rather, they form implicit (tacit) schemata that explain, justify, and rationalize collective action in particular environmental and cultural contexts. Political rhetoric and social logic provide economic and ideological frameworks for a society that can perpetuate particular meta-structural ways of thinking over very long periods of time. In essence, agency is attributable not only to people, not only to objects, but to the collective milieu of argumentation in which complex polities position themselves—for example, in dominion over water resources.

In southern Mesopotamia, the comparative technological simplicity of early irrigation (e.g., crevasse splays) certainly does not mean we should overlook textual records related to water and irrigation. Texts related to water, agriculture, and irrigation even from periods postdating the initial formation of states are a crucially important source of information.²⁷ Such texts not only offer means to evaluate the role the state played in irrigation management but additionally convey a wide range of insights on the social and political contexts of irrigation, including dynamics of status, power, and authority.²⁸ As Richardson²⁹ cogently argues, authority among early Mesopotamian states was far more malleable, rhetorical, and presumptive than indubitable, definitive, and absolute. These arguments have key importance for understanding water, as state authorities’ early involvement with water may not necessarily have entailed direct managerial oversight of irrigation. Thus, it is not only the explicit content of textual records but also the implicit messages conveyed by pronouncements about conflict, military victories, and public monuments such as waterworks that are frequent subjects of texts. Given its origins in arid lands, it is perhaps no surprise that water is a frequent theme in Mesopotamian mythology. But even more notably, a range of key early texts highlight the importance of water in state formation and kingship. These include, for example, the narrative of Gilgamesh and Aga that recounts conflict between the cities of Kish and Uruk over the digging of wells (or canals?) in which Gilgamesh consults two councils, is appointed lugal (king or ruler), declares war, and prevails.³⁰ Similarly, the Lagash-Umma border conflict involved long-running hostilities over land and water.³¹ Another example, the Legend of Sargon the Great, recounts the rise of the first ruler of the Akkadian Empire and depicts Sargon’s coming of age as a gardener who was raised by the humble Aqqi “drawer of water.”³² These examples demonstrate that water

26 Flannery and Marcus 2012.

27 E.g., Rost 2011; Rost and Hamdani 2011; Walters 1970.

28 E.g., Damerow 1996.

29 Richardson 2012.

30 Black 1998–2006.

31 Cooper 1983.

32 Foster 2005, 912–13.

was a critically important matter of concern among early Mesopotamian states, that leaders and cities garnered power and authority (in part) through sovereignty over water, and that this did not necessarily involve bureaucratic management of grand irrigation works.

In many contexts, ancient and modern, grandiloquent pronouncements about water in texts, in art, and through construction of monuments are a persuasive means of communication that works to legitimize state authority and sovereignty. The implicit rhetoric of texts often plays both on anxieties about drought and scarcity and on optimism and aspirations about wealth and abundance. The state proclaims its leaders and elites indispensable and glorifies water control, which offers a vivid green spectacle of prosperity amid the drab and hostile background of hyperarid deserts. In Egypt, for example, one of the earliest known depictions of royal authority, the Scorpion Macehead, shows the pharaoh holding a hoe above water—perhaps opening and inaugurating an irrigation canal.³³ Although technological challenges and task logistics of irrigation are important, state intervention was not always, or not only, through direct management (e.g., oversight of design, construction, operation, and maintenance of irrigation systems). Instead, through rhetoric of cosmological legitimacy and social logic that rationalized the supposedly unavoidable need to harness water in hyperarid deserts, states were often ideologically built (in part) through rhetorical control of water.

WATER AND EARLY AGRICULTURE IN ANCIENT SOUTHWEST ARABIA

Irrigation's role in ancient political complexity is helpfully illustrated through consideration of long-term water histories from the earliest beginnings of crop husbandry in Southwest Arabia. Research on early agriculture has long been dominated by the view that farming began in a few core areas and diffused to secondary, peripheral regions, such as Southwest Arabia.³⁴ This rudimentary view has served us well as an introduction to the problem; it may, debatably, describe the spread of domesticates, but it inhibits deeper understanding of the atypical historical dynamics of transitions to agriculture in lesser-known regions. Would-be farmers in Arabia faced unique social and environmental opportunities and challenges. Unlike Egypt or Mesopotamia, Southwest Arabia lacks perennially flowing rivers and is marked by rugged terrain with deeply incised wadi drainages that experience abrupt water discharges during a bimodal summer rainy season. These flows are difficult to harness and require very different social understandings including rights to water and territory.

A few key pieces of field evidence from Yemen demonstrate the earliest crop agriculture and irrigation during the fourth millennium BCE. In highlands of western Yemen, sediments accumulated behind an agricultural terrace wall yielded a radiocarbon date that calibrates to the mid-fourth millennium BCE.³⁵ Two archaeological sites in the area, Jubabat al-Juruf and Hayt al-Suad, yielded evidence of crops dating to the late fourth and early third millennia BCE³⁶ indicating that crops and terrace agriculture may have appeared

33 Hendrickx and Förster 2010, 838.

34 Sauer 1952; Vavilov 1951.

35 Wilkinson 1999.

36 Ekstrom and Edens 2003.

at roughly the same time. Similarly, in eastern Yemen, *Roots of Agriculture in Southern Arabia (RASA)* research along Wadi Sana documented irrigation dated to the fourth millennium BCE.³⁷ More than a hundred radiocarbon and optically stimulated luminescence dates collected along Wadi Sana, recently subject to Bayesian analysis, further clarify the sedimentary history and timing of early irrigation and demonstrate an early fourth-millennium BCE age for the earliest irrigation.³⁸

Even so, crop agriculture and irrigation appear relatively late in Southwest Arabia in comparison with the Levant and Mesopotamia. Although this is commonly viewed as making the region less significant in terms of explaining agricultural origins, the comparatively late appearance of agriculture is nevertheless crucial as it requires us to consider why people in contact with agricultural societies eschewed farming for millennia. Indeed, the view that agriculture was simply a discovery or invention that expanded outward from a primordial core³⁹ does not accord with clear evidence of a sporadic and discontinuous appearance of agriculture in Arabia and Africa. The most plausible explanations for the seeming delayed and sporadic appearance of farming emphasize the unique sociocultural histories within regions, including the role of ideologies in shaping human choices.⁴⁰ Importantly, the role of social factors in early Southwest Arabian agriculture foreshadows the continuing long-term role of social and ideological dynamics in water and agricultural strategies among complex societies of the region.

WATER AND STATE FORMATION IN ANCIENT SOUTHWEST ARABIA

Irrigation's impacts on ancient political complexity, including in Southwest Arabia, are helpfully illustrated through consideration of spatial heterogeneity, political rhetoric, and social logic. Like research on early agriculture, scholarship on ancient state formation has long centered on the presumption that states originated in a few core areas and diffused to secondary, peripheral regions such as Yemen.⁴¹ However, many civilizations, including Egypt and Mesopotamia, developed while in contact with one another and cannot accurately be described as completely independent or pristine.⁴² Similarly, civilizations in Southwest Arabia indisputably borrowed on earlier developments in surrounding regions but are also marked by unique economic, cultural, and political characteristics, including Ancient South Arabian script. The rise of ancient Yemen's desert kingdoms and the long-term role of spatial heterogeneity, political rhetoric, and social logic can thus serve as an atypical, yet illustrative, example of water's impacts on the rise of civilizations.

By the late second millennium BCE, more than two thousand years of experience with irrigation across a range of different environments contributed to the growth of cities and early kingdoms along the margins of Yemen's Ramlat as-Sab'atayn Desert interior. One might expect in such an arid region that the most influential early polities would have

37 Harrower 2008a, 2008b.

38 McCorriston and Harrower 2020.

39 Bellwood 2004.

40 Harrower, McCorriston, and D'Andrea 2010.

41 Marcus 2008.

42 Wengrow 2010, xvii–xviii.

appeared in areas with comparatively more abundant rainfall, such as in Yemen's western highlands, where most of Yemen's contemporary agricultural production is sustained by rainfall rather than irrigation. However, precisely the opposite is the case. Yemen's most powerful polities emerged in an area with some of the lowest rainfall in the region, but in locations that nevertheless receive powerful flash-flood runoff that afforded opportunities to transform hyperarid areas into lush, bountiful oases. From the early first millennium BCE through the mid-first millennium CE, five kingdoms—Ma'rib, Saba, Qataban, Awsan, and Hadramawt—applied creative combinations of water engineering and collective labor to harness water and vie for control of the incense trade.⁴³ Importantly, the waterworks they relied on were neither agriculturally nor economically required to sustain large populations in Southwest Arabia but rather enabled the rise and perpetuation not only of elites but also of a highly influential network of competing kingdoms that dominated the region for roughly 1,300 years. The largest and most socially and politically impactful construction, the Great Dam at Ma'rib, as described in pre-Islamic texts, in the Holy Quran, and by later Islamic scholars, is arguably one of the most important monuments in the history of Arabia and stands as an important testament to the importance of water in ancient Near Eastern history.⁴⁴

In their earliest stages, Yemen's state waterworks may have been connected or inspired to some degree by developments in other neighboring regions, including the contemporaneous flourish of early first-millennium BCE Neo-Assyrian waterworks in Mesopotamia,⁴⁵ but each region required very different technologies and involved very different social frameworks. In Yemen, a unique local script—Ancient South Arabian—that originated as early as the fourteenth century BCE⁴⁶ attests to the enduring bombast of early leaders' efforts to claim credit for harnessing floodwaters with the blessing of revered gods.⁴⁷

Most importantly, in diverging from the hydraulic hypothesis, a spatial-political interpretation recognizes that elites' pronouncements of authority are often rhetorical and political and do not necessarily represent a real, unavoidable need to build massive irrigation systems. This pattern of claiming credit for construction or reconstruction of megawaterworks, particularly at the Sabaeen state capital of Ma'rib, continues even after power shifts to higher-rainfall highland areas in the first century CE. From the third through six centuries, the Empire of Aksum (Ethiopia) began to exert its influence across the Red Sea and launched periodic military campaigns in an effort to gain control of Southwest Arabia.⁴⁸ Importantly, even though massive waterworks were of only minor significance in highland Ethiopia, their social and political importance in Arabia was not lost on Aksumite elites. Most notably, the Aksumite general Abraha, who skillfully leveraged his position as viceroy in the region in an attempt to gain suzerainty, organized the reconstruction of

43 Breton 1999; Brunner 1997; De Maigret 2002.

44 Brunner 2000; Darles et al. 2013; Schaloske 1995.

45 Ur 2005.

46 MacDonald 2010; Stein 2013.

47 Stein 2010.

48 Hatke 2012.

the Great Dam at Ma'rib not because it served any major agricultural importance at the time but because it held tremendous symbolic and political significance.⁴⁹

CONCLUSION

Given the wide range of social, political, cultural, and environmental factors involved, any wide-reaching interpretation of emergent political complexity (even if specifically focused on a finite theme such as water) must grapple with the challenge of integrating a multitude of influences while acknowledging the importance of historical and cultural idiosyncrasies and particularities. Research on irrigation and political complexity has been dominated by the hydraulic hypothesis for more than half a century, yet scholars often still feel compelled to dispel the notion that an economically unavoidable need for large-scale irrigation systems, requiring bureaucratic coordination, prompted the emergence of states. In addition to the general absence of major waterworks in association with earliest states (including, for example, in Egypt, where water was pivotally important but not, early on, in the form of major irrigation works), there is no clear indication that bureaucracy and centralized coordination were pivotal to water control and food production among the world's earliest states. It is long overdue, I argue, that a new mode of cross-cultural interpretation supplants the hydraulic hypothesis, and I argue that a spatial-political approach that considers the role of political rhetoric, social logic, and spatial heterogeneity is well suited to the task.

Irrigation was not a *requirement* of state formation, but contexts of high spatial heterogeneity (where water is irregularly distributed and intermittently plentiful in otherwise hyperarid areas) enabled the social logic that water needed to be harnessed and the political rhetoric that elites were the legitimate beneficiaries of the proceeds. Most notably, spatial heterogeneity is a variable that can be quantified, and while I have focused on the concept from a humanistic perspective, there are certainly opportunities to adopt a more empirical approach.⁵⁰ Are early political complexity and state formation correlated with spatial heterogeneity of water? If so, are there similarities in the ways very different cultures and societies exploited heterogeneity through political rhetoric and social logic that aligned perceived economic and ideological interests around collective enterprise? These questions and others hold a promising future for studies of water and irrigation among complex polities as both particularistic case studies and wider cross-cultural, nomothetic syntheses.

49 Darles et al. 2013.

50 Bevan and Conolly 2009; Pickett and Cadenasso 1995.

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12

Wells, Small-Scale Private Irrigation, and Agricultural Strategies in the Third and Second Millennia BCE in Egypt

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A DONATION STELA dating to the twenty-first year of Pharaoh Taharka's reign (about 670 BCE) describes in detail an agricultural plot in the following terms. It was a field (*šht*) located in the domain of the god Amun in the province of Coptos, south of the "high land" (*qšyt*) of (the locality) of *Bw-w'b*, west of "the basin" (*hnm*); it measured ten arouras (about 2.75 ha) and was provided with a well (*šdt*).¹ The interest of this brief description lies in the fact that it describes two different kinds of perennial sources of water, each one destined for a particular use. On the one hand, the basin was mainly employed for the provisioning of water for settlements and domestic use (including gardening and watering animals) and could be natural or man-made. On the other hand, the well was artificially constructed (it derives from the verb *šd* "to dig"), possibly for a more individualized and specialized provisioning of water, both for settlements (e.g., villas or even neighborhoods) and for the irrigation of small plots of land.² More generally, this text represents a good starting point for the study of the modalities of private irrigation in ancient Egypt and their distinctive social and economic uses.

Usually described as the quintessential example of "hydraulic" civilization, many studies about irrigation and water use in pharaonic Egypt have focused on large-scale aspects such as the effects and control of the annual flood, the organization and management of the irrigation network, and the implementation of an economic and political order built on them. However, other modalities of irrigation, such as microhydraulics and the private use of water, have not received the same kind of attention,³ even though irrigation devices added value to plots in which specialized and lucrative crops could be planted. Another related problem is that, contrary to many assumptions about the overwhelming weight of institutional agriculture and centralized irrigation in pharaonic Egypt, there is also evidence of individual initiatives independent of any state interference. Moreover, there is evidence for a market-oriented production seeking profit or at least maximizing returns in agricultural crops offered by single field plots. This also leads to the much-debated issue

1 Graefe and Wassef 1979.

2 Franzmeier 2008a, 2008b.

3 Eyre 1994; Moreno García 2014.

of the commercialization of agricultural production in ancient Egypt.⁴ Given the quantity and importance of documents issued by institutions such as temples and diverse administrative bureaus, not to mention the crown itself, redistribution is still considered the mechanism by which agricultural products were circulated. Therefore, market-oriented production and noninstitutional private strategies are considered marginal at best. The fact that the terms “markets,” “profit,” and “market-oriented crops” may evoke anachronistic ideas about modern capitalism and economic growth in ancient Egypt probably still underlies this assumption. However, production for markets, investment in lucrative agricultural assets (date palm plantations), indirect management of institutional land through agricultural “entrepreneurs,” and the use of credit are well-known aspects of ancient Mesopotamian agriculture, where conditions of labor and production were quite similar to those of Egypt.⁵ Traditional subsistence agriculture is perfectly compatible with high levels of commercialization and market growth, but these phenomena do not inevitably lead to capitalist development or a profit-seeking mentality, as Huang and Sánchez León have so brilliantly shown.⁶ Even in ancient and medieval times, early configurations of capitalism were restricted to specific economic sectors (commercial capitalism) and operated within noncapitalist societies.⁷

Under these premises, this chapter is devoted to the analysis of three major aspects of irrigation in ancient Egypt: (1) the role played by microhydraulics and private use of irrigation devices in the economic strategies of landholders and in the organization of agriculture and landscape, (2) the role played by gardens and specialized productions in the context of the interplay between institutional and domestic agriculture, and (3) the role played (if any) by the pharaonic administration in the organization and control of irrigation on a large scale, especially in the light of recent research about the history of the fluctuations of the Nile.

WELLS, BASINS, AND SMALL-SCALE IRRIGATION IN PHARAONIC EGYPT

One of the most ancient and detailed references to the irrigation devices used in pharaonic Egypt appears in the decree of King Pepy I (2321–2287 BCE), a document aiming to protect the property of the funerary foundation of a former pharaoh, Sneferu (2613–2589 BCE), at Dahshur (*Urk. I* 212, 4–6): *jw wd.n hm(=j) nfr-n jp mr.w šd.w hn.(w)t nhwt m njwtj-mr (j)ptnj* “(My) Majesty has forbidden to reckon the canals, pools, wells, cisterns/basins, and sycamores in these two pyramid towns.”⁸ This text reveals that canals and other sources of water, some of them artificial (e.g., wells and, to some extent, pools), others probably natural (e.g., cisterns/basins), were subject to census and, probably, to taxation in the late third millennium BCE. Furthermore, it seems as if a clear distinction was made between intentionally excavated access points to water, such as wells, and other hydraulic devices. In the case of the term *hn.wt*, it appears in an inscription found at Bir Mueilha (Wadi Umm Hoda)

4 Eyre 1994, 1998, 1999, 2004; Moreno García 2014, 2016.

5 Jursa 2010, 2014; Van Driel 1999, 2002.

6 Huang 1990; Sánchez León 1995; Sánchez León and Izquierdo Martín 2002.

7 Banaji 2007, 2014.

8 Schenkel 1978, 26; Strudwick 2005, 104.

in the Eastern Desert, probably dating to the reign of Pepy II (2278–2184 BCE): *jr(j).n(=j) šd[t] hn.wt (j)ptn* “I made the excavation of these water-holes.”⁹ An interesting aspect is that the term *hn.wt* is followed by the hide-and-tail determinative (Gardiner sign list F27), suggesting that it was some kind of watering place for cattle and wildlife. It recalls an expression found in a nearly contemporaneous will from Balat, in the Dakhla Oasis, that describes the distribution of sixteen water places between the sons of a dignitary called Tjeshiu: *mw-mš m šdw.t 16* “sixteen ‘water places of wild animals’ used as wells. . . .”¹⁰ Consequently, one can establish some kind of distinction between more or less “natural” hydraulic systems, such as basins, and artificial wells and basins constructed to irrigate a plot of land, to provide drinking water, or for ritual purposes and pleasure, as for example water sources found in temples and gardens.¹¹ This situation recalls the passage from the donation stela quoted before, where a basin served as a landscape marker indicating the location of a plot of land provided with a well.

In this respect, it is also interesting to note that when early third-millennium texts refer to the digging of a basin or pool and the planting of trees around it, the term used is *š* “pool” and not *hn.wt*, “basin, water place,” thus reinforcing the idea that the latter refers to a natural or perhaps a more irregular, not necessarily man-made source of water. The earliest and most detailed example appears in the tomb of Metjen, a contemporary of King Sneferu, who acquired a garden that contained a pool and was planted with several kinds of trees:

a walled estate 200 cubits long and 200 broad, set out with fine trees, and a large pool (*š*) made in it; it was planted with fig trees and vines. It is written down in a royal document, and their names are (recorded likewise) on (this) royal document. The trees and the vines were planted in great numbers, and the wine therefrom was produced in great quantity (or “of great quality”). A garden was made for him on land of 1 *kha* and 2 *ta* within the enclosure, which was planted with trees.¹²

Later, during the late and final third millennium BCE, many private inscriptions routinely report the digging of a pool and the planting of trees among the prestigious activities carried out by affluent officials: *qd.n=j pr ššd.n(=j) š* “I built a house and dug a basin”;¹³ *qd.n(=j) pr(=j) sḥ(.w) ʔw ššd.n(=j) š srd(.w) nhwt* “I have built my house and set up (its) doors, I have dug a pool and planted sycamores”;¹⁴ *ššd.n(=j) š n mh 100 hr mš^c=f nb nhwt 10 jm=f* “I have dug a pool of 100 cubits on all its sides with ten sycamores thereon.”¹⁵ In fact, a passage from the tale of Sinuhe clearly states that members of the court were supposed to own great houses provided with a *š*-basin as a mark of their privileged social status: *jw rdj n=j pr n nb š m wn m^c smr* “I was given the house of a lord of a basin, the kind that a

9 Kloth 2002, 238; Strudwick 2005, 149; Franzmeier 2008b, 33.

10 Philip-Stéphan 2008, 261.

11 Franzmeier 2008a, 2008b; cf. also Evans 2011.

12 *Urk.* I 4–5; Strudwick 2005, 193.

13 Petrie 1925, 19, pls. 22–23.

14 Strudwick 2005, 329.

15 Strudwick 2005, 361.

courtier should have.”¹⁶ The same idea appears in ritual texts such as the Coffin Texts, usually in the context of the foundation of a house for the deceased: *mšš=sn sn̄.t tn n(y).t N pn jm̄(y).t mw jm̄(y).t ḥw.wt=sn ššd(=w) š.w=sn d=y nh.wt=sn* “when they see that this mansion of mine is founded among the waters and among their mansions, that their pools are dug and their sycamores planted” (CT VI 171 = Faulkner 1977, 172); *qd(w) ḥw.t tn n(y).t N tn swš(w) ḥrw=f jm̄=s jnt=sn n=f ḥš.wt rm̄t bdt-šm̄^cw jt-Mḥw ^cw.t smn(w) nh.wt=s ššd(w) š.w=s wd(w)=t(w) swnw.w=s* “This mansion of mine will be built and my voice will pass through it, so that they will bring to me fields, people, barley of Upper Egypt, emmer and herds; its trees will be planted, its pools will be dug and its towers set up.”¹⁷ In some cases, these formulas establish an explicit distinction between a cistern and a pool: *swr(w)=f m mw n(y).w (h)nm.t=f ḥš(w)=f r š=f* “May he drink of the waters of his basin, may he go down to his pool.”¹⁸ While natural pools may also be found in marshy areas, pools were normally the object of some kind of human intervention, at least to regulate the use of the water: *š pw nn ššd(=w) <m> jdb.w rwd npr.wt* “This is the pool which was dug <in> the riparian lands; the brim is strong.”¹⁹ The text continues with an evocation of fields and threshing floors: *šd.n=j smw.w swšd.n=j wšr(=w) wd^c.n=j dn̄j.wt šh.t ^c.n=j š.w ntr.w sk wj m tš pn m [dr]w tš.w nb(.w)* “I apportioned herbage, I made green the vegetation which was dried up, I cut the dams of the inundation, I cut the pools of the gods while I was in this land, in the limits of all the flat-lands.”²⁰ Finally, digging basins for the benefit of one’s city appears as a praiseworthy, pious activity in late third-millennium private inscriptions. But such hydraulic devices were usually designated by the term *zwr.t*, not *hnm.t*: *jr(j).n(=j) zwr.wt n njwt=j* “I made basins for (my) town”;²¹ *jrj.n(=j) ^c.t n w^b st-swr n šbw* “I made a house for the priest and a drinking place for Elephantine.”²²

A final observation concerns the ambiguity that is evoked with terms like *š*. They could refer to either natural or man-made (or at least managed) former natural access points to water.²³ For instance, in the case of *š*, the term appears eleven times in the Wilbour Papyrus, all of them bearing proper names, which suggests that they had existed for a long time or alternatively that they were closely linked to the persons who built them or to the area in which they were found. But in other instances, *š* could also refer to natural pools.²⁴ A good and very detailed example can be found in the correspondence of Heqanakhte, where the term may refer to a depressed field filled with water to create a temporary lake during the annual inundation.²⁵ According to Heqanakhte’s instructions, he had planted the *š* with flax, but he wanted to convert the field to grain in the next agricultural cycle. He indicates in his letter that he would prefer barley but acknowledges that if the inundation

16 Quirke 2004, 69; Allen 2015, 149–50.

17 CT VI 173 = Faulkner 1977, 173.

18 CT VII 112 = Faulkner 1978, 59.

19 CT VI 316 = Faulkner 1977, 252.

20 CT IV 137–38 = Faulkner 1973, 246.

21 Stelae Firenze 6365 and Berlin 14334: Andreu 1991, 18–20, fig. 1, pl. 2; Bostico 1959, 24–25, pl. 18.

22 Franke 1994, 156–57.

23 Franzmeier 2008a, 2008b; Driaux 2016.

24 Antoine 2011, 22–23.

25 Allen 2002, 150–51.

brought too much water to the š, the crop would not thrive, and it would be preferable to plant emmer instead. As Allen points out, Heqanakhte seems to have little or no control over the water level in his š. Literary texts occasionally refer to the inundation of š when the annual flood arrived: *nn wn srwy m šš pn rnpt h'py ʔ wd wd n sʔw tʔ n tn š r jtrw* “There is no repeller in this field in a year of a great inundation, when command is commanded to the stalls of the land, when basin cannot be distinguished from river.”²⁶

Given the context in which many of these examples appear (biographical inscriptions and funerary texts), it is not surprising that they refer mainly to either ornamental or ritual basins (in temples and private gardens) or to basins that provide fresh drinking water for settlements and expeditions, as was the case for those dug in the desert. Moreover, many of these references seek to highlight the official duties and fame that characterized the lives of their protagonists, such as courtiers and dignitaries. Thus, carrying out “public” works and constructing prestigious hydraulic devices is usually emphasized. As a consequence, the contrast between the passage quoted from the decree of Dahshur and these texts is quite striking. It seems as if agricultural wells were subject to taxation and, consequently, not an unusual element in the countryside. But for some reason, they were practically absent, or at least reduced to a marginal role, in the laudatory and ritual sources of the third and the first half of the second millennium BCE. Archives dealing with agricultural matters, such as the Heqanakhte papyri or the archives from Ilahun, are practically mute about wells in relation to agricultural production. Even a detailed document like the Wilbour Papyrus contains no reference at all to *šdt* “wells.”²⁷ Unfortunately, a papyrus from Ilahun that could have shed some light on this topic is too fragmentary to provide solid evidence. It mentions five conscripts (*hsbw*), each of whom was in charge of a standard agricultural “domain” including 8.5 arouras of (perhaps) arable land, 1.5 arouras of another type of field (gardens?), plus one aroura of “offering” plot, thus making it 11 arouras per worker and a total of 55 arouras.²⁸ If gardens were originally mentioned, it would have been interesting to learn how they were irrigated, where they were located, and which crops were cultivated. The documents do give some clues in that regard. The papyrus continues with the inventory of some more plots of the same three categories (arable land, gardens, and offering land), followed by the enumeration of some fields (*ʔh.wt*) close to the “Lake of Sobek” (i.e., the Faiyum) and basins located in “plots” (*šdy.t*) or, perhaps, located to the south of several royal foundations and close to a toponym called “The Two Islands.” In another document, some *šdy.t* are located close to a *grgt* “flooded area” and to a royal foundation.²⁹ The term *šdy.t* usually refers to a kind of pond where fish were caught and cattle could drink.³⁰ In addition, it is attested as a composite term or a toponym with the term *šš* “the flooded countryside” in at least six instances in the early Middle Kingdom graffiti of Hatnub: *šdy.t-šš* “the pond of the marsh” or, simply, a place named “The-Pond-of-the-Marsh.”³¹ Finally, a passage from the Karnak inscription of Merenptah describes the advance of the Libyans

26 Quirke 2004, 180; Allen 2015, 363–64.

27 Antoine 2011, 24.

28 Collier and Quirke 2006, 75; Griffith 1898, 52–54.

29 Luft 2006, 87–90.

30 Newberry 1895, 23; Posener 1976, 38, 120.

31 Anthes 1928.

in the Nile Delta and how they reached “the Sakhana Canal at the *šdy* of the Ati Canal.”³² Again, *šdy* appears as an area bordering or surrounded by water courses. Thus, the interpretation that some of the plots cultivated by the five conscripts (*hsbw*) were gardens seems quite plausible in the light of this evidence.

This point is particularly relevant regarding the question of horticulture, permanent irrigation, and date cultivation in ancient Egypt. Several studies have been devoted to date cultivation in pharaonic Egypt. Broadly speaking, the consensus is that its presence in the paleobotanical record is rare prior to the beginning of the second millennium BCE. While dates are sporadically mentioned in ritual and medical texts before 1500 BCE, and are even found in some archaeological contexts, their scarcity in the archaeological record is quite surprising considering the alleged importance of dates in the Egyptian diet from the end of the fourth millennium BCE. Furthermore, it is difficult to determine if these dates were cultivated or simply gathered. The palaeobotanical evidence reveals that date palms were known in ancient Egypt since the Predynastic period, and some species may have even been imported from the southern Red Sea during the third millennium.³³ But the scarcity of date stones has led scholars to believe that artificial pollination was introduced in Egypt much later, around the beginning of the second millennium. It has further been argued that the textual evidence for earlier date consumption may only refer to dates as a delicacy (or even an import), not to a widespread consumption of dates or to the cultivation of date palms.³⁴ It is true that the early mentions of dates refer mainly to elite food consumption, as they appear in lists of offerings from the beginning of the third millennium and in ritual compositions such as the Pyramid Texts.³⁵ However, there is also increasing evidence about the routine delivery of dates as rations and wages for workers, soldiers, and agents of the king in the course of their missions.

Early second-millennium administrative documents, for instance, list dates together with different kinds of grain (barley, malted grain, and wheat) given out as regular rations.³⁶ A slightly earlier (late third millennium) corpus of documents provides additional clues. They consist of inscribed vessels found in many tombs in the necropolis of Qubbet el-Hawa at Elephantine, where the local elite were buried around the end of the third and early second millennia BCE. A special feature of this necropolis is that many of the vessels, which were used to present offerings in the tombs during the last two centuries of the third millennium BCE, bear ink inscriptions. These brief notations specify not only the name and rank of the donor but also the actual composition of the vessels' content. From the analysis of these vessels, it is clear that dates were commonly delivered as offerings, together with cereals and other types of vegetables.³⁷ Of course, this does not solve the question about the source of the dates. However, their frequent mention together with other common edible plants, and the fact that they represent one of the most frequently attested commodities recorded in these inscriptions, strongly suggests a local origin, not

32 Manassa 2003, 13, 15e, pl. 3.

33 Newton et al. 2013, 39.

34 Nicholson and Shaw 2000, 348, 617–20; Newton et al. 2013, 36.

35 Allen 2005, 26, 93.

36 James 1962, 71–74; Collier and Quirke 2006, 26–27, 32–33, 106–7, 250–51, 262–63.

37 For a good example, see Höveler-Müller 2006, 32–33.

an import. An exceptional set of administrative documents of slightly later date (beginning of the second millennium) provides an additional glimpse into the local importance of dates. About fifteen plates and bowls from Elephantine were inscribed with administrative notations on the deliveries of food to individuals on their way to Elephantine, as well as to personnel positioned at a local fortress.³⁸ In one case, a plate from House H mentions cereals and dates that were distributed among distinguished dignitaries.³⁹ Thus, for example, Sobekhotep was given four sacks of malted grain, four sacks of Upper Egyptian barley, and two sacks of dates.⁴⁰ Specialized workers also apparently were remunerated in dates: the butcher Rensi, for example, was given a sack of an unspecified cereal as well as one sack of dates.⁴¹

These references are especially significant because the goods mentioned on the plate from House H were delivered by a special category of administrative officer, a “governor of a *hwt*.” *Hwt* were stock and administrative centers of the crown, scattered over the countryside during the third and the very beginning of the second millennia BCE. They collected, stocked, and delivered agricultural crops produced in extensive domains of the crown. Thus, a letter sent by Pharaoh Pepi II to Herkhuf of Aswan in about 2270 BCE states, “Orders have been brought to the governor(s) of the new localities, the companion(s) and the overseer(s) of priests to command that supplies be furnished from what is under the charge of each from every *hwt* belonging to a processing centre and from every temple, without doing any exemption.”⁴² The role played by the *hwt* in providing the agents of the king with supplies is also exemplified by the inscriptions of Hatnub, which mention the equipment delivered by the local *hwt* to the teams of workers sent to the quarries, the organization of the expeditions by an overseer of a *hwt*, or the close relationship between the *hwt* and the agricultural domains of the crown (called *njw.t m3w.t*),⁴³ as pointed out in the autobiography of Herkhuf just quoted and in a fragmentary inscription from the beginning of the Sixth Dynasty.⁴⁴ A fragmentary text from the tomb of Ibi, governor of Deir el-Gebrawi, shows that fields of considerable extent (about 50 ha) belonged to a *hwt* that in turn depended on a processing center, as in Herkhuf’s inscription.⁴⁵ So, the fact that one such “governor of a *hwt*” provided cereals and dates implies some kind of local production and management of dates, delivered in the context of what appears to be ordinary administrative operations. To put it another way, dates do not seem to be luxury items imported at Elephantine or collected from wild date palms. Rather, it seems that their very availability and local use in everyday transactions mean that they were regularly produced and supplied to the governor of the *hwt*, along with barley, malt, and even livestock. Similar pieces of information confirm this administrative pattern, as other plates and bowls from the same period record the delivery of cereals, dates, and several kinds of plants to

38 Andrassy 2012.

39 von Pilgrim 1996, 285–300.

40 von Pilgrim 1996, 287–89.

41 von Pilgrim 1996, 287–89.

42 Sethe 1933, 131; Moreno García 1999.

43 Graffiti 1 and 6; see Anthes 1928.

44 Sethe 1933, 87.

45 Sethe 1933, 144–45.

workers positioned at a fortress.⁴⁶ Moreover, similarly inscribed vessels from other localities seem to follow the same pattern.⁴⁷ The regular use of dates in rations explains why Middle Kingdom mathematical problems deal with rations involving dates and different kinds of grain.⁴⁸

Finally, two recently published archives reveal that already in the middle of the third millennium dates played an important role in the ration system implemented by the pharaohs to feed and pay workers. According to the Gebelein papyri, grain, dates, and flour were delivered to villagers, probably as rations/wages for their work.⁴⁹ Furthermore, the discovery of an important set of papyri at the harbor of Wadi el-Jarf, on the Suez Gulf at the Red Sea, dating to the reign of King Khufu, reveals that dates were also a regular part of the rations delivered to the workers employed in carrying stone blocks from Turah to Giza.⁵⁰ Thus, several crucial questions emerge: Were date palms cultivated on a large scale in Egypt in the third millennium BCE? What was the modality of their cultivation? Were dates mainly produced by individuals in their own private fields and not in large institutional plantations? How were these plantations or gardens irrigated? If dates were cultivated by private individuals, this would point to the existence of substantial private/domestic irrigation management prior to the middle of the second millennium BCE, when textual and iconographic evidence becomes more abundant (see below). This kind of early irrigation would have been geared toward watering private gardens and small plots of land rather than extensive institutional plantations, which would have been difficult to irrigate in the absence of water-lifting devices (some scenes in tombs of the second half of the third millennium show farmers carrying pottery jars suspended on wooden yokes to irrigate small, square-shaped growing beds⁵¹). It also suggests the existence of hydraulic installations such as basins and wells, whose existence is almost entirely concealed in official sources and only suggested by the Dahshur decree and private inscriptions before the middle of the second millennium BCE. Only a passage from the Coffin Texts seems to point to a more extensive presence of agricultural wells in the countryside, as it mentions them together with agricultural plots: *d[.w] jh.wt sšm(.w) šd.wt* “Farm-lands are given and wells divided.”⁵²

Then, it can be tentatively inferred that, in the absence of more sophisticated devices that enabled permanent irrigation (e.g., *shaduf*, *shaqiya*), wells were used in private fields, on a small scale. It remains to be determined what role they played in the production of crops such as dates and vegetables, which made their way at least partially into the economic circuits controlled by the crown. However, wells seem relatively rare despite being taxed. They should probably be distinguished from other installations (e.g., basins, pools) whose main purpose was to provide fresh water for other everyday uses, including watering domestic animals. This would explain why *šd.wt*-wells are completely absent in

46 Andrassy 2012.

47 Seyfried 2014, 75, 77.

48 Imhausen 2003, 116–18.

49 Posener-Krieger and Demichelis 2004, 18–19; Warden 2014, 37.

50 Tallet 2014.

51 Duell 1938, pl. 21; Moussa and Altenmüller 1977, fig. 8.

52 CT VI 348 = Faulkner 1977, 273.

the Wilbour Papyrus, while basins and cisterns (*brk.t*, *hnm*) are frequently enumerated, usually forming clusters and being mainly located next to small settlements.⁵³ The fact that agricultural wells usually appear in descriptions of the composition of particular fields and not at their borders may suggest that they were rarely considered a conspicuous landmark given their domestic use and were therefore seldom mentioned in administrative documents despite the archaeological and textual evidence of their existence.⁵⁴

Such uses should probably also be distinguished from irrigation practices documented around the very end of the third and the early second millennium BCE.⁵⁵ Some inscriptions indicate the retaining and conveying of water to agricultural fields, as well as the “sealing” of plots of land to improve food production. The inscription of Merer is a good example: “I buried the dead and nourished the living, wherever I went in this drought which had occurred. I closed off all their fields and mounds in town and countryside, not letting their water inundate for someone else, as does a worthy citizen so that his family may swim.”⁵⁶ Other examples come primarily from Middle Egypt, around the area of Assyut, Rifeh, and Beni Hassan, the most detailed being a biographical text from Tomb V at Assyut: *htm.n(=j) t3š(.w) [. . .] hr sd3y.t(=j) jr.n(=j) q3[y.wt] m jdh.w rdj.n(=j) mh h'p(y) hr j3.wt=s jr.n(=j) hbs.w m[hw] gs.wj m jb[. . .]* “I have sealed the borders of [. . .] by my authority (lit. seal), I have transformed the high fields into marshes, I have made that the inundation reaches its mounds and I have made (it possible) that the cultivated fields become inundated while (its) neighbours were thirsty.”⁵⁷ And a Middle Kingdom fragmentary inscription from Rifeh in which ‘*ht*-fields and “high fields” were involved: *jn.n=j h'py m [. . .] r q3j.wt nt jh.wt=t(n) jwh(.w) šd.w=tn* “I have brought the inundation from [. . .] to the high fields of your ‘*ht*-fields so your plots are (now) irrigated.”⁵⁸ In other examples, there are references to canals⁵⁹ and to the benefits of the arrival of the annual flood.⁶⁰ In all these cases, the activities described concern “public” works and do not describe private agricultural plots where wells tentatively could be found.

Conditions changed around the middle of the second millennium BCE. Wells and cisterns appear more frequently in administrative sources, quite often as landmarks. Furthermore, next to the traditional Egyptian vocabulary on basins and wells, another Semitic term, *brkt* “well, cistern,” came into use in the Egyptian language. Thus, the Ramesside Wilbour Papyrus contains many terms that designate pools, basins, and cisterns (including those called *brkt*), usually located close to towns and villages and frequently mentioned as toponyms or territorial markers.⁶¹ This is especially true when the borders of plots and fields are described, an aspect that recalls the paragraph from the donation stela cited at

53 Antoine 2011, 16, 22–23.

54 Franzmeier 2008b.

55 Schenkel 1978.

56 Lichtheim 1973, 87.

57 Siut V: 7–8 = Brunner 1937, 65; Lichtheim 1988, 28.

58 Der Rifeh VII: 23 = Montet 1936, 159.

59 Siut V: 3 = Brunner 1937, 65.

60 *Urk.* VII 16.

61 Gardiner 1948b, 29–31.

the beginning of this chapter (and many more examples could be cited).⁶² Thus, in one case, wine was produced next to the *hnm* “basin” of a certain locality,⁶³ while a passage from the late Ramesside Papyrus Leiden I 370 specifies that three *jdb*-plots should be cleared of trees that were on their mounds “as the fields (*ʒh.wt*) which Nesmontu used to cultivate, and you shall prune its trees beginning from the district boundary of Pre to the well (*šd.t*) of the district boundary.”⁶⁴

In other instances, however, wells and cisterns were part of private land tenures and were subject to specific agricultural strategies. Thus, Papyrus Berlin 8523, from the very late second millennium BCE, states, “As soon as my letter reaches you, you shall attend to this field (*ʒh.t*) and not be neglectful of it. And you shall remove its weeds and plough it and farm one aroura of land [in] vegetables (*wʒd.wt*) at this well (*šd.t*).”⁶⁵ A harvest receipt from the reign of Amasis mentions a field planted with flax and called *pʒ šj* [. . .] *ʒmj* (?) “the pool/cistern of [. . .]yami.”⁶⁶ For this reason, wells and cisterns were also listed in some stelae concerning the transfers of land through acquisition or donation. Some donation stelae concern fields (*ʒh.t*, *sh.t*) provided with a well (*šd.t*) or a cistern (*brkt*).⁶⁷ Probably the most detailed document is the Apanage Stela, which lists several tenants who sold their plots to a certain Iuwelot in the reign of Takelot I (around 880 BCE). Each plot is meticulously described, including its surface, types of land, and the price paid for it. In three cases, the presence of one or more wells (up to three) is mentioned, and notably two of these plots were the only ones that contained several types of trees, mainly date palms: (lines 8–9) “The place of the priest of Amon, Neskhonsu, the justified, son of Hori, the justified, son of Ankhefenkhonsu, the justified: 137 arouras of field privately owned with clear title, 99 arouras of ‘tired’ field, total: 236 arouras of field, 1 well (*šd.t*), 8 sycamore trees, 6 date palms, amounting to 8 deben, $\frac{2}{3}$ kite of silver”; (lines 9–10) “the place of the tenant Djedmutiuefankh, the justified, son of Iken, the justified: 66 arouras of field privately owned with clear title, 5 arouras of ‘scrub and tired’ field, total: 71 arouras of field, 3 wells (*šd.t*), 26 large date palms, 50 small date palms, 3 sycamore trees, amounting to 4 deben, 1 and $\frac{1}{12}$ kite of silver”; and (line 20) “the tenant Nesi, the justified, (son of?) Iuwakasar, the justified: 5 arouras of field privately owned with clear title, 2 arouras of ‘scrub and tired’ field, total: 7 arouras of field, 1 well (*šd.t*), amounting to 2 $\frac{2}{3}$ kite of silver.”⁶⁸ In other texts, the area and number of trees of some plots of land are listed, but without any reference to wells.⁶⁹ Finally, Papyrus Brooklyn 16.205 (around 770 BCE) deals with the acquisition of several plots of land made by a certain Ikeni in a year of hard times. The plots are quite small (in three cases hardly more than half an aroura), and in several cases they are described as located next to “the well (*tʒ šd.t*) of Ikeni.”⁷⁰ It seems as if Ikeni followed a calculated strategy

62 Meeks 1972, 28, 31; Manning 1994, 31–44.

63 Gardiner 1948b, 30 n. 8.

64 Wentz 1990, 180–81; Antoine 2015, 107.

65 Wentz 1990, 209; Allam 1994.

66 Donker van Heel 1995, 89.

67 Graefe and Wassef 1979; Hodjash and Berlev 1982, 162, 164–65.

68 Ritner 2009, 271–78.

69 Hagen 2011, 13.

70 Parker 1962, 49–52, pl. 17–19.

of purchases, seeking to acquire plots around a well that bore his own name or that of a member of his kin, perhaps an ancestor. Given the small surface of the fields, it is possible that they were used for horticulture rather than the cultivation of cereals. Later sapiential texts echoed the wealth provided by cisterns and wells to farmers.⁷¹

From the texts discussed, several conclusions may be drawn. Rare and unequally distributed over time as they are, there exists nevertheless some evidence about private possession of wells connected with agricultural activities, and not only for private recreation in a pleasant and luxurious domestic environment made of vineyards, small plantations, and garden plots. Usually of minor dimensions and in the hands of private landowners, these fields are rarely mentioned at all in documents issued from the institutional sphere, which was more focused on specialized plantations (vineyards, olive groves) and on extensive cultivation of cereal on large domains. Usually a less intensive (and, consequently, less onerous) use of workforce prevailed on these large domains and depended only on the natural cycle of the seasonal flood for irrigation. Wells made possible year-round irrigation and the production of high-value crops, perhaps oriented toward local, urban markets (e.g., vegetables, flowers). In some cases, there are indications of intentions of seeking to accumulate land that surrounds wells. In other cases, wells are mentioned together with plantations of date palms. Finally, wells must not have been an unusual element in the agricultural landscape, as they were subject to administrative control and, perhaps, taxation. Given the lucrative but simultaneously expensive nature of wells, and because of the strenuous extraction of water, they were probably owned by well-off landowners. That is why Apiru workers, for instance, drew water while being in state service according to Papyrus Leiden 349, dating from the reign of Ramesses II: "I have taken note of my lord's message to me saying, 'Give grain rations to the soldiers and the Apiru(-laborers) who are drawing (water from) the well of Pre of Ramesses II.'" ⁷² Plots associated with wells were small and probably belonged to relatively well-off tenants, able to employ workers watering small plots with jars, as is depicted in some tomb scenes.⁷³

The condition of such plots would then be quite similar to that of *jdb*-plots. Usually translated as "riverbanks," careful analysis of this term by Antoine based on the Wilbour Papyrus reveals that, in fact, *jdb*-plots probably did not border riverbanks. Instead, they seem to have lain in areas of the floodplain that combined high grounds and depressions sufficiently low to be close to the water table and to permit easy construction of a well or the natural formation of pools fed by flood or underground water. Being on or near high grounds, *jdb*-plots may appear as actual riverbanks during the inundation period. Antoine has also shown that 7.8 percent of the 3,395 plots listed in texts A and B of the Wilbour Papyrus were on *jdb*-land and that only one-third of them were owned by institutions, while two-thirds were in the possession of private landowners. Finally, he has also shown that these plots were taxed at the highest tax rates, probably because of their high yields, and that 73 percent of all the landholders' fields on *jdb*-plots correspond to tiny parcels measuring about one aroura. They were not cultivated with cereals, and about half of them

71 Jasnow 1992, 113–14; Vernus 2010, 448–49.

72 Wente 1990, 124.

73 Duell 1938, pl. 21; Tietze 2011, 100.

were not farmed and probably stayed fallow.⁷⁴ The productivity and reduced surface of these plots points in all probability to their consideration as gardens or orchards, perhaps entailing wells in some cases. In any case, these plots show well the importance of small-scale, privately owned irrigated fields in the context of private irrigation and a relatively affluent sector of rural society.⁷⁵

INNOVATIONS IN THE MIDDLE OF THE SECOND MILLENNIUM BCE

Wells and small, highly productive irrigated fields began to appear more frequently in the written records of the New Kingdom. In fact, it was around the middle of the second millennium BCE, just prior to the beginning of the New Kingdom, when several phenomena seem to co-occur in Egypt: a greater visibility of horticulture in the periphery of urban areas and in gardens located in villas of the elite; the expansion of “commercial” crops such as dates, vegetables, grapes, and fruits; and the introduction of a new irrigation device, the *shaduf*. At the same time, a Semitic term, *brkt* “well, cistern,” entered the Egyptian vocabulary, new plants began to be cultivated in gardens (pomegranate, almond, apple, and olive trees), and new literary/scrival genres, such as the “praise of the city” and the “miscellanies,” introduced the new motif of the opulent town surrounded by villas and luxurious gardens.⁷⁶ Rich villas were also described as overflowing with fruits, vegetables, and all kinds of agricultural produce.⁷⁷ Gardens also became the setting of love encounters in another literary genre, the so-called love songs that flourished in the New Kingdom, in which plants and trees sometimes became a metaphor for the lovers.⁷⁸ Archaeological evidence confirms the importance of such wealthy villas provided with hydraulic facilities (ponds, cisterns) and gardens.⁷⁹ In all these cases, a new kind of private wealth seems to be based, at least partially, on irrigated, private, small-scale agriculture and the cultivation of lucrative crops oriented toward urban markets. Ships and fleets loaded with flowers and agricultural produce, sometimes collected from individuals, traveled up and down the Nile.⁸⁰ There are even some letters and administrative documents that record instructions on to how to plant a plot with fruit trees.⁸¹ Others mention fields planted with vegetables (also used to pay the rent) or grains, sometimes in what seems to be crop rotation.⁸² This was also a period of urban expansion (e.g., the city of Pi-Ramesses, founded in the Eastern Delta, which had a population of about 250,000 people), and a praise of Pi-Ramesses even lauded its market and the money (silver) and commerce associated with it: “Pleasant is the marketplace (*t3 s.t-pzš.t*, lit. place of distribution) with/because of (?) its money (*hḏ*) there, namely the vine tendrils (?) and the business/commerce (*tamkārūtū*). The chiefs (*wr.w*) of

74 Antoine 2011, 14, 24–25; 2015, 113.

75 Antoine 2014; Moreno García 2014.

76 Ragazzoli 2008.

77 Caminos 1954.

78 Vernus 1992; Sheikholeslami 2015.

79 Tietze 2011.

80 Janssen 1961, 2004; Condon 1984; Wentz 1990, 92–93, 119–22, 128, 180; Castle 1992.

81 Wentz 1990, 175–76.

82 Wentz 1990, 46, 209; Kitchen 1970, 804.15, 805.5, 806.5.

every foreign country (usually) come in order to descend with their products (*qm̄.w*).⁸³ Another document from the early New Kingdom, Papyrus Brooklyn 35.1453A, records the delivery of some pieces of silver to a woman at the *mry.t* “quay, marketplace.”⁸⁴ The analysis of the cultivation of dates may provide some clues about these innovations.

Papyrus Louvre E 3226, dating from the reign of Thutmose III (about 1420 BCE), records some administrative operations carried out along the Nile by several ships belonging to “the Granary,” that is, the institution in charge of collecting and storing grain. Several sections of this papyrus reveal that the Granary employed two teams of agents called *bnry.w* or “those in charge of dates.” The system operated as follows: the Granary supplied barley to both teams, and they exchanged the grain for dates at several points along their route. The equivalence system was always the same throughout the papyrus: one sack of barley was exchanged for a sack of dates, which was the same rate used in Mesopotamia. The total quantities exchanged were not very high: between 50 and 100 sacks were exchanged per year between the twenty-eighth and thirty-fifth years of Thutmose III’s reign, and in one case 290 sacks of dates were delivered “from Thinis.” The grain was collected from several granaries and “ships,” as well as from places located between Thinis in the north and El-Kab in the south. It was considered *šmw* “harvest,” so it probably consisted of grain taxes paid by cities, institutions, or individuals and gathered in some places where they could be easily collected.⁸⁵ A later papyrus (the Turin Taxation Papyrus) also records grain collected from the crown fields (*h̄r-t̄*) in the same area, and in one case it is stated that it was *šmw* grain.⁸⁶ Papyrus Louvre E 3226 never reveals how the *bnry.w* obtained the dates, but comparable papyri reveal that small fleets from temples and royal institutions traveled up and down the Nile collecting dates and other goods from individuals, from cereals to flowers and wine.⁸⁷

Considering that an adult palm tree can yield between 60 and 80 kg of dates (roughly 1.1–1.5 *h̄r*-sacks)⁸⁸ and that 1 ha of palms might yield about 6,000 kg (roughly 1,500 kg per aroura), deliveries of between 50 and 100 sacks would correspond to the production of 33–45 palms (50 sacks) and 66–90 palms (100 sacks). If an aroura of date palms thus could contain between 19 and 25 trees, then 50 sacks of dates would correspond to a plantation of 1.3–1.7 arouras (if it only consisted of a single plot), while 100 sacks would be obtained from a plantation of 2.6–3.4 arouras. As urban gardens, located in villas, rarely exceeded 2,500 sq m and were not only planted with palms,⁸⁹ it seems that plantations between 1.3 and 1.7 arouras would be found primarily outside private villas, in the countryside. As for their relatively small size, the plots seem to correspond more to small holdings, in private hands, than to big plantations held by temples, crown domains, or other institutions. One can compare these figures with those of the two plots mentioned in the Apanage Stela

83 Fischer-Elfert 2016.

84 Condon 1984, 63–65.

85 Megally 1977.

86 Gardiner 1948a, 35–44; Mandeville 2014, 145–52.

87 Janssen 1961.

88 One liter of dates weighs about 0.7 kg. One *h̄r*-sack of dates (76.8 liters) would thus weigh 53.7 kg. In date palms five to eight years old, the first crop will be 8–10 kg per palm.

89 Tietze 2011, 202–27.

mentioned earlier: 6 date palms and 26 large date palms (plus 50 small date palms) would fit perfectly with such plantations.⁹⁰ This suggests that the *bnry.w* of Papyrus Louvre E 3226 collected the dates, on a regular basis, from individuals who owned small gardens planted with fruits, vegetables, vines, and so on. This impression is further reinforced by the fact that institutional agricultural documents never refer to plantations of date palms, only to recreational basins in temples and palaces in which date palms grew along with many other types of trees. In fact, only one example of a palm plantation appears among the donations of fields, gardens, and other many goods enumerated in Papyrus Harris I,⁹¹ while, in sharp contrast, huge quantities of dates were donated to the temples,⁹² and even ropes made of palm fiber.⁹³

Papyrus Louvre E 3226 thus provides strong evidence of the importance of irrigated agriculture in small plots, where fruits and other goods (e.g., milk, vegetables, wine, sesame-oil, olives) were partly delivered as taxes, contributions, and so on.⁹⁴ In other cases, it is only possible to speculate about how such plots could be organized. Katary⁹⁵ mentions an ostrakon (an inscribed fragment of pottery) from New Kingdom Deir el-Medina in which a certain Wennofre mentions at least three fields he owned with a total area of 17 arouras. His case was not unique, as other members of his community also owned “fields” 20 km distant from their settlement, but the texts provide no details about their characteristics, use, or crops planted. Bearing in mind that “gardeners” (*k3ry*) were supposed “to bring vegetables” to the personnel working at Deir el-Medina, Katary suggests that such gardeners could have worked the fields of the members of the community. She also stresses the fact that such fields were usually small and consisted of split holdings.⁹⁶ One needs to consider that such plots would be situated relatively far from the settlement because of the scarcity of water at the site, to which water had to be delivered by water carriers. On one occasion, the workers tried to dig a well in front of the village.⁹⁷ Unfortunately, precise information about such small plots and the crops planted is rare. Judging, however, from the evidence provided by these documents, as well as by the Wilbour Papyrus and other papyri referring to the cultivation of vegetables and to the payment of rents in kind, it appears that horticulture and small-scale irrigation became a common feature in the New Kingdom.

Consequently, when literary texts mention rich villas, provided with every kind of wealth, from fields to herds of cattle, that even allowed them to import goods from the Levant on their own ships,⁹⁸ they refer only to a more common agricultural practice. Administrative documents reveal that villas (*bhn*) were, in fact, a conspicuous feature of the countryside. The Wilbour Papyrus provides again a unique overview of the countryside in an area of Middle Egypt, as it mentions fifty-one mounds (*j3.t*), thirty-seven houses (*‘t*),

90 Ritner 2009, 271–78.

91 Grandet 1994, 261.

92 Grandet 1994, 251, 273, 275.

93 Grandet 1994, 244.

94 Janssen 1961.

95 Katary 2000.

96 Katary 2000, 172–73, 207–8.

97 McDowell 1999, 63–64.

98 Caminos 1954, 137–38, 164–65, 412–13; Ragazzoli 2008, 193–202; Baines 2013, 80–82, 148–50, 254–55.

twenty-nine villages (*why.t*), seventeen “villas” (*bhn*), and seven towers (*sg3*) among its main settlements. As Kemp observes, these centers were not evenly spread out; *bhn* and *sg3* clustered in zones marked by larger towns (hardly surprising, as *bhn* was an official’s residence), whereas *t* tended to be more numerous in zones where there were fewer larger towns. Other late New Kingdom and Third Intermediate Period sources confirm this picture, as they list *bhn*, *why.t*, *pr*, and *t* together.⁹⁹ Quite significantly, the “praise of the city” literary genre, with its vivid descriptions of the rich peri-urban horticultural landscapes around some of the most important Egyptian metropolises, also appeared at this time.¹⁰⁰

Thus, the analysis of date production provides useful insights into private small-scale irrigated agriculture, especially when the introduction and diffusion of the *shaduf* in the middle of the second millennium made year-round irrigation of small gardens possible. It is estimated that a *shaduf* could lift more than 2,500 l per day and irrigate fields of up to 0.6 ha. However, operating a *shaduf* was a strenuous job, and two men taking turns every hour could irrigate about 0.1 ha in one day.¹⁰¹ *Shaduf* irrigation made its appearance alongside other agricultural innovations, such as the introduction of pomegranate, almond, and apple trees, around 1600 BCE. However, the economic implications of the latter innovations are much more difficult to evaluate.¹⁰²

It can be argued that extended irrigation capabilities, extensive contact with the Levant, and a relatively affluent sector of Egyptians made a small “agricultural revolution” possible that was based on private orchards and plantations, the circulation of new technologies (e.g., the war chariot, broad use of bronze), and the use of the *shaduf* in a context of an expanded urban life and markets. Tell el-Dab’a, for instance, became an important urban center in the eastern Mediterranean under the Hyksos rule (1700–1550 BCE). The palace of the late Hyksos period included several gardens with tree pits and flower pots.¹⁰³ And when the Theban pharaoh Kamose besieged the palace of King Apophis, he spoke to the Hyksos ruler in the following terms: “Look! I drink of the wine of your vineyards which the Asiatics whom I captured pressed out for me. I have smashed up your resthouse, I have cut down your trees.”¹⁰⁴ It is tempting to argue that these agricultural innovations, with an emphasis on horticulture and small irrigation, were made possible through the more decentralized rule of the Hyksos kings. Contrary to the traditional bureaucratic organization of the Egyptian monarchy, Hyksos rule seems to have been more indirect, based on personal contact and with new forms of commensality. Thus, within the palace, the organization of ritual banquets was of great importance as it helped strengthen patron-client relationships (highlighted by the use of titles like “king’s son”) between the king and the elites of the kingdom. From this perspective, extensive institutional cereal cultivation and an elaborate tax system based on agricultural produce may have been of comparatively little importance, while the trade with commodities such as wine, olive oil, and other

99 Gardiner 1947, 205*–206*; Moreno García 2011, 4.

100 Ragazzoli 2008.

101 Sainte-Marie 1989, 65.

102 Baum 1988; Meeks 1993; for a Late Ramesside letter containing orders to bring twenty pomegranates from an orchard, see Demarée 2006, 25.

103 Tietze 2011, 160.

104 Redford 1997, 14.

goods played an increasingly important role in the eastern Mediterranean at the time. It is probably no coincidence that contemporary villages in southern Canaan, an area that was probably under Hyksos rule, displayed a great degree of peasant autonomy and little internal hierarchy.¹⁰⁵ Thus, small-scale irrigation and agricultural innovations, especially the introduction of new crops, should be understood as part of a socio-productive and technical package that included particular forms of labor organization, territorial management, and peasant strategies. The potential of this new agricultural development could be limited only by the state, its tax system, and imposed agricultural strategies, which were more centered on the cultivation of cereal.¹⁰⁶ By the same token, it is not coincidental that a marked depreciation of silver took place in a period when Egypt shipped grain to the Hittite Empire (and when Hittites also imported grain from northern Syria), possibly a direct result of massive Hittite payments in silver for grain.¹⁰⁷

As for vines and olives, they were grown not only in private gardens but also in substantial institutional plantations from which considerable amounts of oil and wine were collected.¹⁰⁸ It is significant that the temples and crown seem hardly interested in maintaining specialized date palm plantations, in sharp contrast to institutional olive plantations and vineyards. The most likely explanation is that date palm plantations required a specialized workforce that was expensive to maintain. Therefore, as was also the case in Mesopotamia, date palm plantations were usually in private hands and represented a lucrative investment for urban landowners and rural potentates.¹⁰⁹ This would also explain the importance of wells in small plots, as well as the strategies followed by some individuals to purchase plots of land adjoining wells, as revealed in documents such as the Apanage Stela and Papyrus Brooklyn 16.205 from the first centuries of the first millennium BCE. The importance of such private wells would also explain the interest of the monarchy in reckoning them, as described in the Dahshur decree of Pepy I and in the Great Dakhla Stela of Sheshonq I (*t3y 'yr3(.t) dny.w n n3 hnmy.wt k3m.w n Pr-R' j-wt rwd.w 'nh=f s3 Swth-nh.t j(-r)-ht t3y dny Pr-3* “the scroll of the cadastral register of the cisterns and the gardens of the ‘estate of Re’ that the agent Ankhef son of Sutekhnakht issued in accordance with this register of Pharaoh.”¹¹⁰

To conclude, “great” (but natural) irrigation and “small” (partly artificial) irrigation point to different strategies and socioeconomic environments: institutional in the first case, and domestic/private, even market oriented, in the second case.

AND THE STATE? “GREAT” IRRIGATION AND HYDRAULIC CENTRALIZATION, BETWEEN MYTH AND REALITY

Small-scale irrigation, especially in privately owned field plots, constitutes a crucial sector of pharaonic agriculture that is unfortunately insufficiently known. In general terms, it is

105 Faust 2005.

106 Barceló 1996, 40–47.

107 Moreno García 2016, 21.

108 Tallet 1998, 2004; Newton, Terral, and Ivorra 2006.

109 Jursa 2010, 172–79, 363–75, 457–62.

110 Ritner 2009, 176–77.

related to domestic economy, horticulture, and peasant strategies of production that could hardly be reduced to a mere subsistence economy. Markets (urban, rural, and international) seem to have played a role, as was the case for date production, but this crop probably represents only the tip of the iceberg. Careful archaeological and palaeobotanical research shows, for example, that around the middle of the first millennium BCE, cash crops were produced and exported from the oases of the Western Desert into the Nile Valley and elsewhere. Quite significantly, one of the main productions of the oases was castor oil, employed, among other uses, in burning, lighting, and cosmetics.¹¹¹ However, castor oil is also commonly used in leather processing, and, in fact, pharaonic leather workshops were provided with large storage vessels of oil.¹¹² Perhaps the production of castor oil in the oases had commercial ties to the processing of leather in the Nile Valley, as pottery containers from the oases have been found at Dendera, Elephantine, and the Faiyum;¹¹³ castor oil and hides were sent from Elephantine to the area of Memphis;¹¹⁴ and Nubian populations routinely crossed the desert arriving in Egypt with colorful pieces of leather.¹¹⁵ Moreover, hides and leather goods were exported (sometimes as tribute) from Nubian rulers to Egypt and the Levant,¹¹⁶ and Abydos, an important leather-processing center since the third millennium BCE, was well connected by land routes to the oases. Hydraulic facilities in the oases, partially in private hands in the first millennium BCE, allowed for the expansion of agricultural production during this period,¹¹⁷ a period when Egypt exported hides to the Levant.¹¹⁸

While the investigation of small-scale irrigation has yet much to contribute to the better understanding of Egyptian agriculture, paradoxically the same is true about the organization of irrigation on a greater scale. Much has been written about the pharaonic monarchy as one of the most accomplished examples of “hydraulic civilization,” a highly centralized and bureaucratic authority whose wealth (and legitimacy) revolved around the control of the annual flood. However, little is actually known about the means and scale of the interventions (if any) by the king and his agents in the organization of irrigation and the annual flood prior to the Hellenistic period. Moreover, common assumptions about the organization of agriculture and irrigation should be thoroughly revised in the light of recent research. In fact, the annual flood had a much greater effect on agriculture, land use, and the production system than the mere seasonal rise in the level of the Nile. Minor watercourses and swampy areas—mainly at the bottom of the cliffs bordering the desert—dotted the Egyptian countryside long after the flood. The water, moisture, and fresh vegetation they provided allowed for occasional pastoral, fishing, and agricultural activities that could be carried out in areas relatively distant from the Nile. Thus, mounds, settlements, and fields could be found outside the riverbanks of the Nile.¹¹⁹ In fact, *phw* “marshland”

111 Agut-Labordère 2016.

112 Raedler 2016.

113 Marchand 2008; Defernez 2012.

114 Porten 1996, 91–93, 100–103, 128.

115 Skinner and Veldmeijer 2015.

116 Mumford 2007, 159; Török 2009, 193, 271, 290 n. 39.

117 Ritner 2009, 173–77; Agut-Labordère 2016.

118 Lichtheim 1976, 227.

119 Alleaume 1992; Gillam 2010; Antoine 2011.

areas were a conspicuous element of the country, very often mentioned together with *w* “districts” in the canonical representations of the landscape of both the Nile Delta and Valley, in all periods of Egyptian history. The Nile Valley was thus a landscape of marshes, meadows, and cultivated areas, with shrubs and trees limited to the riverbank and to the edge of the valley along the cliffs. Desert fauna was likely attracted to such more-or-less perennial channels and pools,¹²⁰ as were pastoral populations because they allowed for cattle breeding. In any case, hunters and hunting appear frequently in the written record, and capturing the cattle of the desert nomads is sporadically mentioned. The last remnants of the natural environment of the valley with its original vegetation were preserved until recently at Wadi Kubhaniya.¹²¹ Another aspect to consider is that the watercourse of the Nile shifted for millennia, gradually moving toward the east, which allowed former swamps to be drained and cultivated.¹²² In fact, one of the oldest papyrological archives, the Gebelein Papyri (late twenty-sixth century BCE), shows that hunters, nomads, fowling, and honey collectors made up a substantial percentage of the inhabitants of the villages in that area.¹²³ As for irrigation canals and dikes, they are quite rare in both the administrative and the archaeological record. Consequently, the irrigation of agricultural land would mostly have depended on the flood with minimal arrangement of the natural basins in the floodplain, while natural wells and ponds formed additional water sources for the cultivation of fields in the immediate surroundings of settlements.¹²⁴ The pharaonic landscape thus appears more diverse than the alleged homogeneity of fields planted with cereals.

Under these circumstances, the role of the state in the organization of irrigation seems minimal, at least until the Greco-Roman period. Certainly some texts refer to irrigation works, especially in the Old and Middle Kingdoms, but these activities consisted primarily of the excavation of transport canals. Other references to hydraulic works (e.g., in the inscriptions of Nekhebu of the Old Kingdom or Khety of Asyut from the First Intermediate Period¹²⁵) are rather ambiguous and could refer either to local drainage works or to the construction of dikes to retain water for agricultural purposes in an otherwise swampy environment. As for the titles of dignitaries and texts dealing with the duties of high dignitaries (such as “The Duties of the Vizier”), any reference to a centralized organization of irrigation, or even to irrigation duties (e.g., the construction of canals and dikes), is simply absent. It seems, instead, that canals were only small scale and managed locally, and that the pharaonic administration exerted only general supervision over them,¹²⁶ if the interpretation of the term *ꜥ* as a canal is correct (it has also been translated as “dike” and its meaning is far from certain).¹²⁷ But other possibilities should also be considered. Thus, for instance, a Middle Kingdom official declared that he controlled the *ꜥ* of the Thinite province

120 Beierkuhnlein 2015.

121 Wendorf and Schild 1986.

122 Bunbury 2013.

123 Moreno García 2010, 2011.

124 Eyre 1994; Antoine 2011, 24; see also Alleaume 1992; Trampier 2005–6; Gillam 2010.

125 Lichtheim 1988, 12, 28.

126 van den Boorn 1988, 234, 238–42.

127 Luft 1994, 255–56.

on behalf of the king.¹²⁸ Another official, a *jmy-r ʒh.wt m tp-rs Tʒ-wr* “overseer of the fields in the Thinite province of the South,” stated that he had served as scribe of the *ʒh.wt m mw n.w Tʒ-wr ʒbdw* “fields in the waters of Abydos in the Thinite province.”¹²⁹ Considered together, both texts provide information on the location of these fields. First, being described as “in the waters” of a particular locality is an expression that makes sense in light of the inscription of Khnumhotep II of Beni Hasan, which narrates how the king organized the territory of the province by setting up boundary stelae and “dividing the Nile down its middle,” thus “causing city to know its boundary with city (so that) their boundary stelae were established like heaven and their water known according to that which was in the writings, they being assessed according to that which was of old, because of his love of order.”¹³⁰ Second, the “waters” of a particular city could be marked by some kind of dike or other device that had not only a hydraulic function but also an administrative one. In this sense, the passage quoted from “The Duties of the Vizier” becomes more intelligible, as the vizier is “he who dispatches the members of the (local) council to make ‘ in the whole country. It is he who dispatches the mayors and the governors of *hwt* to plough and (collect? the) harvest.”¹³¹ As for Imeny of Beni Hasan, he declared that “there came years of hunger. Then I plowed all the fields of the Oryx province to its southern and northern border, so that I fed its inhabitants.”¹³² The operations involved could have consisted of delimiting an agricultural area once the flood water receded in order to assess its expected yields and taxes¹³³ prior to the creation of fields at the beginning of the agricultural cycle. In this sense, ‘ recalls *b’h* land, an area of controlled water flow that was perhaps embanked to prevent free flooding and whose close association with fruit cultivation excludes the possibility that it was simply a flood basin.¹³⁴ This could also explain why, when conflicts about the use of water erupted in the Dakhla Oasis at the beginning of the first millennium BCE, Wayhaset, a *jmy-r b’h.w* “overseer of the basin areas” and *jmy-r štʒ.w.w* “overseer of the scrublands,” was dispatched to restore order.¹³⁵ The role of the agents of the king thus consisted more of supervising and controlling agricultural areas than of developing hydraulic infrastructures.

128 van den Boorn 1988, 234, 238–42.

129 Lichtheim 1988, 73–74.

130 Lloyd 1992, 22–23.

131 van den Boorn 1988, 234.

132 Lichtheim 1988, 139.

133 Cf. the following texts: “(the one) who registers the islands of new land in the great name of His Majesty, who records the markers on the borders of fields, who acts for the king in his listing of taxes, who makes the land-register of Egypt” (Teaching of Amenemope; Lichtheim 1976, 148–49); “he made land-charters for him of hundreds of thousands of fresh land (*nḥb*), islands (*jw.w*), high land (*qʒy.t*) and every field (*ʒh.wt nb*) which is profitable for corn” (Nauri decree; Kitchen 1969, 50); “I made for you *hʒ-tʒ* domains in the new land (*mʒwt*), with pure barley; I doubled their fields (*ʒh.wt*) which had been left fallow (*fkʒ.w*) in order to double the divine offerings in numerous lists, for your great august and beloved name. I made for you numerous fields (*ʒh.wt*) in the new islands (*jw.w mʒw*), in the northern and southern districts of the country, by the tens of thousands. There were made for them stelae inscribed with your name, abiding for you, bearing decrees forever” (Papyrus Harris I; Grandet 1994, 261).

134 Eyre 1994, 70–71.

135 Ritner 2009, 173–78.

Be that as it may, it is quite astonishing that irrigation played such a small role in the institutional administrative record. It seems as if the fields of the crown and the temples were concentrated in two main areas: (1) on “elevated” land (*q3y.t*), where the use of ploughs and yokes allowed for cultivating extensive domains, but with relatively modest yields, and (2) on “new islands,” where many royal domains were founded and cultivated, usually through forced labor such as prisoners, convicts, and even soldiers. Finally, when extensive royal plantations were founded in the New Kingdom, especially vineyards and olive groves, many of them were located close to natural basins (*b’h*). Consequently, the involvement of the monarchy in the organization of the irrigation system or in the control of the flood seems minimal. The only exceptions are perhaps royal plantations, specific areas around capital cities, temples, and the oases, as mentioned in the Great Dakhla Stela, with its complex network of relations and rights built on water provisioning, including private cisterns (*hnm.t nmḥ.wy*) and “private water” (*mw nmḥ*), as opposed to the “water of Pharaoh” (*mw Pr-ḏ*).¹³⁶

ABBREVIATIONS

CT = de Buck, Adriaan. *The Egyptian Coffin Texts*. 7 vols. Chicago: University of Chicago Press, 1935–61.

Urk. = Sethe, Kurt. *Urkunden des ägyptischen Altertums*. 8 vols. Leipzig: J. C. Hinrichs’sche Buchhandlung, 1932–57.

¹³⁶ Ritner 2009, 173–78.

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13

Water Management at the Liangzhu Prehistoric Mound Center, China

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WITTFOGEL'S HYPOTHESIS OF a "hydraulic-bureaucratic official-state" once provided an influential conceptual framework for understanding the origin and structure of state in Asiatic society.¹ The hypothesis has been rejected after archaeological research in Mesopotamia, China, and Mexico showed that "full-fledged states developed well before large-scale irrigation."² Archaeology at the second millennium BCE sites of Erlitou, Zhengzhou, and Anyang, for example, suggests that state formation in Bronze Age China predated the emergence of large-scale irrigation systems during the late first millennium BCE. These discoveries delinked the state formation process and the logistical needs of managing large-scale irrigation projects. The close connection between the management of large-scale irrigation systems and centralized bureaucracy observed in imperial China, therefore, was a by-product of state formation instead of its cause.

New archaeological research on the prehistoric mound center of Liangzhu in eastern China, however, reveals the construction of a large-scale water management project associated with this very large and stratified settlement during the early third millennium BCE.³ This find raises new questions about the relationship between water management and social complexity in early China. Incorporating preliminary results from remote sensing-aided landscape archaeology survey at Liangzhu, this chapter aims to explore this connection and its place in the comparative study of state formation. Our study of the Liangzhu hydraulic system hopes to provide critical information on the subsistence, social structure, and technology that existed in the Lower Yangzi during the third millennium BCE, well before the rise of the first Bronze Age state in the Central Plains.

1 Wittfogel 1957.

2 Carnerio 1970.

3 Zhejiangsheng 2015a.

THE BUILT LANDSCAPE OF THE LIANGZHU MOUND CENTER

The rise of Liangzhu during the late fourth millennium BCE represents the peak of political development in Neolithic China. Starting in approximately 3300 BCE, mound constructions appeared in a previously sparsely inhabited basin on the coast of the Hangzhou Bay.⁴ Liangzhu material culture represents a significant cultural elaboration of the Majiabang-Songze tradition in the Lower Yangzi, and its highly diagnostic material culture soon spread to the vast coastal regions of eastern China.⁵

The emergence of plains around the Hangzhou Bay during the early Holocene was a relatively recent phenomenon in geological terms. The sea-level curve revealed a rapid rise from -25 m to -5 m 9,000–7,000 cal yr BP, before approaching the present sea level 7,000–6,000 cal yr BP.⁶ The shoreline may have reached the foothills of the Tianmu mountain range during the maximum marine advance, making the Liangzhu region a shallow bay. The stabilization of the estuarine ecosystem involved the transformation of the former tidal marsh into freshwater wetland, which, in turn, was fundamental to rice cultivation in Liangzhu society. As the receding sea level exposed vast lake beds, the people of Liangzhu drained marshes, dug canals, and built mounds connected by long causeways in the largest mound center in early China.⁷

From the Early Phase (ca. 3300–3000 BCE) to the Middle Phase (ca. 3000–2600 BCE) of Liangzhu's occupation, the Liangzhu site expanded from a small settlement into a large mound center spanning an area of approximately 15 km on the east–west axis and 5 km on the north–south axis, with ample evidence of social differentiation and a great concentration of wealth.⁸ Its emergence probably incorporated the existing cultural and technological traditions in the Lower Yangzi, particularly those of Beiyinyangying, Lingjiatan, and other earlier jade-working centers in the Nanjing-Zhenjiang region, which declined around the time that Liangzhu emerged.

The central mound of Mojiaoshan appears to have served as the focal point of Liangzhu religious and political authority. Constructed of rammed earth around the turn of the third millennium BCE, the rectangular mound measured approximately 10 m high and covers an area of 30 ha, making it the largest single structure in prehistoric China (fig. 1). Three smaller mounds were built on top of the large mound platform, probably once supporting temples or palaces overlooking the settlements below.

The architectural layout on the central mound remains poorly known. The discovery of rows of evenly spaced postholes, numerous large pillar bases, extensive rammed-earth foundations, intricately carved wooden beams, and a large number of burnt adobe fragments on the mound platform suggests the presence of monumental architecture.⁹ Deposits of ash and burnt clay in alternating layers suggest complex events associated with use of the site.

4 Liu 2007; Qin 2013; Liu and Wang 2014; Liu 2014; Liu et al. 2015.

5 Zhuang 2018.

6 Liu 2014, vi.

7 Liu 2007, 192.

8 Liu 2007; Zhao 2007; Liu and Wang 2014.

9 Zhejiangsheng 2001, 2005a.



Figure 1. CORONA image of the Mojiaoshan mound, 30 ha in area and 10 m in height (USGS D086 079 S11 FEB 69 1106-2 AFT).

After the mid-third millennium BCE, an impressive rammed-earth causeway 60 m wide was built around the central mound at Mojiaoshan (fig. 2). It was constructed on a stone foundation created with a layer of angular slabs quarried from nearby mountains.¹⁰ The causeway enclosed an area of 300 ha with eight water gates connecting canals inside and outside the enclosure.¹¹ Around the central mound, several mound clusters were used as raised ritual platforms and elite cemeteries at various phases of Liangzhu settlement.¹² Together, these prehistoric mounds formed the core of the Liangzhu center.

Liu Bin¹³ argues that at least some of the ritual activities performed on the platform were aimed at time mapping, establishing alignment with the solar movement and mountain peaks during equinox and solstice. In Bronze Age China, time-mapping ceremonies were closely associated with defining the location of *axis mundi*, the central place through which religious communication with the sacred and ancestral realm took place.¹⁴ After their initial use as ritual platforms, these mounds became the loci of elite tombs richly

¹⁰ Zhejiangsheng 2015b; Wang et al. 2020.

¹¹ Liu and Wang 2014, 31; Liu et al. 2017.

¹² Zhejiangsheng 2003, 2005b.

¹³ Liu 2007, 193.

¹⁴ Pankenier 2013.

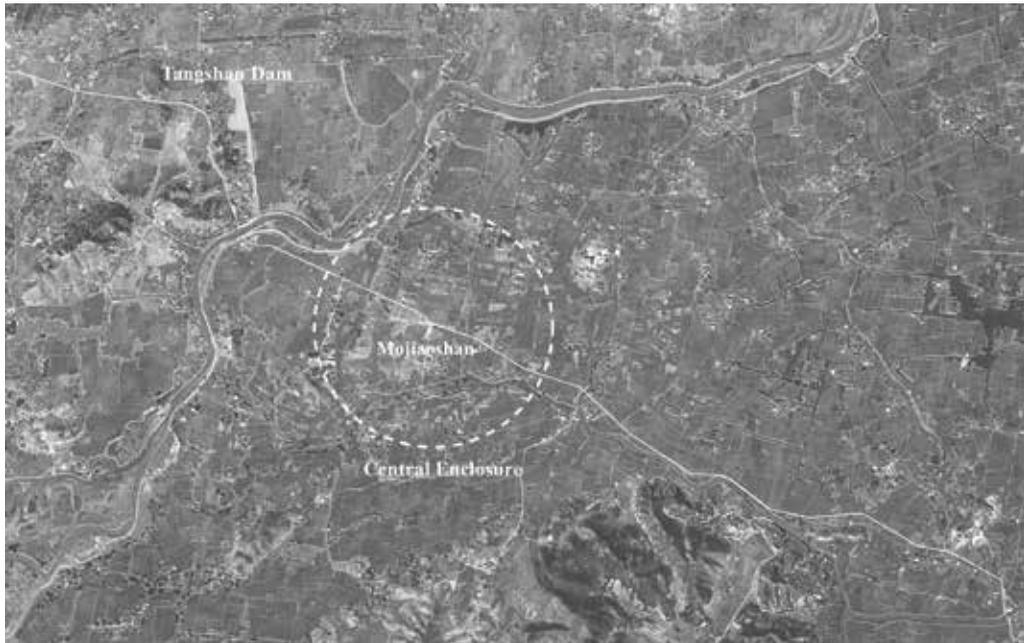


Figure 2. CORONA image of the built landscape of the Liangzhu center around the central mound (USGS D086 079 S11 FEB 69 1106-2 AFT).

furnished with jades and, likely, textiles. Elevated above the rest of the Liangzhu community, both the living and the dead, the incorporation of elite burials in these ritually significant mounds merged the persona of the elite and their authority with the sacred landscape of the Liangzhu world.

The scale and complexity of Liangzhu society were unrivaled during the third millennium BCE, placing Liangzhu society in a class of its own in the prehistoric society of early China. Connected by canals and causeways, the Liangzhu mound center was an agglomeration of major religious-cum-residential compounds concentrated in a vast built landscape of 75 sq km (fig. 1). It was also disproportionately larger than any political centers of Bronze Age China, such as Erlitou (3 sq km), Zhengzhou (15 sq km), Huanbei (4.7 sq km), and Yinxu (36 sq km).

Construction of the monumental earthworks involved planning, investment, supervision, and massive labor mobilization, all attesting to the extraordinary vision of Liangzhu leaders in transforming their coastal world.¹⁵ Its great mound center in Liangzhu is similar in scale and organization to Eridu and Susa in Mesopotamia, Cahokia in North America, Monte Alban in Oaxaca, the great Olmec centers in Mesoamerica, and many Early Horizon centers in Peru.¹⁶ Its construction defines the threshold of the protourban experience at Liangzhu, which was centered on large constructed open spaces with associated elite residences, burials, and craft-working areas. Each included peripheral residential areas, often for generalized food producers.

¹⁵ Zhejiangsheng 2015a.

¹⁶ Pauketat 2004; Wright 2005, 2006; Marcus and Sabloff 2008.

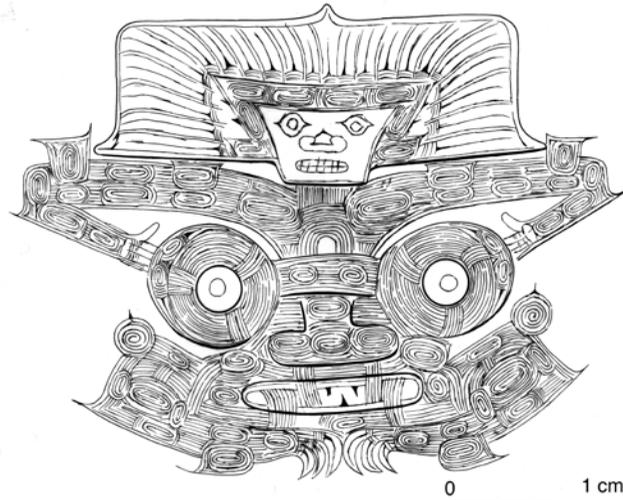


Figure 3. Liangzhu iconography engraved on a jade cylinder from an elite burial at the Fanshan cemetery (illustration by Fang Xiangming).

From the perspective of layout and architectural tradition, Liangzhu displays a striking parallel to the great mound center at Cahokia, which was the center of the prehistoric Mississippian society in North America during the eleventh to twelfth centuries CE. In all, the mound center of Cahokia spans 17 sq km, with more than a hundred mounds in its downtown area during its golden age in approximately 1100 CE.¹⁷ Its mounds probably served as an important political stage in the life of the elite, who conducted “ceremonial displays watched by the gathered people on formal constructed plazas below, who lived there or gathered there for major annual festivals and important religious events.”¹⁸ Its political influence covered the full geographic span of the Mississippi River valley.

Like the Mississippian mounds in North America, the construction of these Liangzhu earthen mounds was a reflection not simply of political institutions but of “institutions *coming into being*.”¹⁹ As in Cahokia, the Liangzhu mound-building effort probably attests to “an ongoing construction of place and collective memory” that took place “through carefully orchestrated and meaning-laden earthen and stone depositional practices.”²⁰ In a similar fashion, the embodiment and emplacement of these great earthen mounds indicate that the ruling elite exercised their religious and political dominance over the surrounding countryside through a complex repertoire of social, political, and religious symbolism.

Members of Liangzhu society forged their collective identity through their participation in the construction of these mounds and other public structures, as well as through war, expeditions, and religious gatherings. The central image of the Liangzhu religious cult was represented by the iconography of a fierce-looking deity wearing a feather crown and possibly a mask (fig. 3). Its upper body took human form, while the lower body

17 Pauketat 2004.

18 Pauketat 2004, 49.

19 Pauketat 2007, 42 (*italics original*).

20 Pauketat 2007, 180.

transformed into a feline, with the breasts of the human figure serving as the beast's eyes. The introduction of a new repertoire of jade forms, such as *cong* cylinders, along with the presence of iconography, suggests that religion may have been the underlying force for the rapid population influx into the newly developed mound centers in the Lower Yangzi.

With a well-established center-periphery structure and social distinction, Liangzhu saw the emergence of a sophisticated political network in and beyond the Lower Yangzi during the first half of the third millennium BCE. From Huating in the Huai River basin in the north to Shixia in the Pearl River basin in the south, Liangzhu elite assemblage has been discovered across a coastal network spanning 1,500 km (fig. 4). The spread of Liangzhu cultural and religious tradition erased the regional variations in its core regions of the Lower Yangzi, creating an easily recognized pattern of social life and material culture. Through the incorporation of local warrior elites, Liangzhu ideals perpetuated beyond their core region.

THE NETWORK OF CANALS AND CAUSEWAYS IN LIANGZHU

Water management for the purpose of agricultural intensification and water transportation contributed to the prominence of the paramount center in the Lower Yangzi. Structured around river navigation, a network of canals, water gates, linear mounds, and causeways connected the great mound center with villages, open water bodies, and rice paddies in the region. The dense distribution of irrigation and navigation features around Liangzhu sites attests to intensification of rice plantation around estuaries where rich environments were closely juxtaposed.

Its large, linear mounds appear to be causeways to live on, rather than defensive ramparts. As seen at the Meirendi locus, these causeways were shielded with wooden beams and planks, complete with wooden wharfs and stone decks for docking canoes and sailboats.²¹ The construction of waterfront buildings along the deck closely resembles the traditional riverside towns in the Lower Yangzi, where stores and warehouses lined the canal. Navigation along rivers and canals may have served as major transportation routes.

Exchange of produce, fish, wild game, aquatic products, and utensils probably took place around the piers and causeways. The marshy deposit along the causeways at Meirendi and Bianjiashan were filled with residential debris, where the excellent preservation of organic remains offers minute details of Liangzhu material culture underrepresented at other sites. These include tens of thousands of artifacts made of pottery, stone, jade, wood, lacquer, bone, and bamboo, representing every aspect of daily life along the canals and including food utensils, implements, toys, and clothing accessories. Some of the products and raw materials, such as cinnabar used for lacquer production, were probably traded in from the Middle Yangzi through well-established arrangements. The diversity of material culture and craft industry involving wood carpentry, basketry, jade carving, lacquer production, and pottery production further suggests that the mound center was the nexus of an extensive Liangzhu exchange network during the early third millennium BCE.

Rich botanical and faunal remains in these waterlogged sites reveal a great abundance of aquatic resources in Liangzhu life. The presence of carp bones, snails, and freshwater

²¹ Zhejiangsheng 2015b.

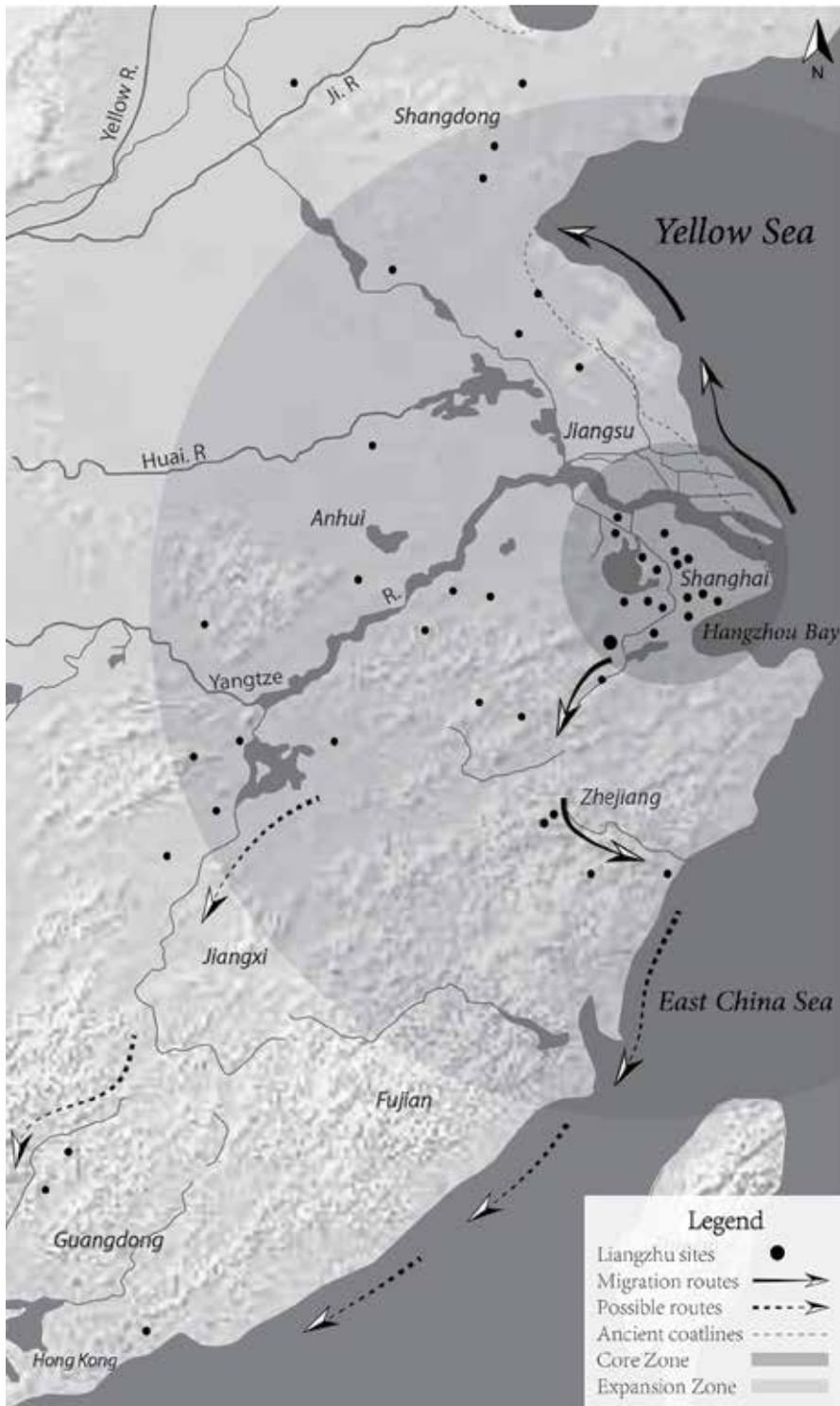


Figure 4. The distribution of Liangzhu material culture assemblage during the early to mid-third millennium BCE (illustration by Su Mingming).

mollusk shells in the deck-side deposit at Meirendi, for example, as well as shark teeth from elite burials, attests to active exploitation of aquatic resources in Liangzhu society.²² These activities, inferred from archaeological remains, suggest that the Liangzhu society had already developed a prosperous and sophisticated rice agriculture supplemented by fishing, foraging, and aquaculture, which had been overlooked in past studies that focused on the central role of rice agriculture in Liangzhu subsistence economy. Together, the abundance of food from diverse sources made it possible for the community to engage in feasting activities and alcohol production.

The wealth of Liangzhu helped sponsor wars, expeditions, and the production of prestige goods such as jade, silk, lacquer, and fine ceramics. A sophisticated textile industry can be inferred from circumstantial evidence. Remains of silk brocades were documented in Qianshanyang, a rich post-Liangzhu site in the region dating to the late third millennium BCE. Contemporaneous with early Liangzhu, traces of fine silk brocade were identified in urn burials from the Qingtai cemetery located in the Central Plains region of Zhengzhou and may have been traded in from the Lower Yangzi region.²³ The discovery in elite burials of jade fittings for looms indicates a high level of textile production.

THE CONSTRUCTION OF DAMS AND RESERVOIRS

Manipulation of waterways was a major undertaking in the transformation of Liangzhu's landscape. In addition to the construction of causeways for residential and transportation purposes, Liangzhu society also constructed a series of dams to manipulate the hydraulic regime in and around the mound center.²⁴ Many of these public works employed the same construction techniques and materials, using basketloads of grayish-green mud for the foundation, presumably dug up from the bottom of canals.²⁵

Based on their shape and location, these dams can be classified into long dams, which run along the foothills that surround the city, and short dams, which connect the two mountains.²⁶ Tangshan is an example of a long dam. Located approximately 500 m south of the foothills of the Tianmu mountain range on the northern edge of Liangzhu, the Tangshan hydraulic system features a double-walled structure 6,500 m long and 50 m wide and standing 5–8 m tall (fig. 5). It appears to have functioned both as a dam for diverting floodwater away from the center of the Liangzhu prehistoric mound city and as an aqueduct for channeling water from the mountain valleys north of Tangshan toward the reservoirs on the northwest corner of Liangzhu.

The eastern end of the Tangshan water management system is located at the opening of the Kengmen valley, where a series of small dams was constructed to harness floodwater flowing out of the valley. The presence of a modern reservoir there attests to its favorable location for water need. The central mechanism of Tangshan was constructed at the Lihutou locus, approximately 1 km west of the Kengmen dams, where a major earthen

22 Zhejiangsheng 2015b.

23 Zhang and Gao 1999; Zhengzhoushi 1999.

24 Liu 2014.

25 Liu and Wang 2014, 36.

26 Zhejiangsheng 2015a.



Figure 5. CORONA image of the Tangshan hydraulic structure with double wall construction (USGS D086 079 S11 FEB 69 1106-2 AFT).

feature separated the stream flow on either side. It may have functioned as a facility (head-gate) for diverting water from the mountain valley to be allocated to rice paddies. The absence of cultural remains in the area between the Tangshan dam and the foothills indicates that the Tangshan system was actively maintained throughout the duration of the Liangzhu settlement and that the local communities did not frequent the areas reserved for channeling stream flow.²⁷

The presence of a jade workshop on the Tangshan dam further suggests that specialized craft production at Liangzhu was closely associated with the water management project. Jade was quarried from outcrops around the Lake Tai region in the Lower Yangzi and transported to Liangzhu mound centers. These jades were carved by skilled artisans at workshops such as Lucun, located at the east end of the Tangshan aqueduct, which features built-in anvil stones, sandstone, quartzite lithic tools for jade working, jade blanks, and leftover pieces from the production of *cong* cylinders, disks, battle-axes, bracelets, and beads. The mound cluster at Yaojiadun immediately south of these dams may also be associated with the water management project.

In the northwest corner of the great mound center, a series of short dams was constructed at the openings of mountain valleys in the Penggong township.²⁸ These dams can be divided into two types: high dams and low dams. High dams were built at the openings of mountain valleys upstream, while low dams were used to connect the plains and the

²⁷ Liu 2004, 108.

²⁸ Zhejiangsheng 2015a.



Figure 6. CORONA image of the Ganggongling dam, cut through by a modern road, in the Penggong locus northwest of the Liangzhu mound center (USGS D086 079 S11 FEB 69 1106-2 AFT).

mountains downstream. These dams appear to form part of a sophisticated hydraulic system for water management that connected several reservoirs, probably intended for channeling floodwater in monsoon seasons and for irrigating the rice paddies during droughts.

Built around 2900 BCE, the major dam of the upper dam system at Ganggongling measures approximately 10–20 m tall, 100 m wide, and 200 m long (fig. 6).²⁹ This dam closed the southern end of the 7 km-long mountain valley connecting Penggong and Deqing. Around the Ganggongling dam, several smaller dams were built at the openings of adjacent valleys, making it possible to control the volume of water flowing into the basin downstream. We have yet to identify any water control devices associated with these dams.

The volume flowing downstream into the mound center was regulated by a series of low dams farther south. These dams connected the isolated hills in the western hinterland of Liangzhu into a dam system that linked with the western end of Tangshan. The area between the high and the low dams, therefore, became the location of second-tier reservoirs between the first-tier ones in the mountain valley and the Liangzhu mound center downstream. These dams formed a complicated system in which each component had its own function and had to be coupled with other components to operate as a whole. This has significant implications for the nature and operation of political leadership at Liangzhu,

²⁹ Zhejiangsheng 2015a, 7.

which was not believed to be present in prehistoric China when the debate over Wittfogel's hydraulic-bureaucratic official-state for Asiatic society unfolded.

Collectively, the archaeological evidence reviewed so far suggests that the Liangzhu hydraulic systems likely served three functions: irrigation, flood control, and transportation.³⁰ Floods from the mountain range during the rainy seasons and fluctuation in sea level both threatened the livelihood of Liangzhu communities. Qiu Zhirong et al. argue³¹ that the low-lying plains during the third millennium BCE were at least 3 m lower than today's ground surface and that water and marshes covered more than 3 percent of the mound center. Such terrain features probably account for the architectural decision to build houses on raised surfaces, such as mounds and causeways. In addition to flooding in the basin from the surrounding mountain range, coping with the fluctuating sea level was also a major concern for the Liangzhu planners.³²

Seasonal fluctuation in water supply appears to be a key issue that the water management system at Liangzhu was intended to address. Although its prehistoric communities faced flooding from mountain valleys and water accumulation on the plains during rainy seasons, the great mound center suffered from water shortage in the winter. The Liangzhu water management system allowed the Liangzhu communities to store and control the distribution of water with its network of two-tiered reservoirs, aqueducts, and canals.

In terms of scale, the Liangzhu water management system exceeded an areal extent of 100 sq km, the benchmark for Hunt's definition of a large irrigation project.³³ Our knowledge of the Liangzhu field system, however, is very limited. At the time of writing, the residential areas and rice paddies between the mounds remained buried under sediments from rising seawater or floods from the last quarter of the third millennium BCE. The distribution of earthen mounds therefore represents only the tip of the iceberg for understanding the settlement pattern of Liangzhu and its field system. This is an area for future research.

WITTFOGEL REVISITED

"Material wealth in concentrated form," Chang argues, "is both a result of and a requisite for political authority."³⁴ The research on Liangzhu provides ample evidence of an unprecedented concentration of wealth: the enormous scale of its mound constructions, the richness in jades (and possibly also textiles) in elite burials, and a wide range and quality of material culture produced by craft specialists at Liangzhu made it stand out from contemporaneous communities in early China. If concentration of wealth is the hallmark of civilization as defined by Chang, then Liangzhu represents the first prehistoric civilization in China, with significant implications for investigating the process of state formation from an archaeological perspective.

The enormous scale of the Liangzhu mound center presents the type of organizational effort that would have rivaled that of Bronze Age state centers from the second millennium

30 Zhejiangsheng 2015a, 13.

31 Qiu et al. 2016.

32 Liu 2014; Zhuang et al. 2014.

33 Hunt 1988.

34 Chang 1983, 124.

BCE. It reveals a high level of complexity that would have required the production of food surplus and some centralized planning—attributes that we usually associate with Bronze Age if not imperial China. The presence of large-scale water management projects at Liangzhu encourages us to reexamine Wittfogel’s theory of state formation, according to which the management of large-scale irrigation systems requires centralized control and was a major impetus for the rise of state apparatus in the ancient world.³⁵ In this regard, Liangzhu presents three important revelations.

First, the mobilization of labor and centralized planning involved in the construction of its hydraulic systems suggests that water management was a major component of the Liangzhu political system. Agricultural surplus generated by the intensification of rice plantation associated with these irrigation projects was likely the source of Liangzhu’s wealth and was needed for the maintenance of the proto-urbanism, craft specialization, and status hierarchy at the mound center. Cross-culturally these are key features of statehood, along with government institutions. In this regard, the evidence for large-scale dams at Liangzhu lends support to Wittfogel’s argument for the critical role played by water management in the state formation process.

Second, the Liangzhu mortuary data suggest that the planning and construction of a massive water management system at the prehistoric mound center did not necessarily contribute to the emergence of bureaucracy and state apparatus as proposed by Wittfogel’s argument for hydraulic states. While differences in gender and rank can be inferred from the Liangzhu elite mortuary assemblage, we cannot identify any traits associated with the administrative specialization that could reveal the establishment of state water bureaucracies, or “hydrocracies.”

From the paramount leaders buried at the mounds around the central mound of Mojiashan to the lower elite buried in surrounding sites, the grave goods show differences in mortuary assemblage in terms of the quantity and quality of jade disks, *cong* cylinders, and battle-axes associated with the Liangzhu warrior elites, but not in kinds that could offer clues about specialization in a state structure. Like Cahokia or San Lorenzo, Liangzhu defies evolutionary typology—the scale of its settlement and hydraulic system rivals that of later states, but its material culture exhibits no compelling evidence for the presence of bureaucracy.

Hunt’s argument for centralized control as a choice rather than a necessity³⁶ would be fitting for the Liangzhu case. As stated in the introduction to this volume, centralized control cannot be assumed based on the physical attributes of an irrigation system (e.g., its size or technical complexity). Instead, the organization of irrigation itself displays greater variation, from highly centralized to fairly decentralized. Liangzhu would fall in the middle of this spectrum—centralized planning without a state.³⁷

The effectiveness of Liangzhu’s enormous water management system can only be inferred from its long duration. In spite of its environmentally vulnerable location, the mound center flourished through the first three quarters of the third millennium BCE and collapsed only at the onset of the Holocene Event 3 climatic anomaly, along with other

35 Wittfogel 1957.

36 Hunt 1988.

37 Renfrew and Liu (2018) argue that Liangzhu may represent the earliest state in East Asia.

major centers such as Shijiahe in the Middle Yangzi.³⁸ In the great mound center's heyday, the presence of these monumental dams must have embodied claims about the power and authority of Liangzhu's elites—Liangzhu's hydraulic system indeed gave it a great role, but it but did not create a state.

Finally, Liangzhu represented a different trajectory from the state formation process in the Central Plains, on which historical observations and conceptions of hydraulic states were based. By 2300–2200 BCE, Liangzhu society, as the most prominent lowland power in early China, was dwindling; its impressive mound centers were abandoned, and its dams and levees were no longer maintained.³⁹ Rises in sea level around 2300–2200 BCE appear to have contributed to the decline of the Liangzhu mound centers and the abandonment of Neolithic settlements in the Lower Yangzi.⁴⁰ Other lines of evidence identify freshwater flooding as the primary cause of social decline.⁴¹

Although the sea level stabilized and subsequently approached that of modern times, the delta plain was still very sensitive to subtle sea-level fluctuations, storm surges, and tidal currents, which affected and restrained the development of the agricultural-based Liangzhu society.⁴² By the time the first signs of bronze metallurgy appeared in western China, around 2200 BCE, the great mound centers had collapsed. The main political theater for state formation shifted north, to the middle Yellow River basin.

As the defining attributes of its protourban landscape, the Liangzhu tradition of mound construction and water management had no parallels in Bronze Age state centers of the second millennium BCE. The estuarine and maritime orientation of the Liangzhu political network presents a sharp contrast to the *Sandai* political landscape centered in the middle Yellow River basin. Although they made extensive use of river valleys to facilitate transportation, the royal centers of *Sandai* civilization were generally land-bound settlements without great mounds, canals, piers, or causeways as major landmarks in their cities. Current evidence suggests that Liangzhu made an indirect but significant contribution to the political and cultural tradition of Bronze Age societies, separated by a period of remarkable transformation known as the Longshan period (ca. 2300–1800 BCE).⁴³

Emerging centuries after the collapse of the Liangzhu mound centers in the Lower Yangzi, the Bronze Age states of the middle Yellow River thrived on dry farming of millet, which had very different water management requirements than the rice paddies observed at Liangzhu during the third millennium BCE. The extensive dry-farming practice of millet cultivation no longer required the huge labor investment associated with Liangzhu rice farming. An expanding component of stockbreeding of cattle, sheep, and later horses, introduced from Eurasian interactions after the Longshan period, further contributed to the increased mobility of Bronze Age state centers.

Erlitou, Zhengzhou, and Anyang each operated for approximately a quarter millennium, a significantly shorter time span than the duration of the Liangzhu mound center

38 Wang et al. 2005.

39 Zhejiangsheng 2005a, 324.

40 Yu et al. 2000, 29; Liu and Chen 2012, 251; Ningboshi 2013.

41 Zong et al. 2011; Liu 2014.

42 Liu et al. 2015.

43 Li 2016.

in the third millennium BCE. Historical sources suggest that the Shang cattle herders relocated their capitals multiple times because of threats of flooding and political conflict, which again presents a remarkable contrast to the long-term stability of the Liangzhu settlement pattern. In contrast to a strong focus on jades at Liangzhu mound centers, these Bronze Age states focused their efforts on a new industry—bronze metallurgy, which has its own implications for the representation of political authority and configuration of exchange networks.

CONCLUSION

Discoveries of a large-scale water management system at Liangzhu offer new insights into the relationship between hydraulic systems and state formation in early China. We can no longer argue that “it was the pre-existing state structures and the large, well-trained labour force provided by the armies that made the great irrigation projects possible.”⁴⁴ The potential contribution of this prehistoric episode of large-scale water management to the emergence of Bronze Age states in China remains unknown. As the deep collapse of the prehistoric mound centers at Liangzhu and Shijiahe during the late third millennium BCE brought an end to their political evolution based on intensive rice farming, knowledge of the complex hydraulic system associated with them may have been lost.

The Liangzhu legacy, however, did work its way into the formation of Bronze Age civilizations in early China. The majority of the technologies and materials used at the mound center, such as jade, ivory, textiles, leather, lacquer, and carpentry, contributed to the development of a high culture in *Sandai* society. The perfection of these technologies and craft skills defined the aesthetics and values for *Sandai* civilization and its immediate predecessors. Without these sophisticated technologies, *Sandai* civilization would look very different. Furthermore, its hydraulic cosmology may have contributed to the eventual rise of a flood-control myth in early China, which became the ideological foundation for early notions of kingship in the Zhou textual tradition. Much more about the history and significance of the Liangzhu water system has yet to be discovered. Further research is necessary to obtain critical insight on the topic.

44 Gernet 1968, 92.

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PART V

THE COSMOLOGICAL DIMENSION
OF IRRIGATION

14

From the Mekong to the Tonle Sap: Water Management and Cosmology in Cambodia's Ancient States

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THE WORLD'S EARLIEST agrarian states arose in river valleys with large alluvial plains, which may explain the persistent historical interest in relationships between water management and early state formation across the Old World, and particularly managerial requirements that large-scale irrigation systems ostensibly required. Historians like Karl Wittfogel¹ first systematized this research; several generations of anthropologists and archaeologists have investigated, challenged, refuted, or confirmed his ideas using empirical evidence from both Old and New Worlds.² As the variety and precision of archaeological techniques for detecting ancient water management systems expand, so too does water management as a global issue that transcends anthropological archaeology. Understanding the growing public and scientific interest in how past peoples used water in many spheres besides agriculture becomes increasingly important in the face of climatic unpredictability,³ which underscores the importance of fine-grained, long-term histories of water management to audiences beyond archaeologists.

This examination of Lower Mekong basin water management focuses on a region that has housed riverine populations for millennia. Today, nearly 50 percent of the available landmass in some regions of the Lower Mekong basin is inundated up to six months each year. We define the Khmer world today by nation-state boundaries that are substantially narrower than the distribution of Khmer speakers. Throughout, the Khmer world is a “water world”:⁴ most lowland Cambodians (also known as Khmers) live within the broad catchment bounded by the Mekong River and its tributaries (including the Tonle Sap), and water has both cultural and practical meanings. One of the most important Khmer annual festivals takes place in April, immediately before the monsoon rainy season begins: Khmer New Year (*Bon Chol Chhnam Thmei*). Another, the “water festival” (*Bon Om Touk*), occurs each November at the peak height of flooding, when the Tonle Sap River reverses its direction and begins flowing back up into the Tonle Sap Lake.

1 Wittfogel 1957.

2 E.g., Hunt and Hunt 1976; Lees 1994; for a recent summary, see Harrower 2016, 10–11, and Harrower's chapter in this volume.

3 Orlove and Caton 2010, 403.

4 Following Orlove and Caton 2010.

Water is intrinsic to Khmer religion and cosmology; it sacralizes and consecrates. Khmer Buddhist monks chant liturgy and sprinkle (or dump) water on participants during ritual ablutions for particular life events; so can traditional guardian spirits, whom the Khmer call *arak devata*.⁵ To prepare the newly dead for their transition out of this world, Khmers wash their corpses; the *acarya* (temple layman who holds formal responsibilities at the temple) boils water in new earthenware pots, breaks them in the street and suspends the bowls from trees around the temples, and places perfumed water in buckets near the gates of the crematorium after the ceremonies have been completed.⁶ *Kru boramei* (spirit mediums) are also integral to Khmer life; they diagnose and treat maladies that modern medicine often cannot cure. Water is integral to treatments: healers sprinkle water on their patients, give them holy water to drink, and concoct medicinal broths designed to heal.⁷

Water shaped ritual as much as it shaped agricultural practice in the Lower Mekong basin, producing a series of landscapes that archaeologists and environmental scientists now study. Most know this region from the massive Angkorian water management superstructure that undergirded a ninth- to fifteenth-century CE state-crafted landscape of reservoirs, channels, and moated temples. Top-down water management regimes characterized two periods in Cambodia's history: the six-century Angkorian period and the four-year Khmer Rouge period. Archaeological research since 1996 suggests that underlying this state hydraulic system (and perhaps independent of it) was a resilient, local water management structure that buffered climatic unpredictability and persisted into the twentieth century. Local and state-level water management systems blended cosmological and practical concerns in the Khmer world, and understanding the historical trajectory of the Lower Mekong's landscape, and some of the social and ideological relationships that were inscribed into its changing water management systems, is the focus of this chapter.

THE LOWER MEKONG AGRICULTURAL CYCLE

The Lower Mekong basin today contains portions of Thailand, Cambodia, and Vietnam. Unlike its neighbors, all of Cambodia lies within this hydrogeographic region, whose seasons are dictated by a tropical monsoon climate and annual fluctuations in the Mekong River. Water management is essential to subsistence and settlement in the Lower Mekong, where an annual flood/drought regime challenges systems of agrarian production and transportation; in the Mekong's lowest reaches of southern Vietnam, the dry season can make fresh drinking water elusive. Archaeological research described in this chapter draws from work in southern Cambodia's Mekong delta and in northwestern Cambodia (fig. 1). These two regions are linked as points at either end of a broad alluvial plain whose physical boundaries coincide roughly with the distribution of lowland Khmer speakers. The country's 15.9 million residents live across an area of nearly 180,000 sq km (70,000 sq miles), much of it riverine, and largely inland. Most ethnic Khmers live along a corridor that runs from the country's northwest provinces of Battambang and Banteay Meanchey southeast into the Mekong delta and its tributaries. Today, the region that we associate with Cambodia

5 Edwards 2008, 145.

6 Davis 2009, 76, 91, 104.

7 Bertrand 2005, 320.

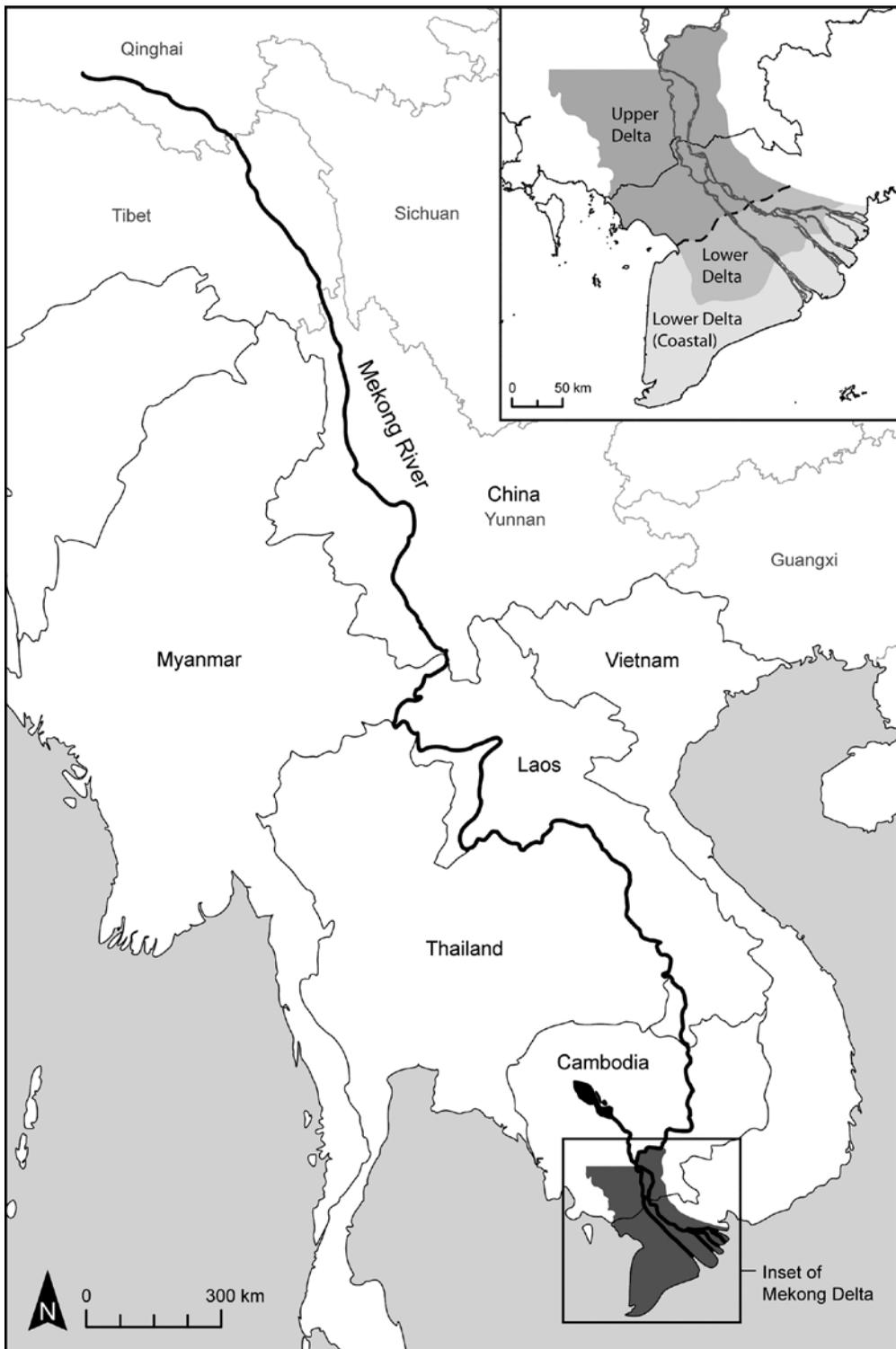


Figure 1. The Lower Mekong region (southern and northwest Cambodia). Figure by Alex Morrison.

is a small country: it is far less prominent now than it was from the ninth to the fifteenth centuries CE when it housed the region's largest empire.

More than three-fourths of Cambodia's current population is rural, and Khmer rural livelihood blends rice production with aquaculture, livestock management, and arboriculture (the latter for sugar palms, fruit trees, and betel). Rice fields, along with drainage canals and natural waterways, provide fish and other aquatic produce for Khmer households. Ducks harvest biota from inundated rice fields, which during the dry season provide fodder for cattle. Khmers cultivate house gardens and other crops, particularly cotton, tobacco, and market-bound vegetables. All activities are located in proximity to water (rivers, streams, canals, ponds, lakes), and most require propitiation of ancestral tutelary spirits (*neak ta*) who watch over and protect these localities.

Lowland Khmer farmers understand their climate and use geography to their advantage during the annual monsoon cycle. The annual southwest monsoon arrives in May, dumping 88 percent of the region's annual rainfall within a five-month period⁸ and absorbing 90 percent of the labor demand for rice production. This intense rainy season and the long dry season that follows challenge farmers to employ different cropping strategies in varied ecological settings: dry fields, flooded fields, deep-water ponds, and—primarily in the last century—canal-fed irrigation systems.⁹ Cambodia's Mekong delta farmers employ at least three complementary farming strategies: short-season/early wet-season farming (*srau konlah*), wet-season farming (*srau vosah*), and wet-dry-season flood recession farming (*srau prahng* or *srau bandynduk*) around lakes and in low-lying areas that remain inundated for extended periods.¹⁰ They use myriad traditional rice varieties, tailored to the elevation and nature of the plot in which they plant their rice.¹¹ Jean Delvert,¹² for example, recorded 180 different rice varieties that Kampong Cham farmers planted in their fields.

The Royal Ploughing Ceremony (*Preah Reach Pithi Chrot Preah Neangkol*), held in the fifth or sixth month of the Khmer lunar calendar (usually May), marks the start of the annual farming cycle. During the ceremony, which takes place in different locations across Cambodia (but often near Phnom Penh's Royal Palace), two sacred oxen plow a furrow in ceremonial ground. Royal astrologers sow rice in the furrows, chant Brahmanic prayers, and sprinkle holy water on the oxen. They then offer the oxen seven different plates of food containing rice, green beans, sesame, corn, fresh-cut grass, water, and rice wine. The oxen's food choices determine the fate of that year's agricultural harvest. Following this ceremony, Khmer farmers begin their season by planting rice nurseries near their homes. Men flood and harrow their banded rice fields using a pair of either oxen or water buffalo. After the rice seeds germinate (which takes thirty to forty days), the farmers drain the fields to lower the water level, and women plant these seedlings in the pond fields. The farmers then harvest the ripe rice two to three months later, in November or December. Farmers in several parts of the Lower Mekong basin also plant dry-season flood recession rice in the back swamps around the Tonle Sap Lake (in northwest Cambodia) and in the

8 Kумму 2009, 1415.

9 Delvert 1961.

10 Fox and Ledgerwood 1999; see also Nuttonson 1963.

11 Lando and Solieng 1991, 21.

12 Delvert 1961, 332.

Mekong delta. Planting in recently flooded deep soils provides the highest per-hectare yields available in this agrarian system.¹³ Farmers plant seedbeds in December, clean their fields of weeds, transplant or broadcast in January, and irrigate their fields with floodwater trapped in neighboring ponds. Some farmers also plant floating rice in deep ponds.

The two crucibles of Khmer state formation are located in areas with gentle flood regimes that deposit rich alluvial soils annually, high water tables, easily reclaimable farmland, and access to riverine transportation routes: the Mekong delta and the Tonle Sap Lake.¹⁴ Approximately 30 percent of Cambodia's soils belong to these alluvial Kbal Po or Krakor soils, which are ideal for rain-fed, dry-season (flood recession), and floating rice cultivation. Rain-fed lowland rice cultivation systems generally produce half the yield of canal-based irrigation,¹⁵ but the Lower Mekong is ideally suited to rain-fed rice farming. In the mid-1990s, for example, Khmer farmers generated agricultural yields (without fertilizer) as high as 1.98–2.87 short tons/ha (1,800–2,600 kg/ha).¹⁶ Delvert's exhaustive Cambodian agricultural study¹⁷ noted that the country's highest rice yields come from Battambang province (northwest of the Angkor region) and Kampong Cham (along the Mekong River), where yields rose as high as 3.5 short tons/ha. These figures are quite high relative to pre-Green Revolution productivity estimates that Lucien M. Hanks¹⁸ supplies, for example, for the Tonkin delta of northern Vietnam (1.48 short tons/ha) or central Thailand (1.09 short tons/ha).

Southern Cambodia (Takeo, Prey Veng, Svay Rieng, Kandal) and the Tonle Sap region were ideal settings for multicrop rice farming regimes that combined floating rice, retreat agriculture, and rain-fed agriculture using banded fields.¹⁹ This multilayered rice-farming system, coupled with ancillary livestock production using these pondfields for duck husbandry and fisheries, produced a remarkably productive economic system.

We begin in the Mekong delta, where robust archaeological evidence now exists for the rise of the region's earliest (or protohistoric) state, and whose roots extend back to circa 500 BCE.

THE ORGANIZATION OF KHMER WATER MANAGEMENT

PROTOHISTORIC AND PRE-ANGKORIAN WATER MANAGEMENT

Mainland Southeast Asia's earliest state populations settled in geographical contexts that maximized nonintensive water management for wet field rice agriculture.²⁰ Mekong populations forged an early polity that visiting Chinese emissaries called the kingdom of Funan²¹ by the mid-first millennium CE. Chinese records suggest that these farmers did not need

13 Fox and Ledgerwood 1999, 38, table 1.

14 Acker 2012; van Liere 1980, 269 et passim; see also Stott, 1992.

15 Wade et al. 1999, 3.

16 White, Oberthür, and Sovuthy 1997, 27–28.

17 Delvert 1961.

18 Hanks 1972, 165, appendix B.

19 Fox and Ledgerwood 1999; van Liere 1980, 272–73.

20 E.g., Ng 1979; van Liere 1980.

21 Pelliot 1903; Stark 2021.

to rely on canal irrigation to reap high yields from their rice fields. What they did need, however, was mastery of knowledge of the floods. They engaged in floodwater farming, which is also called flood recession agriculture. These farmers closely watched the receding floodwaters so that they could sow their seed at the moment when their bunded fields still contained enough water to form small ponds. Careful management generated agricultural surpluses; visiting Chinese emissaries in the third century reported that the residents of Funan “devote themselves to agriculture. They sow one year and harvest for three.”²²

Scholars associate Funan with the Mekong delta for epigraphic and archaeological reasons;²³ the delta straddles southern Cambodia and southern Vietnam, and archaeologists have recorded sites on both sides of the boundary. Today, the Lower Mekong Archaeological Project (LOMAP) survey region is ideal for the two major rice-farming systems that characterized traditional lowland Cambodian agriculture: rain-fed and flood recession farming. These combined systems together produce sufficiently large yields that the region had one of the highest per-hectare rice yields in the country before geopolitical conflict intensified from 1970 to 1993. Research by the LOMAP in collaboration with Cambodia’s Ministry of Culture and Fine Arts investigated the occupational history of a putative Funan capital (Angkor Borei) and landscape history in this capital’s region: the Takeo River drainage system.²⁴ Two major tributaries carry the Mekong’s river and sediment load south beyond Phnom Penh and into the Mekong delta. The Mekong River meanders through southern Cambodia into Vietnam’s northeastern delta. The Bassac River runs due south through Cambodia to meet the Mekong in Vietnam and enter the South China Sea. Protohistoric (or “Funan”) settlements dot the banks of the Takeo River, a tributary of the Bassac River, in southern Cambodia’s Takeo province.

LOMAP field-survey research in the Takeo River system explored both settlement patterns and human-shaped hydrological features, following the possible identification of canals linking protohistoric “Funan capitals” of Angkor Borei and Oc Eo.²⁵ Two central themes emerged from this research program: (1) protohistoric to pre-Angkorian settlement was structured to maximize returns from nonintensive water management, with a particular emphasis on flood recession farming;²⁶ and (2) Khmers constructed an intricate canal network during this time to facilitate transportation, rather than for canal-based irrigation.²⁷

Figures 2a and 2b use dated sites from the sample to illustrate settlement patterning in the earliest occupation of the region and during the period most closely associated with the protohistoric and “Funan” polity. Settlement locations map closely to access to potential flood recession fields.

The study region remained important during the subsequent pre-Angkorian and Angkorian time periods, as populations filled in areas that required rain-fed agriculture (figs. 3a and 3b). LOMAP research on Cambodia’s earliest state documents a settlement influx into one Mekong tributary (the Takeo River) in the mid-first millennium CE, and the use of multiple

22 Pelliot 1903, 254 (translation from French by the author).

23 Coedès 1968; Ishizawa 1996; Stark 1998.

24 Stark 2001; Stark et al. 1999.

25 E.g., Paris 1931, 1941; Stark 2006b; Stark, Sanderson, and Bingham 2006.

26 Following Fox and Ledgerwood 1999.

27 Bishop, Sanderson, and Stark 2003, 320, 333; Sanderson et al. 2003; Sanderson et al. 2007.

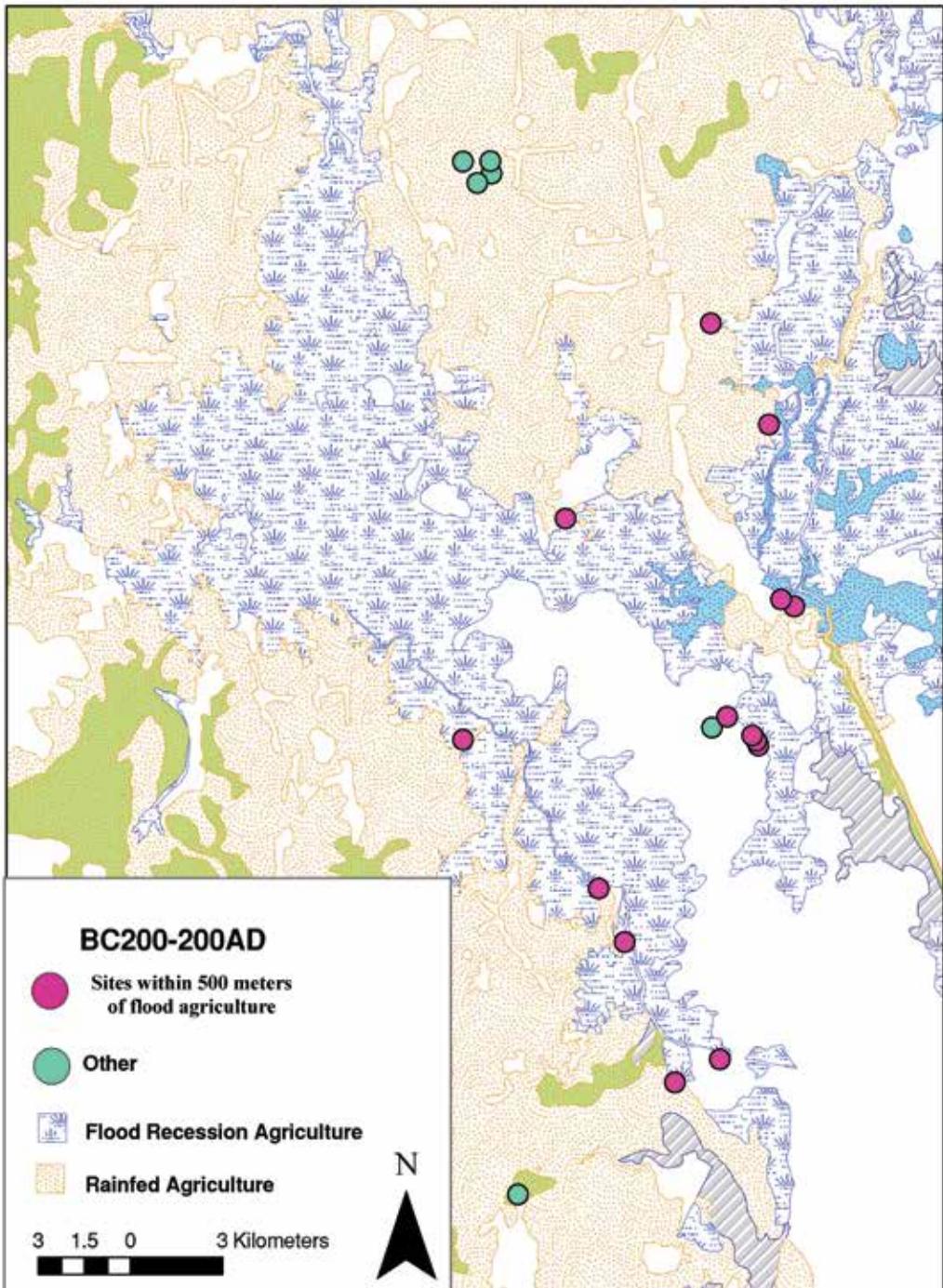


Figure 2a. Northern Mekong delta water management strategies, protohistoric (or early historic) period. Figure by Alex Morrison.

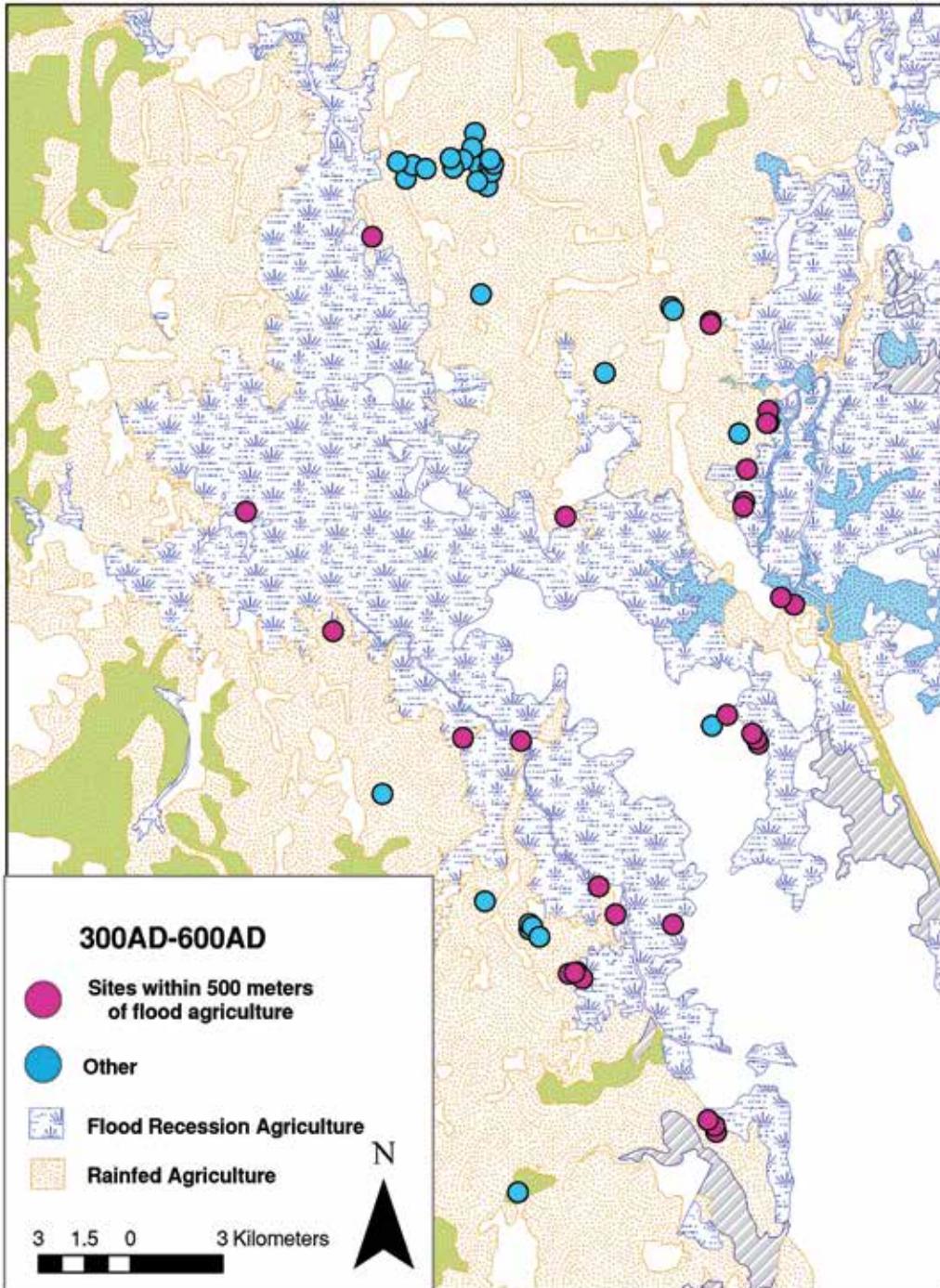


Figure 2b. Northern Mekong delta water management strategies, Funan to pre-Angkorian periods (fourth to seventh centuries CE). Figure by Alex Morrison.

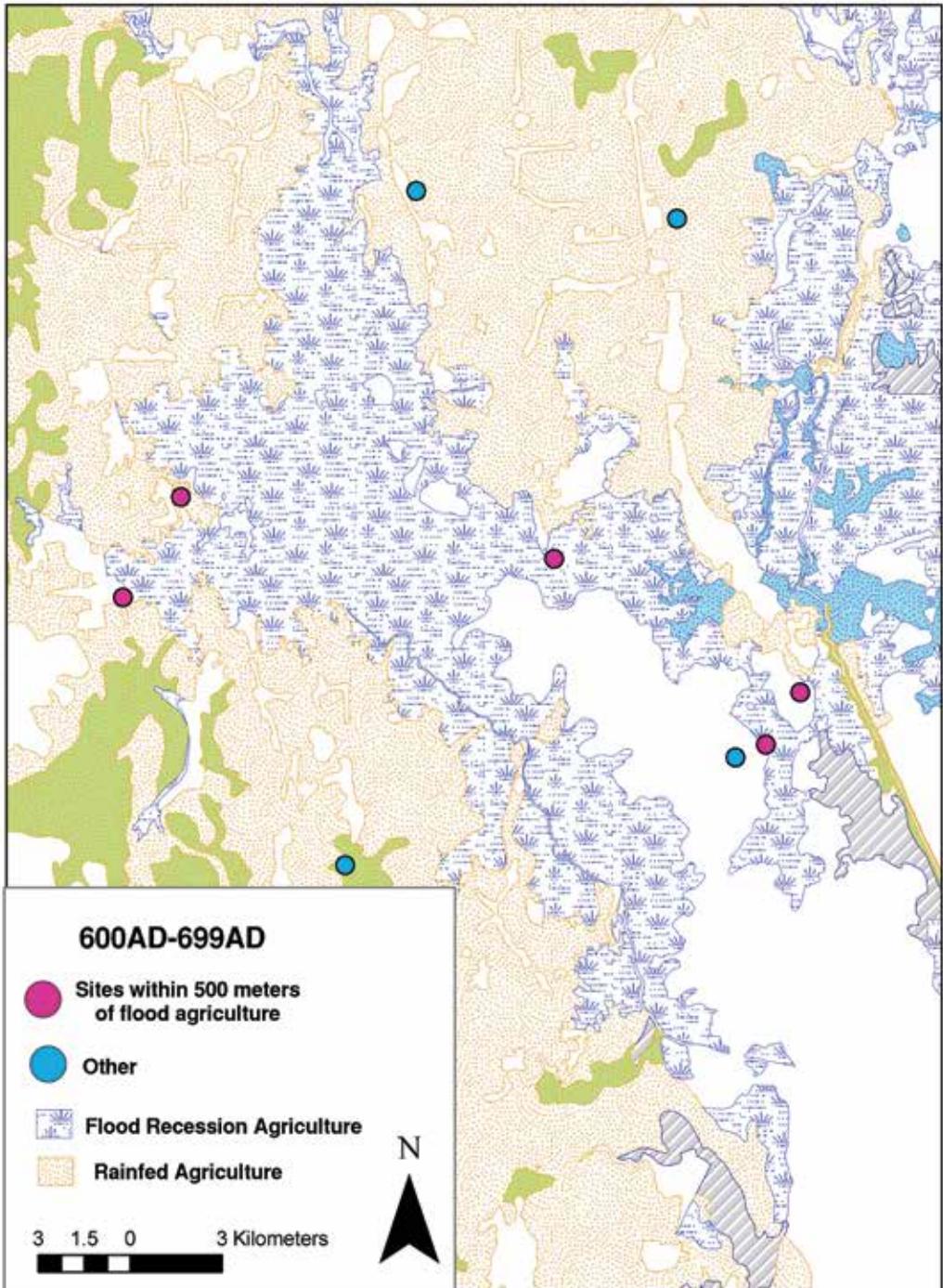


Figure 3a. Northern Mekong delta water management strategies, pre-Angkorian period (sixth to eighth centuries CE). Figure by Alex Morrison.

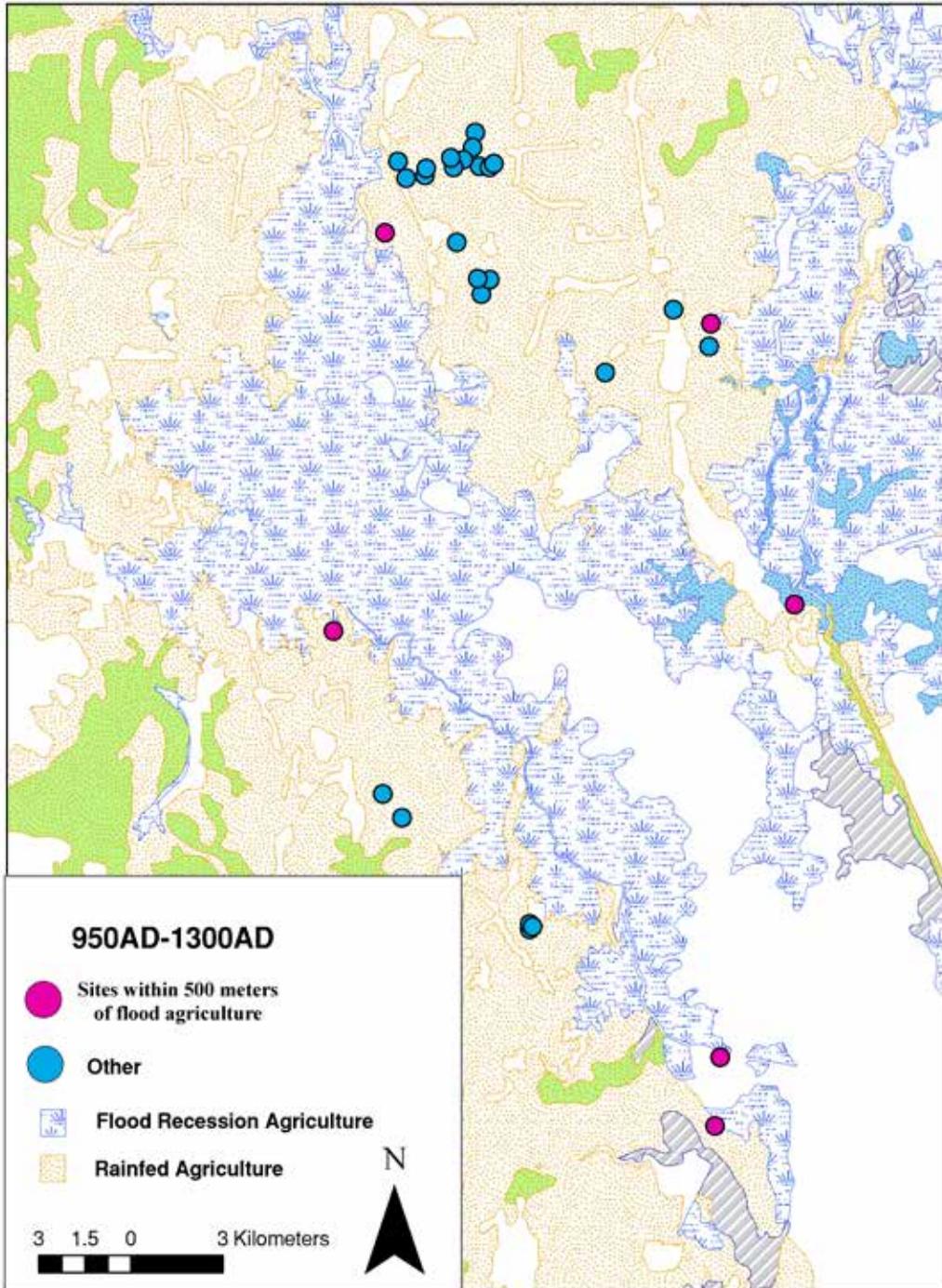


Figure 3b. Northern Mekong delta water management strategies, Angkorian period (tenth to thirteenth centuries CE). Figure by Alex Morrison.



Figure 4. Plowing at the start of the rainy season in Takeo province, southern Cambodia. Photograph courtesy of Nigel Chang.

water management systems (rain-fed and recession agriculture) as the region's population grew over a thousand years. These patterns are resilient, as farmers today and in the recent past have continued to practice multiple cropping strategies in the region (fig. 4).²⁸

The emergence of Angkor Borei and other urban centers throughout the Mekong delta involved land reclamation, canal construction (largely for transportation),²⁹ and a variety of nonintensive farming techniques. Landscape-level studies of ninth- to fifteenth-century Greater Angkor suggests continued use of this typical settlement form outside the urban epicenter.³⁰ Hamlet-level residential clusters were collections of moated households (some of which had ponds), centered on a local moated temple (*prasat*). The temple's large pond (*trapeang*) commonly lay near the main entrance of the complex,³¹ and the complex frequently contained several smaller ponds.³² This pattern withstood the religious transfor-

28 Delvert 1961, map 9; Lando and Solieng 1991, 33–34.

29 E.g., Bishop, Sanderson, and Stark 2003; Sanderson et al. 2003.

30 Castillo et al. 2018; Evans 2007; Hawken 2013; Stark et al. 2015.

31 Pottier 2000, 103.

32 Stark et al. 2015, 1440–44.

mation to Theravada Buddhism and persisted throughout much of the twentieth century in Cambodia³³ and Vietnam's Mekong delta.³⁴ Throughout this period and across religious affiliations, the temple and its water sources formed the core of community interaction.

Farmers can use a multiplicity of water management techniques to cultivate rice in the Mekong delta's floodplains, levees, and back swamps. Whereas Vietnam's Mekong delta creeps southward annually with the river's high sediment load,³⁵ southern Cambodia lies in the delta's more stable upper (northern) portion. Until the 1990s, the chief use of water management techniques in Cambodia's Mekong delta was drainage.³⁶ For these reasons, water management systems that supported the rise of earliest Khmer states drained wetlands and facilitated transportation; canal-based irrigation was likely less important.

Like early states globally, Cambodia's earliest water management systems were non-intensive and relied on flooding to irrigate crops, as was common among Southeast Asian smallholding cultivators in the recent past.³⁷ No convincing archaeological evidence has been recorded to suggest large-scale, state-managed water management of Angkor's agrarian economy. Archaeologists have identified similar strategies in early Mesopotamia,³⁸ the Indus,³⁹ Egypt,⁴⁰ and Anatolia/Çatal Höyük.⁴¹ That this early delta system relied on nonintensive irrigation should come as no surprise, given its high agricultural yields historically. Construction on the delta's earliest canal (the Vinh Te) was begun in 1819 for transportation and to demarcate the Cambodia/Vietnam boundary.⁴² Irrigation canals did not appear in Vietnam's Mekong delta until the French colonial government launched an irrigation canal system as part of its *mission civilisatrice*, beginning around 1880.⁴³

Archaeological knowledge of residential settlement and water management is poorly documented for Cambodia's next, pre-Angkorian period. Work at and around the sixth- to eighth-century site of Sambor Prei Kuk (Kampong Thom province) has documented a complex collection of brick temples, walls, and water management features, most notably ponds and artificial channels, which served as waterways and drainage systems but not as formal aqueducts.⁴⁴ Recent identification of an urban grid underlying Sambor Prei Kuk⁴⁵ suggests the site's rich potential for studying the origins of the ninth- to fifteenth-century CE urban water management that researchers have now documented in the Greater Angkor region.

33 Delvert 1961.

34 Taylor 2014.

35 Gupta and Lieuw 2007, 271; Nguyen, Ta, and Tateishi 2000, 437.

36 Nuttonson 1963, 31.

37 Devendra and Thomas 2002.

38 Algaze 2001; Pournelle and Algaze 2010.

39 Miller 2004.

40 Hassan 1997.

41 Roberts and Rosen 2009.

42 Biggs 2003, 86–87.

43 Biggs 2003, 77–80, 89–91.

44 Heng 2012, 186–89; Shimoda and Shimamoto 2012.

45 Evans 2016, 166–70.

ANGKORIAN WATER MANAGEMENT

By the early first millennium CE, Khmers cultivated arable lands both in the Mekong delta and in regions surrounding the Tonle Sap Lake, the largest and most important freshwater lake in Southeast Asia. During the dry season, this shallow lake is about 120 km long and covers an area of about 2,500 sq km. Flooding that accompanies the rainy season each year expands the lake up to seven times that area (to 17,500 sq km), and its depth reaches 8–10 m.⁴⁶ The Tonle Sap is an intrinsic part of the Mekong River system and one of the world's most productive ecosystems.⁴⁷ Like their neighbors to the west, Cambodia's Khmers incrementally constructed complex and interdependent social landscapes whose large, moated settlements were connected by hydraulic and terrestrial transportation routes.⁴⁸ Understanding why Angkorian Khmers constructed, expanded, maintained, and eventually abandoned their water management system is key to explaining the rise and collapse of the Angkorian state.

In northwest Cambodia, from the ninth through the fifteenth centuries CE, they redirected the Siem Reap River to spare their urban center from flooding and crafted an intricate canal system to form a perimeter around their 1,000 sq km capital (fig. 5). Each major Angkorian ruler constructed one or more temples upon his ascension. Four of Angkor's greatest kings also built huge, above-ground water reservoirs (*baray*) that projected state power, provided reserves for the dry season, and encouraged collective labor for the state. Jacques Dumarçay⁴⁹ identified multiple periods of Khmer water management, from the large basins of the early to mid-ninth century to the development of large *baray* reservoirs with islands; by the early thirteenth century, Angkorian Khmers abandoned *baray* construction and instead relied on smaller water networks. Angkorian engineers had a firm knowledge of water management strategies by the eighth to ninth centuries CE, when they constructed an elaborate system of dikes and dams (including a 3.8 km-long dam at Lolei) to disperse water from Kulen to the lowland Roluos region.⁵⁰ Less than a century later, Angkorian populations moved onto the Central Angkor alluvial plain to site their capital.

The Angkorian capital area was a low-density urban complex that we call Greater Angkor, and it ultimately grew to encompass an area of 1,000 sq km. Its urban core was dense with monumental architecture and residential areas; its periurban periphery intermingled residential areas, infrastructural features, and open agricultural space.⁵¹ Water management was embedded in Angkorian social institutions, serving functional and ideological needs. Angkorian engineers designed structures to protect the urban epicenter and made water available through the massive, above-ground *baray* that each Khmer ruler constructed upon ascending the throne.⁵² Water management legitimated each Angkorian king's rule; each capital had elaborate moats, tanks, and ritual water spaces. No epigraphic

46 Campbell, Say, and Beardall 2009, 252.

47 Kummu et al. 2006.

48 Hendrickson 2010; Stark 2006a.

49 Dumarçay 1994, 373.

50 Chevance, Bâty, and Chantha 2013; see also Fletcher, Pottier, and Johnson 2008, 235.

51 Evans et al. 2013, 12599.

52 Kummu 2009 *passim*.



Figure 5. Map of Greater Angkor (with Lower Mekong Archaeological Project inset). Figure courtesy of Damian Evans.

evidence explains why Angkor's urban planners sited their capital's new location at the northwestern fringe of the Tonle Sap Lake, but this location maximized both agrarian potential and access to water. The Tonle Sap Lake quintuples in size annually with the monsoon rains to cover an area up to 16,000 sq km,⁵³ fertilizing a broad surrounding area whose farmers, like those in the northern Mekong delta, produce some of the country's highest rice yields. By the twelfth century CE, their water management network of dams, dikes, canals, embankments, and reservoirs covered an area of approximately 1,200 sq km.⁵⁴

Deciphering the structure and mechanics of Angkor's water management system has taken more than forty years. Archaeologists now understand its developmental stages and functions. Angkorian engineers divided the region into three zones (fig. 6): a collector zone (to harvest water from the Phnom Kulen watershed), an aggregator zone (to collect water for diversion into the capital's water features and to shunt remaining water away from the city to prevent annual flooding), and a drainage zone southwest of the city to disperse remaining water into riparian wetlands that fringe the Tonle Sap Lake.⁵⁵ The system, which

53 Penny 2006, 310.

54 Kummu 2009, 1419.

55 E.g., Dumarçay 1994; Fletcher, Penny, et al. 2008; Fletcher, Pottier, et al. 2008; Fletcher, Pottier, and Johnson 2008; Kummu 2009.

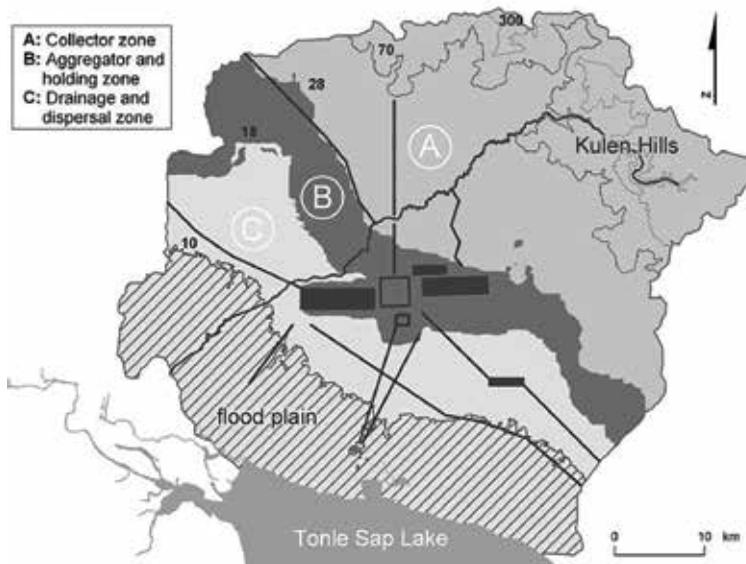


Figure 6. Three water management zones in the Angkor region. Image courtesy of Roland Fletcher and the Greater Angkor Project.

tapped directly into the Phnom Kulen mountains, was designed for efficacy. By modifying the area's two rivers (Puok River, Siem Reap River) as early as the tenth century CE⁵⁶ and constructing a complex system of canals and embankments to direct water flow into the city's temple enclosures and many water features, Angkorian engineers created an urban landscape that Victor Goloubew⁵⁷ described as akin to Venice. Surrounding this epicenter were thousands of villages, many of whose residents were drafted into service for the temples in their capital.

The massive scale of Angkor's hydraulic system has intrigued scholars for more than a century. Each of Angkor's temple enclosures, for example, contained an immense water management system that linked into the city's broader infrastructure of channels and embankments. Angkor Wat is perhaps the most famous of the Khmer empire's monuments; built in the early twelfth century CE by Suryavarman II (1113–1150), the enclosure's outer wall is 1,024 m × 802 m long and 4.5 m high and encloses a space of 820,000 sq m (203 acres). Bernard-Philippe Groslier estimated the capacity of its moat at circa 5 million m³. Khmer workers transported metric tons of sandstone from quarries to the capital for architectural construction projects;⁵⁸ millions of cubic meters of water flowed through the canals that threaded into and through Greater Angkor (fig. 7). No convincing evidence has yet been found, however, that these same canals were designed primarily to irrigate fields.⁵⁹ The dimensions of Angkor's giant urban tanks, or *baray*, increased from the ninth through the twelfth centuries, fed directly through rainfall and a channel network that tapped into

56 Lustig 2012, 209.

57 Goloubew 1941, 5.

58 Evans et al. 2007, 14280.

59 E.g., Evans 2007, 210.



Figure 7. AIRSAR image of part of the Angkorian water management system, looking west and including the West Baray. Image produced by Ian Tapley and courtesy of the Greater Angkor Project.

natural rivers.⁶⁰ A Buddhist advisor of Rajendravarmān II directed the construction of the relatively small Srah Srang reservoir, measuring approximately 700 m × 350 m (fig. 8). Few contemporary urban centers elsewhere in Southeast and South Asia included comparably large urban reservoirs, except perhaps the ninth- to eleventh-century CE Sri Lankan capital of Anuradhapura.⁶¹ Locations of the largest *baray* are included in figure 5, and table 1 lists the dimensions and capacities of the four largest completed Angkorian *baray*. Two of the largest, the East Baray and West Baray, measured more than 7.5 km in length and about 2 km in width; their construction required up to 150,000 workers during a three-month period.⁶² At least some were used by a succession of rulers after their initial construction, such as the eleventh-century West Baray, and the managerial requirements were sufficiently complex to crumple under climatic unpredictability.⁶³

We know more about the timing and mechanics of the construction of Angkor's water management system than we do about its administrative logic.⁶⁴ Angkorian-period Khmer-language inscriptions offer no details about the water management system with its roads, channels, and tanks.⁶⁵ Bernard P. Groslier, the doyen of colonial Angkorian research,

⁶⁰ Kummū 2009, 1416.

⁶¹ Gilliland et al. 2013.

⁶² Pottier 2000, 106, 115.

⁶³ Penny et al. 2005, 499.

⁶⁴ Evans 2014; Fletcher, Penny, et al. 2008, 65.

⁶⁵ de Bernon 1997, 341–42; Lustig 2009, 112.



Figure 8. Srah Srang reservoir as an example of a large Angkorian pond. Photograph courtesy of Diego Delso, Wikimedia Commons, License CC-BY-SA 3.0. https://en.wikipedia.org/wiki/File:Srah_Srang,_Angkor,_Camboya,_2013-08-16,_DD_08.JPG.

Table 1. Major reservoirs (*baray*) at Angkor (from Acker 1998, 11)

Name	Date built (CE)	Length (m)	Width (m)	Depth (m)	Area (ha)	Capacity (thousands sq m)
Indratataka	ca. 880	3,200	750	3	240	7,200
East Baray	ca. 890	7,000	1,800	4.3	1,260	54,180
West Baray	ca. 1040	8,000	2,100	9.3	1,680	156,240
Jayatataka (Preah Khan Baray)	ca. 1190	3,700	900	3	333	9,990

proposed what Philip Stott⁶⁶ calls “the hydraulic paradigm,” arguing that the system was administrated from the top down, in Wittfogelian form. First articulated in the mid-1960s, Groslier⁶⁷ contended that Angkorian water management, as a collective enterprise, required centralized control by a strong ruler. This pattern began with the late ninth-century

⁶⁶ Stott 1992.

⁶⁷ Groslier 1966, 74.

rule of Indravaraman I⁶⁸ and continued until the mid-twelfth-century “death” of the hydraulic city at the end of the reign of Jayavarman VII.

Occasionally acrimonious debate continues regarding the precise mechanics of Angkorian irrigation systems,⁶⁹ and particularly about the role of the reservoirs (*baray*) in irrigating agricultural fields. Groslier⁷⁰ believed that the *baray* (and its associated hydraulic features) buffered the population against climatic unpredictability. In his model, Angkorian engineers released water from the *baray*'s southwestern corner during the dry season and irrigated as much as 600 ha of rice fields southwest of the city. Rice from these fields could support up to 148,000 residents. Christophe Pottier's⁷¹ synthesis identified a potential outlet (a breach with a pipe and sluice) in the tank's southwest corner, a sophisticated hydraulic system (with multiple canals), and an orthogonal field pattern that may have been the irrigated area. Both field-based archaeological research and remote-sensing strategies are essential to improving our understanding of the Angkorian water management system and of how Khmers negotiated a dynamic tension between the cosmological imperatives of public works and the operational needs of a functioning system.

Some scholars, like Dumarçay,⁷² directly attribute the collapse of the Angkorian state to the late thirteenth-century shift in hydraulic management away from the large *baray* reservoirs and toward locally managed water features. Historically speaking, however, the Angkorian state-sponsored water management system was an anomaly in Khmer water management traditions. Most Angkorian farmers grew their crops without the benefit of canal-based irrigation across the Angkorian polity, even as its geographic reach waxed and waned through time. Recent work on Greater Angkor's sequentially constructed field systems, as well as Angkorian epigraphy,⁷³ suggests urban agrarian long-term resilience. Local-level agrarian systems likely changed little throughout six hundred years of Angkorian rule and the collapse of the capital's hydraulic network. What varied was the scale of state demands on rural farming communities.

The essentially rural character of Cambodia's premodern economy explains why most water management operated at the local level.⁷⁴ The logic of Khmer water management paralleled the logic of its tiered settlement organization. Family-based hamlets aggregated into village-level communities; both centered on religious shrines—in larger communities, on temples—and the elite network that supported religious practices at these communal ritual locations. Participatory governance centered on the community and the local temple; direct state intervention at this level was rare, except in economic terms. The Angkorian state extracted taxes and tribute for the capital but, with few exceptions, relied on a system

68 Groslier 1974, 99.

69 E.g., Acker 1998, 2012; Bronson 1978; de Bernon 1997; Evans 2007; Pottier 2000; Stott 1992; van Liere 1980.

70 Groslier 1979.

71 Pottier 2000, 107–12.

72 Dumarçay 1994, 387.

73 E.g., Hawken 2013; Lustig 2009.

74 See also Sedov 1978, 118.

of decentralized production.⁷⁵ Angkor's large-scale hydraulic system emerged many centuries after the establishment of social stratification and the emergence of kingship. This pattern also characterizes much of premodern East and Southeast Asia, where scholars have documented the construction of large-scale, state-sponsored hydraulic works on a foundation of local-level water management systems.⁷⁶ The extent and nature of state control of Angkor's water management system still puzzles researchers, and few scholars have examined fully the role of cosmology and religious ideology in the operation of this system. Doing so requires some discussion of water in Khmer cosmology and culture, which begins with a discussion of Khmer origins.

ORIGINS, COSMOLOGY, AND WATER IN THE ANCIENT KHMER WORLD

Southeast Asian luminaries like George Coedès⁷⁷ and Robert von Heine-Geldern⁷⁸ were among the first to emphasize the close linkage between cosmology and water across Indic Southeast Asia; Paul Mus⁷⁹ argued that these similarities arose from a common pre-Indic base. Current scholarship suggests that mainland Southeast Asians welcomed a succession of South Asian religious ideas, goods, and people by the first century CE (perhaps even earlier) and throughout the first millennium CE. Brahmanical beliefs may have preceded Buddhist ideas in peninsular Southeast Asia.⁸⁰ Buddhism also flourished in South Asia under fourth- to sixth-century CE Gupta and Vakataka patronage and was compatible with trade that took place between South Asia and Southeast Asia.⁸¹ By the sixth century CE, the Chinese considered Cambodia a great center of Buddhism.⁸² A wealth of archaeological research in the past three decades has documented the timing and directionality of these processes.⁸³

WATER, NĀGAS, AND THE COSMOLOGY OF ORIGINS

Khmer traditions past and present merge Hindu and Buddhist ideologies with indigenous beliefs,⁸⁴ and water looms large in Cambodia's origin story. Recorded in tenth-century Chinese sources and Khmer inscriptions and in nineteenth-century Cambodian royal annals,⁸⁵ the Khmers call the serpent (*nāga*) princess *Nāgī Somā* (or *Neang Neak*) and the prince *Preah Thaong* (or *Kaundinya*); the Chinese annals call her Liu-ye and him Hun-tian.

75 For decentralized stoneware ceramic production, see Grave et al. 2021 and Marriner et al. 2018. Iron production is the lone documented exception to this pattern, at least at the site of Preah Khan Kompong Svay (e.g., Hendrickson et al. 2019).

76 E.g., Kang 2006.

77 Coedès 1944.

78 von Heine-Geldern 1942.

79 Mus 1933 (2011).

80 Jacq-Hergoualc'h 2002, 97.

81 Ray 1994.

82 Pelliot 1903, 284–85.

83 E.g., Bellina and Glover 2004; Carter 2015; Manguin, Mani, and Wade 2011; Stark 2006a.

84 E.g., Harris 2005.

85 Coedès 1952, 1968, 37–38; Gaudes 1993; Népoté 1999.

He is a prince from a distant land and a Brahmin, either expelled or compelled to travel to this region. In some accounts a battle ensues, initiated by either the local *nāga* princess or the foreign prince, and Preah Thaong's troops defeat those of Nāgī Somā; in other accounts, the two fall in love immediately. In all versions they marry, and the bride's father "drinks the water" from the surrounding flooded lands so they can found their dynasty. Reenacting this story is intrinsic to every traditional Khmer wedding ceremony.⁸⁶

Central to the story is the serpent or *nāga* princess and her family, who are the original Khmers. In South Asia, the term *nāga* (Sanskrit for *serpent* or *snake*) refers to nature or tutelary spirits linked to places such as springs, rivers, and other water bodies. Nāgas, which Buddhist texts note were converted to Buddhism, were both feared and respected; if angered, they could wreak environmental havoc by withholding monsoon rains or causing excessive flooding.⁸⁷ Like the *neak ta* spirits that the Khmers worship, these *nāga* spirits required veneration and propitiation. By the mid-first millennium CE, Southeast Asians inscribed Indic-derived ideas into their physical, social, and ideological landscapes in uniquely Southeast Asian form.

Sacred sites across the landscapes reflect a blend of indigenous and Hindu or Buddhist beliefs, and stone stelae from these sites are inscribed with both Khmer and Sanskrit texts.⁸⁸ Indic gods, both Brahmanic and Buddhist, took uniquely Southeast Asian forms; the Khmers drafted their alphabet from a Brahmi alphabet. Khmer architects built shrines, temples, and ashrams of brick, sandstone, and—later—laterite to house Indic statues and their caretakers, including reclusive hermits, royally sanctioned priests, and vast entourages of temple support staff. The formal consistency across Khmer temples suggests adherence to steps prescribed in Mauryan-period Indian texts (e.g., Kautilya's *Arthaśāstra*) that outlined appropriate economic, political, and ritual practice.⁸⁹ Some of these practices involved sacred water, like the Brahmanical practice of daily libations for the ancestors (*pitṛarpanam*) recorded in a seventh-century Sanskrit inscription.⁹⁰

Water, and the *nāga* water world, are key elements of the ancient Khmer worldview. Nāgas were protectors of sacred knowledge, and they offered protection against illness and epidemics. Angkorian-period iconography is rife with *nāga* imagery: at the ends of balustrades lining causeways that people used to cross temple moats, as finials on religious architecture, as decorations around large water tanks, and on Angkorian bridges that linked localities into a single Angkorian world (fig. 9). Angkorian texts do not articulate the relationship of the *nāga* to Khmer rulership, though Angkorian rulers were expected to provide for their people. First-millennium CE southern Indians believed that the king held a close relationship with the *nāga* and that the *nāga* could withdraw support if the king did not ensure the prosperity of the kingdom.⁹¹ In Chinese visitor Zhou Daguan's thirteenth-century account of the customs of Cambodia, he noted that a powerful genie (who assumed the form of a *nāga* princess) slept with the king each night to ensure the

86 Stark 2006c, 307–08.

87 Shaw 2004, 18.

88 Stark 2015.

89 Lustig 2009, 22.

90 Sanderson 2003, 386–87.

91 Shaw 2004, 18.



Figure 9. Nāga feature at end of balustrade, Preah Vihear temple, Cambodia. Photograph courtesy of Ea Darith.

health of his kingdom. Doing otherwise would have brought rack and ruin to the polity, and an end to the king's rule.⁹²

Jean-Pierre Gaston-Aubert notes that by the tenth century CE, the Khmer religious pantheon also included Buddhist images with supporting nāgas, perhaps brought in from neighboring Dvaravati Thailand (with original inspiration from Andhra Pradesh, in south India).⁹³ Angkor's last great king, Jayavarman VII, elevated the Nāga Buddha to Supreme Deity status by the emergence of the Bāyon period of the late twelfth–early thirteenth centuries CE. Like other pre-Angkorian and Angkorian Indic art traditions, the Nāga Buddha art style represents a uniquely Khmer tradition that may reflect indigenous Khmer beliefs regarding their origins and the role of their nāga princess.⁹⁴

WATER AND THE COSMOLOGY OF RITUAL SPACE

Three Indic religions structured the pre-Angkorian and Angkorian worlds: Śaivism, Pūficarātrika Vaiṣṇavism, and Mahāyāna Buddhism. Stone inscriptions installed in Indic temples included Sanskrit verses that extolled deities and religious works; only religious

⁹² Zhou 2007, 49.

⁹³ Gaston-Aubert 2010.

⁹⁴ Gaston-Aubert 2010, 137.

buildings were constructed of nonperishable brick or stone to house Indic images. Temple complexes were crafted as cosmograms of the Indic universe, replete with a central continent of Jambudvīpa (the temple foundation) upon which Mount Meru rose to house the Indic gods (the pyramid temple) and the surrounding oceans (construed as moats). That Angkorian temple architecture adhered to clear mathematical formulae is exemplified by research at Angkor Wat.⁹⁵ Angkorian architects also imbued Angkor Wat with astronomical significance. Observers on the temple's western causeway can see the sun rise directly over the central tower on the day of the spring equinox.⁹⁶ Angkor Wat's status as a temple of Vishnu (the Hindu god who presides over solar-related deities) may explain its westward orientation, which is unusual among Hindu temples, most of which face eastward. In her exhaustive correlation of Angkor Wat's metric dimensions with Hindu cosmology, Eleanor Mannika concludes that Angkor Wat resembles a mandala of deities and an example of cosmological architecture.⁹⁷ Variations of the Hindu temple grace Greater Angkor's major monuments; although the temple form was uniquely Angkorian, South Asian Hindus would recognize architectural components.⁹⁸

How Indic architectural knowledge reached Angkorian Cambodia remains unclear. Art historians have convincingly argued that Indian monks brought both Buddhist ideas and objects from their homeland to mainland Southeast Asia⁹⁹ and that Angkorian Khmer elites wore textiles from South Asia.¹⁰⁰ Temple construction protocol, clearly articulated in Indian texts,¹⁰¹ seems to have guided Angkorian temple building. Recent lidar work identified the grids atop which Angkorian temples were constructed,¹⁰² and field investigations confirmed their structure.¹⁰³ Angkorian Khmers materialized this cosmology in their daily practice; cosmology also guided their construction and use of water systems on a grand scale:

Selon le point de vue où l'on se place elle nous apparaît tantôt comme l'évocation matérielle d'un vaste concept religieux, pénétré d'éléments cosmomagiques, tantôt comme la réalisation d'un programme technique utilitaire, conçu par d'habiles specialists.¹⁰⁴

Archaeological research documents how Indic religion and water were inscribed into the Angkorian landscape,¹⁰⁵ from small rural hamlets to the great city of Angkor Thom, Jayavarman VII's crowning achievement.¹⁰⁶ Each temple enclosure had its own hydraulic infrastructure, with moats, ponds, and possibly gardens.¹⁰⁷ Water management not only

95 Mannika 1996.

96 Stencil, Gifford, and Morón 1976, 281.

97 Mannika 1996, 266.

98 Sahai 2012.

99 Brown 2011.

100 Green 2000.

101 Kramrisch 1946.

102 Evans et al. 2013; Fletcher et al. 2015.

103 Stark et al. 2015.

104 Goloubew 1941, 3.

105 E.g., Groslier 1979, 110–14.

106 Gaucher 2004, 78–82.

107 Evans et al. 2013, 12596.

provided clean drinking water but was also epitomized in the lotus flower and its iconography, which decorates myriad Angkorian walls. This water management also created lush spiritual spaces for the gods and their human attendants, including the Angkorian ruler.

Distinguishing pragmatic from ritual function in the large *baray* reservoirs is particularly vexing; on the one hand, they served as giant collective temple mounds, not entirely unlike those used more recently in Buddhist pagodas. The term *baray* is not found anywhere in the epigraphic corpus.¹⁰⁸ Some scholars, like George Coedès,¹⁰⁹ argue that Angkorian Khmers viewed *baray* as sacred, akin to Prayâga (or Prayag, Allahabad in northern India), where the Yamunâ and Ganges Rivers join and Hindu pilgrims come to pray, cremate their dead, and scatter their ashes on the water. In his model, three bodies of sacred water (*tīrtham*) were the West Baray (Vishnu), the East Baray (Yasodharatātāka—Siva) and Preah Khan Baray (Jayatatāka—Buddha). French scholars reported that one pit in the central platform in the West Mebon temple (in the West Baray) had the shape of an inverted linga, with a consecration deposit at its base,¹¹⁰ and inscription K. 259 describes the East Baray as a *tīrtha* or sacred place.¹¹¹

The late twelfth- to early thirteenth-century island temple called Neak Pean exemplifies the cosmology of water management (fig. 10). *Neak* refers to *nāgas*, and *pean* means “entwined”: two entwined *nāgas* surround the central temple and face east in this reservoir, called Jayatataka or the Preah Khan Baray. Jayatataka was the last great reservoir built by Angkorian kings, and it may have held as much as 4.5 million m³ of water.¹¹² Four square basins surround the small central temple, which houses an image of the Boddhisattva Avalokiteshvara, the Buddha of compassion. Each basin houses an image derived from the Khmer humoral system of medicine (also called the doctrine of the four elements): elephant (water), human (earth), lion (fire), and horse (wind). Each of these four images has a spout that pours water into the basin, and French colonial scholars suggested that Neak Pean represented the sacred Buddhist Lake Anavatapta, where pilgrims rebalanced their four elements through bathing in its waters.¹¹³

Angkorian Khmers expected their rulers to bring prosperity, which at a minimum meant a secure supply of water to produce food.¹¹⁴ Religion and rule intertwined; kings included gurus and priests in their courts and as their teachers; and a king's rule was judged partly by his activities in founding and supporting state temples and hermitages throughout his domain. One particular guru to Suryavarman II, Divâkarapandita, was tasked with visiting five different sacred sites (including Preah Vihear and Phnom Sandak) to establish hermitages with staff, supporting villages, and an endowment. Building a reservoir was intrinsic to this process.¹¹⁵ Successive generations of Angkorian rulers sought to transform Greater Angkor into a truly imperial landscape. Certainly by the mid-twelfth century

108 de Bernon 1997, 342.

109 Coedès 1941, 257–58.

110 Penny et al. 2005, 499.

111 Sanderson 2003, 431 n. 295.

112 Dumarçay 1994, 380.

113 Finot and Goloubew 1923.

114 Lustig 2009, 73.

115 Sanderson 2003, 420.



Figure 10. Neak Pean temple, Angkor Archaeological Park.
Photograph courtesy of David Brotherson.

CE, the increasingly dense and interdependent web of channels, embankments, dikes, and reservoirs that defined Greater Angkor began to falter. The end of Jayavarman VII's reign less than a century later signaled the beginning of what Groslier called the "death" of the hydraulic city.¹¹⁶

WATER, COSMOLOGY, AND ANGKOR'S "COLLAPSE"

In both pragmatic and cosmological respects, water management played a central role in the collapse of Angkor's capital. Prosperity, in the form of water, flowed from the Phnom Kulen mountains northeast of the Angkor plain during years of average rainfall.

That the Khmers recognized the watershed's importance is clear in their sacralization of the Phnom Kulen water sources, including the Kbal Spean, which flowed into the Puok River, which fed areas west of the epicenter (fig. 11). If Dumarçay¹¹⁷ is correct, then the earliest change in the water management system occurred in the thirteenth century when the state moved from using large reservoirs to relying instead on canals and embankments for trapping and moving water across the landscape. A series of sustained droughts (or "megadroughts") may have begun less than a century later;¹¹⁸ their severity climaxed in the fourteenth and fifteenth centuries.¹¹⁹ Each bad rainy season weakened the

116 Groslier 1979, 187.

117 Dumarçay 1994, 373.

118 Day et al. 2012.

119 Buckley et al. 2010; Penny et al. 2005, 497.



Figure 11. Kbal Spean, one of the Phnom Kulen water sources for the Angkorian plain. Photograph courtesy of Charmaine Wong.

operation of Angkor's vast water management network, prompting ad hoc modifications; many of these fixes produced combinations of operational constraints¹²⁰ that resulted in an increasingly vulnerable system.¹²¹ As the state-sponsored hydraulic system that ordered the Angkorian cosmos and provided an ecological buffer faltered, so too did the ideological legitimacy of its rulers.¹²² By the mid-fifteenth century, the center of Khmer political gravity moved south to the first of a series of post-Angkorian capitals, which ultimately included the current capital of Phnom Penh.

Angkor's "collapse" was political and involved the abandonment of a state-sponsored hydraulic infrastructure, perhaps parallel to the collapse of the Sri Lankan capital of Anuradhapura.¹²³ This political and infrastructural collapse was not, however, accompanied by an abandonment of Greater Angkor, as several recent studies indicate.¹²⁴ Recent archaeological research identifies fourteenth- and fifteenth-century use of key temple enclosures

120 Fletcher, Pottier, and Johnson 2008; Lustig 2012.

121 Buckley et al. 2010, 6749; Evans et al. 2007, 14281.

122 Sedov 1978, 114.

123 For Angkor, see Stark 2019; for Sri Lanka, see Gilliland et al. 2013, 1026.

124 E.g., Carter et al. 2019; Castillo et al. 2018; Penny et al. 2019.

such as Angkor Wat,¹²⁵ the reconstruction of the Baphuon into a Theravada Buddhist monument,¹²⁶ and a range of fifteenth- and sixteenth-century activity¹²⁷ that suggests continued use of the region, rather than wholesale abandonment. Rural communities within Greater Angkor and around the Tonle Sap Lake continued to function after the political capital moved south.¹²⁸

CLOSING THOUGHTS

Just as water poured on a hill
flows down and around it, sustaining the land all around,
so a gift from here benefits ghosts in precisely the same way.

—Tirokudda Sutta (Pali) text (Davis 2009, 167)

Cambodia offers ample material for the archaeological and anthropological study of water management over more than 1,500 years: the structure and function of systems, their relative resilience, and their cosmology. For generations, Cambodia's Khmers blended practical and cosmological considerations in their hydraulic engineering projects. More than a millennium before the earliest-documented Khmers appear in the archaeological record, farmers aggregated into large settlements whose moats (or "irregular earthworks"¹²⁹) formed the earliest-documented water control in the Lower Mekong region.¹³⁰ By 500 BCE, farmers settled along the edges of the northern Mekong delta's floodplain to capture receding floodwaters for their crops; they surrounded their shrines with moats, dug ponds in every hamlet, and supplemented their riverine network with canals to connect communities and facilitate commerce. The Lower Mekong was frequently a watery world.

Water was also an important element in the order of the Khmer universe, and Angkorian rulers recreated this order by constructing what was ultimately a complex system of water management in the state's epicenter. As in neighboring Sri Lanka,¹³¹ cosmological imagery served as one of several "texts" that organized Angkorian space. Dynastic histories and institutionalizing religions, inscribed in sixth- to eighth-century pre-Angkorian landscapes across Cambodia and southern Laos, provided a foundation on which Khmers constructed their Angkorian world. The system protected the capital and offered an ecological buffer against short-term climatic stress. That it neither formed the foundation of

125 Carter et al. 2019; Stark et al. 2015.

126 Leroy et al. 2015.

127 E.g., Polkinghorne, Pottier, and Fischer 2013.

128 Penny et al. 2019. For a Near Eastern example, see Wilkinson and Rayne 2010, 140.

129 Williams-Hunt 1950.

130 Boyd and Chang 2010; Hawken 2013; Moore 1988a, 1988b, 1992, 2000.

131 Coningham 2000.

Angkor's economy nor represented a form of authoritarian social engineering¹³² makes it comparable to contemporary systems in medieval South India.¹³³

Whether the authoritarian water management system that the Khmer Rouge engineered from 1975 to 1979 has its roots in a notion of the Angkorian hydraulic city remains a question of some debate.¹³⁴ Certainly the French colonial administrators, who built ultimately unsuccessful irrigation programs, were inspired by Groslier's ideas.¹³⁵ Angkor's monumentality resonated with the Khmer Rouge who followed, and Pol Pot announced in 1977, "If our people were capable of building Angkor, we can do anything."¹³⁶ In the three and a half years that the Khmer Rouge ruled Democratic Kampuchea, millions of Cambodians participated in large-scale water management construction (including irrigation canals and reservoirs) throughout Cambodia's Lower Mekong basin.¹³⁷ Built along Universal Transverse Mercator lines to service 1 ha rice fields,¹³⁸ these canal systems are still visible in satellite imagery; their forced-labor construction was responsible for countless deaths, yet some remain in use today. The Khmer Rouge regime lasted less than four years, but managing Cambodia's water at the local and broader levels remains salient today.

Angkorian art, epigraphy, and architecture collectively reflect a deep-seated familiarity with Indic cosmology and political ideology, whose earliest expressions are well dated to the sixth century CE across much of the Lower Mekong basin.¹³⁹ Angkor's mammoth reservoirs and its convoluted hydraulic system of canals continue to fascinate scholars and provoke debate regarding its construction history, function, and administration. I have traced long-term patterns in Lower Mekong water management in this chapter to illustrate how Angkor's agrarian foundations, like those of its predecessors and successors, likely rested on the backs of local rural farmers and their communities. It was through these agents that nonintensive water management systems of household ponds, temple pools, and farming systems were built and maintained to accommodate changing monsoon climates through the millennia. That Angkor's state-sponsored water management system in its capital persisted for centuries attests to the tenacity of its rulers. Continuities in rural settlement in communities around the Tonle Sap region after the collapse of Angkor attest to the resilience of the local-based water management structure.

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132 E.g., Scott 1998.

133 E.g., Stephen 2008.

134 Evans 2007, 107–15.

135 Groslier 1966, 1974.

136 Chandler 1993, 13.

137 Tyner and Will 2015.

138 Martin 1981, 16 and fig. 2.

139 E.g., Brown 2011; Lavy 2014; Stark 2006a, 2006b.

Damian Evans, Dan Penny, Roland Fletcher, Matti Kummu, Eileen Lustig, Christophe Pottier, Martin Polkinghorne, Mitch Hendrickson, and Scott Hawken. Conversations with Heng Piphah, Robert Acker, Michael Vickery, Ea Darith, and Paul Lavy have greatly enhanced my understanding of Khmer water management and political economy. Thanks also to Jonathan Padwe for sharing rice yield figures with me. I am grateful to Alex Morrison, Nigel Chang, Charmaine Wong, and David Brotherson for sharing their graphics with me. All weaknesses in this chapter remain my own.

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15

World-Encircling River

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IN THE SEMIARID environment of southern Mesopotamia, rainfall was hardly the most obvious source of life-giving water. Instead, it was necessary to rely on what we call groundwater, the *apsû*, which lay beneath the earth's surface and into which wells could be dug to obtain water for palm groves and vegetable gardens. For wheat, barley, and other crops, advantage was taken of the great rivers that flow through the Mesopotamian floodplain and that could be controlled and channeled to provide water for irrigation. This chapter explores the cosmological concepts generated by ancient Mesopotamians to explain the origins of these precious water sources upon which their lives literally depended.

Given the importance of irrigation water for southern Mesopotamia, it is hardly surprising that, in the Babylonian Epic of Creation (*Enūma eliš*) and in late commentary texts, the formation of the two great rivers that encircle the Mesopotamian alluvium is attributed to the Demiurge Marduk himself. The basis for that creation was the corpse of Marduk's ultimate ancestress, Tiamat. This primordial creature is well known as a creator of monsters opposing the gods in cosmic conflict in a vain attempt to prevent the creation of the world we know and of human beings to inhabit it. Cosmologically speaking, however, she was a cosmic earth-and-water mixture¹ known in later Achaemenid creation accounts as *bumi*.² In short, Tiamat represents the materials for creation actively resisting their use for that purpose. A remnant of Tiamat's cosmic waters left over from creation formed the marshlands of southern Mesopotamia, a rich source of fish and fowl. This was still a mud-water mix from which new land could be artificially precipitated, and was correspondingly called Mat Tamtim ("Sealand") despite being largely freshwater.

Only the upper, purer half of Tiamat was needed for Marduk's creation of the heavens, leaving the lower half to provide the raw material for the creation of that earth inhabited by humans. With his mighty hands, Marduk raised up the mountains that ring the Mesopotamian floodplain to the north and east, thus confining the rivers to their current courses, and poured out dry land between them, being ever careful to make room for springs,

1 Lambert 2013, 44–47.

2 Lincoln 2007, 53.

wells, and catchwaters in the process.³ In late commentary texts, the Tigris and Euphrates are correspondingly described as the eyes of Tiamat.⁴

But what, Sumerians wondered, was the ultimate source of this life-giving water that flowed past the cities of the floodplain into the marshes, providing water for irrigation and ensuring the marshlands' continual renewal? Their answer was fascinating, if counterintuitive. The island of Dilmun (Bahrain) was famous in antiquity for its freshwater springs that are fed through channels under the Persian Gulf, bubbling up at several points off the coast as well as in springs on land.⁵ Similar freshwater springs underlie the Mediterranean off the island of Arwad, as mentioned by Strabo.⁶ According to Sumerian legend,⁷ both the Tigris and the Euphrates had their sources in these fountains of Dilmun. Sumerians understood this relationship as one of a constant interchange of waters in which the rivers drank via this underground channel from the fountains of Dilmun and then flowed back into Enki/Ea's *apsû*.⁸

This motif of Enki/Ea at the source of the rivers is depicted on Mesopotamian cylinder seals in a number of different forms. The god with his high crown and long beard may always be recognized by the double streams, sometimes with fish in them, that flow from a vase or vases in his hands and rise above and over his shoulders on either side.⁹ Sometimes we see him enthroned in his *apsû*, represented as a double-braided stream that surrounds him on all four sides.¹⁰ At other times, he appears enthroned above the *apsû*, represented by a collection of flowing vases that directly connect from below to Enki/Ea's flowing riverine vases.¹¹ Finally, Enki/Ea also appears standing, grasping his vases whose flowing, fish-filled streams connect below his feet to two water gods (fig. 1). These latter are shown

3 Ee V 53–58; Talon 2005, 58; Horowitz 1998, 118–19. Pace Horowitz (1998, 117), Marduk does not create *ex nihilo* the waters above and below the earth, nor indeed anything else. It is Aššur (Anšar) and not Marduk who, in the *Enūma eliš*, has the power to “create and to destroy.” Marduk can, at best, recreate what he has already destroyed. He is thus not a creator but a recreator and rearranger. Yet he makes wondrous weapons from preexisting materials, rearranges Tiamat into the world that we know, and commissions humankind's creation. These are truly marvelous things, and it is high time we stopped having to make false attributions to Marduk because his actual accomplishments do not measure up to our ideas of what a creator god ought to be able to do. Or, to quote the most beautiful of Shakespeare's sonnets: “And yet I find my love as fair, as any I belied by false compare.” For a discussion of Marduk's limitations, see Scurlock 2013a, 266–67.

4 Livingstone 1989, no. 39 rev. 3.

5 Arabs surmise that this water comes from the Euphrates, going underground in the marshes to pass via underwater channels to Bahrain. Pliny makes similar claims for springs in South Arabia (Albright 1919, 184–85).

6 Strabo, Geography 16.2.13.

7 Horowitz 1998, 104–5; George 2003, 1:520–21.

8 Enki is the Sumerian name and Ea the Akkadian name of a divinity who, besides being lord of the *apsû* (sweet water), was a sort of Prometheus figure who rescued the Babylonian Noah from the Great Flood and taught humanity arts and crafts through the mediation of the Babylonian sage Adapa. It was also he and not Marduk who created humankind.

9 For flowing vases as symbolic of the sources of rivers in Egypt, see Albright 1919, 174.

10 Black and Green 1992, 27, fig. 19; Parrot 1960, 193, fig. 240. Behind Ea kneels a Laḫmu-abzu gate-guardian holding the floor bolt of the *apsû*.

11 Black and Green 1992, 139, fig. 115.



Figure 1. Seal impression with Enki/Ea holding his vases and standing on the *apsû* (Parrot 1960, 309, fig. 383).

foot to foot, forming a sort of watery boat that dips beneath the ground line to represent the *apsû* as the underground channel that is the actual source of Dilmun's freshwater.¹²

I say that the Sumerian account of the origins of the Tigris and Euphrates is counter-intuitive because both of these rivers flow from the northern mountains southward toward the Persian Gulf. Moreover, the fact that the actual sources of the Tigris and Euphrates lie in springs beneath the Taurus mountains was already known in antiquity. Indeed, the Assyrian king Shalmanesar III had inscriptions placed in the Tigris tunnel describing this channel through the rock as the "source" (*rēš ēni*) of the Tigris and the "mouth of the rivers" (*pî nārāti*).¹³ Similarly, the other great rivers of the Mesopotamian floodplain—the Karun, the Diyala, and the Greater and Lesser Zab—all originate in the Zagros Mountains.

Representing mountains as the ultimate source of the rivers' waters was, then, unsurprisingly widespread in the ancient Near East. For example, the mountain of the main god of the Ugaritic pantheon, El, was imagined by the people of Ugarit as located at the source of the rivers (*mbk nhrm*) but also in the midst of the channel of the two deeps (*qrb ḥpq thmtm*).¹⁴ Ugaritic *thm* and the later Hebrew *tehōm* are etymologically related to Tiamat and Akkadian *tamtim*: "sea." These terms refer, however, to freshwater. This is why the Septuagint translation of Genesis renders the primordial waters of creation (*tehōm*) as *abyssos* (i.e., *apsû*). Apart from freshwater located physically under the Amanus Mountains, there were suboceanic freshwater springs off the island of Arwad¹⁵ to which the "channels of the waters" underneath the ocean mentioned in the Thanksgiving Psalms 2, Samuel 22.16, and Psalm 18.15 presumably also refer. This Dilmun analogue would seem to

12 Woods 2005, 15, fig. 2; Parrot 1960, 309, fig. 383.

13 Albright 1919, 172–73.

14 CAT 1.4 iv 22–24; Lewis 1997, 127; Albright 1919, 65–69.

15 Strabo, Geography 16.2.13.

be included in the location of El's mountain as cited above, which means that the Arwad springs and the mountain springs of the Amanus were considered to be parts of a single water source.

El's mountain as the source of the rivers is presumably a reference, *inter alia*, to the Tigris and Euphrates.¹⁶ This must mean counting the Amanus and Lebanon ranges as a southward extension of the Taurus Mountains connecting them to the Mediterranean.

With the Taurus range, we pick up yet another mountain at the source of the rivers. A number of hymns, including a Sumerian/Akkadian bilingual text from Boazköy, offer water to the sun god Šamaš that, it is claimed, is no ordinary water. Instead, it is water from the Tigris and/or Euphrates, and not just any water from these rivers but actually drawn from their source, at a "mountain of the springs" that is also a "mountain of cedars and/or cypresses."¹⁷

The "mountain of springs" and "mountain of cedars and/or cypresses" is usually identified with the legendary Mount Ȟašur of the Taurus range in which the actual sources of Tigris and Euphrates are located. I would, however, argue that the home of the *ħašurru*-cedar was not just the Taurus, and that "Mount Ȟašur" should be extended not only backward to the Amanus and Lebanon but also forward to the Zagros down to the Persian Gulf so as to include the mighty rivers that have their sources in that range and to connect up with Dilmun's springs in a complete system of which Ugaritians, Hittites, Babylonians, and Sumerians could all claim to possess the essential part.¹⁸

The scene on the "mountain of cedars" may be illustrated on a seal from Mari that shows a bearded god in the style of representations of Enki/Ea but accompanied by stars, perhaps at home in the sky (fig. 2). He is sitting on a mountain with two bird heads expelling water from their mouths at his feet. The waters thus produced become boats propelled by water gods on which stand two facing goddesses. Each embodies a set of trees, which sprout from them. The left-hand goddess holds a conifer aloft, and the right-hand goddess seems to embrace a pot of water.¹⁹ Also of relevance is a Kassite cylinder seal found in Boeotian Thebes that shows a mountain god grasping two flowing streams connected to

16 There was a grand argument about the modern equivalent of El's cosmic mountain. Pope favored Hirbet Afqa in Lebanon, the source of the Nahr Ibrahim (apud Albright 1919, 14). Albright, by contrast, opted for Mount Hermon, source of his beloved river Jordan (Albright 1919, 15–69). Neither the Nahr Ibrahim nor the Jordan River qualifies, in my humble opinion, as something to have had a fuss made about it in second-millennium Ugarit. In any case, the texts say rivers plural (*nhrm*) and not just a river. I would include both suggested rivers in that plural alongside the much more significant Tigris and Euphrates.

17 Cooper 1972, with corrections in Woods 2009, 204 n. 84.

18 Pace George 2003, 2:864, Rowton's argument that Mount Ȟašur was to be identified with the eastern Taurus and part of the northern Zagros is not "based on a misunderstanding of this (KAR 34: 14–15) and other literary sources." It is instead the idea that "the Tigris and Euphrates were considered in antiquity to sink underground in the southern marshes and emerge again in the far east at the place called *pi nārāti*" that is based on a misunderstanding or rather misapplication of Sumerian sources to much later material. The Assyrian authors of KAR 34 knew that the Tigris and Euphrates had their sources in the Taurus Mountains north of Assyria, since Assyrian monarchs left inscriptions to this effect in the Tigris tunnel (see above).

19 Woods 2005, 18, fig. 8; Parrot 1960, 189, fig. 228. The many seals showing an association between Niraḥ and Ištaran, on the one hand, and Šamaš, on the other (Woods, 2004, 67–76; cf. 58, 62), would seem to point to Der (city of Ištaran) and thus the Tigris and Šamaš of Larsa to pair with the association of the Euphrates with Šamaš of Sippar.



Figure 2. Seal impression from Mari with Enki/Ea sitting on a mountain (Parrot 1960, 189, fig. 228).



Figure 3. Kassite seal impression of a mountain god gasping two flowing streams (Parrot 1969, 341, fig. 50).

two sets of vases, one above and one below him (fig. 3).²⁰ The fact that this representation clearly shows not a single mountain but a whole range of peaks as dominated by a single god would seem to support the argument for an expansive understanding of Mount Ғаšur.

Continuing eastward, the east–west range of the Taurus meets the north–south range of the Zagros that continues on to the Persian Gulf with the exception of a spur, the Jebel Hamrin, that crosses the Tigris and ends between the rivers just south of Aššur, forming a natural boundary between Assyria and Babylonia. This spur was known in antiquity

²⁰ Parrot 1969, 341, fig. 50.



Figure 4. Middle Assyrian holy water basin from Aššur with a representation of Mount Ebiḫ (Parrot 1969, 7, fig. 9).

as Mount Ebiḫ, and Assyrians, perhaps not surprisingly, located it at the source of the rivers. From Middle Assyrian Aššur, contemporary with Hittites and Ugaritians, we have a holy-water basin decorated with a representation of Mount Ebiḫ, shown as a typical Hittite mountain god (dressed in a long skirt covered with rows of cones representing rocks) wielding a pair of tree scepters at which two mountain goats nibble (fig. 4). At his sides stand two figures, each holding a vase from which flow two streams, an iconic representation of the mountain at the source of the rivers.²¹ A second, ivory representation of the mountain has him holding a vase with four streams of water flowing out in the four

²¹ Black and Green 1992, 80, fig. 63; Parrot 1969, 7, fig. 9.



Figure 5. Neo-Assyrian basin decorated with *apkallu* fish-men (Parrot 1969, 74–75, figs. 82–83)



Figure 6. Seal impression from Mari of Iluna-Kiriš, servant of Zimri-Lim (Otto 2000, fig. 435).

cardinal directions.²² A later, Neo-Assyrian basin dated to Sennacherib shows the mountain and streams being blessed by *apkallu* fish-men (fig. 5).²³

Connecting together this Assyrian image with Sumerian representations of Enki/Ea is a seal impression from Mari that belonged to Iluna-Kiriš, servant of Zimri-Lim (fig. 6).²⁴

²² Parrot 1969, 257, fig. 329.

²³ Parrot 1969, 74–75, figs. 8–83.

²⁴ Topçuoğlu 2016, no. 251 = Otto 2000, fig. 435.

It shows a seated, beardless divinity with a goat under one arm and another goat at his feet. In his/her free hand, she/he holds a flowing vase with four streams coming out of it. Beneath the scene are the foot-to-foot flowing water gods that appear on one of Enki/Ea's portraits, both of them also holding vases. The water god on the left has one stream that connects to a "nude hero" figure (Laḫmu/Laḫama)²⁵ with two streams, and the water god on the right has three streams, one of which comes up to a female figure with a mountain skirt holding a tree. Above each of the standing figures is a bifurcating branch of two rivers.

The merging of Assyrian and Babylonian concepts can be found in the seated figure, which is unlikely to be Enki/Ea, as the figure's attributes (see above) might imply, since it is clearly shown as beardless.²⁶ If not a mountain god, it could be a representation of Inanna enthroned on Mount Ebiḫ,²⁷ since this goddess, otherwise much revered at Mari, is known from the Sumerian myth *Inanna and Ebiḫ* to have had, in some quarters at least, a dominance relationship with Mount Ebiḫ, for whose forest fires she was held responsible.²⁸

Farther north in the Mesopotamian floodplain, beginning roughly at Aššur, annual rainfall of 200 mm or more makes rain-fed agriculture possible. However, even here irrigation remained important, which raised interesting questions about the origins of rainfall and the connection, if any, between the waters that came down from the sky and the waters that came up from under the earth.

To understand the Mesopotamian concepts of celestial versus terrestrial water sources, we need to consider the creation myth *Enūma eliš*.²⁹ In the beginning, according to the myth, all that existed were Tiamat and her sort-of husband Apsū, a mixing and mingling of cosmogonic waters, and a primal soup in which the primordial gods "were created"—or, as we would say, there was "evolution before life." When Marduk finished his work, there were, according to developed Mesopotamian cosmology, three heavens and three earths, the former of which were separated from one another by distinctive stone floors of different colors.³⁰

25 For the interpretation of the so-called nude hero as Laḫmu/Laḫama, see Black and Green 1992, 185, fig. 153. For the Laḫama as gate-guardians of the abzu, see Lambert 1983.

26 Topçuoğlu 2016, no. 251.

27 This interpretation receives support from another seal illustrated in Woods 2005, 15, fig. 3, which quite clearly shows Inanna mounted over the back-to-back water gods. Woods (2005, 14–21) argues that both of these figures represent the river Euphrates, as indeed do both goddesses holding flowing vases that are depicted on the Mari palace painting. I think it more plausible that the two goddesses represent the Tigris and Euphrates and that the back-to-back water gods represent the springs that were the sources of these rivers.

28 Cunningham, n.d.

29 I 1–13; Talon, 2005, 33.

30 Livingstone 1989, no. 39, lines 30–38; for details see Horowitz 1998, 3–19. As Horowitz (1998, 9) points out, the turquoise color of the floor of middle heaven accounts for the blue color of the sky by day, which is visible through the clear floor of the lower heaven. I would add that the stone floor of upper heaven "girded" with red, white, and black represents the sky at sunrise and sunset (the red) followed by the black and white of the night sky as it appears in parts of the world where it can still actually be seen. This night sky will have been seen through both lower and middle floors, the latter's blue color being extinguished by the absence of light. Pace Horowitz (1998, 10), there is no reason to resort to "unknown religious or mythological considerations." We may also safely presume that the colors of Anu's bird and of the cones that once decorated his temple (1998, 10 n. 17) were chosen to reflect the colors of his heaven and not the other way round.

This complex creation could only come about in stages. First came the uppermost heaven of Anu and the lowest earth of the Anunnaki of the Netherworld.³¹ The future middle earth was the possession of the god Enki/Ea, who acquired it by treacherous slaughter of (personified) Apsû, established his Agrun sanctuary³² over the corpse, and called it *apsû*.³³ Marduk supplied the remainder from Tiamat's remains. After his mighty battle with Tiamat and her allies, Marduk split his ancestress in half lengthwise like a split fish. He made the upper half into a replica of the *apsû* (and its overlying Agrun sanctuary), albeit in the sky, above the remaining half of Tiamat, which was to become the upper earth. He also took the precaution of using her skin to form a floor secured with a bolt to prevent unauthorized loosening of her cosmic waters.³⁴

It was essential for the future middle (upper Agrun) and lower (upper *apsû*) heavens to fit exactly over the already-existing middle earth with room left for the future upper earth but without over- or underlapping edges, so Marduk made his replica by thoroughly examining³⁵ the lower heavens-in-the-making (Ašrata) and by taking careful measurements of the already-completed lower *apsû* and Agrun before making the middle heaven (Ešarra) and the lower heaven (Ešgallu) as duplicates of each other. This done, he assigned the upper heavens to Anu, the middle heaven to Enlil, and the lower heaven to Ea.³⁶

Not mentioned in the *Enūma eliš*, but directly referenced in a cultic commentary, is the fact that Ea was present in the night sky (shepherding various enumerated constellations along their paths) “as the *apsû*,” also explained as “the Sea (*tamtim* = Tiamat),”³⁷ doubtless the very same “replica of the *apsû*” that Marduk went to such trouble to create from Tiamat's corpse.³⁸

We know of this heavenly Agrun-*apsû* complex also from healing rituals that reference stars as sources of illness.³⁹ Particularly striking is a passage from *Uttuku lemnūtu* that describes the heliacal rising of the Pleiades in the fall and their setting in the spring in the following words: “in the depths of the *apsû* they are seven; adorned in the sky they are seven; in/from the depths of the *apsû*, in/from the Agrun sanctuary they grew/came forth (fall rising) . . . they went off to the heavens on high, departed to the unapproachable

31 This is not described as such, but is indirectly referenced when Anšar (“infinite heaven”) is said to have made An (“finite heaven”) in his own image (*umaššil*) (Ee I 14–16; Talon, 2005, 33).

32 In its strictest sense, this refers to the private residence of a divinity, particularly the place where he/she sleeps. In more general parlance, it serves as a synonym for the *apsû*.

33 Ee I 61–78; Talon, 2005, 35–36; for details see Horowitz, 1998, 110–11.

34 Among those authorized to open these bolts was the sun god Šamaš (CAD S 258b s.v. *sikkūru* mng. 1b). This may account for the tradition that Sippar was the only city to survive the flood (Woods 2004, 31–32 n. 30).

35 For a similar moment in creation in the biblical narrative using what I have argued to be a functional equivalent of the Akkadian term (*hiātu*) used to describe Marduk's examination of the mangled mess to decide what to do with it, see Scurlock 2013b, 48–61.

36 Ee IV 137–46; Talon 2005, 56; for details, see Horowitz 1998, 112–14.

37 Livingstone 1986, 187–204.

38 See above.

39 Caplice 1973, 299–305.

heavens; they cannot be recognized among the stars of heaven in their three watches (spring setting).⁴⁰

Every observant person in the ancient Near East would have known that any particular constellation was only visible for part of the year, which raised the question: “Where will absent constellations have gone?” Since constellations rise in the east and set in the west, we would think it logical for the Pleiades to be going underground in the spring and then completing the circuit from west to east to rise again in the fall. As described, however, the Pleiades are disappearing not into the Netherworld below ground but into the “heavens on high.” A similar problem appears with the sun god, who would seem logically to be imagined as making a daily circuit, which took him underground at night.⁴¹ Nevertheless, it is explicitly stated that Šamaš’s Agrun, his bedchamber where he slept, rested, and engaged in pillow talk with his wife, was located “in the interior of heaven.”⁴²

As Wolfgang Heimpel notes, this conundrum can only be explained by the “concept of heaven’s interior as the invisible part of heaven below the earth.” This further implies thinking of the heavens as spherical in shape, a concept that Assyriologists other than Heimpel⁴³ insist on imputing to the Greeks even though Ptolemy himself credits “the old ones” for its discovery. Once this conceptualization of spherical heavens by ancient Mesopotamians is accepted, all that remains is to work in the system of multiple heavens and multiple earths.

The best way of understanding this system is to think of jointed spheres fitted inside one another like a Russian doll, with upper heaven and lower earth joining to surround middle and lower heaven and middle earth, which, in turn, join to surround an upper earth consisting of earth’s surface together with the air above it and the ground above the water table below it. From this perspective, it is readily apparent that the highest heaven (Heaven) and the lowest earth (Netherworld) are the same because they join at the horizon to form a single entity, part of which is above and part of which is below the observer on the earth’s surface. The lower two heavens also join up with middle earth to form a single entity, meaning that the *apsû* is both above and below the earth at the same time.⁴⁴

40 Caplice 1973, 303, 305. The article was meant to establish the reading and interpretation of Agrun. He understood that stars were born in the *apsû*, but did not quite realize that the Seven were stars.

41 For a full discussion of this problem, which is complicated by the fact that the sun was imagined as having various activities to perform at night, see Heimpel 1986, 127–51.

42 Heimpel 1986, 128–29.

43 Heimpel 1986, 181. He cites Neugebauer, but see also Rochberg 2005, 328–29. Rochberg presents ample evidence for conceptualizations of the heavens in terms of circles and spheres in both “literary” and astronomical texts and concludes that there is an “apparent lack of a conception of a celestial sphere” that forces us to suppose that Babylonian astronomers conceived the ecliptic as a “repeating linear sequence of 360 points.” All that is “apparent” is that the first Greek to mention the concept is Plato in his *Timaeus*, supposedly derived by him from his metaphysical arguments. Actually, the *Timaeus* is a summa of Eastern wisdom drawn from a variety of sources probably channeled via the Greek community in Egypt. The astronomical parts bear the stigmata of ultimate Mesopotamian origin. Similarly, Aristotle (also cited as independent inventor) sent a student to collect information specifically from Mesopotamia. The extent to which Greek philosopher-scientists based their theories on actual evidence (if not collected and analyzed by themselves) is wildly underappreciated.

44 Woods (2009, 209) is quite correct in identifying a commonality between Sumerians, on the one hand, and Indo-European traditions, on the other, on the subject of the identity of Heaven and the Netherworld. However, it does not follow that the celestial sphere was believed to rotate, bringing up the stars from

Thus, trapped between the jasper floor of the lowest heaven and the turquoise floor of the middle heaven was a portion of the original cosmogonic waters along which were channeled primordial gods visible to humankind for part of the year as constellations in the night sky. This celestial *apsû*, or, perhaps better, upper half of the *apsû*, had a clear floor through which its starry denizens were visible at night. When constellations such as the Pleiades disappeared from the sky, they left the hollow sphere of *apsû* at its western edge and went outward at the junction point of the horizon into the hollow sphere of Anu's Heaven/Netherworld, which they crossed from west to east so that they could eventually re-enter the hollow sphere of *apsû* at its eastern edge where they were (re)born.

None of this movement was voluntary; a number of cylinder seals represent one of the Laḫmu/Laḫama gate-guardians of the *apsû* interacting with a very unhappy constellation, either shoving him down out of the sky or pushing him up into it.⁴⁵ The most interesting of these representations shows one gate-guardian pushing up a mightily resisting Leo while his companion sits astride an already-risen Taurus, striking him on the haunches with a goad to keep him plodding forward (fig. 7). Beneath the scene flows the braided stream of the heavenly *apsû*.⁴⁶

From biblical texts we are familiar with the “waters above the heavens” (Gen. 1.6-8; Ps 104.3; 148.4), the ultimate source of rain. The celestial *apsû*, the watery upper half of Tiamat, was also the ultimate source of rainwater for Mesopotamians.⁴⁷ This was supposed to reach the clouds for interim storage via the “teats of heaven,” still attached to Tiamat's belly skin and petrified into ducts in the upper *apsû*'s stone floor, which could be opened from above or below by pulling on ropes attached to them.⁴⁸ As for how the outflow from these teats was managed, we have a number of cylinder seals that show a recumbent wild bull with a winged ladder on his back and, on either side, figures pulling at ropes attached to it (fig. 8).

Versions of this image that also show an enthroned moon god Sin point to an identification with Numušda, son of the moon god.⁴⁹ This wild-bull-cum-lion-faced dragon

the Netherworld at night and then putting them back below again during the day. This idea, derived from Huxley (2000, 125), is effectively refuted by George (2003, 1:493 n. 170). To be noted is that there is a Sumerian text that explicitly states that the stars were physically present during the day, if obscured (“covered”) by the brilliance of the sunlight (Woods 2009, 209 n. 97).

45 For the interpretation of the so-called nude hero as Laḫmu/Laḫama, see Black and Green, 1992, 185, fig. 153. For the Laḫama as gate-guardians of the abzu, see Lambert 1983, 431. For the scenes, see the Old Akkadian or Isin-Larsa/Old Babylonian seals illustrated in Topçuoğlu 2016, nos. 19, 27 (Laḫmu pushing up Taurus); Parrot 1960, 187, fig. 225; Collon 1982, no. 114 (Laḫmu pushing up Leo, who is struggling to resist him—shown twice facing toward each other to represent both directional journeys); Collon 1986, no. 112 (Goat star being dragged down by Laḫmu and fighting Leo, who is rising as Goat star is setting, again shown twice facing toward each other).

46 Parrot, 1960, 193, fig. 242.

47 Jensen 1928, 123a; Rochberg 2005, 324.

48 Horowitz 1998, 262–63, 265; cf. 119–20.

49 I owe this suggestion to Monica Phillips. For the seal type, see Collon 1982, no. 181. In one Cappadocian seal, the ladder is replaced by an image of Numušda's daughter, the goddess Adgar-kidu, famous as the would-be spouse of the god Amurru/Martu as described in “The Marriage of Martu” ed. Vanstiphout (n.d.). The eager teenager is flanked on one side by her approving mother Namrat and on the other by her future husband. For this seal, see Amiet 1977, 440, fig. 787.



Figure 7. Cylinder seal impression showing gate-guardians pushing up Leo and goading Taurus (Parrot 1960, 193, fig. 242).

had his cult center at Kazallu, which was renowned as the home of a “mountain ladder.”⁵⁰ Numušda’s star was famous for “letting the rain pass through,”⁵¹ presumably by using the ladder as a sort of spillway.

Also connecting upper and lower *apsûs* were what is variously referred to as the “bond” (*turru*) or “mooring rope” (*markasu*), a piece of cosmic hardware desired by many a Mesopotamian city. Babylon’s claim to this particular fame could be traced to Marduk himself, who is supposed to have twisted up Tiamat’s tail (about which we otherwise hear nothing) and wedged it between the lower heaven and upper earth at the relevant spot.⁵² As may be seen from the specific usage of these terms in cosmological context, the implication is of a cosmic center that provides a link between heaven and earth (CAD M/1 283 s.v. *markasu* mng. 4) by means of which various things, including cosmic water, could be passed between them. So, for example, the seven and seven daughters of Anu bearing down water from heaven to cure a patient are once described as facilitating their descent by grabbing hold of the *turru* (CAD T 165 s.v. *turru* A mng. 1f).

50 “Nunamnir, the lord who determines destinies . . . the city of plenty, placed in a pure place, Kazallu, mountain of abundance, he designated for you as your cult center. The mountain ladder, dias of your en-ship, he commanded its birth with his word that cannot be altered” (Sin-iqīšam A lines 42–47, Tinney, n.d.; Dupret 1974). After the destruction of Kazallu, the cult of Numušda seems, to judge from a comparison of the iconography on the seals illustrated in Parrot 1960, 192, figs. 235–36 (= fig. 8 in this chapter), to have been absorbed into the cult of the snake god Nirah. The ladder may be shown on a Neo-Assyrian cylinder seal (Collon 2001, no. 206).

51 For Numušda, see Cavigneaux and Krebernik 2001, 611–14. The verb *šutebrû* is usually translated “to last long,” and that is certainly implied. However, in omen texts it can refer to something passing through a hole, which is more than appropriate to this context. For references, see CAD B 281.

52 Ee V 59–68; Talon 2005, 58; Horowitz 1998, 119–20, 265. Pace Horowitz, I do not understand the bonds of heaven as pillars to keep the sky from falling or as tethering ropes to keep it from floating away.



Figure 8. Cylinder seal impression depicting a wild bull with a winged ladder and figures on either side pulling ropes attached to it (Parrot 1960, 192, fig. 235).

Of interest, then, is evidence for Assyrian cosmological concepts available from what might seem the most unlikely of sources, namely the Assyrian herbal handbook known as URU.AN.NA.⁵³ Aššurbanipal's final redaction of tablet 2 of this handbook, cited from my forthcoming edition of these texts, has the following to say of Mount Ebiḫ:

141 ³	Ú EN.TI <i>si-kur</i> KUR	<i>kur-[(ka-nu)-u]</i>
nR2 _{2a} i 13	Ú EN.TI <i>si-kur</i> KUR	Ú <i>kur-[(ka-nu)-u]</i>
M ₁ ii 29	Ú EN.TI <i>si-kur</i> KUR	Ú <i>kur-ka-nu</i>
M ₅ ii 37'	Ú EN.TI <i>si-kur</i> KUR	Ú [<i>kur-ka-nu</i>]
MC 10	[Ú EN.TI s] <i>i-kur</i> KUR : <i>E-bi-iḫ si-ik-ku-ur ma-a-tú</i>	
141 ³	<i>kurkanû</i> is a plant of Mount Ebiḫ, (floor) bolt of the land	
142 ³	Ú ILLAT <i>si-kur</i> [KUR]	Ú <i>ku[r-ka-nu-u]</i>
nR2 _{2a} i 14	Ú ILLAT <i>si-kur</i> [KUR]	Ú <i>ku[r-ka-nu-u]</i>
142 ³	<i>ku[rkanû]</i> is a plant of the underground watercourse, (floor) bolt of the land	

53 This is now commonly read ERI.AN.NA following the latest fad in Sumerology. However, this is not real Sumerian; it is academic Sumerian and of a type well attested also in Ḫarra Ḫubullu where Akkadian and even Aramaic plant names are given fake Sumerian equivalents. So "Sumerian" SI.ḪU for Aramaic *sīḫu*: "wormwood." The first entry of the first tablet of the series has an equivalency between the well-known plant *urānu* given a pseudo-Sumerian fake name, URU.AN.NA, and another plant called *maštaka*.



Figure 9. Old Akkadian cylinder seal impression depicting the *apsû* underneath the feet of two nude heroes (Laḫmu/Laḫama) (Parrot 1960, 186 fig. 223).

“(Floor) bolt of the lands” renders the axis mundi, that is, the junction between heaven and earth. ILLAT (written with the combined signs KASKAL.KUR: “Netherworld road/path/channel”) is the Sumerian term used by the Hittites to designate underground channels through karstic rock. These are quite common in Anatolia, and a valued source of groundwater.⁵⁴ The Hittites deified their ILLAT and collected their waters into sacred pools.⁵⁵ ILLAT was also used by Mesopotamians to describe the Balih River, which actually flows underground for part of its course.⁵⁶ It is probably this imagined channel through the rock that is invoked in a Old Akkadian cylinder seal that depicts the *apsû* underneath the feet of two nude heroes (Laḫmu/Laḫama) with flowing vases as a line of water encased between two lines of conical rocks (fig. 9).⁵⁷

Similarly, the nude hero on the previously discussed Mari seal⁵⁸ will have represented the westernmost source of sweet water, namely El’s cosmic mountain with its underground connection to the channels of Arwad. On the right, the mountain goddess with her tree is a good candidate to represent the springs of the Zagros, leaving the central scene to show Mount Ebiḫ as axis mundi and, fed by the cosmic waters of the *apsû* as represented

54 Gordon 1967.

55 For example, Hawkins (1995, 44–45) argues that Südburg §18 identifies the monument as a VIA+TERRA “earth-road,” the Luwian hieroglyphic equivalent of the cuneiform Hittite Sumerogram KASKAL.KUR.

56 Gordon 1967, 77–79. Similarly, the Ugaritic expression for “channel” (*’pq*) is echoed in Mount Hirbet Afqa in Lebanon from a cave in whose base flows the Nahr Ibrahim (Pope, apud Albright 1919, 14). The translation “spring,” “source” for *’pq* is usually preferred, but this glosses over the natural features to which the term refers—yes, a spring, but specifically one flowing through a channel in the rock. Albright’s countersuggestion for the identification of El’s cosmic mountain with Mount Hermon and the sources of the Jordan River also involves underground springs (Albright 1919, 36–41).

57 For the interpretation of the so-called “nude hero” as Laḫmu/Laḫama, see Black and Green, 1992, 185 fig. 153. For the Laḫama as gate guardians of the abzu, see Lambert 1983. Pace Black and Green (1992, 184), the two vases symbolize the sources of the two rivers (which is why we have two of them) and not just “fertility and abundance.”

58 Topçuoğlu 2016, no. 251.

by the flowing water gods, the four great rivers of Mesopotamia.⁵⁹ In this context, it would seem that the Mari seal represents an imagined water-bearing channel in the rock flowing under the Zagros-Taurus-Amanus mountain chain to connect on one side with the fountains of Dilmun and on the other with the under-the-sea springs off Arwad to form the underground portion of that “Bitter” World-Encircling River shown on the famous Neo-Babylonian Map of the World.⁶⁰ It is bitter rather than sweet because the overlying waters of its southern part are at best brackish (the term used actually refers to marshes). We might think of freshwater as floating on top of saltwater but, in the Mesopotamian floodplain, the aboveground freshwater will have been polluted by salt-encrusted fields, making it saltier than water drawn up from beneath the earth’s surface. The water pulled out of the sea-springs off Bahrain or Arwad would also have been a bit salty but still in both cases fed from underground sources of freshwater.

Of the rocky northern half of this underground river, the Jebel Hamrin (Mount Ebiḥ) will have formed a sort of outtake that, by virtue of its “bolt of the lands” status, also channeled upward into the waters above the heavens and downward into the waters below the ground. On the other end of the mountain chain, El’s mountain at Ugarit, with its channel of the two deeps (*ʾpq thmtm*), served a similar purpose. We may actually see these connections on Assyrian cylinder seals where there appears the symbol of the national god Aššur, whose seat was on Mount Ebiḥ. In a number of representations, there are ropes issuing from the divine symbol grasped by royal figures on either side (fig. 10).⁶¹

Sometimes, we see descending streams grasped in the hands of a winged genie below. Each of the streams ends in what looks like a flower with a central bulb and three petals.⁶² Most striking is a cylinder seal in which a flying figure beneath the winged disk accompanies two flowing streams connected to two sets of vases, one above and one below him (fig. 11),⁶³ very much like the Kassite seal we have already mentioned (fig. 3).⁶⁴

Some forms of the sacred tree that is often situated underneath the Aššur symbol directly invoke the theme of Ištar/Inanna and Mount Ebiḥ, showing what is distinctly a floor bolt, invoking the mountain’s claim to be a cosmic center connecting heaven and earth,⁶⁵

59 This impression would seem to be confirmed by a scene that appears on a circular stone mold depicting a deified Naram-Sin sitting facing the goddess Inanna/Ištar (Braun-Holzinger 2017, figs. 2–3). Of interest is the stepped platform on which the royal couple sit. That this was intended as a symbolic representation of Mount Ebiḥ is, I would argue, clear from the procession of defeated mountain gods whom the goddess Inanna/Ištar is leading, literally, by the nose, and from the fact that she is depicted in the style of Ninḫursag (“mistress of the mountains”). Beneath this schematized mountain is clearly depicted the water boat, aka Mount Ebiḥ’s ILLAT/*apsû*.

60 Scurlock 2018.

61 Parrot 1969, 162, fig. 205; Collon 2001, no. 163.

62 Parrot 1969, 1, fig. 2; Collon 2001, no. 204.

63 Collon 2001, no. 202.

64 Parrot 1969, 341, fig. 50.

65 This provides some textual support for part of the old interpretation of the Assyrian Sacred Tree as the Mesopotamian equivalent of the omphalos. Ištar—whom I would argue most of these images, whether depictions of actual cult objects or symbolic of imaginary presence, represent—was a goddess of liminality with intercessory functions. Not all of the trees need, therefore, refer specifically to this particular type of connection between heaven and earth. For a full discussion of this and all theories pertaining to this symbol, see Giovino 2007, esp. 150–51 with nn. 393–95.



Figure 10. Assyrian cylinder seal impression of the symbol of the national god Aššur, with attached ropes grasped by royal figures (Parrot 1969, 162, fig. 205).

but also a flowing fountain with streams emerging from it on all sides,⁶⁶ or even with a rocky pedestal at the bottom and a rosette blossom at the top.⁶⁷ Last but by no means least, there is a seal on which the usual sacred tree under the divine symbol is replaced by an irregular circle of water, most probably the underground river supposed to spring from Mount Ebiḫ (fig. 12).⁶⁸

Fast-forward from the first millennium BCE to the first millennium CE, and three religious traditions—nascent Judaism, Syriac Christianity, and nascent Islam—envisage a cosmic geography that would appear to reference ancient Near Eastern material in ways that suggest some sort of connection, despite the considerable gap in time involved. As outlined by Tommaso Tesei, three motifs cross in the relevant passages.⁶⁹ The first is the idea that the life-giving water of the rivers of eternal Paradise flows into this time-bound world through channels in the rock passing out from under the World-Encircling Ocean.⁷⁰ The reference is at least partly a description of real geography as observed locally, since the Syriac Alexander legend states that one of the rivers of Paradise was made by God to flow from a cave.⁷¹ As we have already noted, all of the rivers of the Mesopotamian floodplain have their sources in the Taurus and Zagros ranges. One of them, namely the Tigris, a river

⁶⁶ Collon 2001, nos. 151, 174.

⁶⁷ Collon 2001, no. 179.

⁶⁸ Collon 2001, no. 283.

⁶⁹ Tesei 2015.

⁷⁰ Tesei 2015, 24–26.

⁷¹ Tesei 2015, 25.



Figure 11. Neo-Assyrian cylinder seal impression with a flying figure and flowing streams beneath the winged disk (Collon 2001, no. 202).



Figure 12. Neo-Assyrian cylinder seal impression with an irregular circle of water in place of the usual sacred tree under the divine symbol (Collon 2001, no. 283).

of Paradise according to Genesis, does indeed flow from a cave, the already-mentioned Tigris tunnel.

The second recurring motif is the idea of the sources of two rivers/seas, to which Tesei compares Ugaritic El's cosmic mountain⁷² and the Sumerian motif of Ut-napištum at the mouth of the rivers.⁷³ Quranic literature simplifies the Tiamat-and-Apsû complex into a

⁷² Tesei 2015, 26–27.

⁷³ Tesei 2015, 27.

Freshwater Celestial Ocean (heavenly Apsû) versus an earthly Saltwater Ocean (earthly Tiamat), which meet, allowing celestial water into the earthly rivers of Paradise.⁷⁴ The Mesopotamian case is clearly more complex, but the connection is still relatively clear.

Finally, there is the motif of the cosmic mountain, which is the axis mundi, the junction between heaven and earth and also, according to Ephrem, “a mountain circling the whole of creation.”⁷⁵ All three Abrahamic religions associate this axis mundi with Mount Zion in Jerusalem and its Gihon spring, which, in turn,⁷⁶ is equated with one of the rivers of Paradise. It is hard not to think that the mountain in question was originally that river-through-rock that separates Mesopotamia from Anatolia and Iran and is the source for the two main rivers of Paradise, the Tigris and Euphrates. As we have seen, Mount Ebiḥ was understood as the “(floor) bolt of the lands,” the Mesopotamian expression that renders the axis mundi, so the junction between heaven and earth but also, since the Jabal Hamrin is a spur of the Zagros/Taurus mountain chain, quite literally Ephrem’s “a mountain circling the whole of creation.”⁷⁷

However, although every indication points to an ancient Near Eastern origin for these heavenly sources for earthly water traditions, one unfortunate fact remains, and that is the gaping gap between the third- to first-millennium BCE Mesopotamian traditions and the first-millennium CE traditions that are supposed to be based on them. What is worse, both Hittite and Ugaritic civilizations disappeared forever at the end of the Late Bronze Age. One can always argue for a proto-Jewish tertium quid for the Sumerian traditions as still preserved in Neo-Babylonian Mesopotamia, and it is popular to suppose that Hittite and Ugaritic traditions passed to Canaan and hence to Judah. However, neither of these links is secure, and the last is particularly shaky.

Faute de mieux, the hypothesis of ancient Near Eastern origin still stands, but would it not be better if some connection that bridged the gap could be found? Ideal would be something Zoroastrian—why should this religion centered on notions of Paradise contain no echo of Paradise motifs picked up in Judaism, Christianity, and Islam? Not only this, but there is a potential of tracing such motifs back to the Achaemenids who ruled Mesopotamia in the first millennium BCE.

In the *Bundahišn* (and earlier Avestan texts), the world is described as consisting of seven “islands” (*karšuuar*).⁷⁸ As the name “island” implies, the known world is surrounded on all sides by a cosmic sea, the *Vouru.kaša*, also known as the “Sea that flows from Persia.”⁷⁹ These seven *karšuuar* are organized with one in the center—the one always inhabited by men—and the other six in a ring around it.⁸⁰ In the central *karšuuar* is a mountain at the center of the world that is also the mountain range that rings the disk of the world.⁸¹

74 Tesei 2015, 28–29.

75 Tesei 2015, 29.

76 Tesei 2015, 29–30.

77 Tesei 2015, 29.

78 Silverman 2013, 204–5.

79 Silverman 2013, 206.

80 Silverman 2013, 205.

81 Silverman 2013, 196.

The *Vouru.kaša* is part of a complex circulating water system that supplies not only the terrestrial waters of the seven *karšuuar* via a personified mythic fountain Ardvīsūra Anâhita (“the great unblemished life-giving river”) that is located on the summit of the cosmic mountain (Mount Hukairya), but also rainwater. This last is by a mechanism that should now sound rather familiar, minus the natural sciences’ explanation for how this is all supposed to work. Future rainwater is allegedly pumped up by pressure from returning waters via special channels through the rock of the cosmic mountain up to the top where rain clouds can pick it up.⁸²

Iranologists identify the central *karšuuar* with modern Iran and as dating to the Achaemenid period.⁸³ That Sassanian sources would have made this identification is plausible enough; that it goes back to the Achaemenid period is extremely unlikely, for several reasons. First, the mountain range at the center of Achaemenid Persia was the Zagros, not Mount Alburz—Persian rulers practiced transhumance between the upland centers of Ecbatana and Persepolis and the lowland centers of Babylon and Susa.

Second, the central *karšuuar* was supposed to have always been inhabited,⁸⁴ whereas the Iranian central desert is not where the bulk of the modern population lives. In Sassanian times, irrigation works, now abandoned, turned parts of this desert into gardens. When Persians first arrived on the scene, by contrast, the nearest lush garden will have been in Mesopotamia, a fact that mediated the shift in meaning between the Avesta’s use of the term Paradise as a desert walled enclosure and place of punishment and the currently more familiar Paradise Garden that symbolized the Wise Lord’s original creation.⁸⁵

A priori, then, the location of the original Mazdean Paradise Garden was in Mesopotamia, and the original central mountain was in the Zagros chain at the center of the Achaemenid Empire—in particular, that spur of the Zagros, the Jabal Hamrin, that crosses the Tigris and ends up between the rivers. And if there were any doubt on this score, the third reason to suppose that Iranian placement of the central *karšuuar* is not original is that the *Bundahišn* specifically states that the eastern and western boundaries of this central island were two great rivers, hardly a description of Iran and almost certainly a reference to the Tigris and Euphrates.⁸⁶ In this context, the cosmic river that flows from Persia will have been fed from the Zagros/Tigris complex, fairly clearly described in both Mesopotamian and Persian traditions as a central mountain that is also a mountain ringing the known world.

To sum up so far, we have an Achaemenid Persian conceptualization of the world that features a non-Mesopotamian motif of seven islands but also includes notions of cosmic rivers that seem to be grounded in the Mesopotamian landscape. We also have cosmic mountains and flowing water—potentially, even probably, the very same cosmic mountains and flowing water that we see in ancient Mesopotamian texts.

82 Albright 1919, 189.

83 Silverman 2013, 205.

84 Silverman 2013, 205.

85 Lincoln 2007, 83–84. Silverman 2013, 207, confuses imitation with origination.

86 Silverman 2013, 205. The Mandaeans also reference the Jaxartes and Oxus (Albright 1919, 189), but these rivers may hardly be said to encircle Iran.



Figure 13. Achaemenid gold earring in the Boston Museum of Fine Arts representing seven world islands and the World-Encircling River (Markowitz 2011, 29).

The connection that has been claimed with the Babylonian map of the world⁸⁷ is, then, correct up to a point. Here, too, we have a world surrounded by a World-Encircling River with other regions around it represented by triangles. However, there is only one region encircled by the Bitter River; there are eight and not six surrounding regions; and, most strikingly, the Tigris is missing. This last detail, and other oddities of placement of toponyms, reflect, as I have argued elsewhere, the ideological intent of this so-called map.⁸⁸

Ignoring this and concentrating only on the World-Encircling River and the eight triangles, we have a match in an Achaemenid gold earring, now housed in the Boston Museum of Fine Arts, that also references the seven world islands (fig. 13). We have a round plate with a border of triangles, and inside are seven disks with figures inside them. Of these, the central disk is the largest and the other six form a ring round it. At the bottom is a water lily, arguably representing the World-Encircling River.⁸⁹

The figure in the central disk is Ahuramazda, whom Iranian nationalists, and all too many Iranologists, wish to see instead as a symbol of kingly fortune.⁹⁰ In fact, the ring, which this figure is routinely seen handing the king in Sassanian reliefs, is the symbol

87 Silverman 2013, 202.

88 Scurlock 2018.

89 Silverman 2013, 206; Markowitz 2011, 28–29.

90 Silverman 2013, 206 with n. 112.

of kingly fortune given to the human king as part and parcel of that divine election so emphasized at Behistun, where these symbols also appear.⁹¹ The motif is unquestionably Mesopotamian in origin and is not a new invention of Indo-European immigrants from the Iranian desert bringing with them in their saddlebags novel concepts of imperial “divine fertility and peace.”⁹²

Denials by Iranologists and Assyriologists alike to the contrary notwithstanding, we have represented on our earring and at Behistun a syncretic identification of the Persian Wise Lord with the Assyrian national god Aššur upon whose imperial gardens was based the conceptualization of Paradise as a walled garden in which examples of all the varied animals and plants of the known world were to be gathered. The ideological complex of a Creator god who personally chose a human king to create unity through diversity by forming a political entity that promised peace, justice, and prosperity for all was a brilliant projection of Assyrian soft power that, there being no Assyrians left to claim it back, Persians were free to appropriate and make their own.⁹³

Of all the gods of ancient Mesopotamia, Ugarit, and Hatti, there was only one, namely Aššur, who was both transcendent and eternal, and that from his earliest appearance on the scene.⁹⁴ Described in the *Enūma eliš* as the personification of infinite time and infinite space (the literal meaning of AN.ŠÁR), in the time before time, he separated off a piece of his own cosmic watery essence and surrounded it with his son Anu, the outermost of the three spherical Mesopotamian heaven/netherworlds, thus simultaneously creating both himself and the universe.⁹⁵ Like transcendent and eternal gods modeled after him, he was associated with a mountain, that selfsame Mount Ebiḥ, which we have identified as the axis mundi and the confluence of the rivers.

As imagined, then, the Zagros/Taurus chain of mountains surmounted an underground river, or, to put it differently, the World-Encircling River had a solid aboveground upper part and a liquid aboveground lower part. Feeding both parts from underground was the fountain of Mount Ebiḥ, which, as floor bolt, channeled upward and outward to Aššur himself a source of heavenly water from outside the created cosmos in the world of eternal life. Appropriated by Achaemenid Persians to ground their own soft-power ideology, these motifs of eternity’s connection with the time-bound world through life-giving water resonated, I would argue, with all four salvation religions that had their origins in the ancient Near East: Zoroastrianism, Judaism, Christianity, and Islam.

91 Silverman 2013, 208.

92 Silverman 2013, 208.

93 There shall be further discussion of this issue in a planned future article.

94 Scurlock 2010.

95 This follows from a careful reading of Ee I 9-16 (Talon 2005, 33) and the knowledge that Aššur’s “son” Anu represents the highest heaven.

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RESPONSES

16

All Water Is LocalSylvia Rodríguez, *University of New Mexico*

LIKE POLITICS, ALL water is local. This may be the most important insight an ethnographic perspective can bring to a discussion about the role of irrigation in early states—or, for that matter, in modern states as well. Despite being refuted over the past half century by the many investigations it inspired, few formulations have proved so provocative to scholars across a range of disciplines as Wittfogel’s hydraulic hypothesis. The studies in this volume show that the pathways to state formation and the relationship of irrigation to early states did not follow a single, uniform pattern. Instead, they differed according to time and place, subject to geographic, environmental, ecological, hydrological, climatic, demographic, economic, and social variation. Furthermore, the relationship changed through time.

While all agree that the emergence of primary and secondary states in both wet and dry regions of the world required the elaboration of hydrotechnology and water management, the question of how irrigation relates to power has evolved from the premise of centralized, despotic control to increasingly refined understandings of how local irrigation communities operate internally and become externally articulated with states under different temporal, spatial, environmental, and political-economic conditions. Still, the relationship between irrigation and “the state” remains a compelling question.

As a sociocultural anthropologist who studies contemporary small-scale, gravity-flow *acequia* irrigation systems in northern New Mexico, I marvel at the kinds of insights archaeology can offer. The array of techniques M. Kyle Woodson describes for the investigation of the Hohokam in southern Arizona underscores the need to grasp the full extent of the infrastructure, cropping pattern, landscape and field layout, soil type, sedimentation, surrounding flora and fauna, and other physical attributes of any given irrigation system, past or present. Robert C. Hunt uses computer simulation to demonstrate that despite extensive irrigation works and a large population, Hohokam society never developed a state because there was insufficient water to produce a reliable food surplus. Miriam T. Stark examines agrarian and cosmological dimensions of water management in Cambodia’s early Khmer states, showing how their hydraulic systems evolved through time and focused more on engineering flood control and reservoir storage than creating networks for canal irrigation. Vernon L. Scarborough and Christian Isendahl, working in the humid environment of the ancient lowland Maya, document a comparable water management emphasis on capturing runoff from tropical rains for reservoir storage and use during

the dry season. Familiar with ancient settlement strategies in both tropical and semiarid environments, they suggest that archaeologists are in a position to offer potentially useful insights to urban and regional planners faced with the global consequences of anthropogenic climate change.

Scarborough notes elsewhere that “archaeology is the only vehicle for long-term comparisons of the growth, maintenance, and decline of water systems in various parts of the world, enabling us to identify ecological and cultural constraints on water management.”¹ Hence archaeologists continue to arrive at new and enhanced understandings of hydraulic technologies in early states. But he also acknowledges that the details of how these systems actually operated and were managed by human actors on the ground remain beyond archaeological recovery.

As fellow respondent McGuire Gibson observes, what is missing from archaeological discussions are the “folks”: the particular, on-the-ground agency of kinship and social organization operating at the level of lineage, tribe, community, nuclear family, and individual actors in any given irrigation system. States develop out of it, they ride on it, and they benefit from it. While the organization and practice of water management can be gleaned from historic accounts, the pragmatics are directly accessible only through ethnographic observation. And as Stephen Lansing’s groundbreaking work on the Balinese *subak* and water temple irrigation system has shown, the optimal program of investigation should focus on the ethnographic particulars of each case, encompass change over time, and transcend the methodological confines of any single discipline.²

The preponderance of ethnographic and historical evidence from around the world supports a bottom-up rather than a top-down interpretation of how irrigation systems come into being and sustain themselves through time. From a practical standpoint, any irrigation system would have to be self-organized and small-scale at its inception. Under some conditions an emergent indigenous state or a foreign imperial state might appropriate and exert direct control over a local system, while in other cases irrigation management would remain under or gradually devolve to local control. Ancient and modern states alike often find it expedient to leave the day-to-day practical management of irrigation (including canal maintenance and cleaning, distribution of water, internal conflict resolution) in the hands of local farmers while at the same time such systems become embedded in and subject to various levels, branches, or agencies of state oversight or regulation. Whether the structures of power are hierarchical or hetarchical, statecraft’s ultimate imperative is to render constituent populations legible for the purposes of “taxation, conscription, and the prevention of rebellion.”³

Drawing on ethnographic fieldwork in Peru and Spain (Valencia) and informed by the work of Elinor Ostrom, Paul Trawick⁴ proposes a moral-economy model of small- and medium-scale community-managed irrigation systems found around the world that exhibit a common set of organizing principles: autonomy, alternation or turn-taking, contiguity in distribution, uniformity, proportionality, transparency, boundary maintenance, direct

1 Scarborough 2003, 107.

2 Lansing 1991, 2006; Lansing et al. 2014.

3 Scott 1998, 2.

4 Ostrom 1990; Trawick 2003.

feedback, and graduated sanctions.⁵ He takes these common principles to be evidence of convergent evolution and proposes that such findings have practical relevance to a modern world faced with environmental crisis:

This convergence among societies evolving independently in different parts of the world is unprecedented and has important implications for social scientists as well as farmers, especially for small farmers who are struggling to cope with the growing scarcity and unpredictability of water being brought on by population growth and by climate change.⁶

Ostrom's Institutional Analysis and Development (IAD) framework incorporates methodologies and findings from political science, economics, anthropology, game theory, and law to define collective action situations in which individuals adopt strategies to advance their interests. Applying her approach in a comparative study of forty-seven case studies of locally as well as bureaucratically managed modern irrigation systems around the world, Shui Yan Tang offers a few conclusions that shed light on the question of irrigation–state relations both past and present:⁷

Local, self-governing organizations have several advantages over centralized bureaucratic agencies with respect to water allocation and maintenance.

. . . In most situations, irrigators have the most intimate knowledge about their own physical and social environments. Furthermore, their proximity to the appropriation area enables them to utilize their knowledge effectively and to act quickly in solving problems. This is contrasted with many bureaucratic agencies

. . . where the responsible officials live far away from the appropriation area and possess little knowledge about the physical and social environments at the local level.

. . . The shared community of understanding among participants affects the way they relate to one another. Rules can be effective only if a shared community of understanding exists among participants.

. . . Individuals who have lived together for a sustained period may be able to develop various social networks and reciprocal relationships with one another.

. . . Rules adopted by farmers are also likely to be more relevant to local circumstances because farmers who decide to adopt the rules have to bear the consequences of their own decisions.

. . . The effective functioning of community organizations often requires a hospitable macropolitical regime. In countries where well-developed legal systems are available and the political system facilitates local public entrepreneurship, community organizations can be developed and sustained more easily than in other places.⁸

Yan Tang's reference to macropolitical context hints at the need to consider both top-down and bottom-up perspectives when examining local–state relations⁹ and moreover to take into account the influences of broader hetarchic or polycentric configurations of power.

5 Trawick, Reig, and Salvador 2014, 93.

6 Trawick, Reig, and Salvador 2014, 88.

7 Yan Tang 1992.

8 Yan Tang 1992, 13–14, 129–31.

9 Hayashida 2006, 244.

Regardless of whether they employ a moral economy, social-ecological systems, complexity, or other theoretical framework, anthropologists who work closely with contemporary small-scale, farmer-managed gravity-flow irrigation communities describe remarkably similar internal processes of water governance and management. They also report an inherent tension between local systems and the state. In Paul Gelles's words, "Irrigation politics in widely diverse settings such as Peru and Bali must be understood in terms of conflict between bureaucratic and local forms of understanding."¹⁰

The relationship between local irrigation communities and the state is far from monolithic, however. Nor is "the state" a monolithic entity. J. Mark Baker's characterization of state-*kuhl* (local irrigation system) relations in northern India can as easily apply to *acequia*-state (including municipal, county, state, and federal) relations in northern New Mexico:

We must view the state as an internally fractured set of institutions competing with one another, connected to a wider set of policy concerns and directives, and entering into strategic alliances and negotiations with local groups in a manner that both strengthens state authority and benefits segments of the local "community."¹¹

Today, New Mexican *acequias* (a term that refers to both the irrigation canal and the association of *parciantes* who own and operate it) are simultaneously autonomous, self-governing associations and political subdivisions of the state, subject to state statute. *Acequia* governance and management clearly correspond to Trawick's moral-economy model.¹² An *acequia* association consists of farmer-rancher *parciantes* and landowners who share a common stream diversion (*presa*) into a hand-dug *acequia madre* ("mother ditch") from which laterals (*linderos* or *sangrías*) convey water to individual properties. Their basic canal structure and operating principles derive from Iberian-Islamic rules, technology, and practices introduced to the upper Rio Grande valley by Spanish colonial settlers who occupied *mercedes reales* or grants of land awarded by the Spanish Crown starting in the late sixteenth century. *Acequia* agriculture extended riparian habitats, transformed regional ecology, and created the northern New Mexican landscape seen today. *Acequia* irrigation was integral to the agropastoral economy that persisted into the twentieth century and survives today in reduced and modified form among rural and semiurban Nuevomexicanos. Even though few *parciantes* subsist entirely or even primarily on agriculture, *acequias* remain the organizational backbone of many rural Nuevomexicano communities.

Acequias have operated to the present day as autonomous local common-property regimes that attract official attention only in legally adjudicated cases of dispute over land or water. They functioned according to unwritten but well-understood customs and practices under both Spanish (1598–1821) and Mexican (1821–1848) rule. Codification of customary governance and practice under territorial and then state law began in the late nineteenth century after the conclusion of the Mexican–American War and incorporation into the United States. Territorial legislation formalized the corporate status of *acequias* and required them to elect three commissioners annually along with the traditional *mayordomo*

¹⁰ Gelles 2000, 159.

¹¹ Baker 2005, 40.

¹² Rodríguez 2006.

or ditch boss, an arrangement that continues today. *Acequia* associations began keeping ledgers and written records in the twentieth century, and most now have written bylaws that must be filed with the State Engineer's Office to qualify for loans and grants-in-aid programs.¹³ Their ever-expanding administrative burdens include filing annual financial reports and showing compliance with Open Meetings and Public Records legislation.

The New Mexico *Acequia* Association has documented 547 *acequia* associations in the state and estimates a total of around 700. Some of these associations are organized into regional coalitions or federations, a defensive step first taken during the 1980s and resulting in the formation of basin-wide (e.g., Taos Valley *Acequia* Association, established in 1989) and statewide (New Mexico *Acequia* Association, established in 1990) nonprofit organizations missioned with the protection and defense of *acequia* and related agricultural interests including *parciantes*' precious water rights—in a state where every drop of water is allocated and a ravenous, escalating market values water rights according to priority in time, as in mining claims. A crucial difference exists between customary *acequia* water-sharing practice based on equity and need and state and Western water law based on prior appropriation.¹⁴ *Acequias* have never been so adjudicated, organized, self-aware, advocated, celebrated, defended, studied, talked or written about, or close to extinction as they are today. They all operate in roughly the same way, some more cooperatively than others, some slowly unraveling or fractured by bitter conflict. Almost all struggle with decaying infrastructure, knowledge loss, and the dilemma of attrition involving *delincuentes* who do not irrigate, contribute labor, or pay dues.

Every ditch, like every community and neighborhood, has its own character, circumstance, location on a stream, and long-standing families with *parciantes* who irrigate, come to meetings, vote for officers, negotiate ditch matters, and themselves serve as *mayordomos* or commissioners. Like all self-managed irrigation systems, the successful operation and persistence of an *acequia* comes down to the commitment and ongoing interaction of a critical number of individuals. The specific size or proportion of that number depends on the size and demography of the ditch, in addition to a constellation of other environmental, political, economic, and social factors.

Scientists and other scholars who study *acequias* tend to focus on questions of history, governance, agricultural economy, hydrology, systems modeling, sustainability, and hypothetical tipping points. My own current project focuses on the ethnography and ethnohistory of one particular *acequia* in the upper valley of the Rio Hondo watershed, a tributary of the Rio Grande in northern Taos County. Of seventy-six listed *parciantes* on this *acequia*, roughly fifty are active members who pay their dues, contribute labor for the annual ditch cleaning, and irrigate. Almost all grow alfalfa; some have orchards and/or kitchen gardens; some have livestock and/or chickens. None depend exclusively on agriculture for their livelihood, although most who grow alfalfa for their cattle or to sell derive a degree of economic benefit from it. This pattern appears to predominate among all seventy-some *acequias* in the central Taos valley and probably most others in the northern part of the state.

13 Rivera 1998, 60–62.

14 Rodríguez 2006.

Increasingly, middle-class, semiurban *parciantes* continue to irrigate and tenaciously to defend their water rights and agricultural interests not because it sustains them economically, but because it sustains them socially, culturally, and in terms of personal meaning and identity. Given the premier value of land with attached surface water rights on the New Mexico real estate market, there is little doubt that their main wealth resides in their property even though they may operate their *ranchitos* at a loss—particularly if personal time investment is taken into account. When pressed to explain why she and other *parciantes* continue to irrigate and maintain their ditches even at some degree of loss, a *mayordoma* and friend from a neighboring watershed answered, “Because it’s tradition,” then paused and added, “If I didn’t irrigate, I would never have to talk to my neighbors. It’s the connection. It’s community.”

It is my observation that the most committed *parciantes* and proponents of *acequias* are not necessarily those who benefit most from them economically, but rather those who voluntarily devote considerable time, energy, and personal resources to other local institutions as well, such as their (Catholic) parish, Mutual Domestic Water Association, land grant association, extended family, and *morada* (chapter house for a lay religious confraternity). Within the enacted but unspoken moral economy of the ditch, those individuals who demonstrably serve the welfare of the “community,” who embody a spirit of mutualism¹⁵ and *respeto* (respect) for others yet rarely talk about it, tend to be trusted and watched or listened to when it comes time to make a collective decision. Only occasionally do such individuals register on the radar screens of official or outside observers.

Two concepts help to illuminate my reading of how an *acequia* manages to keep operating under today’s difficult and increasingly ominous climatic conditions: trust and the hydrosocial cycle. It is significant that at the end of her career Ostrom was focused on the central role of trust in sustainable and resilient common pool regimes. In her Nobel address, she reported the following:

Building trust in one another and developing institutional rules that are well matched to the ecological systems being used are of central importance for solving social dilemmas. The surprising but repeated finding that users of resources that are in relatively good condition—or even improving—do invest in various ways of monitoring one another relates to the core problem of building trust.¹⁶

My inquiry concerns the dynamic interrelation between trust or *confianza*, mutualism, ritual, attachment to place, and social capital in an *acequia* community that also intersects with a polycentric or hetarchic constellation of spheres and scales of power. The hydro-social cycle concept of water as connective process takes into account the social-political agency of water and its ontological inseparability from the human domain.¹⁷ No one who has irrigated or worked on an *acequia* for any length of time would deny the palpable agency of an *acequia* or of water, and especially of water running in a ditch. The *acequia* is a living process that connects people on a stream who together must manage the flow and equitable distribution of water among deserving *parciantes*.

15 See Rivera 2011.

16 Ostrom 2010, 435.

17 Linton 2010; Linton and Budds 2014; Latour 1993.

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Discussant Remarks

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THE DISCUSSION IN this volume of irrigation in early states is timely and well placed, for a number of reasons. First, for the past decade or so, the field of archaeology has benefited from a profusion of new and previously unavailable technologies, such as progressively high-resolution and low-cost remote technologies and dating methods. The promise of these new tools has focused renewed attention on long-standing anthropological, archaeological, and historical questions, such as the role of irrigation and water management in early complex societies. Second, understanding the role of irrigation or even resource management at large in early states is what the natural sciences would term a “wicked problem,” a term most recently linked to issues of global environmental change and climate change. The definition of a wicked problem is a societal problem that lacks a simplistic or straightforward response.¹ As the studies in this volume describe, the role of irrigation in early states exhibits all the foundational conditions of a wicked problem: It is difficult to define and has many multicausal interdependencies, its understanding is constantly evolving, no clear solution exists, and socially complex variables interact. It is a topic that does not sit within the responsibility of any one organization. And finally, it involves changing behaviors.²

Successful strategies to address wicked problems include taking a holistic or systems approach, as we have termed it in the past; innovative and flexible building on action; working collaboratively across boundaries; and recognizing the long-term focus. Historically, the University of Chicago and the Oriental Institute have led in these approaches to large-scale problems, and I think we see this continuing in the contributions to this volume.

The topic of water management and aspects such as its features and economic, sociopolitical, and cosmological dimensions have a reach far beyond the ancient world. For example, studies of the social processes of human transformation necessary to cope with environmental change are a core component of the United Nations’ Sustainable Development Goals ratified in Paris in December 2015.³ At a national level, the US Environmental Protection Agency’s environmental indicators report water availability and quality as

1 Rittel and Webber 1973, 160.

2 Rittel and Webber 1973.

3 <http://www.un.org/sustainabledevelopment/sustainable-development-goals/>.

having key impacts on agriculture, food supply, and national security.⁴ While the studies in this volume make a strong case for the importance of context, the social, political, economic, hydrological, and resource transformations they discuss can play a role in understanding the complexity of long-term sustainability, human responses, decision making, and behaviors around resource changes, as well as perceptions and communication of risk within communities. I do not intend to suggest that we have one-to-one analogies from the ancient world to the modern, but I do think that the synthetic narratives we reconstruct about human behavior may provide insight into understanding the current challenges we collectively face. In the relative sense, Mesopotamian agricultural communities were resilient in the face of long-term climate changes, and some cities were sustainable for longer than any subsequent cities.

I know that the focus here is on the historical role of irrigation agriculture management in early complex societies. However, I encourage us to think about the applications our work has and the contributions it can make to the topics of the day. For example, major global funding initiatives focus on the intersection of food, water, and energy in an urban context to try to provide solutions to food security and resource depletion in developing economies. As a field of experts in detecting and analyzing human behaviors around resource changes, use of proxy records, and understanding the cultural dimensions of physical systems, I think that the interdisciplinary work reflected in this volume has much to offer on the global stage.

THEMES

As the papers presented at the “Irrigation in Early States” seminar indicate, the role of irrigation management in early complex societies is of broad interest to archaeologists and anthropologists. Each participant took Karl Wittfogel’s hydraulic hypothesis⁵ as the starting point and presented a direct challenge to the simplistic framework that suggests the development and managerial implementation of large-scale irrigation systems resulted, in a linear progression, in a despotic administrative bureaucracy characteristic of the formation of early states. Each set out to dispel this model and provide a more nuanced and contextual framework for understanding the relationship between early states and irrigation systems. Collectively, the papers addressed several key themes related to a re-envisioning of the role of early state governments in irrigation agricultural systems. These themes offer a new framework to approach the differences and similarities of early irrigation systems across the Near East and beyond, the importance of empirical evidence from descriptive case studies documenting irrigation systems, and the imprint of local organization and systems within state structures. Exploring these themes, all of the papers found some commonality in confirming that the causal role assigned to irrigation to explain the development of sociopolitical complexity falls short, heterogeneity in the footprint of early irrigation agricultural systems and states is apparent even in the same environmental and geographic context, and integrated data sets from various related fields are necessary to produce a robust narrative describing these dynamic relationships through space and time.

4 <https://www.epa.gov/climate-indicators>.

5 Wittfogel 1957.

PAPERS

The papers are best discussed by starting with framework and proceeding to evidence and then to descriptive case studies and examples. Beginning with a new framework to approach the question of the relationship between irrigation systems and emergent states in the ancient world, Michael J. Harrower addressed the question of balancing historical particularities of ancient societies and broad, cross-cultural similarities in the role water played among ancient societies. He determines that it is necessary to contextualize the interactive dynamics of political rhetoric, social logic, and spatial heterogeneity of water to understand the influence of irrigation in the emergence of states in arid regions. These unifying concepts bring together environmental, ecological, and ideological components of state formation. Stepping through the case study of the growth of cities and kingdoms in Yemen's desert interior in the late second millennium BCE, Harrower describes the relationships among geographic conditions, resource needs, and the emergence of elites. In this example, early polities and political elites emerged in an area of unstable water availability that required creative engineering to maintain a steady and direct supply. Irrigation water formed a component of elite authority, but not a core component to sustain populations or subsistence activities. Harrower concludes with two questions: Are early political complexity and state formation correlated with spatial heterogeneity of water? If so, are there similarities in the ways very different cultures and societies exploited heterogeneity through political rhetoric and social logic that aligned perceived economic and ideological interest around collective enterprise?

The link between spatial heterogeneity of water and early political complexity is a key question for understanding the trajectory of settlement across the region. Whereas the Yemen case study illustrated the influence of neighboring polities, Emily Hammer's paper on Urartian irrigation demonstrated the importance of local development and spatial heterogeneity of water availability and use. She explores a different aspect of water management, namely, the use of locally constructed irrigation systems for the intensification of pastoral products such as animal fodder rather than for crops for human consumption and water storage. Despite the differences in data and environment, with the evidence pointing toward disproportional reliance on snowmelt and groundwater rather than perennially flowing surface water, the underlying similarities between her case study and others presented at the seminar are the conclusion that local-level organization would suffice and that canal systems that may appear physically extensive could be modular copies of small-scale systems with tenuous integration on the regional scale, an idea implicit in Wilkinson's understanding of overall irrigation systems in the region.⁶

Using the data from Yemen and Urartu as case studies, Harrower and Hammer provide two alternate models or reconstructions of irrigation in early states that rely on the premise that although the resulting systems may differ in form, the underlying emergent behaviors behind the development of irrigation systems are linked to spatial heterogeneity. Harrower summarizes the complexity of the question: "How, then, do we move forward in examining water's role in ancient political complexity in a manner that acknowledges both the importance of historical particularities and contingencies—that is, the unique

6 Wilkinson 2003.

nature of different societies and cultures—and the fact that there do seem to be some broad, cross-cultural similarities in water’s influences among ancient societies?” He emphasizes the role of political rhetoric, social logic, and spatial heterogeneity as drivers for emergent state formation and provides a case study of state formation in southwest Arabia, suggesting that these underlying conditions may be generalizable to other areas. The strength of Harrower’s study is the emphasis on the complexity of conditions and feedback loops in socio-environmental interactions. In places such as southern Mesopotamia, where there is both archaeological and textual evidence of linkages between evolving levels of management of water resources for irrigation agriculture and food production, application of this new “interpretation” may provide insights into the emergence of various levels of controlled irrigation systems.

My own recent work in southern Mesopotamia has begun to explore this type of alternate scalable framework.⁷ In 2010, Jennifer Pournelle and I began focusing efforts at mapping the landscape of the former marshes of southern Iraq. Uniquely accessible due to a combination of the drying of the marshes, availability of low-cost and high-resolution satellite imagery, shifting land-use activities, and recent work on ancient texts related to wetland resources such as reeds, pigs, fish, fowl, and trees, this area south of the Shatt al-Gharraf River to the head of the Gulf contains some of the earliest permanent occupation sites in southern Iraq. The long-term record already available by excavation and survey in the surrounding area, coupled with the emerging preserved irrigated landscapes—consisting of tell sites, relict channels and canals, and possible ancient field systems—provide a diverse set of archaeological data with which to begin to tackle questions around the role of irrigation in the formation of the first urban-sized cities in the south.

The earliest *visible* settlements on the alluvium proper appear to cluster in the extreme south, but this may be an artifact of a combination of selective recording of excavated material, limited excavation of the earliest occupation levels, survey methodology (i.e., the process of driving from mound to mound across the plain rather than site visitation and collection), and highly variable aeolian deflation resulting in variable surface exposure of material. This is a counterbalance to the long-standing emphasis on the burial of features that have led some to conclude that the earlier layers are far too deeply buried to access successfully. Pournelle has argued that these Ubaid 0 to Ubaid 5 sites represent the small, early farming villages of the southern alluvium.⁸ Spanning two millennia of occupation and located atop turtlebacks, representing remnants of the Pleistocene era fluvial landscape, these settlements are presumed to have supported relatively small permanent populations.

Whether as an artifact of exposure or an empirical reflection of change, previous surveys⁹ indicated a significantly different settlement pattern beginning in the fourth millennium BCE. Rather than isolated clusters atop turtlebacks characteristic of the Ubaid settlements, by the early Uruk period settlements were dispersed throughout the alluvium and could be mapped in linear patterns along what were presumably relict branches of the Tigris and Euphrates Rivers.

7 Hritz 2010, 2014; Hritz, Pournelle, and Smith 2013.

8 Pournelle 2003.

9 Adams 1981.

What has been less systematically explored and remains obscure is the impact of the gradual regional climatic change and the diverse ecological context of these settlements in a prograding deltaic system marked by the branching river systems, creating small pockets of diverse riverine and marsh landscapes. From the mid-fourth millennium BCE, as the delta prograded southeastward and the regional climate became drier, through time urban centers such as Uruk, Girsu, Lagash, and Larsa could continue to exist by investing in increasingly managed hydrological control, including extending their agricultural irrigation networks along expanding river levees. At the same time, new settlements connected by waterways would have been founded farther afield to exploit marshland resources at the tips of the prograding delta. This would suggest an ongoing cycle of urban centers first growing from settlements founded on minimally higher ground within inundated areas, then becoming proportionally more reliant on irrigated crops and pastoral exchange as those wetlands infilled with sediments. Finally, as the transaction costs of maintaining those irrigation systems became too high, fields were permanently abandoned. This descriptive model intends to address the complexity, dynamics, and instability of the landscape and environment in this formative period while at the same time approaching the behaviors and conditions that supported the long-term survival of some sites over others. The conditions of this model enable the linkage between archaeological material and behavioral assumptions, as well as the scaling of irrigation systems. For example, if this model is correct, earlier villages, including those whose long-term descendants became early and long-lived urban centers, should be located in the former marshes of southern Iraq.

Scalability is an issue at the heart of Stephanie Rost's presentation, which examined the social organization and assumption of centralized control of irrigation in early states from the governor's archive of the Umma province during the late third millennium BCE Ur III period (2112–2004 BCE). She points out that the complementary strands of data that are needed to present a holistic and empirical interpretation of irrigation management are not available. For example, the textual archive provides detailed information on specific practices of a single irrigation system, but correlated archaeological evidence is lacking, making direct connections between textual and archaeological analysis difficult.

The archive of the governor of Umma consists of 30,000 tablets, 3,000–4,000 of them dealing with irrigation and water control. As Rost describes, the archive presents key information on how many workers were needed to accomplish irrigation projects such as canal cleaning, where the work occurred, and who supervised and authorized the process. The archive provides detailed descriptions of the layout of the irrigation system, including canal size. From this information, the Modeling Ancient Settlement Systems project at the Oriental Institute (specifically, Magnus Widell and I) attempted to correlate visible landscape features from satellite imagery, geological maps, and archaeological survey data with the information from the texts.¹⁰

As Rost points out, the texts provide a window into the complexity of canal modifications and may provide insight into labor needs and organization as well as anthropogenic impacts on the landscape. However, her study illustrates the limits of textual data alone. Presented is a very detailed reconstruction of a piece of a system, somewhat floating in space. Without archaeological data on the broader landscape around Umma, it is not

¹⁰ Hritz et al. 2013; Hritz, Pournelle, and Smith 2013.

possible to understand the role of this canal system within the broader Umma province or the context of southern Mesopotamian irrigation systems. Rost concludes, and rightly so, that the organization described in the text is highly centralized at the local level and not at the national one. But I wonder how this local-level organization was nested within the national bureaucracy for which the Ur III period is so well known. How does this system of water management scale up to the regional level to produce the complex and spatially extant irrigation systems that are described across southern Mesopotamia in this period? Rost's study opens the door to exploration of the scalability of these data sets and reinforces the necessity for multiple complementary and spatially diverse data.

While Rost presents a detailed view, Jason Ur pulls back for the broad view without high-resolution detail to explore the overall structure of irrigation systems. Through a series of case studies, Ur argues that proxies such as satellite imagery provide the view and narrative of entire systems. For example, he demonstrates that the systematic engineering of the Nineveh system is apparent only with large-scale mapping rather than with mapping of individual elements. Using this proxy data, he outlines a methodology for mapping and interpreting canal systems in the dry-farming regions of northern Iraq, describing the signatures of state-sponsored canals with corresponding textual data, fossilized systems preserved in modern systems, and the impact of locally managed regional qanat systems versus large-scale state water management systems. Ur deliberately avoids the systems of southern Mesopotamia and presents a picture of water management systems in a different environmental context. Social, economic, and political organization plays out differently in this region than in the irrigation-dependent south, and the differences in the resulting water management activities and their longer-term trajectories are apparent. Ur draws attention to the importance of local environment conditions, local systems nested within larger regional water management strategies, and the way those conditions fundamentally impact the structure and organization of human–environment relationships. New methods and understanding of landscape connections make it possible to take a new look at these topics in southern Iraq, rather than dismiss the area as too complicated to untangle, prior to the Sassanian period.

We are in a period of opportunity to take a fresh look at the archaeological landscape and the potential evidence of ancient agriculture, afforded by a combination of ongoing and prolonged natural environmental change and new agro-investment in southern Mesopotamia. From a systems framework, the feedback of these coupled processes reveals new features in the landscape. For example, the landscape palimpsest in this area has been characterized by periods of prolonged sedimentation or alluviation, the presence of dunes in the central alluvial plains, and the archaeologically inaccessible marshes in the far south. The movement of these features has the potential to shed light and reveal features missing from visibility during previous large-scale surveys in the area forty years ago.¹¹ While still a complicated palimpsest of preservation, the uncovering of preserved features has the potential to provide new data sets that enable spatial analysis and landscape interpretations.

11 Adams 1981.

CONCLUSION

The papers of the “Irrigation in Early States” seminar presented a diversity of materials and research questions, and demonstrated the differences across regions and within regions in terms of technology and social frameworks. These are key topics in the advancement of our understanding of ancient irrigation systems, water resource use and allocation, the emergence of political hierarchy, and state formation. These topics hold a great deal more potential to answer broad societal questions. Just as Wittfogel’s original world was placed in the context of understanding the powers and societies emerging after World War II, our revisiting of this topic has the potential to inform ongoing global discussions of resource justice in developing societies, to understand the importance of context for the concept of community vulnerability, to redefine concepts of resilience and adaptation from a historical and humanistic perspective rather than a biological framework, and to explore the innovative new analyses that are possible using advanced tools and methods to address wicked questions.

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18

Response

McGuire Gibson, *University of Chicago*

THE STUDIES IN this volume all address the supplying and/or control of water, but they hinge on differences in scale and degree of difficulty in those tasks. Maurits Ertsen outlines in broad strokes the variations in these factors, although I would like to see attention paid not just to “agents” but also to social organizations that sometimes act in ways that systems analysts think are irrational. There are documented cases in which an irrigation system need not be understood by the people involved, as long as they keep to a set of rules. For instance, in the Swiss Alps,¹ a system for watering pastures, depending on two small springs, has a distribution scheme that appears irrational and certainly not what an irrigation engineer would approve of. Although the pattern is understood by the anthropologist but not by the participants, once begun it works to everyone’s satisfaction.

Large river valleys, such as the Tigris and Euphrates basin, the Nile, or the Indus, present very different opportunities and risks than areas in which the water is limited but can be manipulated for sustainable life. Systems with small supplies of water, or supplies that are limited to a few weeks each year, as is the case in monsoon-fed terraced agriculture in Yemen, where I worked, can comprise entire mountainsides covered with hundreds of small terraces that are structured so as to allow seasonal rains to be absorbed and channeled from upper terraces to lower ones. The engineering of terraces or runoff diversions is relatively simple, but the social arrangements that keep such systems working are often highly complex and are the result of hundreds of years of incremental additions and constant maintenance. But this system depends totally on local arrangements and entails the commitment by individuals and families to quickly repair breaches in terrace walls so that the system does not fail, and to keep to the agreed schedule of watering and not to allow, through negligence, the overwatering of a section and possible damage to the terrace walls. A system like this is too small for a state to attempt to regulate, and why would it do so when the lineage or tribal structure is enough of a mechanism to keep it working? The state need be present only at the harvest, if it has the power to claim a portion as a tax. Exceptions did take place in Yemen, as is outlined by Michael J. Harrower, placing state-sponsored irrigation in a broader context of the incense trade. Large, high dams were obviously created by state rulers who left their inscriptions on them. But every one of these dams, including the famous one at Marib and the dozen or so in the Dhamar area

1 Netting 1974.

where I worked, were breached in antiquity. There is evidence at one dam west of Dhamar that indicates that an attempt was made to strengthen the structure with new blocks of a different kind of stone laid against the original face, but the dam still failed, presumably as the result of a larger-than-average amount of water from the rains.

These dams in Dhamar were very similar in design, ponding monsoon rains behind high dams in narrow, deep valleys. From the edges of the dam, small channels (no more than 1 m wide) hugged the valley walls for up to 7 km, gradually dropping down to water approximately 50 ha of fields in the plain below major towns set on high, defensible mesas. These systems are late (Sabeian or Himyarite, ca. 500 BC to 100 AD) and are clearly state sponsored. In contrast to these expensive engineering attempts in deep valleys are other areas in which the mountainsides were (and still are) covered in terraces that slow down and absorb the rain. In these areas, there are often fairly low (4–5 m high) walls running across the valley floors. These walls have not failed, and originally they were meant to hold back water but to let it flow out rather quickly. Almost all of these walls are now the retaining walls of large terraces created by the silting up of the reservoirs, which are sometimes held as common pasturage.

The invention of the qanat/foggara, such as Martin Sterry, David J. Mattingly, and Andrew Wilson describe for Libya in this volume, solved difficulties of a small water supply in hot climates, and again usually do not imply state sponsorship. By running the water from the base of a mountain in a sloping tunnel, sometimes kilometers long, the farmers prevent a great loss through evaporation. The watering of gardens by means of wells, which Sterry and his colleagues describe, is a mechanism for dealing with even more restricted water availability. I would note that the authors' proposition that cairn burials near their sites imply village populations is questionable. In Saudi Arabia, I recorded hundreds of cairn burials on the tops of ridges that were nowhere near any settlement. These burials were, instead, along camel-herding routes and most probably were constructed incrementally over many years, probably near places that were traditional camping stops.

M. Kyle Woodson's Arizona case is a fascinating combination of a relatively restricted water supply with a large-scale irrigation and water-control system feeding 70,000 acres. Robert C. Hunt describes a related system among the Hohokam, detailing the need for a food surplus to bring about complexity. But in his case, the available water supply and temperature fluctuation were limiting factors for the possibility of surpluses. He argues that there was no need for institutional surpluses because there was no social complexity.

In mountain or piedmont zones, irrigation is mainly supplemental to rain-fed agriculture. Both Jason Ur and Emily Hammer deal with ancient irrigation, in Mesopotamia and Urartu, respectively. In the first case, canals are in fact state sponsored to feed the great cities of Assyria. Later, in this area, qanats that were probably not state sponsored supplemented rainfall for better yields. In Urartu, Hammer sees irrigation as initiated in part by local rulers a hundred years after the formation of states, and some channels incorporate dams and reservoirs. Here, as with the Assyrian case, the irrigation is to supplement the water supply of cities. But Hammer also sees evidence of smaller-scale irrigation as related to hay meadows, for animal sustenance.

Contrasted with the areas of limited water is the situation in great river valleys, but the means of controlling and using the water vary. The irrigation solution even on a single

large river can be very different depending on the local geography. For instance, until the advent of modern pumps, the Euphrates in Syria could be used only on a relatively small scale, often as canals that would take off from one or both sides of a river and run more or less parallel to it for up to 10 km. Once it entered the area of modern Iraq, the Euphrates flowed (before the creation of the Haditha Dam in the 1970s) between high banks, leaving a narrow cultivable strip on one or sometimes both sides, creating an almost continuous garden of date trees, fruit trees, and vegetables from Ana to Fallujah. In this stretch of the river, there were almost no towns, but instead a continuous garden with houses set at intervals within it. To supplement what the roots could tap from groundwater next to the river, the local people used waterwheels to feed narrow channels that would run 200 m or so to more distant gardens. Although a minor area of irrigation, the Ana-to-Fallujah strip was very productive and, before the construction of the dam, used to furnish more than half the onions and potato seed crops for Iraq.

Once it reached the alluvium at Fallujah, the Euphrates divided into several channels. From as early as the sixth millennium BC, long before state formation, human engineering began to distort the natural regime through the easy tapping of the high-running channels for flow irrigation.

The Tigris, before it lost most of its water to modern dams in Turkey, had a very different regime than the Euphrates and could not be used for flow irrigation until it reached Kut, well below Baghdad. The problem with both rivers, however, was that their spring floods arrived too late for prime use and often resulted in vast inundations that could destroy large areas of crops, change river courses, and create large marshes. But the marshes provided an alternative source of food (fish, birds, turtles) and raw material (reeds) that supplemented agriculture and pastoral resources. It is the interplay of the human use of rivers, marshes, irrigation agriculture, and pasturage that gave southern Mesopotamia a diversity of production that allowed it to make up for the lack of other natural resources (e.g., stone, metals) and to develop the earliest states. In doing so, it created and maintained a strong cultural tradition that lasted from at least 5,000 BC to 200 AD. The evidence from area mapping and cuneiform texts presented by Hervé Reculeau for the Mari area and by Stephanie Rost for southern Mesopotamia illustrates the tremendous information that can be derived from that combination of sources. The *corvée* labor that is seen to exist in canal construction and maintenance has to be given a context that is more than state related. Under all these ancient (and modern) state structures is a web of kinship that carries the people in times of crisis. This kinship web can be tapped for state purposes, without the need to create other structures. Often, kinship leaders may be listed in the state's texts as "overseers," in effect co-opting the naturally occurring kin leaders and their groups into the state system for bureaucratic purposes. Even in modern Iraq, when the state has designed major irrigation and drainage schemes and has dug the major and even minor canals, the management and distribution of water from the secondary canals was left to local groups, organized on a tribal basis. Even when landlords owned huge tracts of land, they utilized the tribal structures to carry out the work, while the government recorded a landlord-tenant relationship. The detailed reconstructions by Reculeau and Rost have to be viewed in light of such state/nonstate contacts, masking a dynamic playing-out of organizational cooperation and resistance on the part of local people in relation to a centralizing power.

Christopher Woods² takes cuneiform sources into a very different realm, exploring concepts of space and a person's relationship to it (deixis). He sees river and canal banks as central to these concepts in Sumerian language and culture. He proposes that distance—here, there, yonder—are expressed in terms of “this side of the canal, that side, etc.” and sees such concepts passing into the temporal plane (“beyond memory or experience”). I wonder, however, if these expressions might not just be “this bank” or “that bank” expressing distance but might also relate to the relative difficulty of getting to that place from here, since any canal can be a hindrance to passage. Anyone who has ever done survey in an irrigated area of southern Iraq knows that a site that is just across a canal may involve a detour down the canal of many kilometers and much time lost to gain access to the other bank by way of a bridge.

The irrigation system in Egypt discussed by Juan Carlos Moreno García, which is also based on a large river, shows similarities with the Mesopotamian situation but also differences. The basin retention method is significantly different from the gravity flow system in Iraq, but there are similar aspects of diversity of resource areas (marshes, pasture, groves of dates and other trees, and perennial canals). Moreno García stresses small-scale irrigation, especially of lucrative crops such as dates, as the dominant pattern in pre-Hellenistic Egypt, with no state oversight, and he sees the state's role in those periods as the construction of transportation canals. The important role of canals as transport and communication routes was the same in Mesopotamia and other riverine systems.

I found fascinating the examples given here of systems in which human communities adapt in extraordinary ways to an abundance of water (Kathleen D. Morrison for India,² Miriam T. Stark for Cambodia). Both tie a centralized authority to a religious ideology. The Chinese case outlined by Jing² is similar in effect, if not in the great expenditure of water.

It should be pointed out that although we know that states did not come into being in order to regulate irrigation, once states did depend on irrigation, they were usually stuck with it and had to try to keep it running and even expand it, not always with good results. Even though wise rulers left most of the managing of the irrigation regulation to local community/tribal arrangements, they could exercise great power merely by taking the initiative to cut new major canals into an area, from which the local people would then construct their own minor canals. Likewise, a state could divert water from an area to bring it into submission. Of course, that entailed some place to put that diverted water, which could bring about problems in itself. I would also mention, however, that a local group can breach a canal as a measure of resistance. In the late nineteenth century, Ottoman governors in Iraq would collect taxes in cash or more often in grain or dates. There are several accounts of areas that refused to pay for years, leading, finally, to the sending of army troops. The local tribesmen would cut one or more canals to flood huge tracts. They waited in the middle of the new marsh until the army grew tired and withdrew. Then they repaired the breach and resumed farming.

As a final thought on these studies, let me add the following. In my first year of teaching, in an anthropology department, I was lecturing on the “rise of civilization” when a student in the class asked, “Yeah, but where are the folks?” He was right. In dealing with great transformations abstractly, we lose sight of the human beings who made up the

² Not included in the present volume.

social organizations that underlay, affected, and survived the achievement of “complexity.” Just as there is an intricate negotiation of relationships between local groups and a state, there are even more intricate relationships within the local groups themselves. Although, in the studies in this volume, there is some mention of “communities” and “agents” and even “lineages,” I would like to see more attention paid to “the folks” and how they are organized in these irrigation systems and how they relate to the state. To a certain extent, the move away from social anthropology in the 1970s caused a loss of the human organizational element in cross-cultural studies. I am hoping for a revival.

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Irrigation has long been of interest in the study of the past. Many early civilizations were located in river valleys, and irrigation was of great economic importance for many early states because of the key role it played in producing an agricultural surplus, which was the main source of wealth and the basis of political power for the elites who controlled it. Agricultural surplus was also necessary to maintain the very features of statehood, such as urbanism, full-time labor specialization, state institutions, and status hierarchy.

Yet, the presence of large-scale or complex irrigation systems does not necessarily mean that they were under centralized control. While some early states organized the construction, operation, and maintenance of irrigation works and resolved conflicts related to water distribution, other early governments left most of the management to local farmers and controlled only the surplus.

The cross-cultural studies in this volume reexamine the role of irrigation in early states. Ranging geographically from South America and the southwestern United States to North Africa, the Middle East, and Asia, they describe the physical attributes and environments of early irrigation systems; various methods for empirical investigation of ancient irrigation; and irrigation's economic, sociopolitical, and cosmological dimensions. Through their interdisciplinary perspectives, the authors—all experts in the field of irrigation studies—advance both methodological and theoretical approaches to understanding irrigation in early civilizations.

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